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THE IMPORTANCE OF BED MATERIAL CHARACTERISATION IN PLANNING DREDGING PROJECTS

ABSTRACT

Practical experience of dredging projects has demonstrated the importance of understanding the nature and composition of seabed material before dredging starts. The dredging industry strongly encourages clients to undertake detailed geotechnical investigations at an early stage in project design to avoid any expensive “surprises” once work starts. Despite this, mainstream engineering consultants are not taking specialist advice and proponents are not being advised about what to do, nor does it appear that dredging contractors and specialist consultants are being consulted at an early enough stage in project development.

Attempts to make very minor cost savings early in a project by undertaking inadequate sampling and testing of bed materials routinely leads to serious project problems with significant consequences in terms of project schedule, project cost and company profit. Consequently, the reputation of the dredging industry suffers and the perception of dredging being a claim-ridden activity persists.

This article focusses on when, how and why projects suffer as a consequence of inadequate sampling and testing of bed materials. Having identified the problems guidelines are set out to allow these to be avoided in the future. This article is based on a paper which appeared in the *Proceedings* of the WODCON XIX in Beijing, China in September 2011 and has been published here in a revised version with permission.

INTRODUCTION

When planning dredging projects, a key factor is the ability to describe the site and define the nature of the ground. This information, together with physical, environmental, operational, statutory and legal constraints provide the tendering Contractor vital information which, in conjunction with the Specification, helps the Contractor understand what work has to be done.

There is little doubt that the importance of accurate and comprehensive geotechnical information is necessary to facilitate the design and execution of any construction project (Figure 1). However, time and again it is found that insufficient, inaccurate and irrelevant data are used to inform dredging projects.

The purpose of this article is to address factors that are of specific relevance to dredging rather than maritime structures as a whole, and which therefore have a significance that may not be recognised when planning the development of a maritime project. Model results are used to help illustrate the points made within the article.

Above: A geotechnical site investigation for a major marine development with, nearshore, a small elevated platform for geotechnical sampling through a shallow rock seabed and, offshore, a landing craft for soils sampling in excess of 5 m water depth. Characterising bed material prior to dredging is essential.

Figure 1. Close-up of the elevated platform for geotechnical sampling through a shallow rock seabed.

Whilst many examples of bad practice (and resultant delays, costs and legal action) exist, discussion of specific projects is not considered appropriate and is not undertaken here.

For any dredging project, the understanding of the bed material, its variability, how it behaves when it is dredged, transported, placed or enters the water column is vital to determining how best to dredge it and how best to mitigate impacts both in the near and far field.

WHAT IS WRONG

Dredging works are frequently a component of a large maritime engineering development scheme, such as a new harbour, barrage or immersed tube crossing. Dredging is perceived as being a simple operation, far less complex, in terms of design, than berthing structures, barrages, locking structures and immersed tubes. In some ways the dredging design *is* simple and this traps the design engineer into thinking that the dredging activity is less important than other construction activities in the project. This is not so; it is quite the opposite in fact.

The value of the dredging work often equals and may exceed the value of the other works being carried out. A small change in the sub-soils along a berthing line may cause there to be increases in construction cost because of the need to lengthen piles or carry out soil replacement. A similar small change in the sub-soil in the dredging area may have a profound effect on dredging productivity and cost the contractor 10% or 15% more – which may be the difference, for the dredging contractor, in making a profit or loss on the project. In some cases, where for instance environmental sensitivities are heightened, the costs or impact of the differences may be far more fundamental – possibly bringing the works to a halt until the problems have been overcome.

Another factor that influences the amount of preliminary sub-soil investigation carried out for dredging works is that this type of work is expensive and moderately difficult to execute with the necessary quality, both on site and during laboratory testing. Clients are thus faced with significant expenditure upfront, sometimes on a project that only has a slim chance of getting past the planning stages. They are naturally reticent about spending this risk money. This makes it difficult for design engineers to convince clients that they should spend money upfront. One objective of this article is to assist design engineers in educating clients to understand the site investigation needs for their work.

A third problem that is found is that the design engineer is unaware of the factors that influence the environmental effects of dredging works. This is unsurprising. Dredging itself is a sub-set of maritime civil engineering, and the environmental effects of dredging are a sub-set of dredging works. As a result, specialist support is needed to understand the site investigation requirements (Figure 2).

PLANNING A SITE INVESTIGATION FOR DREDGING WORKS

The scope of the works

When site investigation works are going to be expensive, such as in maritime sub-soil investigation, a tiered approach to investigation is recommended. This approach has been described elsewhere (Bray 2008), both in terms of the approach to the investigation and the evaluation of the data so collected. The intent is to reduce the quantity of upfront expenditure in the initial stages, so that only sufficient data are collected to determine:

- determine whether the project is likely to be technically and financially feasible;
- identify how more detailed investigations can be tailored to suit both the project envisaged and the ground conditions found in the initial stage; and
- ensure that investigation methods, and sample collecting and testing, are all suitable in extent and relevant to the types of dredgers to be used in the works.

Subsequently, further investigations can be planned if it is determined that the project is going forward. However, at this stage the client is likely to be more favourably disposed to carry out more extensive investigations, because the project is moving forward and the investigations are being moulded to the type and nature of the project and the construction methods likely to be needed. For example, the initial investigations may have shown that a seismic survey would reduce considerably the cost of future investigations, combined with only a limited borehole campaign.

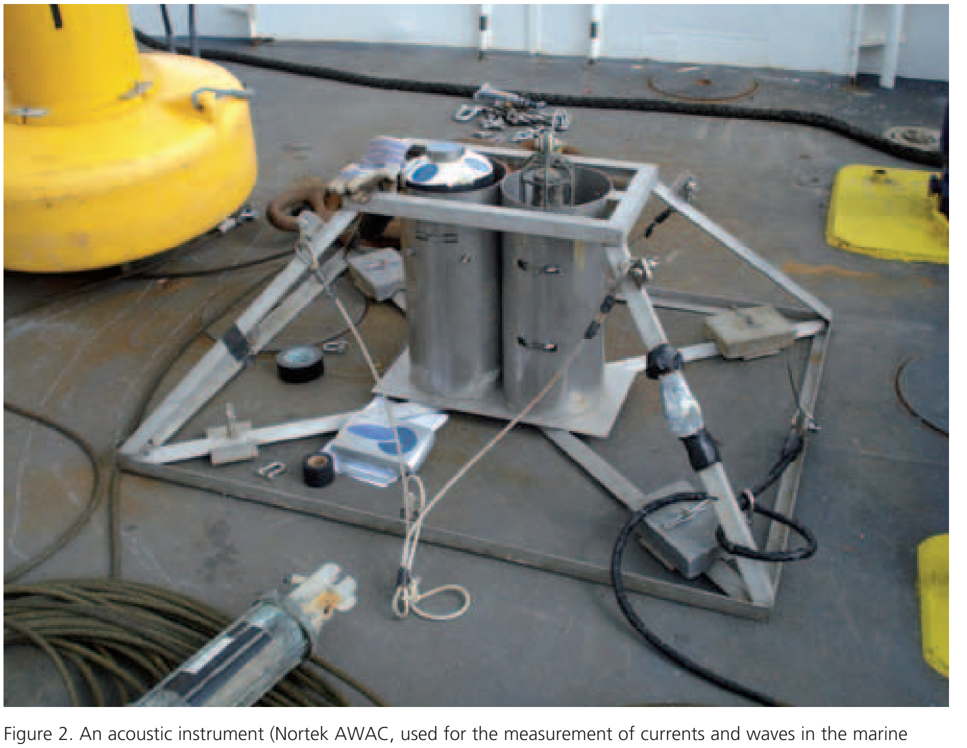

Figure 2. An acoustic instrument (Nortek AWAC, used for the measurement of currents and waves in the marine environment, is one of many tools for gathering essential geotechnical information.

Figure 3. A Vibrocorer in use during site investigation works.

Figure 4. Undertaking undisturbed soil sampling using a ship-mounted rotary drilling rig as part of offshore site investigation works for a major marine development.

Focus of the investigations

When design engineers are considering the information they require for a berthing structure or reclamation area, the focus tends to be on bearing strata and the compressibility of any weak overlying soils. This is not so for the dredging engineer or contractor, where a number of other parameters are of vital importance.

Firstly, the engineer/contractor needs to know what type of dredger is best suited to the materials on site and the method of excavating and moving this material to its final destination.

Secondly, they need to evaluate how productive the dredging equipment will be and, finally, what the environmental effects of the dredging works and construction methods are likely to be. In addition, if the material is to be used for some beneficial purpose, the engineer will need to know whether its characteristics have changed during the dredging, transport and placing processes, and, if so, what its final state is.

To carry out these evaluations, information about both the strong and the weak materials on the site is needed. Therefore the number and locations of the boreholes, vibrocores or other sampling methods used to investigate and collect samples must be adjusted accordingly. It is too prescriptive to suggest a formula for determining the optimum number of investigative points. These will be determined by the overall geology of the site, the sensitivity of the probable dredging method and, to some extent the stage of the development at that time.

A potential method for determining where to focus marine site investigation resources is given in the following section. Additional information can also be gained by talking to Dredging Contractors during the planning of the site investigation works.

SAMPLING AND TESTING

Sampling

The following points are particularly relevant when considering sampling:

- Weak soils need to be collected with minimum disturbance. Hence wash boring is not particularly useful. Ideally, the traditional shell and auger methods should be used. Not only do they allow for identification of every change of strata, but samples taken during the boring, although disturbed, are generally representative of the material at the sampling depth;
- Vibrocoring is an alternative method for obtaining information about weak material, but it must be recognised that the depth of investigation may be limited by the maximum length of core recoverable relative to the required dredge depth or material that is too strong to be penetrated (Figure 3);
- Weak soils need to be sampled and tested frequently. It is almost always the case that there are not enough samples or the testing carried out has been limited. Engineers are not just interested in a range of values. They need to know how the strength and size characteristics vary across the site (Figure 4);

- Detecting the variability of the materials on the site is one of the most important objectives of the site investigation;
- Correct logging of rock cores is vital. The quality of the rock is as important as its strength. Hence core recovery, RQD and Fracture Index should be recorded on all cores.

Testing

Testing of samples needs to reflect the sensitivity of the dredging method to changes in soil or rock characteristics. For example, the standard sieve sizes are not necessarily ideal for testing loose granular materials, particularly when hydraulic methods of excavation are envisaged.

The shape of the PSD curve between 80 and 200 microns is very influential in determining overflow losses from trailing suction hopper dredgers (TSHD, see below) and the sizes below 20 microns are also very important for determining the fill characteristics of materials and the permeability, which will affect consolidation of fill.

Where soils or rocks are particularly weak, it may be necessary to carry out specific tests to assess degradation of dredged materials during the dredging process or thereafter. Testing of materials to determine the way in which they break-up can be important for two primary reasons:

1. there can be a very significant impact on the losses from a dredging project and, consequently, the likely environmental impact (potentially affecting the viability of the project); and
2. if the material is to be used for reclamation then the design and construction of the reclamation and the mechanical properties of the fill will be very heavily influenced by the character of the material which is liberated by the dredging process.

Dredging has the potential to degrade bed materials in different ways. These can be summarised as follows:

a) Mechanical breakage where the plant comes into contact with the bed (e.g., at a cutter head or a backhoe bucket);
b) Impacts / contacts between clasts / particles (e.g., in pumps and pipelines);
c) Material coming into contact with pipe and pump surfaces; and
d) Flow of water around fragments / grains.

A number of established lab tests exist for measuring the breakage / abrasion of rocks /

Figure 5. Laboratory tumbling equipment is sometimes used to simulate the degrading of sediment during dredging.

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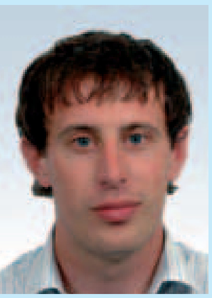

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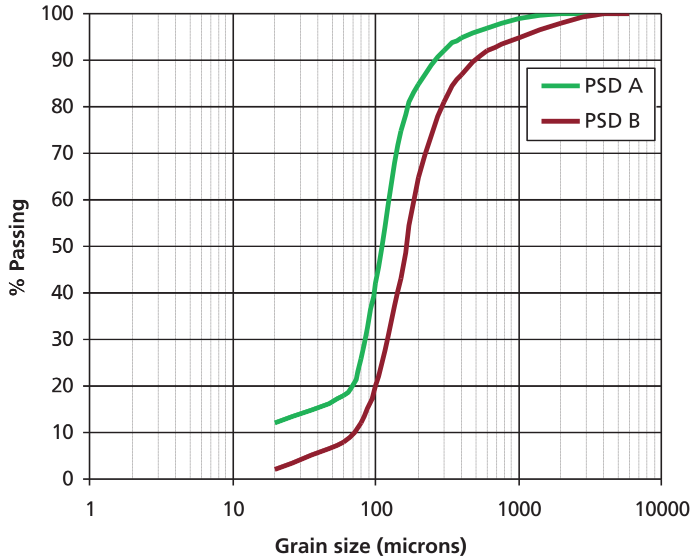


Figure 6(a). Parallel shift in PSD.

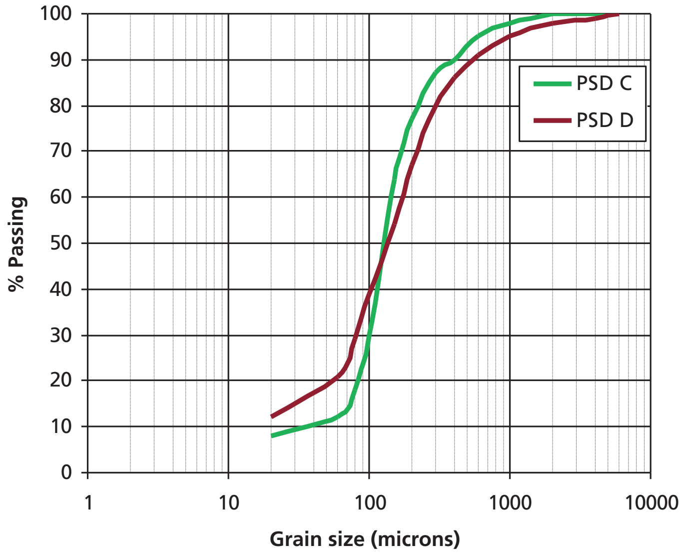


Figure 6(b). Rotational shift in PSD.

granular material, these include:

- Los Angeles test
- Deval Test (aggregate attrition value)
- Micro-Deval test
- Aggregate Abrasion Value (AAV) test
- Polished Stone Value (PSV) test
- Slake Durability test

However, none of these tests has been designed to assess the impact of dredging processes on materials; instead they tend to have origins in industries such as road construction. As a consequence, none of the tests represents well the physical conditions that materials are subject to during dredging. For example, both the Los Angeles test and the Micro-Deval test both involve placing samples in a rotating cylinder with steel balls, while the Aggregate Abrasion Value test involves pressing samples against the surface of a steel disc while feeding with Leighton Buzzard sand.

Previous studies of abrasion of both grains and shelly material have shown that failure to properly represent the physics that materials are subject to can lead to unexpected / incorrect results. Ngan-Tillard *et al.* (2009) found that, using the French Micro-Deval test, quartzitic sand suffered unexpectedly high degradation as compared with carbonate sand (the shape of the carbonate grains leading to them being suspended away from the bottom of the cylinder). The authors sought to address this perceived anomaly by changing the rotation speed and the character of the steel balls used. Similarly, the use of tumbling barrel experiments to simulate shell abrasion in fluvial environments has been shown to have serious shortcomings (Newell *et al.* 2007) (Figure 5).

More representative, specifically designed, tests are required to properly represent the physical processes that materials are subject to during dredging. In the absence of such tests, existing laboratory methods should be used with careful thought, thorough procedures and caution.

EXAMPLES OF SITUATIONS WHERE SITE INVESTIGATION RESULTS ARE CRITICAL

For the examples presented in the following section, costs have been developed using the suite of HR Wallingford Dredging Research

Table I. Cost uncertainty resulting from varied ground conditions

Item	Sand	Soft Clay	Medium Clay	Stiff Clay	WK Rock	MS Rock	VS Rock
Marine operations platform	Base Case	+20%	+10%	same	+10%	+20%	+30%
Berth	Base Case	+20%	+10%	same	+10%	+20%	+30%
Trestle	Base Case	+20%	+10%	same	+10%	+20%	+30%
Breakwater	Base Case	+50%	+10%	same	same	same	same
Construction Dock	Base Case	+30%	+10%	same	+5%	+10%	+20%
Dredging	**Base Case**	**+5%**	**+10%**	**+20%**	**+100%**	**+300%**	**+500%**
Shoreline protection	Base Case	+30%	same	same	same	same	same

Dredger Simulation Models. The HR Wallingford Dredging Research Dredger Simulation Models are a set of proprietary models that take into account the physical processes involved in the excavation and transport of material for a variety of standard dredge plant. Each model has the ability to deal with operator controlled usage and variable ground conditions to estimate production. The costing modules use the soil characteristics and production estimates to develop wear rates and incorporate the CIRIA Cost Standards for Dredging Equipment (2009) to calculate the depreciation and interest, maintenance and repair, insurances, crew and fuel costs that all factor into the cost of the plant and the unit rates produced.

Trailing suction hopper dredger (TSHD) operations

Just a small parallel shift in the particle size distribution (PSD) of material being dredged can have a marked effect on the cost and execution of a dredging project. The example is given whereby the initial site investigations for a sand sourcing study are limited with only a small number of samples taken to characterise the area.

The results of PSD analysis identify an average PSD akin to PSD A as shown in Figure 6(a). The dredging contractor tenders for the work and is successful on the basis of his price for dredging PSD A. Throughout the execution of the works the contractor discovers that the soils being dredged are better described by PSD B in Figure 6(a), a coarser PSD which produces a higher quality fill. This puts the dredging contractor in an advantageous position as he/she will have to dredge less material in situ to provide the same quantity of fill.

Assuming that PSD A and PSD B both have the same characteristics (density, angularity and mineralogical composition), this leads to lower overall wear on the moving parts of the dredger than had been budgeted for in the tender price, but higher wear in the pipelines ashore. Furthermore, the amount of material lost through the overflow process will also be reduced giving the contractor more freedom to work unrestricted should there be any environmental restrictions in place.

The differences in the required in situ productivities to achieve the same fill output are small (~ 5%) but in the context of a € 50M dredge contract this may amount to a difference in excess of €2.5M, which in this case would be an additional 50% profit to the contractor.

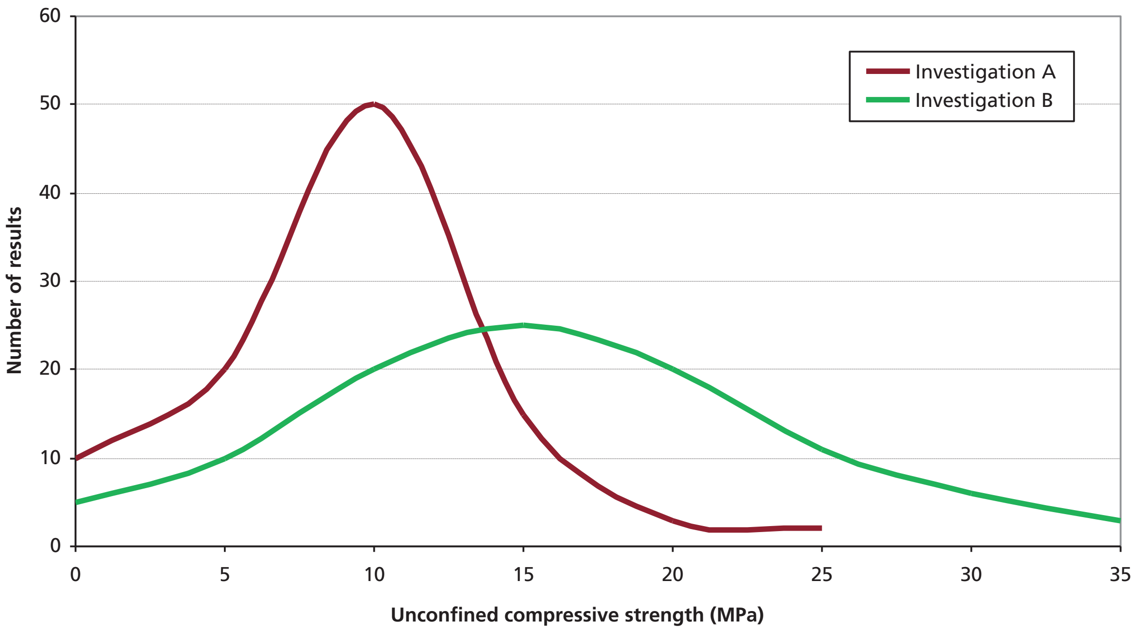
This sensitivity is also present for a shift about the D_{50} of the PSD as illustrated by PSD C and PSD D in Figure 6(b), where the two average soil PSDs have the same D_{50}, but a marginally different amount of sorting. Thus, a similar cost result is obtained if the degree of sorting of a granular material is not assessed adequately.

Cutter suction dredger (CSD) operations

For rock dredging projects, the impact of poorly characterised materials has the potential to have a far more significant impact on the total cost and schedule of a dredging project. Figure 5 shows rock strength distributions obtained from two differently targeted site investigations at the same site:

- The strength distribution obtained from Investigation A is based around limited geotechnical data in the dredge area and comprehensive coverage around the piled structures.
- The strength distribution obtained from Investigation B is based upon a well-targeted and comprehensive investigation across all areas and clearly shows the presence of stronger material that had been missed by Investigation A.

Faulty testing equipment has also been known to be another contributing factor towards producing similar variations in testing results as shown in Figure 7 (i.e., the rock strength is biased downwards).



Unconfined compressive strength (Mpa)	Distribution (%) Investigation A	Distribution (%) Investigation B
0 to 5	30	16
5 to 15	65	44
15 to 25	5	31
25 to 35	0	9

Figure 7. Two rock strength distributions from the same site.

If a comparison of costs is made, based upon the results of Investigations A and B, the total cost of dredging is 51% higher for the rock strength distribution described by Investigation B which would result in the filing of a substantial claim against the client.

The effect of poor Site Investigation results in the context of the overall project

A typical Phase 1 LNG project (up to 8 MTPA) may consist of two berths, one marine operations platform and a 2.5 km trestle, 1300 m of breakwater in 10 m water depth and 15M m^3 of dredging. In total this may amount to an investment of approximately US$ 1 billion. The figures shown in Table I are based on a cost analysis of several Phase 1 LNG projects around the world.

Table I illustrates the cost sensitivity of the individual engineering components of a typical Phase 1 LNG project to variations in ground conditions relative to a base case condition. Table I clearly demonstrates that the potential variability in cost and the level of risk linked to each individual engineering component is the most significant for dredging. The examples presented above show the importance of undertaking adequate site investigations to inform the tendering process and highlighted the relevance for both client and contractor.

Based upon the figures presented in Table I, and bearing in mind that the monetary value of the dredging works could represent 50% of the cost of the marine works, the current definition of an "adequate" site investigation for dredging should be revised. This article suggests that the design engineer should weight geotechnical investigations such that the number of cores drilled is biased towards characterising the areas to be dredged. Involving the Contractor early on is one of the ways of developing the right focus for these investigations. Alternatively, a procedure should be adopted that results in the engineer allocating a sufficiently high enough number of boreholes in the dredging area to permit a reasonable estimate of the cost of dredging to be made. This could be based on a system that takes account of the rough estimates of the values of the marine components of the project (see Figure 8).

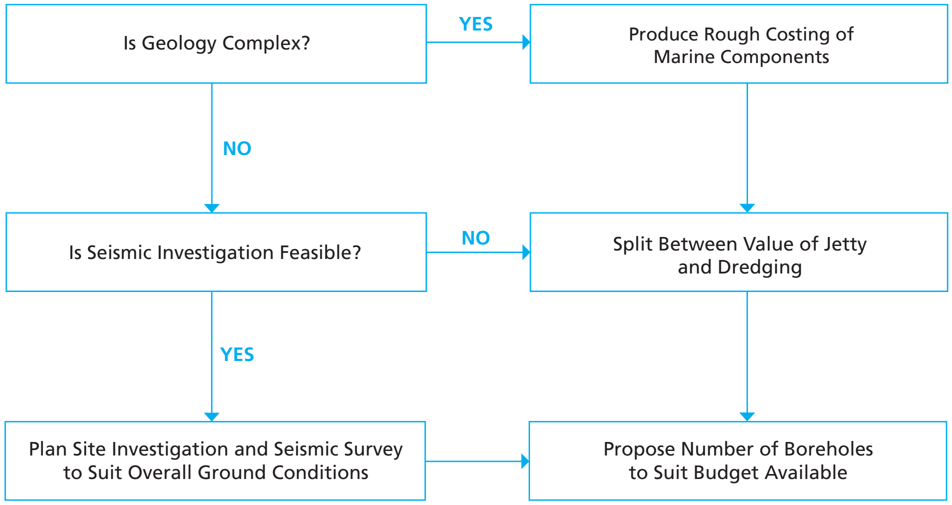


Figure 8. Proposed system to define the number of boreholes to characterise dredged areas relative to other marine components.

CONCLUSIONS

Bed material characterisation for dredging projects is a significant factor in defining how dredging works will be undertaken. It also demands an understanding of the dredging process and how this influences/impacts both the marine environment and areas where dredged material is placed – intentionally or otherwise.

Comprehensive geotechnical information is important for any construction project. How this is collected, assessed and extrapolated is vital to understanding the risk associated with dredging works and ensuring the right equipment is selected first time. This requires an acceptance that the requirements of a dredging site investigation are not the same as those for a construction project. Further, it demands a change in the mindset away from the idea that any site investigation should be developed proportionally to the capital investment per unit area for the project as a whole.

Recognising that the comprehensive all-embracing site investigation is a utopian ideal, this article highlights the key attributes of soils that need to be determined and where testing should be focussed. It explains the significance of material characteristics in the context of TSHD and CSD operations. Following on from this, it highlights a weighting or procedural approach to focussing the marine site investigation resources and encourages project owners to consult dredging contractors and specialist consultants at an early stage in project development.

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