GRAVESEND PIER PONTOON
Geomorphic Study

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Report for Gifford
Carlton House
Woodlands
Southampton
SO40 7HT

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1. Introduction

This report details a qualitative assessment of the sedimentological regime within the environs of Gravesend Pier Pontoon. This assessment was undertaken to ascertain the effect of a new pontoon proposed at Gravesend Pier for use by the Gravesend to Tilbury ferry, and occasionally by other vessels including the Waverley and Balmoral leisure craft.

This report identifies the fundamental geomorphological issues concerned with the pontoon development. Essentially, this study has been undertaken to inform of potential changes to sedimentation patterns (erosion and/or accretion) in the vicinity of and under the pontoon.

1.1. Aims

The aims of this report are to provide the following with respect to both pre- and post-pontoon installation:

- Provide an explanation of the sedimentology regime;
- Provide a review of the seabed morphology;
- Provide an explanation of the temporal and spatial bathymetric variation within the area of the pontoon;
- Discuss the potential need for a dredging programme (if any).

1.2. Site Description

The design of the pontoon is outlined in Figure 1. The inside edge of the main pontoon is located approximately eight metres from the edge of the pier head. The proposed pontoon will extend from the eastern boundary of the Town Pier jetty head, and will be 80 metres in length. Access to the pontoon will be via a twin brow and intermediate platform arrangement, which will rise and fall with the corresponding variation in tidal elevations. The platform floats between mid and high tide. For mid to low tide, the intermediate platform will rest on beams between vertical piles.

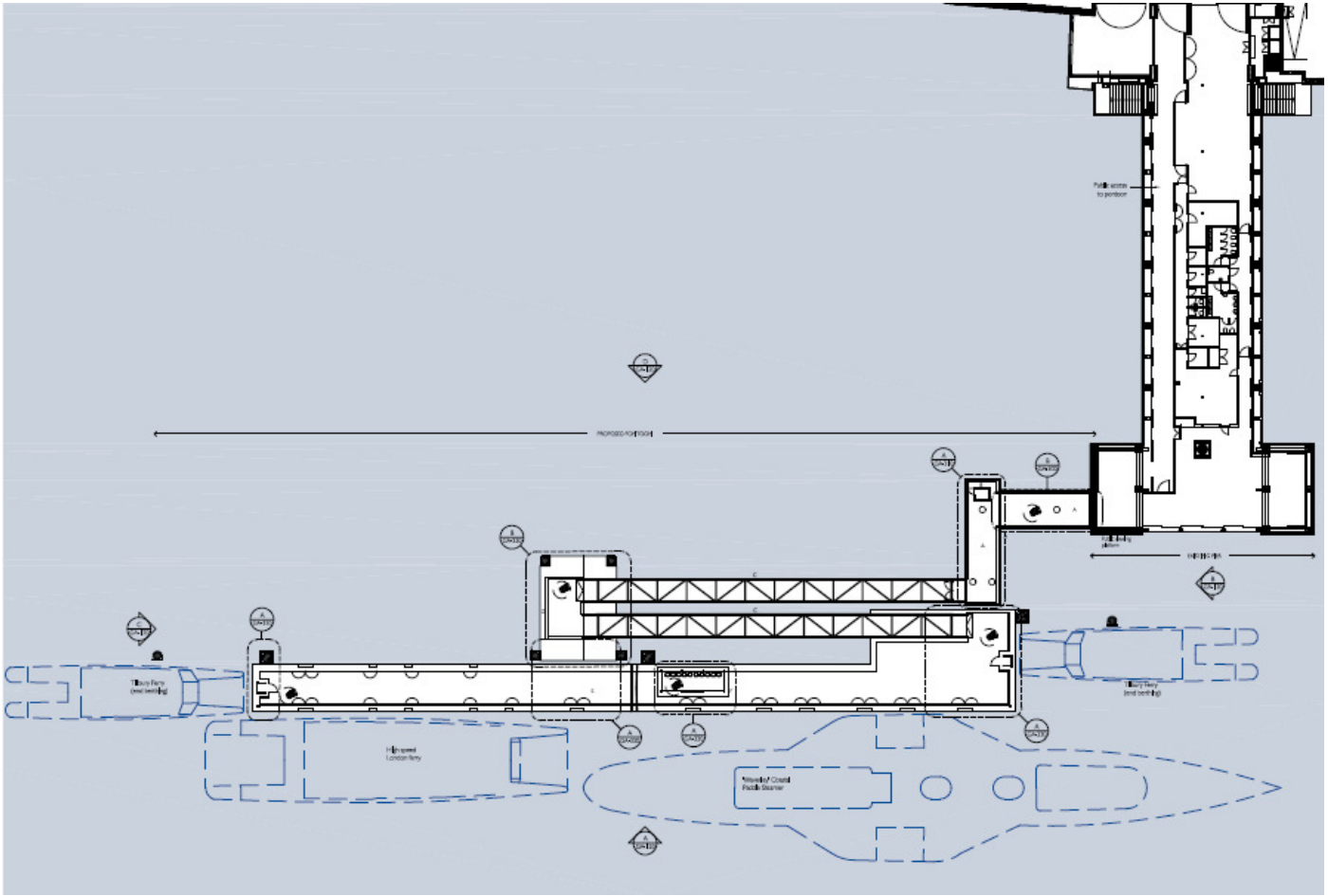

Figure1. Proposed pontoon design

2. Methodology

This geomorphological assessment has utilised the following information:

- HR Wallingford report (2009), which provides a quantitative analysis of the flow information at the pontoon site;
- Noble Denton wave modelling report (2009);
- Archival series of bathymetric charts. Four surveys have been undertaken by Port of London Authority (PLA) of the area from between 1977-2009. Charts for 1977, 1984, 1999, 2006-7 have been examined to identify seabed morphology change. This has been undertaken to potentially identify changes in the seabed which may purport to a natural sedimentation cycle;
- Photographic evidence and site observations.

To measure bathymetric change, a series of ten points have been chosen around the pontoon development site to illustrate temporal change. A map illustrating the positions of the sample points is illustrated in Figure 2. The position of each of the sampling points has been chosen to represent a good cross-section of changes occurring in the locality of the pontoon installation.

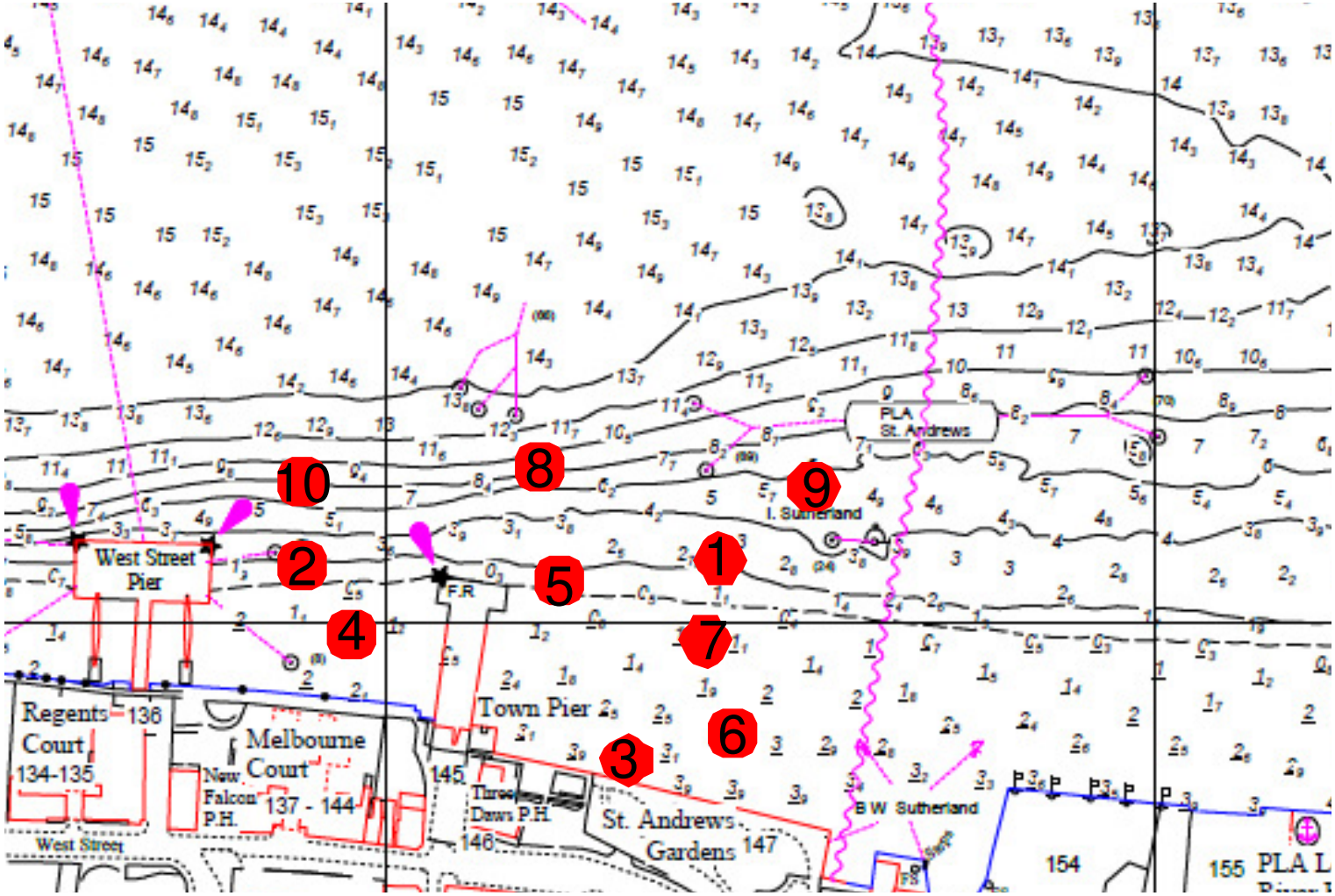

Figure 2. Locations of sampling points for bathymetric chart analysis

3. Results

3.1. Bathymetry Change

The bathymetric charts supplied by PLA have been reviewed to identify changes to the seabed morphology, particularly within the pontoon area. It can be seen that over time, there are small-scale changes to the bathymetry, which may be associated with various factors, including sediment regime, availability of suspended sediment, competence of suspended sediment load transport thresholds, provenance for siltation, water levels, tidal variation, and changes to current thresholds, directions and velocities. Lower water velocities have less competence to transport sediment, which results in sedimentation.

Tables 1a and 1b illustrate the rates of bathymetric change occurring at each of the ten sampling points for the period 1977 to 2007 (see Figure 2 for sample point locations). Most variation between surveys occurs in the deeper water, further away from the pontoon, such as in points 8, 9 and 10 (Figures 2; 3; 4; and 5). The least amount of variation occurs in points nearest the intertidal zone.

Table 1a. Analysis of bathymetric change taken from sampling points on PLA charts (1977-1984). All values in metres

Sample Point	Level 1977 (mCD)	Difference 1977 to 1984 (m)	Level 1984 (mCD)	Difference 1984 to 1999 (m)
1	-3.9	1.1	-2.8	-0.5
2	-3.3	0.9	-2.4	-0.6
3	3.4	-0.6	2.8	0
4	1.5	0.8	2.3	-0.2
5	-3	0.6	-2.4	-1
6	2	-0.2	1.8	0.8
7	-0.8	-0.8	-1.6	0.1
8	-9.1	-0.9	-10	1.8
9	-8.6	3.2	-5.4	2
10	-12.1	2.1	-10	1

Table 1b. Analysis of bathymetric change taken from sampling points on PLA charts (1999-2007). All values in metres

Sample Point	Level 1999 (mCD)	Difference 1999 to 2006-7 (m)	Level 2006-7 (mCD)	Difference 1977 to 2006-7 (m)
1	-3.3	0.6	-2.7	1.2
2	-3	0	-3	0.3
3	2.8	0.7	3.5	0.1
4	2.1	-0.1	2	0.5
5	-3.4	0.8	-2.6	0.4
6	2.6	-0.6	2	0
7	-1.5	1	-0.5	0.3
8	-8.2	0.2	-8	1.1
9	-3.4	-2.6	-6	2.6
10	-9	-1	-10	2.1

The results of Tables 1a and 1b are illustrated graphically in Figures 3 to 5.

Figure 3, which indicates the amount of change between 1977 and 1984, illustrates that most sites had a change of between minus one and one metre. Samples nine and ten show the most sediment change between the two surveys with approximately two and three metres of change.

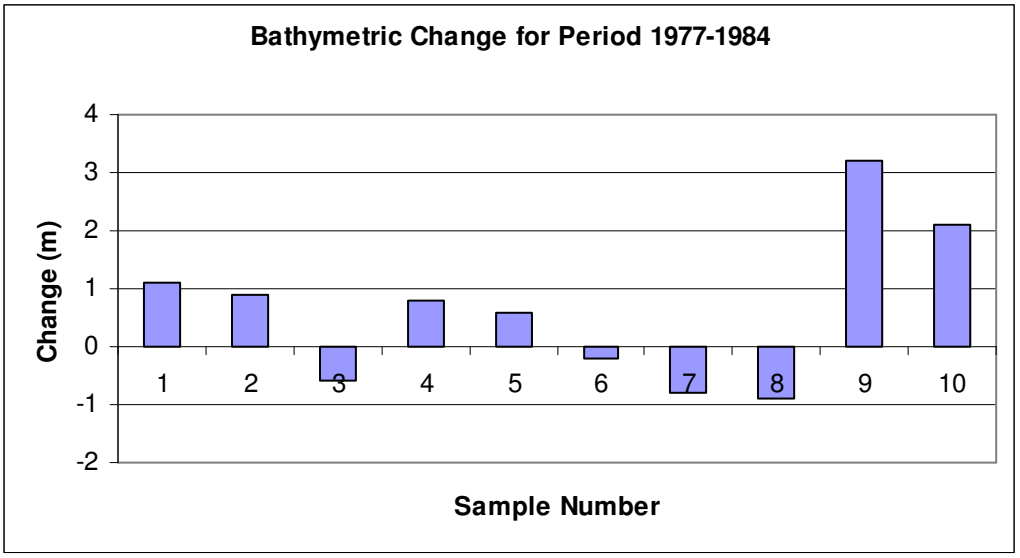

Figure 3. Bathymetric change for period 1977-1984

Figure 4 illustrates that the bathymetric change between 1984 and 1999 represented a small change in elevation between the two charts. Samples nine and ten exhibit most variation. These samples are the most distal and in deeper water compared to samples one to eight.

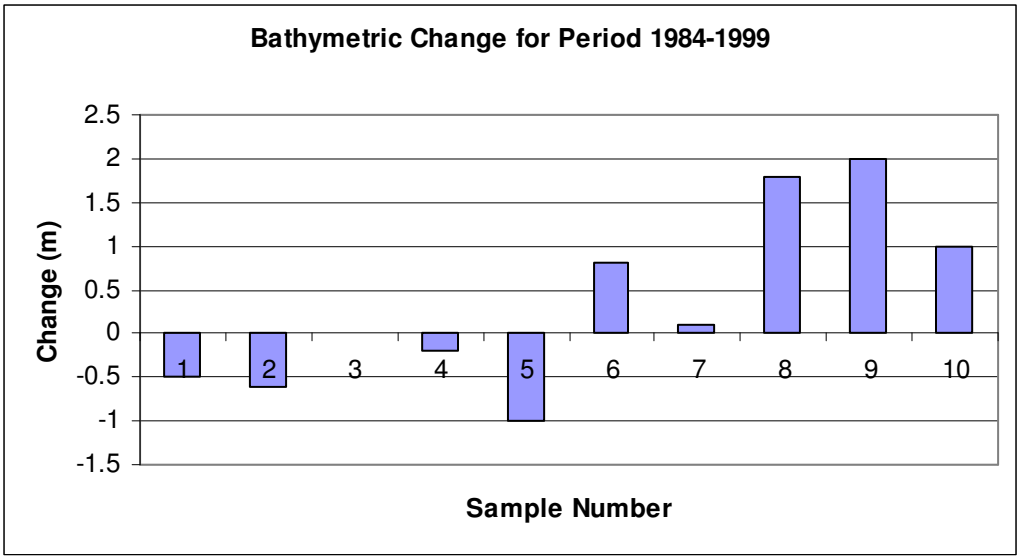

Figure 4. Bathymetric change for period 1984-1999

Figure 5 illustrates the bathymetric change for the period 1999 to 2007. Figure 5 suggests that the positions of four, six, nine and ten became deeper, whereas the other points became shallower.

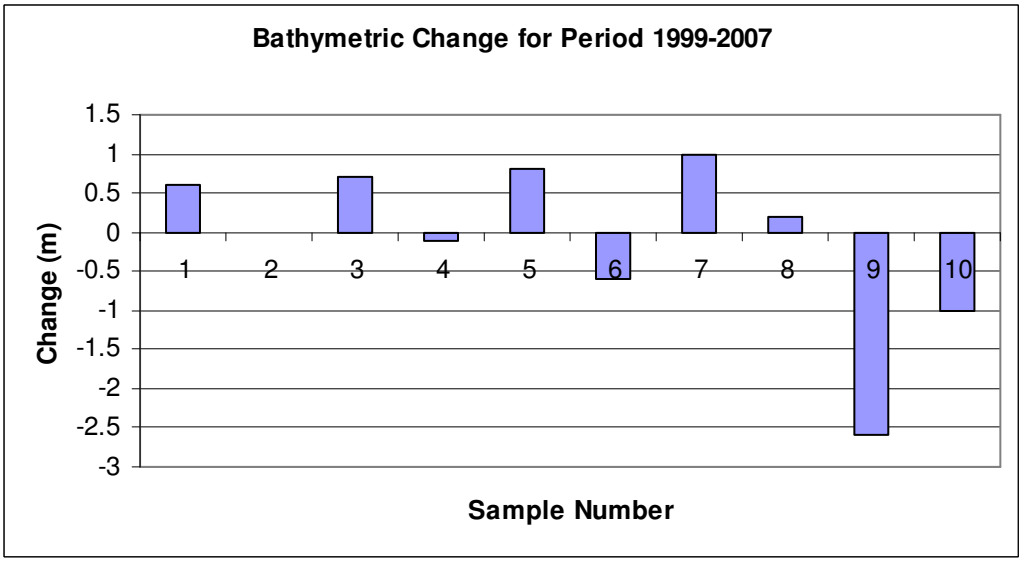

Figure 5. Bathymetric change for period 1999-2007

If the differences between 1977 and 2007 are extracted for the points, there is a difference of between 2.6 metres and zero metres change, as outlined in Table 1.

Table 2 and Figures 6 to 8 illustrate the annual mean bathymetric change for the durations between each of the surveys. The mean changes in depth between each sampling point are very small (between 0 and 0.4 metres). Samples eight, nine and ten exhibit the most change. Most samples exhibit changes of a few centimetres.

Table 2. Mean annual bathymetric change (m)

Sample Point	1977-1984	1984-1999	1999-2007	1977-2007
1	0.16	-0.03	0.08	0
2	0.13	-0.04	0	0
3	-0.09	0	0.09	0
4	0.11	-0.01	-0.01	0.04
5	0.09	-0.07	0.1	0.01
6	-0.03	0.05	-0.08	0.
7	-0.11	0	0.13	0.02
8	-0.13	0.12	0.03	0.01
9	0.46	0.13	-0.33	0
10	0.3	0.07	-0.13	0.01

It can be seen that the mean change in level between 1977 and 2007 for which data are available is negligible.

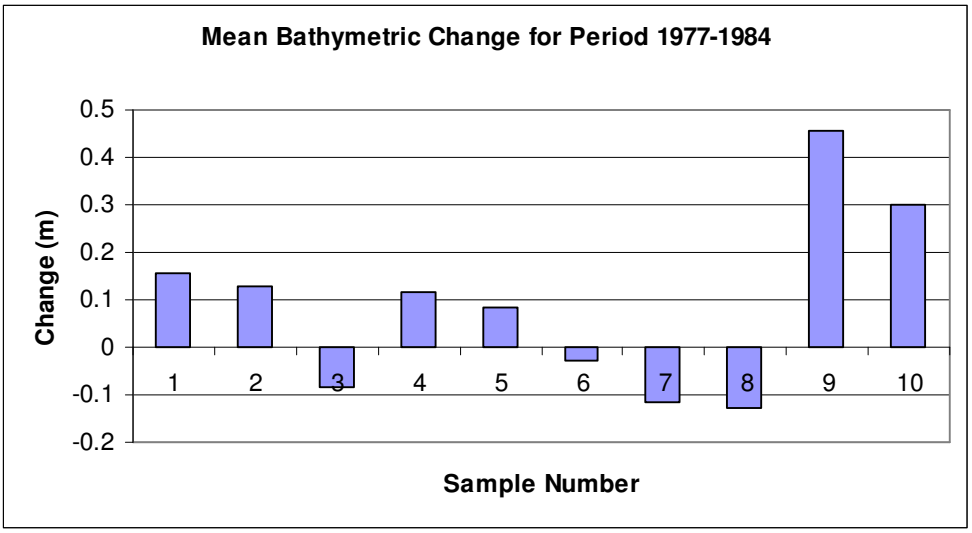

Figure 6. Mean bathymetric change for the period 1977-1984

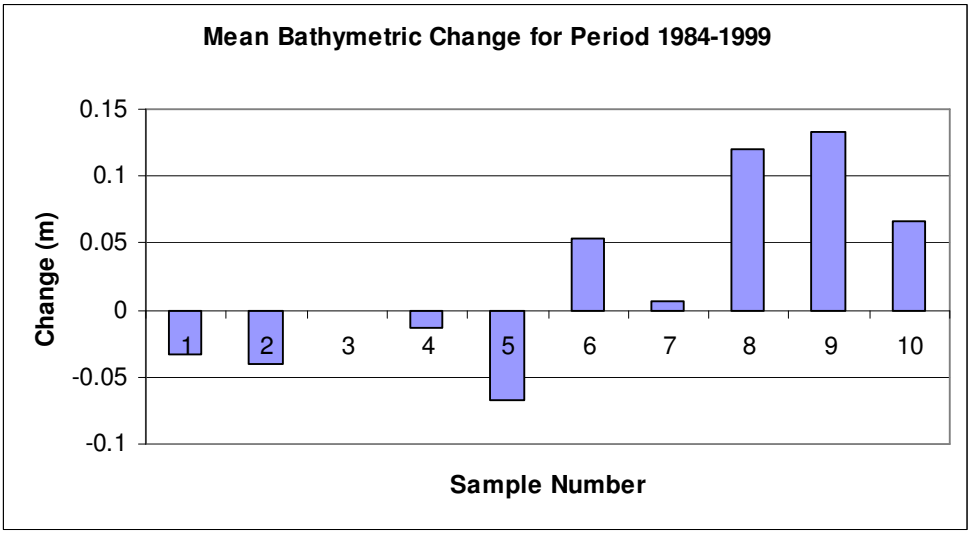

Figure 7. Mean bathymetric change for the period 1984 – 1999

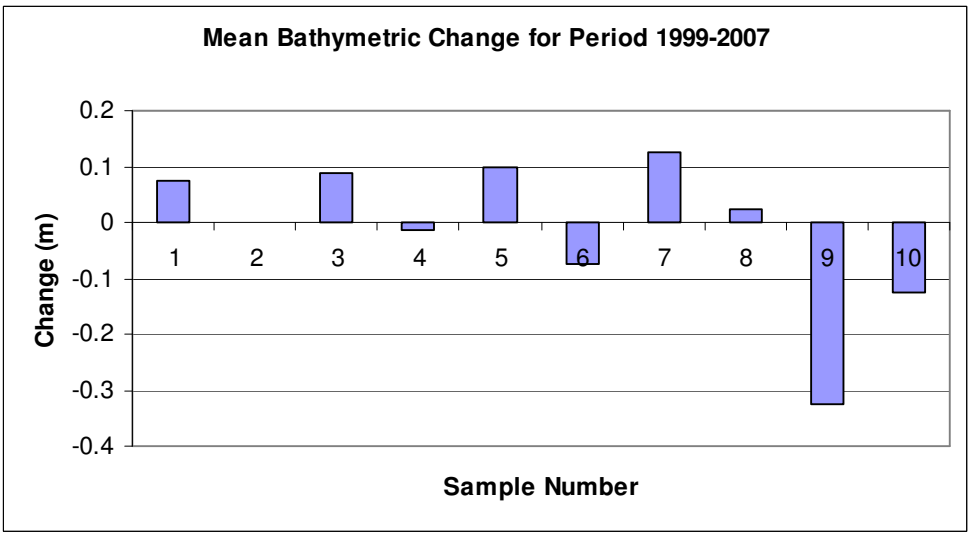

Figure 8. Mean bathymetric change for the period 1999 - 2007

3.2. Geomorphic Regime

Little is known about the sedimentary and geomorphic regime of the site due to paucity in field data. From observations of site photographs, it can be surmised that the sediment regime of the area is characterised by dense sandy silts, forming a cohesive layer, with occasional gravel deposits. The geomorphological regime of the intertidal zone suggests an intertidal habitat typified by intertidal muds, deposited in a tidally dynamic estuarine/riverine environment.

Bathymetric charts of the area show a shelving intertidal zone, which is exposed subaerially at points along the estuary (depending on tidal elevation), and a deep water channel in the middle of the River Thames reach. There is evidence of small shoals within the river channel. These may be antecedent sediment deposits.

The morphology of the Thames is maintained by a dredging programme to ensure vessel traffic is unimpeded. This practice limits bedload sediment availability within the Thames.

The River Thames exhibits a highly turbid environment, as can be seen from photographic evidence. Turbidity is a reflection of the concentrations of suspended sediment within the water column. Suspended sediment concentrations are flocs of clay and silt sized particles which are transported in the water column until they are deposited within the intertidal zone or on the seabed as muds.

The Gravesend area of the River Thames is affected by high water levels with a tide that has an elevation of 6.4 mCD (Chart Datum) on Mean high Water Spring (MHWS) and 0.5 mCD on a Mean Low Water Spring (MLWS), measured at Tilbury directly opposite Gravesend on the north bank of the Thames. Tidal range between high and low water springs is 5.9 metres. Table 3 has been extracted from Noble Denton (1995), which summarises the mean tidal elevations.

Table 3. Tidal levels at Tilbury measured in CD (Chart Datum)

Mean High Water Spring (MHWS)	Mean Low Water Spring (MLWS)	Mean High Water Neap (MHWN)	Mean Low Water Neap (MLWN)
6.4 mCD	0.5 mCD	5.4 mCD	1.4 mCD

3.3. Waves

A review of the Noble Denton (2009) report suggests if waves are an important function of both the hydrodynamic and sedimentary regimes, then wind waves are the most important type. The fetch across the River Thames is insufficient to produce higher energy swell waves or long period waves.

Noble Denton (2009) also referred to wave reflection. Reflection modelled by Noble Denton (2009) suggests that the waves hitting the wall behind the pontoon would be reflected back off the wall. This may be a factor preventing siltation in the pontoon area.

3.3. Currents

The area undergoes strong tidal currents on all tides, with strong and dynamic flows on the ebb tide in particular. HR Wallingford (2009) suggests that the post-construction alteration to the flows will be small, although the proposed development of the pontoon is not particularly well-aligned to the flow. This is however reported by Gifford to be due to navigational restraints imposed by the PLA barge in the locality.

A small current increase is expected adjacent to the river wall. Depth averaged velocities at the new pontoon are expected to increase by 0.1 ms^{-1} on the peak flood and remain the same on a peak ebb, according to the HR Wallingford report. However, depth averages through tide velocity differences suggest a pattern of slowing velocities around the pontoon. HR Wallingford suggests that there may be slight localised increase in velocity after installation.

The time series analysis undertaken by HR Wallingford (2009) shows little change in peak speeds at all locations. Velocities do not exceed 1.1 ms^{-1} with no major change in flow direction.

Figure 4 in the HR Wallingford report (2009) illustrates the existing and proposed speed magnitude and direction for the pontoon site at three hours before High Water (HW). Velocities vary from between 0.0 and 0.6 ms^{-1} across the River Thames to the centre of the river (incorporating the pontoon development). The velocities and vectors show little variation between the current and proposed situations. Other figures extracted from the HR Wallingford (2009) report suggest little variation across the site in vector speed and direction between three hours before High Water and one hour before High Water.

Figure 7 in the HR Wallingford report (2009) illustrates the existing and proposed speed magnitude and direction at High Water (HW). Again, little spatial variation occurs between velocity and vector directions.

Figure 8 in the HR Wallingford report (2009) illustrates the existing and proposed speed magnitude and direction for the pontoon site at one hour after High Water (HW). The direction of the vectors differs from High Water (Figure 7; HR Wallingford, 2009) with an upstream orientation. At two and three hours after HW, the velocities are faster within the intertidal zone (Figures 9 and 10; HR Wallingford, 2009) than on previous tides.

4. Discussion

4.1. Temporal and Spatial Bathymetric Variation

Analysis of the historic bathymetric series suggests that temporal changes are very small between surveys Mean annual change is a matter of centimetres. There could be several reasons for changes in depths; the most likely is factors resulting from dredging. The dredging regime in this area is not well-defined. Advice from Port of London Authority has, however, been sought. They inform that no channel or local dredging has been undertaken in recent years. Dredging near to HM Customs pontoons up and downstream of Gravesend Pier is undertaken using agitation dredging processes.

Another reason for bathymetric change can be natural variability in the geomorphic system. Variability in the system can cause sediment redistribution due to either accretion or erosion. The elevation changes are small given the potential magnitude of change caused by the switching of tides and the force exerted on the system caused by the tide ebbing and flooding. The system is essentially in equilibrium.

Seabed mobility or sediment distribution changes can often occur due to mobility in seabed features such as sand bars. The bathymetric charts do not illustrate such features, although there are spatial variations in the contour morphologies.

It has been noted upon comparison of the Admiralty charts that some of the contours have varied position spatially. This change is likely to be a natural change caused by sediment accretion or erosion in response to either dredging within the Thames, storms or obstruction to the whole water column.

4.2. Sediment - Siltation and Scour Factors

Wind waves are considered to be small and would not impact on sediment mobility. They are highly unlikely to have an impact on sediment redistribution over and above the processes that are already occurring.

Reflection off the flood wall onto the pontoon, as suggested by Noble Denton (2009) may cause sediment redistribution, maintaining an active seabed. This would potentially limit sedimentation, hence reducing the requirement for dredging.

The change in current velocities between the existing site and the proposed pontoon are very small, according to the HR Wallingford report (2009). An increase is noted within the intertidal area fronting St Andrew's gardens. However, this is slight, and would not change the integrity of the intertidal zone. Once deposited as cohesive beds, there needs to be a significant increase in current velocities to encourage redistribution of sediment into the water column.

In contrast, the area between the pontoon and the seawall is unlikely to dry out, except on an exceptionally low tide. Likewise, there needs to be a sufficient decrease in current magnitude and velocity to cause an increase in deposition. This is outlined in the shear strength curve (Figure 14). This depicts the magnitude of velocity which cause redistribution or settling of sediment within a marine environment.

A variation in current directions is unlikely to exacerbate siltation or sedimentation rates because they are so slight.

There is a propensity for sediments to become transported within the water column, and only deposited when shear stresses drop with a corresponding drop in both water elevation and current velocities, particularly on slack water. The magnitude of the tide elevation change and corresponding water velocity is likely to erode sediment and entrain it within the water column, hence the turbidity of the water. This is a natural process, and will not be exacerbated by the pontoon development. The corresponding entrainment of suspended sediment is not likely to cause a problem to intertidal and benthic habitats further downstream. The scale of entrainment, transport and deposition is likely to remain the same as under normal circumstances. In fact, it is likely that the scale of change induced by a storm or very large spring tide would have more of an impact.

Muds remain in suspension for the majority of the tide. Generally, mud is transported on both the ebb and flood tide; via suspended sediment transport pathways. Suspended sediment concentrations within the water column (turbidity) may vary throughout the tidal cycle. At maximum current on a spring tide, concentrations are likely to be uniform throughout the water column. As the current strength diminishes, turbulence is usually insufficient to maintain suspension, thus resulting in sediment deposition. The impact of nearbed shear on floc sizes within suspended sediment concentrations throughout the water column is higher when the proximity of the bed is closer (Van der Lee, 1998).

Currents and vessel traffic already occurring in the river, disturb much of the sediment. Overall sediment disturbance is unlikely to increase as a result of the pontoon development.

Depth averages through tide velocity differences suggest a pattern of slowing velocities around the pontoon. HR Wallingford (2009) postulate that there may be a slight localised increase in velocity after installation. This change may re-suspend some sediment, transporting it downstream. This change has not been quantified but is likely to add little to the suspended sediment regime already present in the Thames. The use of the Critical Shields' stress parameter can be used to explain this point.

4.3. Critical Shields' Stress Parameter

Shear stress defines the amount of force required to transport differing sediment types, such as cohesive and cohesionless sediments. Cohesionless sediments comprise sand and gravel size particles. Fine muddy sediments, which comprise silt and clay, are cohesive (Woodroffe, 2002). These grains are usually held together by electrostatic forces (flocculation). Organic films increase cohesion, and mean that greater forces are necessary to entrain them. In the case of muddy sediments, the stress applied results in a strain (change in unit length), which increases until the yield strength is reached (plastic limit) or until they undergo liquefaction (van Rijn, 1993).

Sediment entrainment thresholds occur at the critical shear velocity. This primarily depends on grain size. For turbulent flows over a plane bed Shields' parameter relates flow velocity and grain diameter, but the nature of the relationship is complex where the nature of the substrate is irregular and grain sizes are varied.

Variation in the threshold of movement for different grain sizes was first postulated by Hjulström (1935) and defined as the Hjulström curve; (Figure 9). Although there has been more variability demonstrated for fine-grained sediments than the curve shows, it indicates the greater cohesion of muds. Above a grain diameter of 0.6 mm, there is a more regular relationship between grain size and the velocity or critical stress required to entrain sediment (Figure 9).

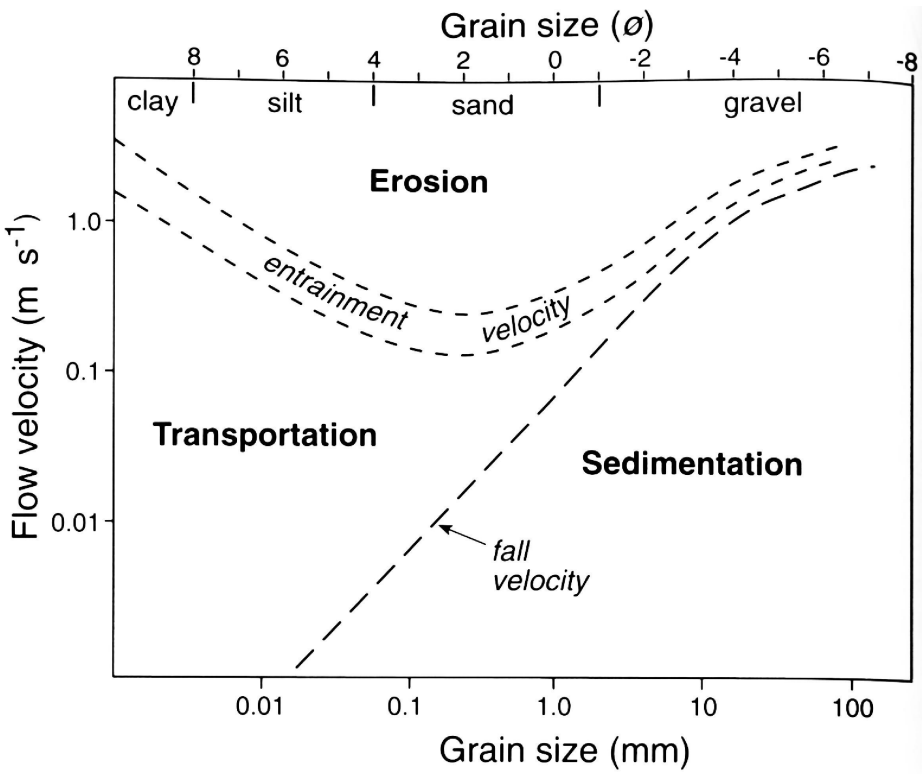

Figure 9. Hjulström curve (extracted from Woodroffe, 2002)

Shear stress entrainment thresholds can only be postulated from using the Hjulström curve and the associated sediment sizes found within the Thames at the pontoon site. These are not definite as there is a lack of detailed sediment and flow and sediment data are lacking for this site. Table 4 outlines typical sediment sizes deemed to be present in the Thames and typical velocities required to entrain sediment (shear velocities).

The Hjulström curve (Figure 9) suggests that the velocity required to induce erosion of sediment would need to be 0.2 to 1 ms^{-1} for sand. Clays and silts require 0.3 to 2 ms^{-1}. Most sand transport occurs near peak ebb/flood currents. Velocities of 0.1 ms^{-1} are required to transport quantities of unconsolidated sediment; 0.1 ms^{-1} flows are needed for suspended sediment transport of clay. The velocities in the River Thames exceed this, hence the high turbidity and transport rates of suspended sediments.

The erosion rate of mud increases with bed shear stress, once the critical shear strength is exceeded. However, resistance to erosion of fine grained particles increases progressively with decreasing grain size. Therefore, it is more difficult to erode muddy sediment present on the banks and beds of the Thames.

Table 4. Sediment description and associated shear velocity

Sediment description	Sediment size	Shear velocity
Coarse sand	0.5 -2 mm	0.2 to 1 ms^{-1}
Medium sand	0.25 – 0.5 mm	0.2 to 1 ms^{-1}
Silt	0.002 – 0.008 mm	2.0 to 0.3 ms^{-1}
Clay	Below 0.002 mm	2.0 to 0.3 ms^{-1}

At Gravesend, this means that suspended sediment is an important process local to the pontoon. It also means that any sediment deposited, it has a high resistance to erosion, so requires fast velocities to re-entrain the sediment. However, as the pontoon is going to be constructed in deeper water, the risk of this occurring is much lower due to faster velocities.

4.4. Dredging Programme

Given the evidence reviewed in this report, and water depths at the location of the pontoon, it is very unlikely that any maintenance dredging in the locality of the pontoon will be required to maintain depths. The pontoon is not causing an obstacle to river flow, which means that tidal flushing will still occur.

Any deposition beneath the pontoon is likely to be caused by natural processes within the riverine system, which would have occurred anyway regardless of the presence or not of the pontoon, and does occur beneath Gravesend Pier at present. However, as it has been postulated that there will be a slight increase in both currents and wave reflection, which will also cause

disturbance to the water column, there may be disturbance to the river bed, causing slightly less potential for sediment accretion.

Increased velocities are likely to result in some entrainment of the river bed sediment. Although not quantified it is only likely to be surficial. The magnitude of change will be greatest during construction and initially after completion. Once the physical system has reached equilibrium, the natural cycle of change will again operate.

5. Conclusions and recommendations

The evidence suggests that the geomorphic regime has undergone small perturbations over time, particularly within the seabed. Essentially, the seabed is in equilibrium. Most variation to the system is as a result of suspended sediment, which is not of local origination, and forms a component of the wider geomorphic system.

Overall, it is anticipated that the pontoon will have little impact on flow regimes, waves and the sedimentary regime. From reviewing the data in the HR Wallingford report (2009), and the Noble Denton wave analysis report (2009), it is felt that there will be little change to the geomorphic regime as a result of the pontoon.

The currents will also change little, although it has been suggested there will be a slight increase in current velocities.

As a result of increased velocities, accretion of sediment is likely to be less prevalent due to increased shear stresses and increased competency of the water to transport suspended sediment. Any potential increase in sediment transport will be small, however.

Due to the location of the proposed pontoon as described in Section 1.2, no capital dredging will be required. A slight increase in flows in the locality of the pontoon, plus very localised vessel wash, will mean that maintenance dredging is also unlikely to be required in the future. This conforms to the dredging programme at the majority of other pontoons within the area, which have not been dredged for a long period of time.

Any alterations to both the hydrodynamic and sedimentary system will be slight, if at all. The presence of the pontoon is not likely to increase the magnitude of suspended sediment movement as presently transported with the tide. The switch from high to low tide is likely to cause more change to the sedimentary regime than any change caused by the pontoon. Natural habitats will not be affected by a sudden increase in sediment deposition and hence smothering.

It is recommended that the future pontoon operator should monitor depths at the pontoon on an annual basis. In addition, PLA charts of the surrounding area should be consulted when produced.

6. References

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