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Port of East London: design and optimisation of the sand traps

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Information on the sedimentary processes at East London was obtained to optimise various facets of the required port maintenance dredging, including a redesign of the old (pre-1994) sand traps. Thus, the location and layout of new sand traps were determined so as to intercept the main sources of sediment deposition in the harbour and entrance channel. The optimum dimensions of these sand traps were also determined in terms of theoretical sand trapping efficiency and practical dredging guidelines. These 'new' sand traps were implemented in 1994, leading to a recent investigation of their effectiveness. Bathymetric surveys were compared, contour maps were analysed regarding sediment build-up and erosion, synoptic difference maps indicating patterns of bottom changes were produced and cross-sections through the sand traps were analysed. Dredging data were analysed to determine any noticeable trends and were also linked in general to deviations from the long-term average wave conditions. The present main sand trap was found to be between 80 % and 90 % effective. The design locations, layouts and dimensions of the sand traps are virtually optimal. Recommendations regarding further possible optimisation of sand traps and dredging were also made.

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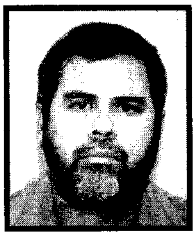

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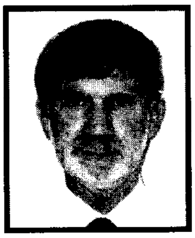

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INTRODUCTION

East London is situated on the south-eastern coast of South Africa, fronting the Indian Ocean. The sedimentary regime at East London is quite unlike the regimes at other ports in South Africa and is therefore of particular interest (Theron & Schoonees 1998). A major ocean current, the Agulhas, flows exceptionally close to the coastline in this area, thus significantly affecting nearshore sediment movements. The proximity of a strong ocean current mostly opposed to the net longshore drift creates an anomalous sediment regime in contrast to the regimes usually found at coastlines around the world. Furthermore, the Port of East London (fig 1) is the only major river harbour in South Africa. (It is located in the mouth of the Buffalo River.) All these factors result in a very intricate pattern of sediment movement in the area. The harbour, one of the six largest ports in South Africa, is operated by the National Ports Authority of South Africa (NPA). Regular dredging in the order of 600 000 m^3/year of sand, at a present day cost of about R10m, is needed to maintain channel and harbour depths. East London is also renowned worldwide as the birthplace of the dolos breakwater armour unit.

Every year, sedimentation in the sand traps, along the entrance channel and inside the harbour contributes to the maintenance dredging costs of the port. However, the amounts and exact causes of the sedimentation were not well understood. Thus, there was a need to determine the extent of the problem and the causes thereof, so that solutions could be sought if necessary. The purpose of initial studies was to determine the rates of sand deposition and to determine from where this sand originates. *The aims of further investigations (as reported here) were to obtain relevant information on the sedimentary processes at East London and to apply this information to redesign the old (pre-1994) sand traps.*

This led to various recommendations regarding the old sand traps (CSIR 1994a). Amongst others, a new layout and location of the main sand trap near the

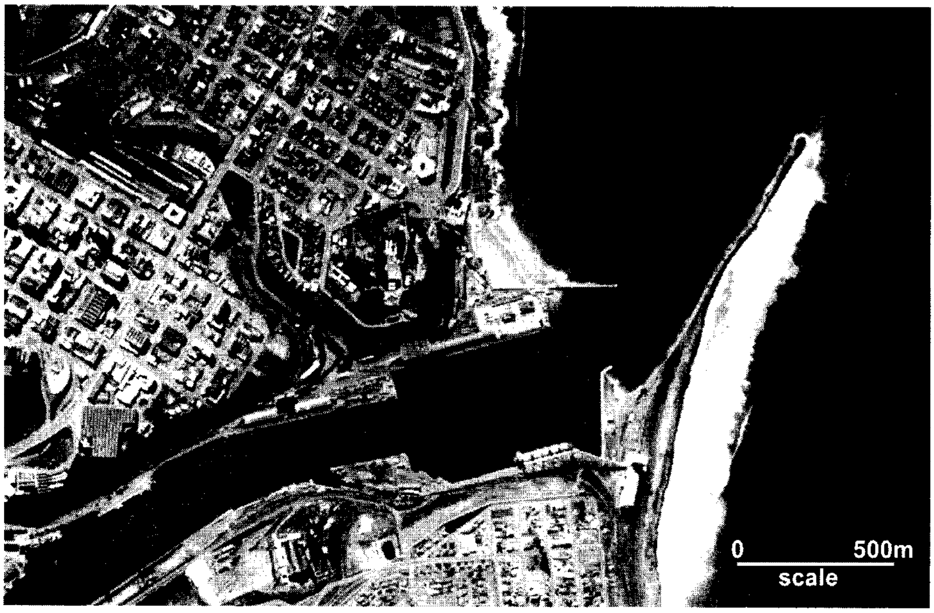

Figure 1 The Port of East London

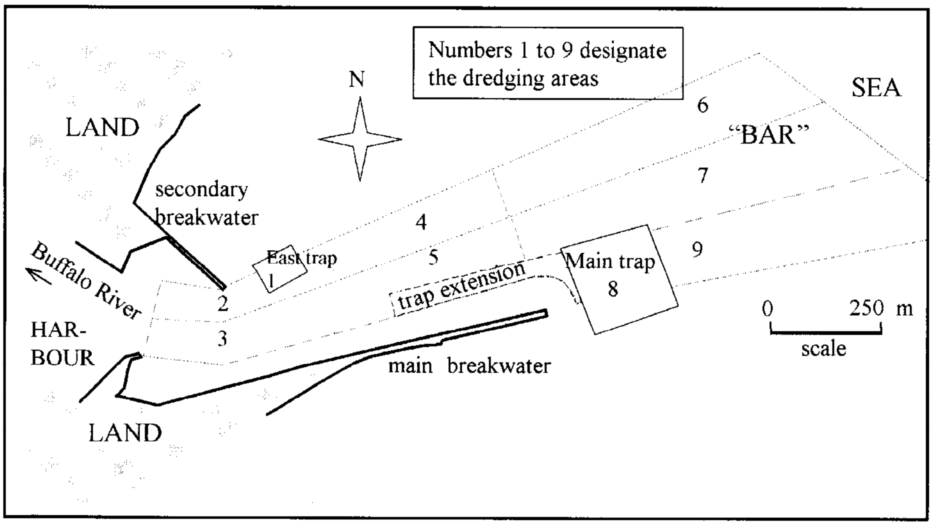

Figure 2 East London sand traps, breakwaters and dredging areas

head of the main breakwater was recommended, as well as a new sand trap near the head of the Eastern (Orient Beach) breakwater. These recommendations were subsequently implemented by the NPA in about mid-1994 and the 'new' sand traps have therefore been in use for some time. The location and layout of the existing sand traps, as well as the breakwaters, are shown in figure 2 (the port and breakwater layout can also be seen on the aerial photograph (fig 1)). It can therefore now be determined how well these sand traps function. *The primary aims of this study are to investigate the effectiveness of the present sand traps, whether improvements are possible, and if so, how these can be accomplished.*

DATA, COASTAL PROCESSES AND SEDIMENT TRANSPORT REGIME

Environmental data and coastal processes

The prerequisite to understanding the sedimentary processes is a thorough investigation of the relevant coastal processes. Thus, an in-depth study was undertaken of the physical environmental data and coastal dynamics that determine or affect the sedimentary regime. This included studies of the continental shelf sediment dynamics, tides, sediment characteristics, aerial photographs, the wind, wave (including refraction modelling) and current regime, dredging records and bottom topography changes (CSIR 1994a, 1994b, 1995a, 1995b, 1996, 1998). These studies were based on data recorded in the field, as well as physical and mathematical model simulations. For example, besides many current measurements, currents were also simulated by means of the Delft 3D mathematical model (WL|Delft Hydraulics 1996). Figure 3 shows an example for the most common situation which is a south-westerly current of 0,3 m/s.

Dredging data

Maintenance dredging at the Port of East London is conducted mostly in four zones (fig 2), named the 'main sand trap'(Area 8), 'bar'area (Areas 6,7 and 9) and 'entrance channel' (Areas 1, 2, 3, 4 and 5), as well as in the inner harbour (the basins and quays). The total volume of sediment dredged annually from the main sand trap was found to be about 320 000 m^3 on average (until 1994).
In the bar and entrance channel areas, a total amount in the order of 200 000 m^3 has been dredged annually,while about 50 000 m^3 in total has been dredged annually from the inner harbour.

Transport through and around the main breakwater

A separate study (CSIR 1995b) was conducted to determine the rate of sand deposition on the inside of the main breakwater and from where this sand originated. A wide variety of means were employed to determine the sand transport rates. These were: long-term dredger records, repeated surveys of specially dredged test pits and measurements of suspended sediment concentrations (Nicholson & Swart 1985 and Schoonees 1991 discuss some of the methods used), and current recordings employing an electronic current profiler, drogue- and dye-tracking and drifter buoys. The latter measurements were coupled with a theoretical determination of the suspended-load versus bed-load ratio (Einstein 1950). The results of a side-scan sonar survey of the area provided circumstantial evidence, completing a part of the sediment transport puzzle. Eventually, a holistic understanding of the local transport regime evolved, which made it possible to determine that, on average, about 35 000 to 70 000 m^3/year of sand moves through the main breakwater, and about 23 000 to 42 000 m^3/year around its head.

Longshore transport

The potential mean longshore sediment transport rate was theoretically determined by means of the modified Kamphuis method (Schoonees & Theron 1996) to be about 500 000 m^3/year adjacent to the root of the main breakwater towards its head. The actual rate is estimated at between 200 000 to 500 000 m^3/year, due to reduced availability in this area of sediment to be transported. (Gonsalves & Bartels 1990 discuss how sediment transport is limited along a rocky coast.) The directional distribution of the longshore sediment transport was determined from the nearshore wave climate.

Transport in deeper water

The sediment transport in deeper water, due to the combined effects of currents and waves, was also estimated by means of the Van Rijn (1989) method. Thus, the sediment-carrying capacity of the currents

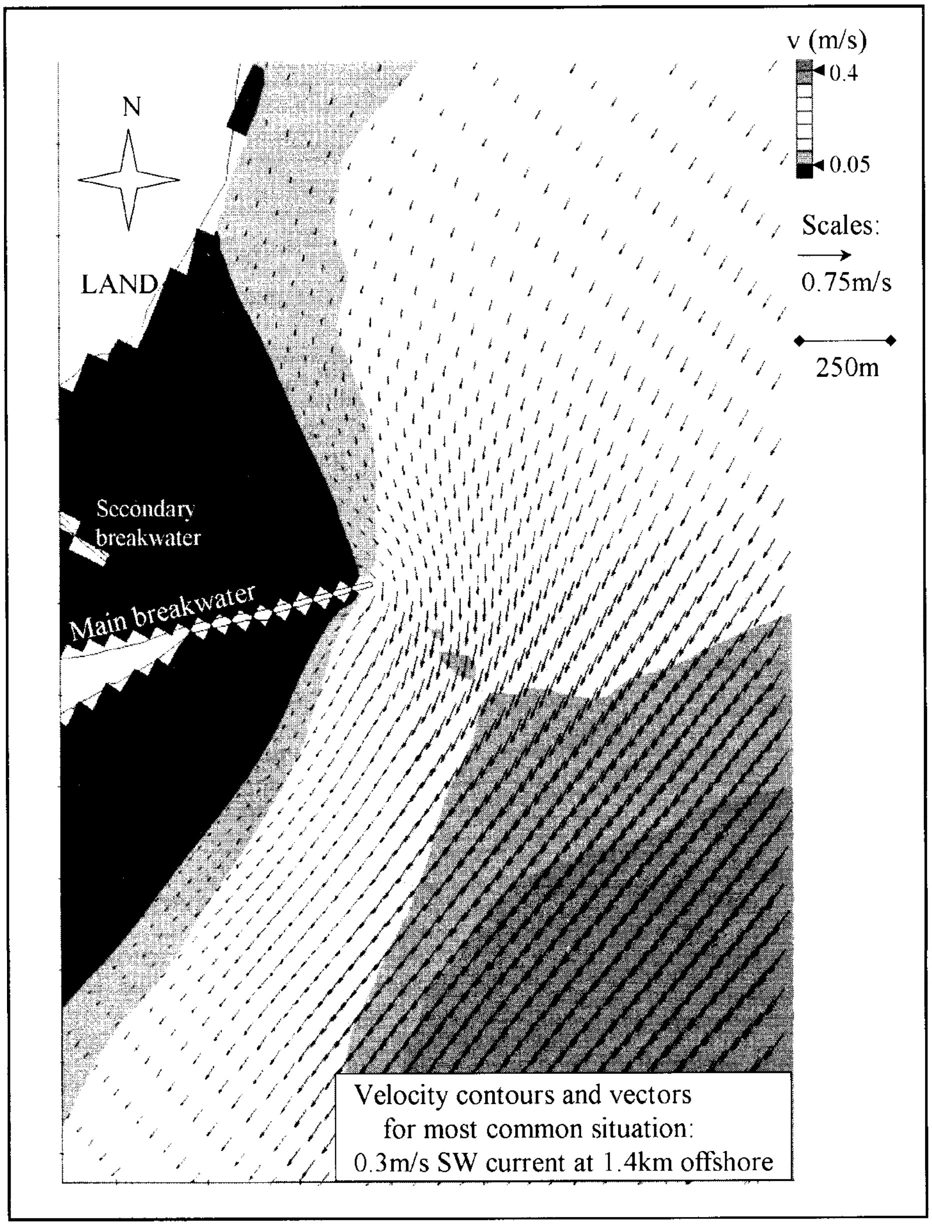

Figure 3 Simulation of currents at East London

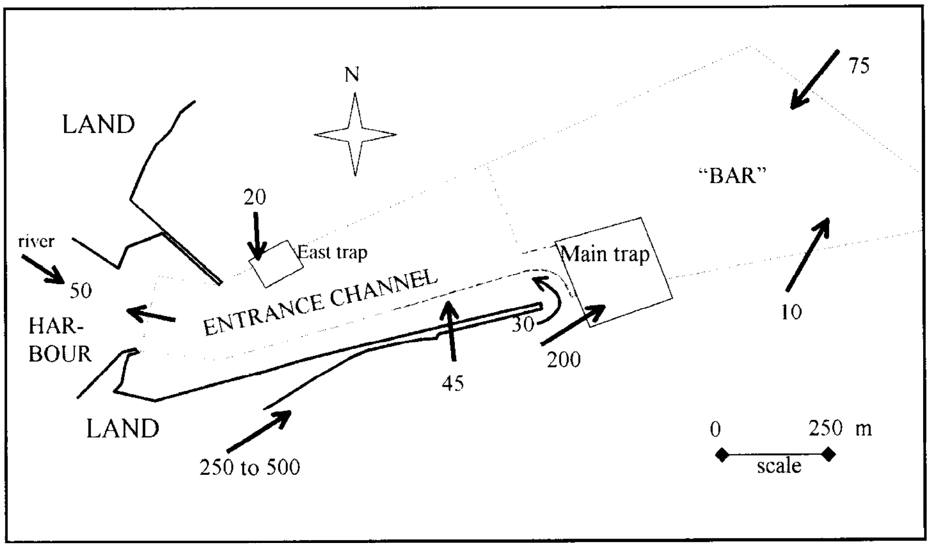

Figure 4 East London sediment regime (m^3/year x 1 000)

was assessed, leading to estimates of the sediment transports at the dredge dumpsite and in the deeper water port approach area. The strong Agulhas deepwater current predominantly flows in the opposite direction of the longshore current in the surf zone.

Fluvial transport

Riverine sediment inputs were calculated from sediment production charts and the sediment trapping efficiency of dams in the river. The mean runoff of the Buffalo River is estimated to be about 41 million m^3/annum with a sediment load of about 80 000 m^3/annum. However, the dams trap more than 90 % of the sediment; thus, the sand transported into the port is estimated to be less than 10 000 m^3/annum.

Sediment budget

The main components of the sediment transport patterns around the port, as depicted in figure 4, can be inferred from a synthesis of all of the above information as well as previous findings regarding the local sediment transport regime. More detailed information regarding the local sediment transport regime and dredging is given in CSIR (1994a, 1994b, 1995a, 1995b, 1996, 1998, 1999 and 2000), Theron and Schoonees (1998), Theron *et al* (1998) and Theron and Schoonees (1999).

Transports into the sand traps

Virtually all sediment deposited in the main sand trap is due to sediment transport from the southwest. Some sediment also passes through the gap between the breakwater head and the main sand trap, to be deposited in the lee of the main breakwater. Virtually all sediment deposited in the East sand trap is due to sediment transport from the north to west. Some sediment also passes through the gap between the eastern breakwater head and the East sand trap, to be deposited in dredging Area 2 or in the lee of the eastern breakwater.

REDESIGN OF OLD SAND TRAPS

Background

Once the sedimentary regime at East London had been defined, this knowledge was utilised to optimise maintenance dredging activities in the area (CSIR 1994a, 1995b, 1996, 2000). In this paper the focus is on the sand traps; thus, this section is devoted to the redesign of the sand traps as conducted in previous investigations (CSIR 1994a).

Theory of sedimentation in sand traps

A literature survey was conducted into the more recent methods of predicting the sedimentation of sand traps and harbour entrance channels (CSIR 1994c). Both flows crossing and along the trap were considered for non-cohesive sediment and including the effects of waves. Empirical methods for determining siltation were also investigated.

For the case of flow-crossing traps (or channels), the following methods to predict sedimentation were recommended (arranged in increasing order of sophistication):

- Van Rijn's practical graphs (Van Rijn 1986)

- Massie's estimates of upper and lower limits (Massie 1980)
- Bijker's analytical solution (Bijker 1980)
- Detailed mathematical modelling (Van Rijn 1986)

Further findings and conclusions were:

The use of a sophisticated mathematical model is only justified if accurate and detailed data are available. Preferably, infill rates from a test pit should be available. O'Connor (1985) covers the treatment of tidal influences on sedimentation in detail. The method of Fredsoe (1978), which has been shown to be accurate, is also recommended if the flow direction is along the waterway or trap/navigation channel. It has been shown empirically that shoaling takes place exponentially over time (O'Connor 1985 and Vincente & Uva 1984). Calibration data regarding the sedimentation of harbour entrance channels/sand traps are available from at least 27 physical model tests and field measurements from eight different sites around the world.

Optimum sand trap dimensions

The optimum geometry, including width, depth, orientation and side slopes, of the sand traps was determined by means of the theoretical methods (Fredsoe 1978, Lean 1980, Mayor-mora *et al* 1976, O'Connor 1985, and Swart & Fleming 1980), which were found applicable during the literature review.

A realistic range of values for depth, current, wave and sediment parameters was used as input (table 1):

The impacts of all of these inputs were considered, which led to theoretically optimum values for the sand trap dimensions. For typical values of the input parameters, two results are shown in figures 5 and 6 in terms of optimum depth and width respectively.

Inputs were also solicited from, amongst others, Dredging Services, the NPA dredging contractor, in terms of practical operational guidelines, such as:

- What are the draughts of the dredging vessels (full and empty) and of vessels to be used in future?
- What are the maximum and economic dredging depths for these vessels?
- What is considered to be the maximum wave conditions in which dredging can still be practically conducted?
- Information on the dredging schedule for the dredgers was required as it influences the required storage volume of the sand traps.
- What is the minimum length of the trap so that it can be trail-dredged (which is cheaper than bow-pipe dredging)? Manoeuvrability of the dredgers also affects the dimensions (width and plan-form) of the sand traps.
- How critical is it for the dredgers to traverse the sand trap at right angles to the wave fronts and against the current?

The optimum theoretical and practical dimensions thus determined are summarised in table 2.

Table 1 Ranges of input parameters to determine optimum trap dimensions

Parameter	Minimum	Typical	Maximum
Median grain size (mm)	0,165	0,183	0,267
Wave angle (degrees)	0	2 to 15	90
Current velocity (m/s)	0	0,2	0,6
Wave height (Hs, m)	0	1,9	7,5
Wave period (Tp, s)	5	11,2	23
Surrounding depth (m)	1,5	14	20
Depth in sand trap (m)	1,5	18	23
Width of sand trap (m)	75	150	250

Table 2 Optimum theoretical and practical sand trap dimensions for East London

Parameter	Theoretical	Practical
Depth (m)	Optimum: 27 Minimum: 19	Maximum: 26 Economical: 10 to 22
Width perpendicular to flow direction (m)	Optimum: 160 Minimum: 75	Optimum: 150 to 300
Orientation (long axis)	Optimum: perpendicular to sand transport direction Minimum: 60 degrees to sand transport direction	Parallel to wave and current direction
Length (m)	Determined from required volume = 1 to 2 times the average annual sedimentation in the trap (for safety)	Optimum: 700 to 1 000 for trailing suction dredging
Side slopes (vertical:horizontal)	The optimum is as steep as possible but should be at least 1:2,75	Natural angle of repose
Distance from breakwater (m)	As near as possible without impacting breakwater stability	Minimum: 75 to 135

Optimum sand trap layout and location

Having obtained a holistic understanding of sediment transport patterns, we could use this information to redesign the old (pre-1994) sand trap (CSIR 1994a). Thus, the location and layout of a number of new sand traps were designed to intercept as much as possible of the main sources of sediment deposition in the harbour and entrance channel. Other important considerations were:

- The traps should be able to be safely and easily dredged in terms of proximity to breakwaters, wave exposure, wave and current directions and water depth.
- As far as possible, only sand that would be deposited in the entrance channel or harbour should be trapped.
- Traps should have no negative impact on the breakwaters in terms of increased wave action and toe scour.
- The traps should concentrate dredging effort into small areas, since concentrated dredging is more economical than dredging small quantities spread over large areas.
- If possible, traps should be able to be trail-dredged, which is more economical than bow-pipe dredging, but requires greater trap lengths.
- Trapping efficiency should not be rapidly lost due to sedimentation.
- Dredging operations should not unduly hinder shipping access to the port.

In view of all of the above, three preliminary sand trap layouts were conceived. The optimum dimensions of these sand traps were also determined in terms of theoretical sand trapping efficiency and practical aspects of the dredging. The pros and cons of these layouts were then

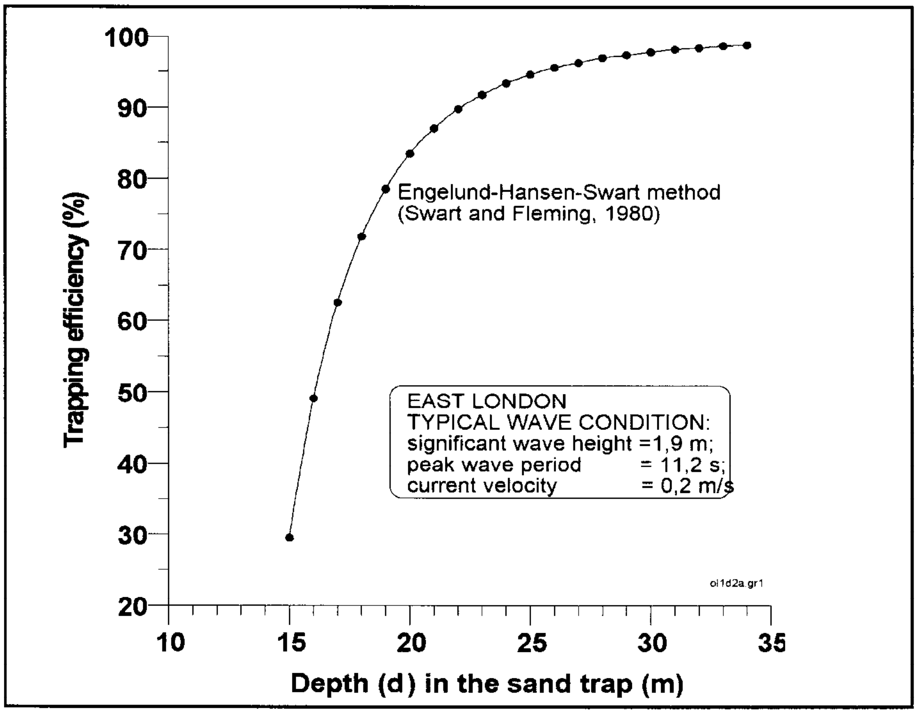

Figure 5 Trapping efficiency versus depth of sand trap

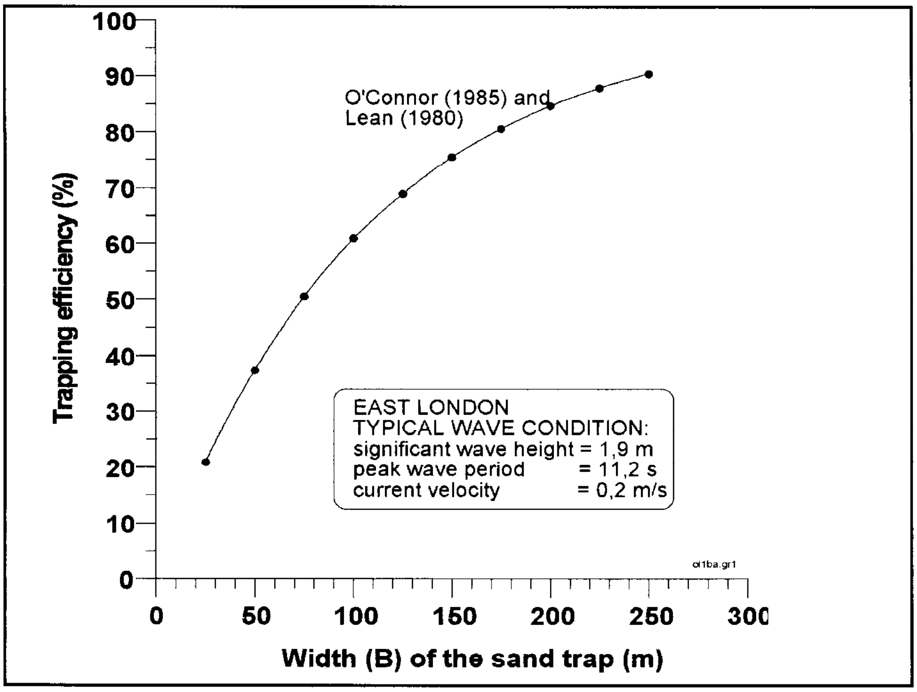

Figure 6 Trapping efficiency versus width of sand trap

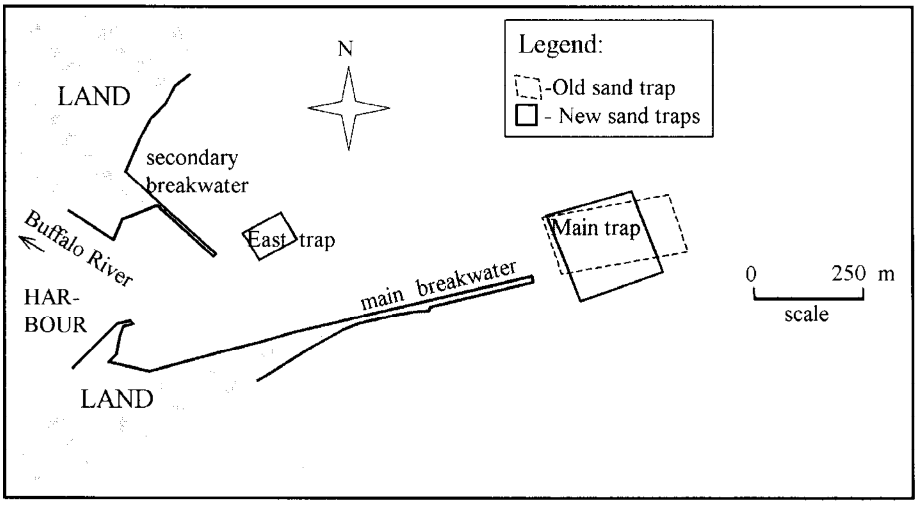

Figure 7 Old and new (1994) sand traps

investigated in more detail. Additional aspects considered at this stage were:

- minimum safe distances between traps and breakwaters in relation to design depths of the traps
- equilibrium slopes of the sand bottom and safety against toe scour of the breakwaters
- physical constraints regarding maximum achievable dredging depths due to the occurrence of hard bottom conditions
- required trap storage capacity
- capital costs of creating the new sand traps
- the phasing in of additional sand traps

A synthesis of these investigations led to final recommendations, which included significant adaptation of the old primary sand trap, the addition of a small new sand trap off the head of the secondary (eastern) breakwater and a long sand trap along the northern border of the entrance channel. Consequently, some of the recommended adaptations to the primary sand trap as well as the new East trap were implemented in 1994. The old and new (ie present) sand traps are depicted in figure 7.

EVALUATION AND OPTIMISATION OF THE PRESENT SAND TRAPS

Background

In the previous section it was shown that, amongst others, a new layout and location of the main sand trap near the head of the main breakwater was recommended, as well as a new sand trap near the head of the eastern breakwater. The NPA subsequently implemented these recommendations in about mid-1994 and the so-called new sand traps have therefore been in use for some time. It could now be determined how well these sand traps function. The aim of this final part of the study was to investigate the effectiveness of the present sand traps, which could lead to further optimisation.

Bottom changes

Bottom changes

Existing contour maps of the port area were obtained. It was possible to select consecutive surveys (here called survey couples) between which no or very limited dredging took place. This is important in analysing bottom changes, as changes due to dredging will not distort the observed changes resulting from natural processes. The surveys also need to be of good quality and contain no anomalies. (Note that in this paper, levels are relative to the harbour chart datum, CD_{port}, which is 0,7 m below Mean Sea Level.)

From the selected survey data, difference maps were produced. These maps show changes in vertical elevation

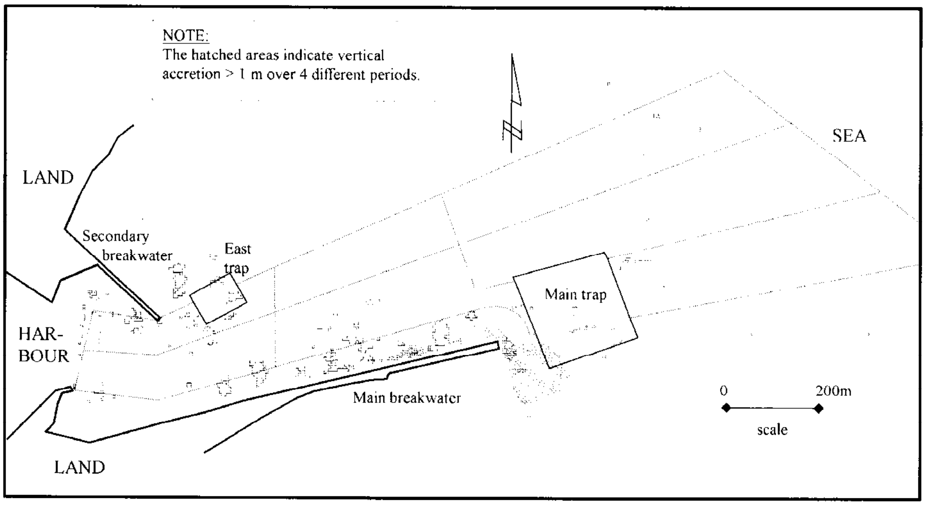

Figure 8 Port of East London - synopsis of accreted areas

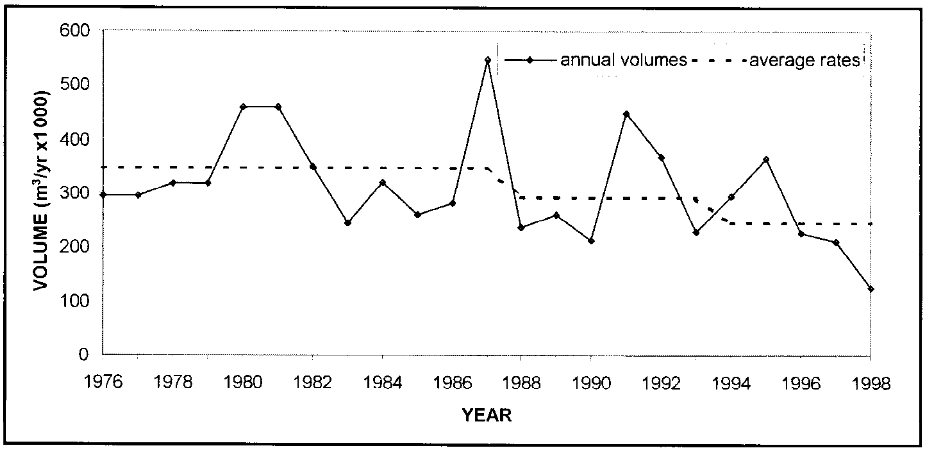

Figure 9 Annual volumes dredged from main sand trap

between consecutive surveys as well as volume changes per unit area. To clearly identify the depositional patterns found in the difference maps, a synoptic chart has been drawn up, which shows all the areas where more than one metre of vertical accretion occurred in each of four selected survey couples. This is depicted in figure 8. The pattern now becomes quite clear: significant deposition occurs at the south-western corner of the main sand trap, between this sand trap and the aleeward side of the main breakwater, within the East sand trap, between this sand trap and the head of the eastern breakwater, and finally on the leeward side of the eastern breakwater. A similar synoptic chart was drawn up, which includes areas of vertical accretion larger than 0,7 m. The main patterns remain the same, but widely spread areas of more limited accretion are now indicated to the north and east of the main sand trap.

Sections through the sand traps

To analyse and elucidate the bottom changes that have taken place, a number of sections were taken through the two existing sand traps. The bottom changes can be observed by studying the two profiles that make up a specific survey couple, that is, by comparing sections through the sand traps that reflect changes due to natural processes only. Two main conclusions are reached regarding the main sand trap:

- The main sand trap primarily accretes from the south-western corner. Very little sediment enters the trap from any other direction.
- The central part of the main sand trap is adequately dredged. It is realised that, practically, the trap cannot be dredged exactly to the design dimensions; however, the corners and eastern side of the trap do often appear to be significantly under-dredged.

The importance of attaining the design depth is clearly illustrated in figure 5. If, for example, the depth is reduced from 20 m to 16 m (which frequently happens in practice), the reduction in trapping efficiency of the main sand trap is more than 30 % for a typical wave condition. Likewise, attaining the design width is important, as illustrated in figure 6. If, for example, the width is reduced from 200 m to 100 m (which has also occurred), the reduction in trapping efficiency of the main sand trap is more than 20 %. Efficiency is significantly reduced by not fully dredging out the corners of the trap. Relatively small amounts of sediment appear to move into the main trap from the north, while most transport is from the south. Therefore, it is especially important to dredge the south-western and south-eastern corners of the main trap to design depth.

Although the *East sand trap* often appears to be over-dredged on the eastern side, it is usually under-dredged on the western side (towards the head of the secondary breakwater). The East trap bottom width is often in the order of 25 m (or $^1/_3$) narrower than required, and somewhat under-dredged in the vicinity of its southern edge. The significant reduction in trapping efficiency, resulting from a too narrow or too shallow trap, has already been discussed in the previous paragraph.

Dredging records

Main sand trap

Figure 9 shows the annual volumes dredged from the main sand trap since 1976. The mean annual volume since 1994 (when the existing traps were completed) is about 245 000 m^3, 16 % less than the average for the previous five years and 29 % less than the longer-term average for 1976 to 1987. In view of the significant reduction over the last few years, the existing sand trap layout is most probably more effective than the previous layout. However, it cannot be proven absolutely that the reduction is not due to natural variability resulting from changes in the environmental conditions (eg winds, currents and waves). This is discussed in the section on wave climate below.

Dredging areas

Since 1995, dredging data have been collected for nine separate sub-areas (fig 2). From this data, the average annual volumes of sediment dredged from the different areas over the last four years could be determined. To accurately determine this, the volume changes as derived from surveys were also taken into account. A comparison of the mean annual sedimentation rates for the nine dredging areas is shown in figure 10, which also shows where these sediment volumes are deposited. Clearly, by far the largest amount of sedimentation occurs in the main sand trap, which accounts for more than half of the total. The other areas where significant sedimentation occurs are Areas 3, 5, 6, 7 and 9. This shows that except for the main sand trap, sedimentation mainly occurs along the central entrance channel to the port and in the deeper areas east of the harbour. The sedimentation rate per unit area calculated for each of the dredging areas shows that by far the highest unit rate occurs in the main sand trap, followed by the East sand trap and then Area 5. Areas 3, 6, 7 and 9 have smaller, relatively similar sedimentation rates, with a small decreasing trend from Area 6 towards Area 9. Area 2 has a low rate followed by Area 4 with a zero rate.

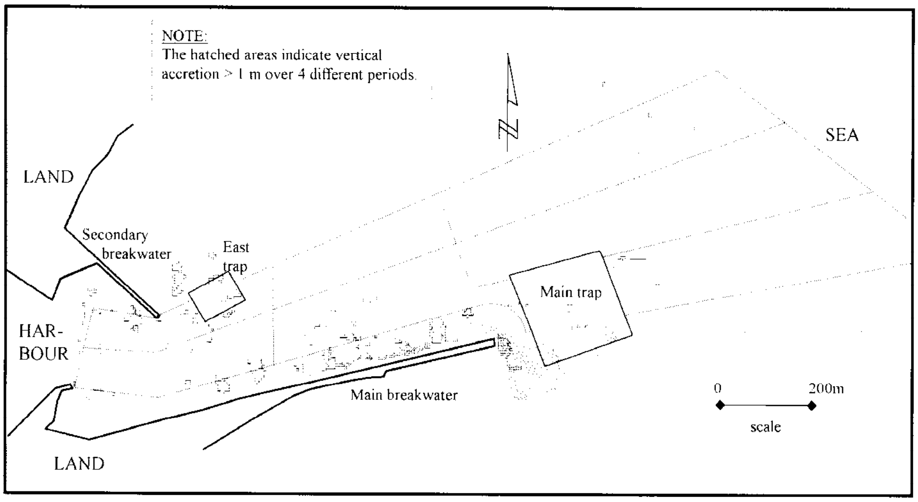

Figure 10 Mean annual sedimentation in different dredging areas

Correlation between bottom changes and dredge data

The findings derived from the dredge data can be compared to the conclusions reached from the bottom changes (see section above). Not surprisingly, both the survey and dredge data indicate major sedimentation in the main sand trap and significant sedimentation in the East sand trap. The sedimentation between the main sand trap and the breakwater head, and along the leeward side of the main breakwater, as derived from the survey data, correlate with the relatively high sedimentation found in dredging Areas 3 and 5, as derived from the dredge data. The survey data showed significant sedimentation between the East sand trap and the head of the eastern breakwater, as well as on the leeward side of the eastern breakwater. The dredge data also showed significant sedimentation in the East trap and Area 2, but the volumes are relatively small. The survey data indicate widely spread areas of more limited accretion to the north and east of the main sand trap. This correlates to the moderate sedimentation in Areas 6, 7 and 9 deduced from the dredge data. Both the survey and dredge data indicate virtually no sedimentation in Area 4. These comparisons indicate that the conclusions derived from the survey and dredge data correlate extremely well.

Wave climate

Comparing the post-1994 wave data (since completion of the present sand traps) to the longer-term total record (1992 to 1999) shows that the two wave-height exceedance curves are virtually identical. (Wave directions off East London have unfortunately only been recorded since late 1997.) The statistical values confirm that the post-1994 period is very similar to the longer-term record, with the wave heights since 1994 being slightly less than that for the longer term (CSIR 2000). For example, the average significant wave height for the post-1994 period is 1,51 m versus 1,55 m for the longer-term total record, while the 1 % exceedance height is 3,30 m for the post-1994 period versus 3,37 m for the longer term. Thus, the reduced dredging required since completion of the present sand traps is most probably not due to reduced transport rates resulting from lower wave heights, but likely, due to the more effective sand trap layout.

Effectiveness of present sand traps

Main sand trap

Based on the sedimentation volumes in Areas 3 and 5 as well as in the main sand trap, and depending on the percentage of sediment bypassing the head of the main breakwater (30 % to 55 %), the main sand trap is trapping between 80 % and 90 % of the sediment that it could potentially trap. Owing to structural considerations, the present main sand trap cannot be relocated closer to the main breakwater, which means that it cannot be made to trap more of the sediment moving between the breakwater and the present location of the trap. Despite this limitation, the trap is evidently very effective, and close to the optimum in design location, layout and dimensions. However, in the section on bottom changes above it was shown that the south-western corner of the trap is often not fully dredged. If the western side of the trap were always fully dredged, the trap would draw more of the sediment passing between the breakwater head and the trap towards itself.

East sand trap

The average annual sedimentation in Area 2 has been determined to be about 6 000 m^3, while sedimentation in the East sand trap was determined to be about 9 000 m^3. If half of the sedimentation in Area 2 is due to the sediment contribution from the river, then it means that the East sand trap is trapping about 75 % of the sediment transported towards this trap and Area 2 from the north and northwest. If only 1 000 m^3 of the sedimentation in Area 2 is due to the river, then the East sand trap is trapping about 64 % of sediment that it could potentially trap. Again, owing to structural considerations the East sand trap cannot be relocated closer to the eastern breakwater, which means that it cannot trap more of the sediment moving between the breakwater and the trap.

The available information indicates that sediment does not bypass this trap on its eastern side. It is evident that this trap is relatively efficient in terms of the percentage of the available sand transport that it traps. Its design location, layout and dimensions are apparently relatively close to optimal. However, as indicated above, this trap is often under-dredged (especially on the side towards the breakwater). If it were always fully dredged, its efficiency could be increased somewhat and it should trap a slightly larger portion of the sediment deposited in Area 2. The total volume of material dredged from the East sand trap is, however, relatively small. If this trap were not maintained, it would mean that a larger volume of sediment would have to be dredged over a more spread-out area within Area 2. It is therefore considered that maintaining the East sand trap is justified, especially if its efficiency can be increased by more accurate dredging.

Further optimisation of main sand trap

After the main sand trap, the most significant sedimentation is in dredging Area 5, which results from sediment transport through and around the head of the main breakwater. By extending the main sand trap westwards, a significant part of this transport could potentially also be trapped. The proposed design is to extend the north-western corner of the trap 400 m to the west between the dredging limit line adjacent to the main breakwater and line 23, as shown in figure 2. The bottom width should be about 50 m on average with a bottom elevation of -16m to CD$_{\text{port}}$. This depth is feasible as it is in line with the available information on rock levels in the area. Such an extension of the main trap should trap a significant part of the sediment that bypasses the head of the main breakwater as well as a considerable amount of the sediment that is transported through the breakwater. This addition to the main trap should trap at least three-quarters of the present sedimentation in Area 5 and at least a quarter of sedimentation in Area 3.

An additional advantage is that due to its increased length, this trap's layout should be more suitable for trail-dredging. Although this extension of the trap would be located along the southern edge of the entrance channel, dredging in this area could interfere with shipping. It is possible, however, to schedule a dredging programme with limited effects on commercial shipping. The initial volume that would have to be dredged to create this trap is about 60 000 m^3 (with 'natural'

20 ° side slopes). In deciding whether to construct this trap or not, the potential reduction of maintenance dredging should be weighed up against the cost to create this trap, as well as the possible hindrance to shipping.

CONCLUSION

Every year, sedimentation along the entrance channel, in the sand traps and inside the harbour contributes to the dredging costs of the Port of East London. Studies were undertaken to determine the rate of sand deposition and from where this sand originates. Information derived from various components of the sediment transport regime led to a holistic understanding of the sediment budget. In turn, this information could be applied practically in terms of a redesign of the old (pre-1994) sand traps. Thus, the location and layout of new sand traps were determined so as to intercept the main sources of sediment deposition in the harbour and entrance channel. The optimum dimensions of these sand traps were also determined in terms of theoretical sand trapping efficiency and practical operational dredging guidelines. These sand traps were created in 1994, and have been in use since.

A further aim of this study was to investigate the effectiveness of these sand traps, which could lead to their further optimisation and/or new sand traps. Bathymetric surveys of the port area, conducted after construction of the present sand traps, were compared. The contour maps were analysed in terms of sediment build-up or erosion and volume changes. Difference maps were produced, which show the patterns of vertical bottom changes. Volume differences per bottom area were also determined and cross-sectional profiles through the sand traps were plotted. The work also entailed a study incorporating all past and presently available dredging data (in terms of the volumes of sand dredged over time in certain areas). An analysis of this data showed that there has been a significant reduction in the average dredging volumes since 1994. A categorisation of the dredging data in terms of sub-areas, for which separate dredging data were collected, was also taken into account. A limited analysis of the available wave data showed that the reduced dredging since the completion of the present sand traps is most probably *not* due to lower transport rates that may have resulted from slightly lower wave heights observed over the period.

A synthesis was made of all of the above information and analyses, including previous findings regarding sediment transport and sedimentation. The present sand traps were found to trap from 64 % to 90 % of the sediment they could potentially trap, and their design locations, layouts and dimensions are close to optimal. Recommendations regarding further optimisation of sand traps and dredging were also made.

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