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Effects of offshore dredging - Results of the SANDPIT project

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EFFECTS OF OFFSHORE DREDGING – RESULTS OF THE SANDPIT PROJECT

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Abstract

An important aspect of any proposed dredging, whether for navigation or aggregates, is to understand and be able to predict the consequential impacts on the surrounding seabed and nearby coastlines. The recently completed three-year, 17-partner, 7-nation European project SANDPIT has addressed these questions, focussing especially on the hydrodynamic, sediment dynamic and morphodynamic impacts, and the time-scales over which they apply. Defra co-funded the contribution of HR Wallingford to the project, and this paper presents a brief summary of the project as a whole, with more detail on the work co-funded by Defra.

Introduction

Offshore sand and gravel deposits are increasingly under pressure as a resource for dredging material for building purposes and for beach nourishment. Concerns about the environmental impacts both in the vicinity of the extraction and on adjacent coastlines have recently become greater.

The SANDPIT project (2002-2005) was a European collaborative research project with 17 partners in 7 states aimed at addressing questions focussed especially on the hydrodynamic, sediment dynamic and morphodynamic impacts, and the time-scales over which they apply.

The project as a whole achieved the following:

- Tabulations (for UK, Netherlands, Denmark, France, Norway and Italy) of national dredging quantities, types and uses; their regulation procedures; their environmental impact study requirements; and any evidence of harmful effects (none had been found).
- A review of the state-of-the-art of hydrodynamics, sediment transport and morphodynamics (i.e. changes to the sea bed and coastline) related to extractions from offshore pits and sand banks, and also impacts on, and recovery of, the ecology.
- Calculations of the net and gross annual sand transport (on the ambient sea bed) at four sites in the seas off the UK, Netherlands and France
- Measurements of waves, currents and sediment transport at a sandy site in 10m of water off the Dutch coast, including current profile data collected by HR Wallingford using an Acoustic Doppler Profiler (Hearn*,* 2004)
- Laboratory measurements of ripple formation and sand transport by waves and currents
- Substantial advances in the methods of calculating the sediment transport rate at a point on the sea bed in response to combined waves and currents, including the "SedFlux" model at HR Wallingford (Van Rijn *et al,* 2005, Papers D, E and AD)
- Substantial advances in the methods of computing the distributions of currents and waves, the distribution of sediment transport, and the resulting changes in bed morphology such as infill and migration of a dredged pit, and recovery of a dredged sand bank, including HR Wallingford's PISCES modelling suite, Van Rijn *et al,* 2005, Paper AO)

- Simple methods of quickly calculating infill rates of pits (HR Wallingford, Van Rijn *et al,* 2005, Paper E)
- Analysed comparative data of the behaviour after dredging of various pits, trenches, spoil dumps, and sand banks off the Dutch and French coasts
- Scenario testing using models of the inherent stability and recovery of sand banks and sand waves at sites in the North Sea, French Atlantic coast and Straits of Messina (Italy)
- Scenario testing using models of the infill and migration of idealised pits, including impacts near the pit, and the changes at the adjacent coastline, for a wide range of contrasting sizes and shapes of pit, location, wave-current climate and sediment types (Van Rijn *et al,* 2005, Paper I).

Details of all these results are too lengthy to present in this short paper. Full details can be found in the book that presents the results of the SANDPIT project (Van Rijn *et al*, 2005). The book contains both summaries aimed at end-users, and detailed reports on the scientific results. The remainder of this paper summarises the answers found, using the scenario-testing for pits, to a number of questions that were posed by UK, Dutch and French end-users at the start of the project.

Scenario testing - methodology

A "baseline" extraction pit was specified in terms of its dimensions, location, and wave/current climate. This was modelled by all the participating partners, and then various options of dimensions or location were explored by altering the inputs and set-up of the models. The baseline case around which the scenario tests were varied was designed to be schematic and non-site-specific, yet based on realistic quantities. A simplified version of a large, actual Dutch pit was chosen, schematised as an inverted truncated pyramid with depth of 10m below sea bed, base dimensions of 100m cross-shore and 900m longshore, with sideslopes of 1:20, giving dimensions at the ambient sea bed of 500m x 1300m, and an excavated volume of 3.5Mm^3. This was set 1.5km offshore at a depth of 10m on a schematised coastline based on the cross-shore sea-bed profile off the town of Noordwijk, NL, at the site where the SANDPIT field measurements were made.

The pit and its location were defined by certain quantities ("axes") that were varied around the values used as the baseline to achieve the scenario testing. These "axes" were:

- Water depth at which the pit was centred (on a fixed cross-shore depth profile), from 5m to 20m
- Pit shape, varying length, breadth, depth & aspect ratio for fixed volume of 3.5Mm^3
- Pit volume, from 0.4 to 28Mm^3 for fixed aspect ratios of pit length:breadth:depth
- Distance from shore by varying cross-shore profile (with pit location fixed at depth of 10m)
- Sediment characteristics, finer and coarser (representing different EU coastlines)
- Tides, larger (e.g. UK, France) and smaller (e.g. Mediterranean, Baltic)
- Waves, larger (e.g. Atlantic coasts) and smaller (e.g. Mediterranean)

The users posed 20 well-defined research questions that were to be addressed by the model outputs. These, combined with the 7 scenario axes, resulted in a large number of output quantities that were presented in full by Chesher and Soulsby (2005), a selection of which are summarised below.

Infill and migration rates of pits

An important question posed by the end-users was: *Over what time-scales will the effects be felt?* This can be measured in terms of the half-life of the pit, i.e. the time after which the pit has only 50% of the originally excavated volume. For the baseline case, the half-life was predicted by most of the modellers as between 3 and 8 years. The half-life is longer for larger pits (increase/decrease of half-life by factor 5 for pit volumes increased/decreased by factor 8 respectively). Placing the pit in deeper water (on a given cross-shore bed profile) increased the half-life up to a point (moving the pit from 5m to 10m depth doubled the timescale, but there was no clear trend for depths between 10 and 20m). The half-life appeared to be relatively insensitive to the shape of the pit (varying the length, breadth, depth and plan-shape while maintaining constant volume varied the half-life by less than factor of 2).

Effects on waves, currents and sediment transport in vicinity of pit

An excavated pit will modify the currents and waves, and consequently the sediment transport, both immediately above it, and in a surrounding area. User questions are: *How large are these changes, and how far does the area of influence extend?* The model scenario tests gave the following answers.

For the baseline case, there is a reduction in **current speed** in the pit of 10-20%, and an increase in the area surrounding the pit of a comparable amount. Varying the dimensions and location of the pit showed that larger pits have a bigger impact on the currents outside the pit – up to 40% larger for the largest pit simulated. Pits in deeper water have a reduced impact on currents in the pit (a reduction of only 10%), whereas those in shallower water have a greater reduction (up to 25%).

For the baseline case, there is an increase in **wave height** in the centre of the pit by 1-5%, and a larger increase reaching 10-15% in the area surrounding the pit. Varying the design and location of the pit showed that smaller pits give rise to smaller impacts, but the magnitude of the impact on wave heights is not sensitive to the other factors tested.

For the baseline case, in the centre of the pit a reduction in the **sediment transpor**t rate of 40-90% was predicted, and outside the pit the transport rate increased by 70-200%. However, large differences in the magnitudes were found between models. Outside the pit, shallower pits have a smaller impact (although over a greater area) than deeper pits of the same volume.

For the baseline case, the **influence area** within which the currents, wave heights and sediment area were modified by a factor 5% extended a distance of order 1-1.5km around the pit. This zone of influence reduces for pits in deeper water, and increases with pit size, (and vice versa).

Effects felt at the coastline

The end-users asked: *How large are the effects on waves and currents at the coastline? How does this affect the longshore transport? What effect does this have on the beach?* Pit factors affecting the coast were assessed by determining the changes on the 5m contour, since the type of models used in this study are not designed to simulate surf-zone processes.

A large pit (3.5Mm^3) at 10m depth off the Dutch coast (the baseline case) was predicted to have the following impacts.

For the baseline case, pit-induced changes to the **currents** were of the order of 10%. The impact on currents at the coast is bigger for larger pits, with an eight-fold increase in pit volume giving rise to a two-fold increase in the impact. Pits further offshore (for a fixed depth at the pit) have a smaller impact: a pit at 1.0km offshore alters the currents (positively and negatively) by between –18% and +11%, whereas a pit at 2.4km alters the currents between –6% and +10%.

For the baseline case, pit-induced changes to the **wave heights** were of the order of 10%. Pits in shallower water (nearer the shore) give rise to a larger impact (siting the pit in a depth of 5m increases the impact to 50%).

For the baseline case, the longshore transport rate on the coast was impacted by the presence of the pit by order –50% to +50%. There was a greater impact for larger pits and for pits in shallower water. For the same size pit, placing the pit further from the shore (but at a constant depth) reduces the impact (100%, 30% and 15% impact for offshore distances of 1.0, 1.5 and 2.4km respectively).

Changes to the beach were assessed by examining the maximum (+ or -) changes in depth along the original 5m depth contour, because the models were not designed to model detailed processes right at the coast. For the baseline case, changes between –2m and +1m over 20 years were found. The changes decreased markedly for pits of smaller volume (changes between 0 and 0.5m for a 0.4Mm^3 pit) and increased for pits of larger volume (changes between –3 and +2m over 20 years for a 28Mm^3 pit). For the same size pit, siting it further offshore decreased the changes in the bathymetry at the coastline (typical values of 1.4m, 0.5m and 0.1m impact for offshore distances of 1.0, 1.5 and 2.4km respectively).

Optimum location and dimensions

Deciding the optimum location and dimensions of pits involves a complex value judgement based on weighing the relative importance of physical and ecological impacts against the economics of the extraction, and the competing merits of low impact and short impact-duration. For example, placing pits further offshore in deeper water will reduce the coastal impacts but increase the cost of extraction. Likewise, a fast infill time means that the impacts will only be felt for a short time, but also implies a large disruption to the sediment budget of the area to deliver the necessary sediment. Such decisions were outside the scope of the SANDPIT project, which was purely concerned with improving scientific predictions. The decision process itself, based on scientific and other considerations, is within the ambit of the regulatory authorities. This topic was addressed by Diesing *et al* (2004), who concluded: "…..there is no 'ideal' location for marine sediment extraction. The appropriate place for extraction should be a well-balanced compromise allowing relatively fast regeneration together with a minimised impact on the coastal sediment budget."

Conclusions

The results can be summarised in qualitative terms, including:

- The half-life for infill increases with deeper water and larger pit volume.
- The maximum changes to the current speed in the vicinity of the pit increase with volume of pit and shallower water.
- The maximum changes to the wave height in the vicinity of the pit increase with volume of pit, and shallower water
- The area of impact on currents, waves and sediment transport increases with size of pit, and shallower water
- The maximum changes at the coastline to the currents, waves, longshore transport and bathymetry increase with volume of pit, and decrease with distance of pit offshore.

The qualitative results obtained from the scenario testing should assist with choosing the initial design and location of sand extraction pits in the seas around Europe. For more detailed design, the quantitative results reported by Chesher and Soulsby (2005) can be consulted. Finally, candidate designs can be tested using one of the detailed morphodynamic models described in the book by Van Rijn *et a*l (2005).

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NOTES

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