Port of Hastings Development Project

Dredging and Reclamation Options Report

Port of Hastings Development Authority

April 2015

Final Working Draft

8A030026

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Document title	Port of Hastings Development Project Dredging and Reclamation Options Report
Document short title	Dredging and Reclamation Options Report
Status	**Final Working Draft**
Date	April 2015
Project name	Port of Hastings Development Project
Project number	8A030026
Client	Port of Hastings Development Authority
Reference	HAS-CEP0-HY-REP-0032-0

Drafted by	Greg Britton	
Checked by	Greg Britton	
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Date/initials approval	30/04/15	[signature]

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EXECUTIVE SUMMARY

The purpose of this report is to synthesise the findings of a number of studies undertaken under the Dredging and Reclamation Work Package and the Dredged Material Management (DMM) Work Package so as to identify a list of dredging/reclamation/DMM strategies, including ground improvement, that are suitable for taking forward.

Two general port concept options are under consideration for the container port:

- an Along the Shore Option (refer **Figure 4**), and,
- a Basin Option (also referred to as Option 'D' in other reports) (refer **Figure 5**).

An approximate staging for the terminal development in each concept option has been developed (Terminal 1 - Stage 1, Terminal 1 - Stage 2 and Terminal 2), as shown in **Figure 6** and **Figure 7**. Dredging (or excavation) is assumed to generally match the staging of the terminal development. It is noted that Terminal 1 - Stage 1 and Terminal 1 - Stage 2 of each port concept option are equivalent.

Ground conditions in the port area in the zone of likely dredging, excavation, reclamation and ground improvement typically comprise:

- Quaternary marine deposits (marine areas only), overlying;
- Baxter Formation, overlying;
- Sherwood Formation.

A description of each of the above materials is provided in **Section 2.1**.

When pumped by hydraulic dredging methods (i.e. cutter suction dredger) the Quaternary marine deposits will become disaggregated in the pipeline and form a sand/fines slurry. In the case of the Baxter and Sherwood Formation materials, where materials comprise stiff to hard silty and clayey materials, or sands with a high fines content (such that they exhibit cohesive engineering behaviour), dredging by hydraulic means will result in the formation of clay balls and a fines slurry (and sand). Pumping distance will affect the proportion of clay balls and fines slurry (the greater the pumping distance the greater the proportion of fines slurry). The suggested behaviour of Baxter/Sherwood materials including proportion of sand, clay balls, and fines slurry, and associated bulking factors is outlined in **Section 2.4.1**.

When dredged mechanically (i.e. backhoe dredger) materials will retain much of their in situ soil structure. The stiff to hard clayey and silty materials from the Baxter and Sherwood Formations would form large lumps/blocks.

Ground improvement options for the port reclamation area and within onshore dredged material management (DMM) areas have been considered in other reference reports. The main findings of these reports are summarised in **Section 3**. These reports identify a shortlist of applicable ground improvement measures. However, the selection of a preferred method or combination of methods is subject to a range of factors including ground conditions, design and performance requirements, time available, costs, environmental

considerations and the type of structure or facilities being constructed on the improved ground.

A breakdown of dredging/excavation and reclamation volumes per stage (and according to material type) for the Along the Shore and Basin Option is provided in **Section 4**.
Rough Order of Magnitude (ROM) costing is presented in **Section 5** for a range of different combinations of dredging methods according to four main scenarios:

- Scenario 1: reclamation material sourced from port capital dredging/excavation;
- Scenario 2: reclamation material sourced from land, e.g. from the SUZ1 land or a commercial quarry;
- Scenario 3: reclamation material sourced from offshore; and,
- Scenario 4: reclamation material sourced from a mix of the above.

ROM costing is based on unit rate and mobilisation/demobilisation cost estimates prepared by Baggerman Associates. For comparative purposes, graphs showing the variation of dredging unit rates and production rates between work methods provided by Baggerman Associates are provided as **Figure E1** and **Figure E2**.
As an outcome of the comparison of ROM costs associated with different scenarios and work method combinations, realistic strategies for dredging, reclamation and DMM are proposed.

For Terminal 1 – Stage 1 and Terminal 1 – Stage 2 development a suggested strategy was developed from a cost and technical point of view and minimising the impacts of DMM on the SUZ1 land, which comprises:

- use of a Jumbo TSHD (Trailer Suction Hopper Dredger) to win sand from offshore for reclamation;
- use of a Large CSD (Cutter Suction Dredger) loading split hopper barges for disposal of port dredged material at an offshore DMG (Dredged Material Ground); and,
- identification of opportunities to incorporate locally excavated material from the SUZ1 within the reclamation where material is suitable, and subject to costs.

This strategy has an elevated approvals risk since there are no approvals in place for offshore sand extraction and there is no established offshore DMG. The cost of the strategy is also sensitive to the amount of overflow which would be permitted from the barges. A strategy with a lower approvals risk would involve an ‘all land solution’ reclamation using a combination of dredged material and sand from a land source (for those areas of the reclamation where dredged material is unsuitable) and disposal of the balance of the dredged material on the SUZ1 land. There are two options for disposal of dredged material to the SUZ1 land:

- Large CSD pumping to a bunded area, which is lower cost but requires a larger land area;
- Jumbo BHD into split hopper barges and unloading at a dock for distribution by a road system, which requires less land (about 50% less) but is significantly higher cost (difference of several $100M).

In the case of the Terminal 2 development, in practice this development would be undertaken in a number of stages which are unknown at this point in time. Accordingly, comments of a general nature only are made in **Section 6** as a comparison between the Along the Shore Option and Basin Option. Based on current understanding, it is recommended that both options should continue to be developed in parallel until full development costs are better understood and project staging beyond Terminal 1 – Stage 2 is defined.

A number of recommendations for future work activities to enable further refinement of port development options and their associated dredging, reclamation and DMM strategies are provided in **Section 7**.

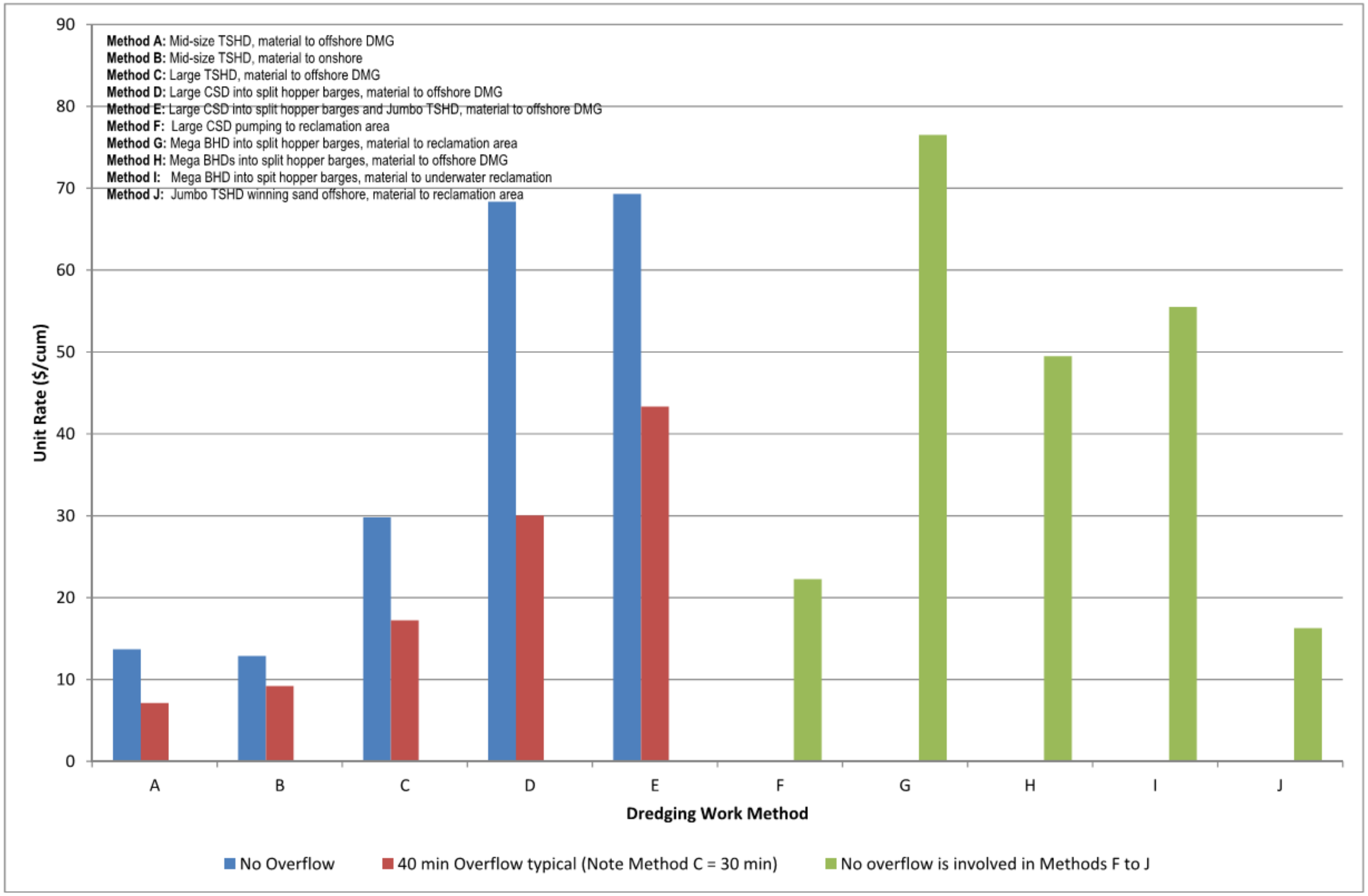

Figure E1 Unit rates for various dredging methods

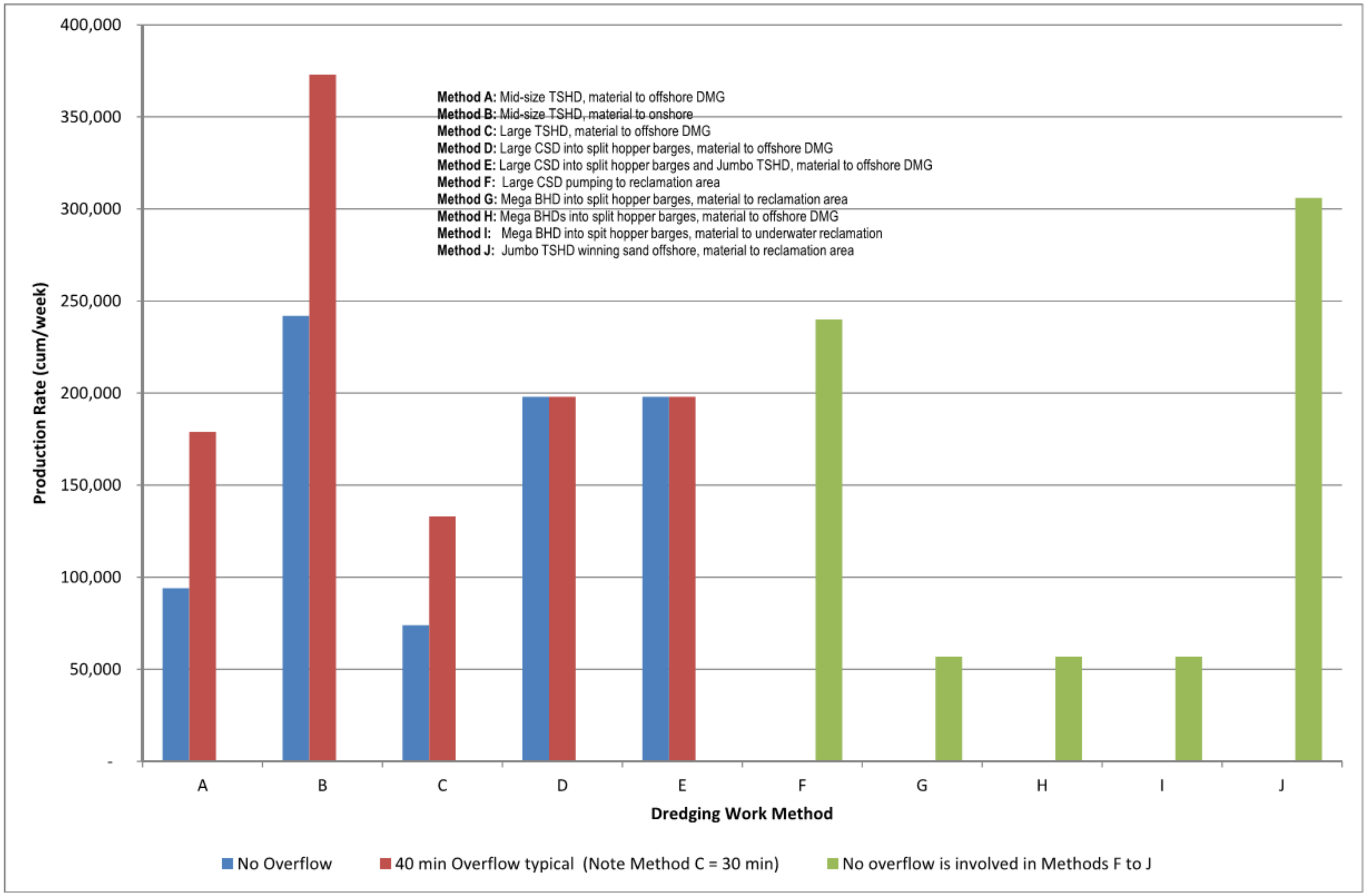

Figure E2 Production rates for various dredging methods

1 INTRODUCTION

1.1 Background

In 2012 the Victorian Government established the Port of Hastings Development Authority (the Authority) to investigate the development of a second container port at Hastings. The Authority is progressing staged planning of the Port of Hastings Development Project (the Project) from 2014 to 2018, culminating in a preliminary business case and environmental and social impact assessment. It is envisaged that the container port will begin operations in the mid-2020s with a capacity of 3 million twenty-foot equivalent (TEU) per year, increasing to 9 million TEU by 2060.

The Port of Hastings is located within Western Port (refer **Figure 1**). More than 3,000 hectares (ha) of foreshore land has been zoned since the late 1970s as Special Use Zone – Schedule 1 (Port Related Purposes) (SUZ1) for development and expansion of the Port (refer **Figure 2**).

Figure 1 Location of Hastings in Western Port

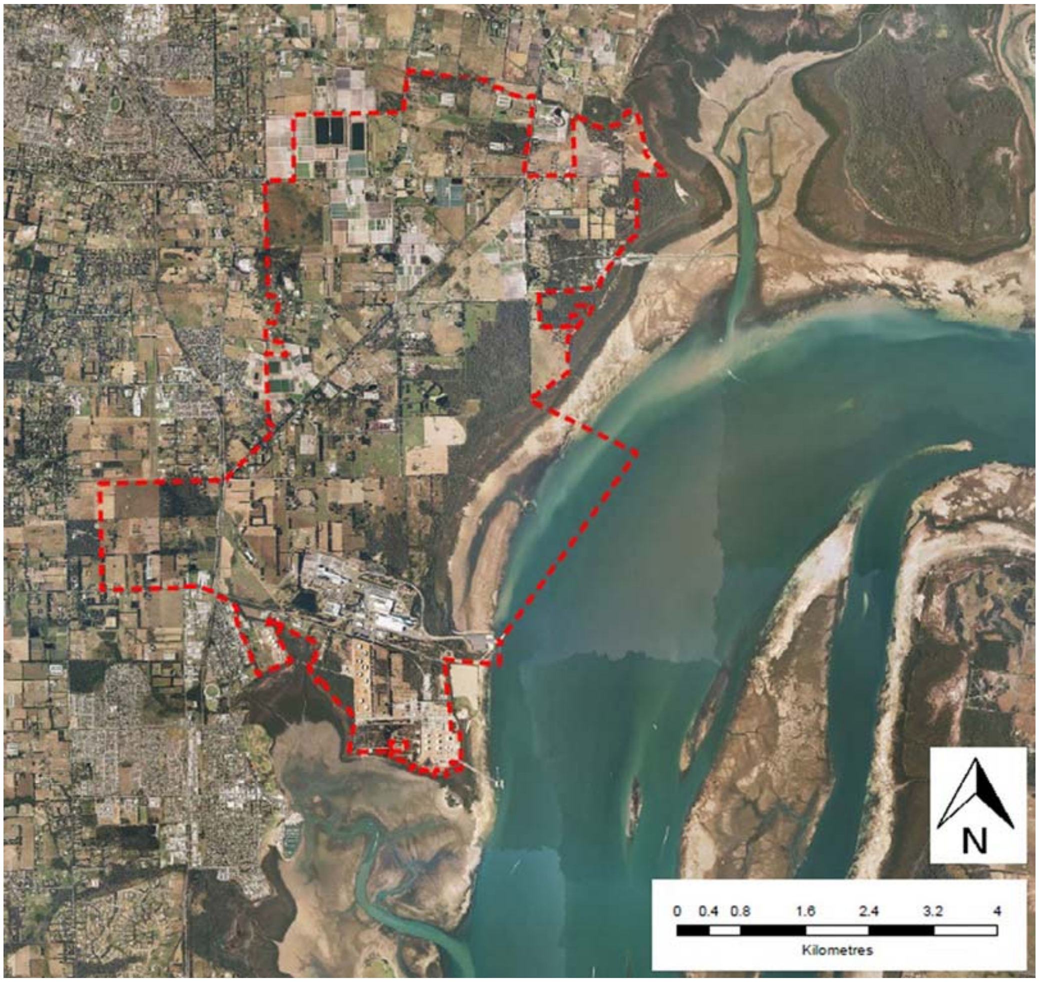

Figure 2 Extent of SUZ1 north of Hastings (red dashed line)

1.2 Dredging, Reclamation and Dredged Material Management

The Project will require capital dredging. The capital dredged material is proposed to be beneficially reused as fill within land reclamation to create a container terminal, if the material is suitable for this purpose.

Capital dredged material that is unsuitable for reclamation material or is surplus to the volumetric requirements of reclamation, will be disposed of elsewhere. Management of this material is referred to as Dredged Material Management (DMM) and the material itself is referred to as DMM material. Disposal of DMM material could potentially be to land or to sea, in the latter case within Western Port and/or offshore from Western Port.

The above relationship between reclamation material and DMM material is depicted graphically in **Figure 3**. This figure also depicts that some of the dredged material initially directed to the reclamation may subsequently be removed from the reclamation area and become DMM material (refer dashed line). This could include fines (silts and clays) that are dredged using hydraulic methods, e.g. by a cutter suction dredger (CSD), and which form a

fines slurry that must be removed from the reclamation area for geotechnical reasons, e.g. due to their low strength and high compressibility.

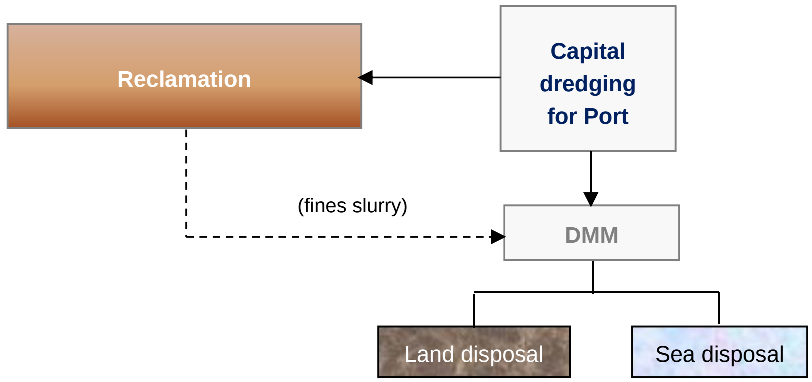

Figure 3 General relationship between capital dredging, reclamation and DMM

Where the required reclamation cannot be fully achieved using capital dredged material, it may be necessary to obtain reclamation material from other sources. Broadly speaking, these sources could comprise a land source, either from within the SUZ1 or from commercial quarries, or an offshore source outside of Western Port.

Following reclamation, it is anticipated that ground improvement works will need to be undertaken in the reclamation area so as to provide adequate support for structures, pavements, services and general infrastructure; to reduce post construction settlement; and to mitigate against liquefaction.

Where DMM material is disposed of to a land area, ground improvement of this area may also be required subject to the proposed end use of the land area and the timing of this use.

1.3 Port Concept Options and Quay Walls

Two general port concept options are under consideration for the container port:

- an Along the Shore Option (refer **Figure 4**), and,
- a Basin Option (also referred to as Option 'D' in other reports) (refer **Figure 5**).

An approximate staging for the terminal development in each concept option has been developed (Terminal 1 - Stage 1, Terminal 1 - Stage 2 and Terminal 2), as shown in **Figure 6** and **Figure 7**. Dredging (or excavation[1]) is assumed to generally match the staging of the

[1] In the case of the Basin Option it has been assumed that the basin would be created by excavation rather than by dredging, for example by dewatering and excavating, or by using land based equipment excavating below the water table. Generally speaking, excavation 'in the dry' allows better control, avoids large soil bulking factors (particularly if the alternative to excavation is hydraulic dredging), and can be less costly. The feasibility of the use of excavation techniques (and the cost) is significantly influenced by a knowledge of groundwater conditions and behaviour. Further knowledge on these factors would be required to take the Basin Option forward.

terminal development. It is noted that Terminal 1 - Stage 1 and Terminal 1 - Stage 2 of each port concept option are equivalent.

The position of the quay line in each option is subject to further design refinement.

A number of quay wall structural options for the container terminal are also under consideration. Due to the geotechnical conditions at the site, the focus is on a bulkhead wall or a suspended deck over a rock armoured slope (refer **Figure 8** and **Figure 9**).

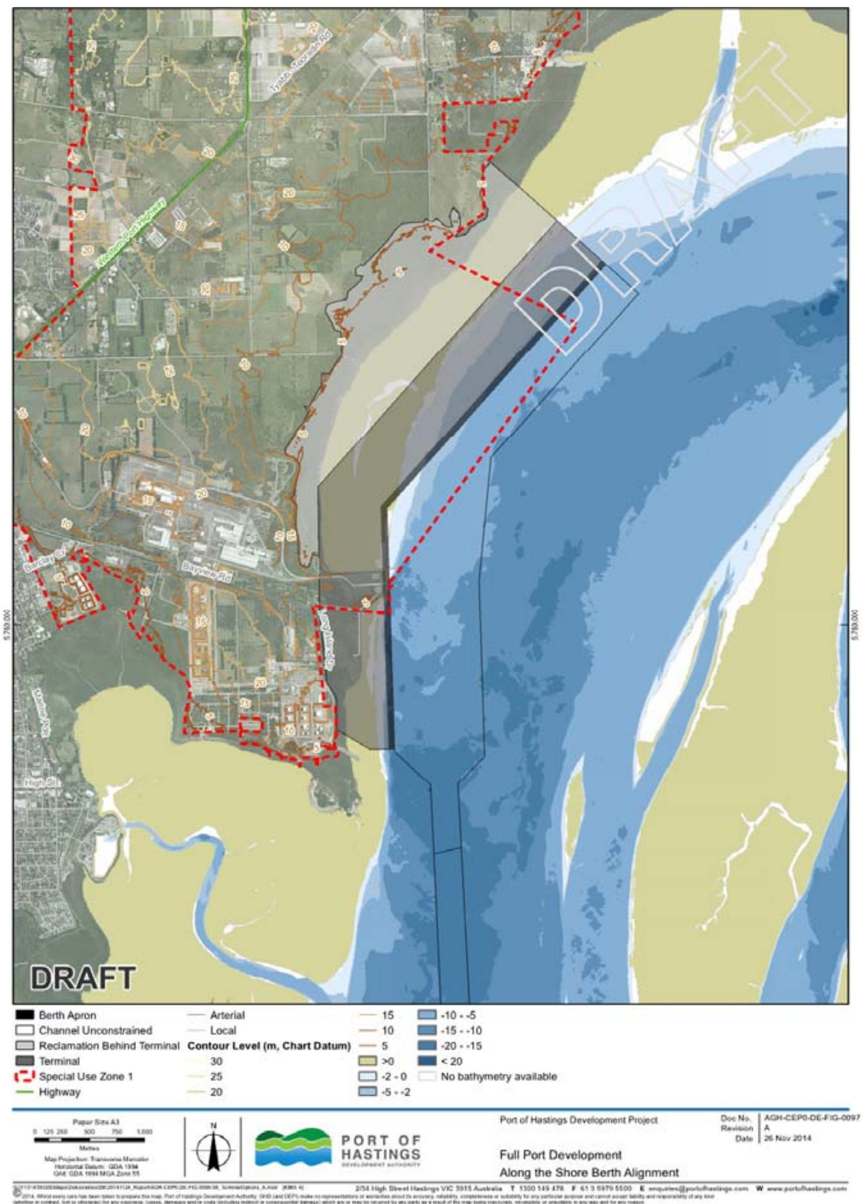

Figure 4 Along the Shore Port Concept Option

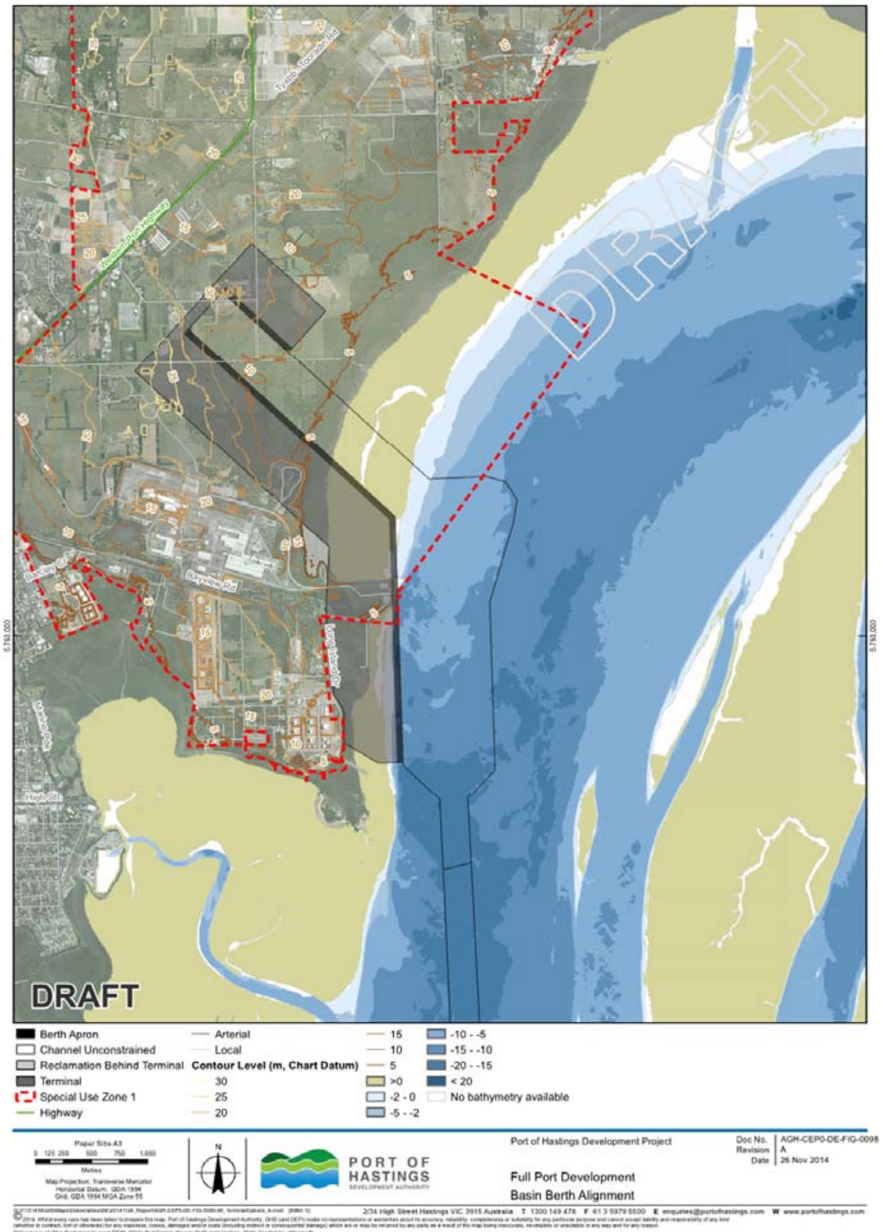

Figure 5 Basin Option

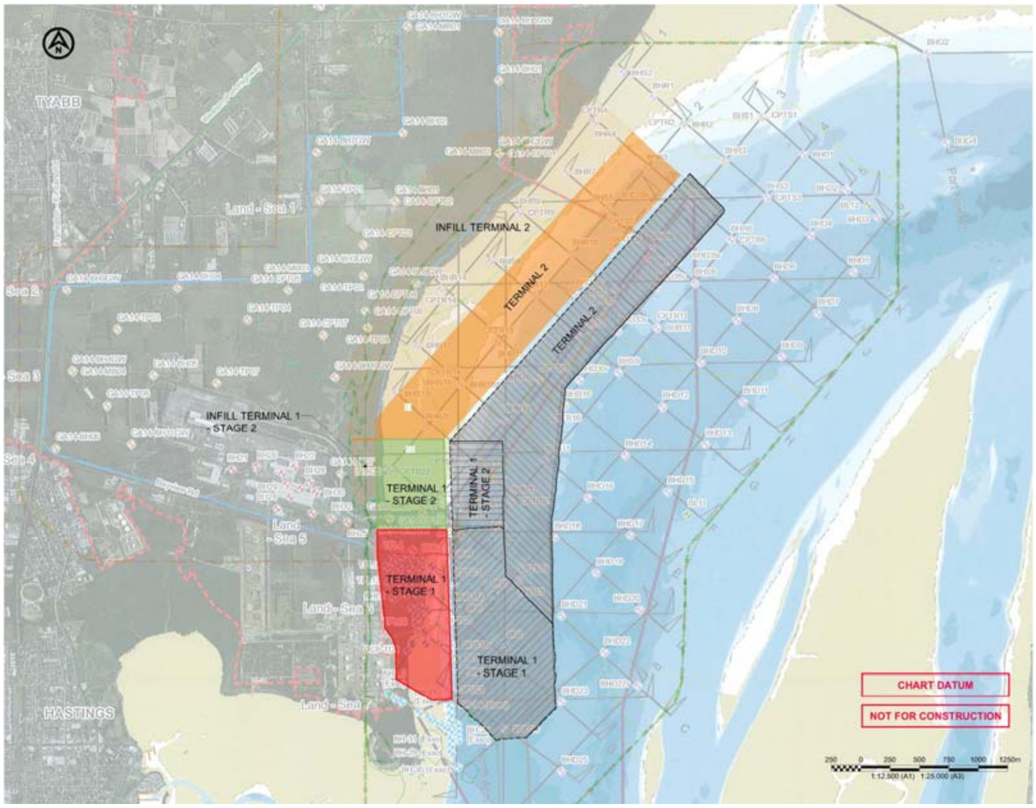

Figure 6 **Along the Shore Option showing navigation areas (black outline) terminal areas (coloured) and approximate staging**

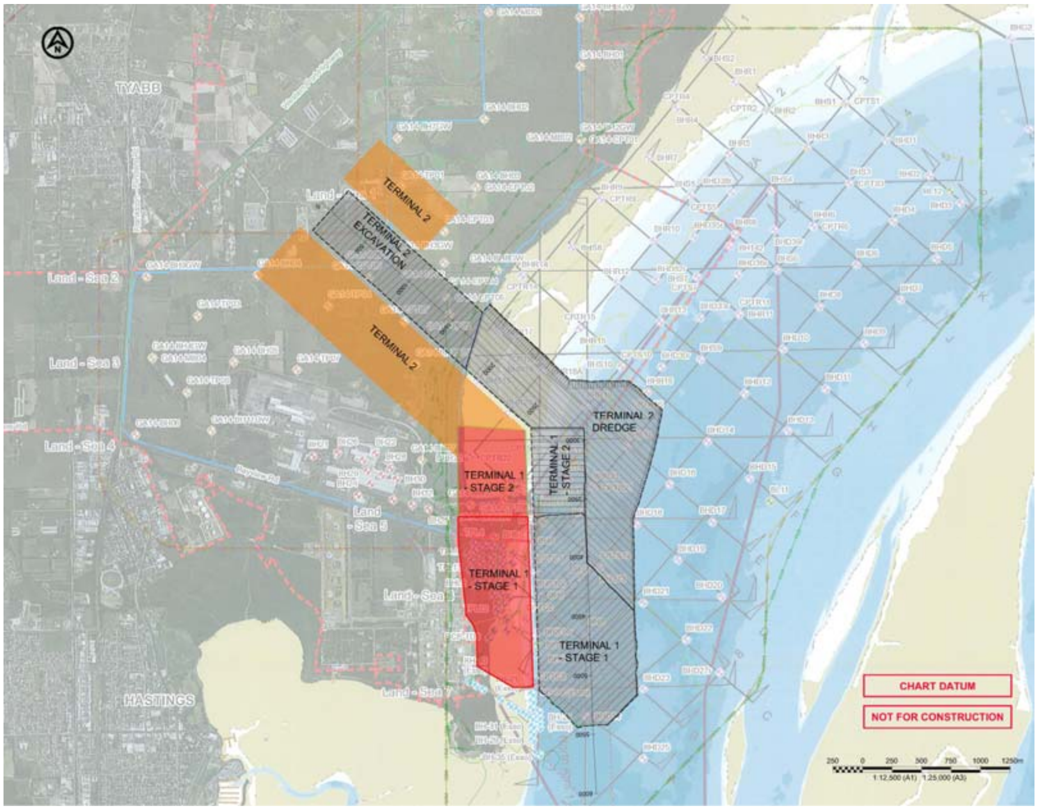

Figure 7 Basin Option showing navigation areas (black outline), terminal areas (coloured) and approximate staging

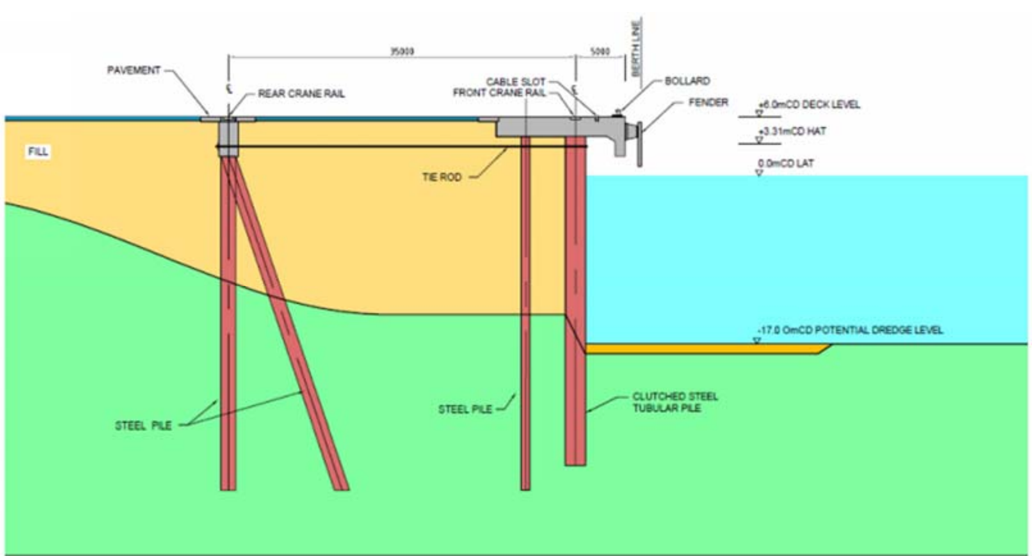

Figure 8 Bulkhead wall

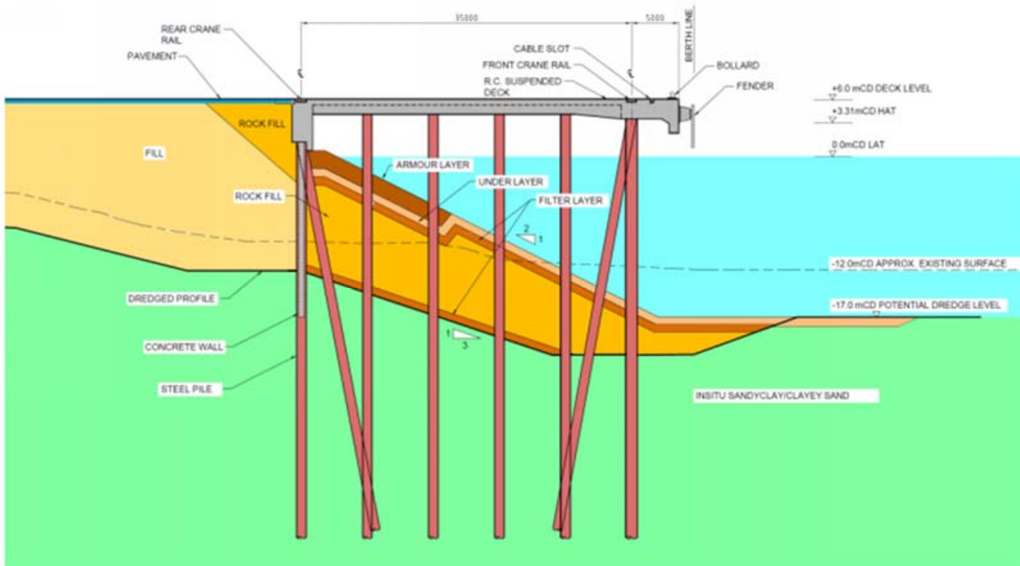

Figure 9 Suspended deck over rock armoured slope

1.4 Purpose of this Report

The purpose of this report is to synthesise the findings of a number of studies undertaken under the Dredging and Reclamation Work Package and the Dredged Material Management (DMM) Work Package so as to identify a list of dredging/reclamation/DMM strategies, including ground improvement, that are suitable for taking forward. While the work is directed mainly at the container port concept options outlined in **Section 1.3**, the findings have wider application for other port development initiatives associated with oil and gas, bulk products, break bulk, and other trades.

It is not the intention of this report to repeat large sections of material from previous reports but rather to present key findings from relevant reports, indicate how these findings influence strategies for dredging, reclamation and DMM, and then proceed to present the strategies themselves.

The report assumes the reader has a reasonable knowledge of the Project, the site and dredging work methods.

1.5 Available Studies and Information

The following key studies and information were available to support the preparation of this report:

- Geotechnical Interpretive Report (AECOM/GHD JV, Document Ref: AGH-CEP0-EG-REP-0009);
- Dredging and Reclamation – Ground Improvement (AECOM/GHD JV, Document Ref: AGH-CEP0-EG-REP-0018);

- Offshore Sand Availability (Haskoning Australia, HAS-CEP0-HY-REP-0019);
- Onshore Sources of Reclamation Material (Haskoning Australia, HAS-CEP0-HY-REP-0027);
- Sediment Settling Tests (Haskoning Australia, HAS-CEP0-HY-REP-0030);
- specialist input from Baggerman Associates on possible dredging work methods and associated unit rate and mobilisation/demobilisation cost estimates.

1.6 Structure of the Report

The report is structured in the following manner:

- **Section 2** briefly summarises the different types of materials to be dredged and excavated in the port area and reaches a number of conclusions regarding their ability to be dredged and excavated, work methods, and their behaviour due to the dredging process;
- **Section 3** summarises the volumes of the different types of materials that would be involved in the staged development of the two general port concept options, namely the Along the Shore Option and Basin Option;
- **Section 4** summarises the findings of investigations into ground improvement options for the port reclamation and onshore DMM areas;
- **Section 5** sets out various scenarios that can be considered to inform development of strategies for dredging, reclamation and DMM, and consideration of the associated volume balances, work methods and costs;
- **Section 6** sets out a number of realistic strategies for dredging, reclamation and DMM; and,
- **Section 7** outlines recommendation for further work.

Calculations to support the rough order of magnitude (ROM) cost estimates contained in this report are provided within **Appendix A**.

2 MATERIALS TO BE DREDGED AND EXCAVATED

2.1 Description from Geotechnical Interpretive Report

Ground conditions in the port area in the zone of likely dredging, excavation, reclamation and ground improvement typically comprise:

- Quaternary marine deposits (marine areas only), overlying;
- Baxter Formation, overlying;
- Sherwood Formation.

There is also an area of previous reclamation (known as the Old Tyabb reclamation) which is underlain by Quaternary marine deposits and the Baxter and Sherwood Formations.

2.1.1 Quaternary Deposits

The Quaternary marine deposits typically comprise very loose and loose carbonate and siliceous sand, and soft and very soft clay, silty clay and sandy silt. Where these materials exist under a proposed reclamation area, it is likely they would need to be removed prior to reclamation to meet required performance criteria for a container terminal. The need for pre-removal and replacement of the Quaternary deposits adds to the dredging volume and the reclamation volume.

2.1.2 Baxter Formation

The Baxter Formation includes variably interbedded silty sand, silty clay, clayey sand, sandy clay, sand, clayey silt and clay materials. The predominant material types are clayey sand, sandy clay, silty sand and silty clay. This unit is typically relatively competent comprising clay and silt materials of stiff to very stiff consistency and dense to medium dense sand materials. The sands are typically fine to medium grained. There does not appear to be any significant lateral continuity of material types between adjacent boreholes which are generally at 500m centres.

2.1.3 Sherwood Formation

The Sherwood Formation is typically relatively competent and comprises sand, silty sand, silt, sandy silt, silty clay, and clayey silt. The sandy silt, silt, silty clay and clayey silt are typically of stiff to hard consistency. Silty sands and sands are typically fine or fine to medium grained and of medium dense to very dense consistency. There does not appear to be any significant lateral continuity of material types between adjacent boreholes which are generally at 500m centres.

2.2 Description from Baggerman Associates

Based on review of the Geotechnical Interpretive Report, field logs and a visual inspection of stored samples, Baggerman Associates classified the materials to be dredged into five soil types, as follows:

- Soil Type 1: very soft to firm clays and silts;
- Soil Type 2: sand, clayey sand, and silty sand typically with fines content ranging from 20% to 30% by weight;
- Soil Type 3: stiff to hard clays (sandy clay and silty clay);
- Soil Type 4: stiff to hard silts (sandy silts and clayey silts);
- Soil Type 5: weathered rock overlain by sands, gravels and clays.

Rock in the port area is situated typically deeper than 40m below Chart Datum (-40m CD) and would not be encountered in dredging or excavation for the port facilities (dredging and excavation depths would not exceed a level of around -16.5m CD). Accordingly, rock is not an issue in the port area[2].

Soil Type 1 is the Quaternary marine deposits referred to in **Section 2.1.1**.

Soil Types 2, 3 and 4 are collectively the Baxter Formation and Sherwood Formation materials referred to in **Section 2.1.2** and **Section 2.1.3** respectively. As will be outlined in **Section 3**, the majority of the materials to be dredged and excavated are from the Baxter Formation.

2.3 Dredgeability of Materials and Work Methods

Three main dredging techniques would potentially be used for the Project, a trailing suction hopper dredger (TSHD), a cutter suction dredger (CSD) and a backhoe dredger (BHD) (refer **Figure 10**, **Figure 11** and **Figure 12**). In terms of other possible dredging equipment, a large proportion of the materials to be dredged are too hard to be economically dredged by a grab dredger, consequently there is a very large schedule risk and a higher dredging cost for this equipment. Bucket dredgers (previously used in the Port of Hastings in the 1970s) are no longer competitive against other work methods except in specific circumstances which are not applicable for this Project. Furthermore, there are very few dredgers of this type available, world-wide.

[2] Rock may be a consideration in the Western Channel in localised areas. This is subject to the findings of further channel design studies.

Figure 10 **Trailing suction hopper dredger (photograph courtesy of Boskalis)**

Figure 11 **Cutter suction dredger (photograph courtesy of DEME)**

Figure 12 Backhoe dredger (photograph courtesy of Shipyard De Donge)

Based on input from Baggerman Associates, **Table 1** sets out the Soil Type and the dredging work methods that would be possible, subject to other factors to be considered, e.g. behaviour of material during dredging and placement, cost, and approvals. It is noted that large TSHDs dredging the stiff to hard clays and silts do not feature as a preferred work method in the table. This is because of the large schedule risk, considerably higher dredging cost and greater potential environmental impact (due to hopper overflow) associated with this work method in these materials. However, the use of large TSHDs to dredge stiff to hard clays may be considered if this equipment is mobilised for another primary purpose (e.g. winning sand from offshore sources) and this work method should be maintained in the list of options for future consideration. TSHDs are a suitable work method for dredging of other Soil Types.

Selective dredging of specific Soil Types would not be possible by TSHD and CSD due to the interbedded nature and variable particle size distribution of the soils, and due to the lateral variability. Selective dredging of different Soil Types is also unlikely to be possible with a BHD for the above reasons and the inherent difficulty of achieving a good soil model.

Table 1 Soil Type and Applicable Work Methods

Soil Type	Material Description	Applicable Work Method
1	Very soft to firm clays and silts	• TSHD to offshore DMG[3] • TSHD pumping ashore • CSD to reclamation • CSD loading hoppers to offshore DMG • BHD loading barges, rehandle to onshore • BHD loading barges to offshore DMG
2	Sand, clayey sand, silty sand typically with fines content 20% to 30% by weight	• TSHD to offshore DMG • TSHD pumping ashore • CSD to reclamation • CSD loading hoppers to offshore DMG • BHD loading barges, rehandle to onshore • BHD loading barges to offshore DMG
3	Stiff to hard clays (sandy clay and silty clay)	• CSD to reclamation • CSD loading barges to offshore DMG • BHD loading barges, rehandle to onshore • BHD loading barges to offshore DMG
4	Stiff to hard silts (sandy silt and clayey silt)	• CSD to reclamation • CSD loading barges to offshore DMG • BHD loading barges, rehandle to onshore • BHD loading barges to offshore DMG

Source: Baggerman Associates

2.4 Behaviour of Soil Types due to Dredging Processes

The behaviour of the individual Soil Types when dredged will depend on a range of factors but, significantly, will depend on the adopted method of dredging; whether hydraulic (TSHD or CSD) or mechanical (BHD).

2.4.1 Hydraulic Dredging

The Quaternary marine deposits, i.e. the very loose and loose sands, and soft and very soft clay, silty clay and sandy silt, will become disaggregated in the pipeline and form a sand/fines slurry[4].

In the case of the Baxter and Sherwood Formation materials, where materials comprise stiff to hard silty and clayey materials, or sands with a high fines content (such that they exhibit cohesive engineering behaviour), dredging by hydraulic means will result in the formation of clay balls and a fines slurry (and sand). Pumping distance will affect the proportion of clay balls and fines slurry (the greater the pumping distance the greater the proportion of fines slurry). Images of clay balls formed by hydraulic dredging are shown in **Figure 13**.

[3] Dredged Material Ground
[4] Fines is the collective term used to describe materials less than 0.075mm in size, i.e. materials in the silt and clay size range.

Figure 13 Formation of clay balls by hydraulic dredging (Hydraulic Fill Manual, 2012)

An analysis has been undertaken of the marine geotechnical data to assess the likely behaviour of the soil types when dredged hydraulically. This has included re-examination of the borehole logs, CPTs (Core Penetrometer Tests) and laboratory data, with the particular purpose of identifying where soils have been logged as sands but, due to the fines content, are likely to exhibit the engineering characteristics of a cohesive soil[5].

The analysis of the data indicated that the Baxter Formation and Sherwood Formation soils logged as a sand were likely to exhibit cohesive behaviour when the fines content of these materials exceeded about 35%. The overall breakdown of the total soil quantity expected to behave as a sand (non-cohesive material) and as a cohesive material was approximately 50%:50%. Of the material expected to behave as a sand, the data indicated that the average fines content of the sand would be about 25%.

In relation to the proportion of the cohesive material that would be expected to form clay balls as opposed to being broken down into a fines slurry, the following 'rules of thumb' in **Table 2** were considered appropriate for preliminary study purposes based on discussions with persons experienced in the dredging industry (Mr Frans Hoogerwerf of Hoogerwerf Maritime and Mr Hadyn Pike of Baggerman Associates). A typical pumping distance of 2km has been assumed and therefore a ratio of clay balls to fines slurry of 40%:60%.

[5] It is a feature of the Australian Standard for Geotechnical Site Investigations (AS 1726) that soils are classified by their particle size distribution rather than engineering behaviour, which can create a potentially misleading picture. For example, in AS 1726 sands are defined as material with greater than 50% particles exceeding 0.075mm, or alternatively up to 50% fines. The Geotechnical Interpretive Report notes that sandy materials having a fines content greater than 30 to 40% are likely to behave as a fine grained material in respect of engineering properties.

Table 2 Adopted Percentage Clay Balls and Fines Slurry in Hydraulic Dredging for Preliminary Study

Pumping Distance	Percentage Clay Balls	Percentage Fines Slurry
1km	60%	40%
2km	40%	60%
3km	30%	70%

The dredged materials will also be subject to bulking. Based on discussions with Mr Frans Hoogerwerf and Mr Hadyn Pike, and the results of settling tests conducted on selected samples (HAS-CEP0-HY-REP-0030) the bulking factors in **Table 3** have been adopted for preliminary study purposes. These factors represent bulking prior to any ground improvement. In the case of the fines slurry, the factor excludes allowance for supernatant water, e.g. within a settling pond, and for any significant self-weight consolidation.

Table 3 Adopted Bulking Factors for Preliminary Study

Main Material Type	Bulking Factor
Sand	1.1
Clay Balls	1.2
Quaternary Marine Deposits	2.0
Fines Slurry	3.5

As the clays are likely to be dredged in combination with more sandy layers (due to the interbedded nature, variable particle size and lateral variability of the materials) clay balls may be encapsulated in a sand matrix in a disposal area.

On the basis of the above discussion, it is possible to summarise the behaviour of the soils as a result of hydraulic dredging, for preliminary study purposes, as shown by the flow chart in **Figure 14** (excludes Quaternary marine deposits). The relevant bulking factor (BF) is also shown.

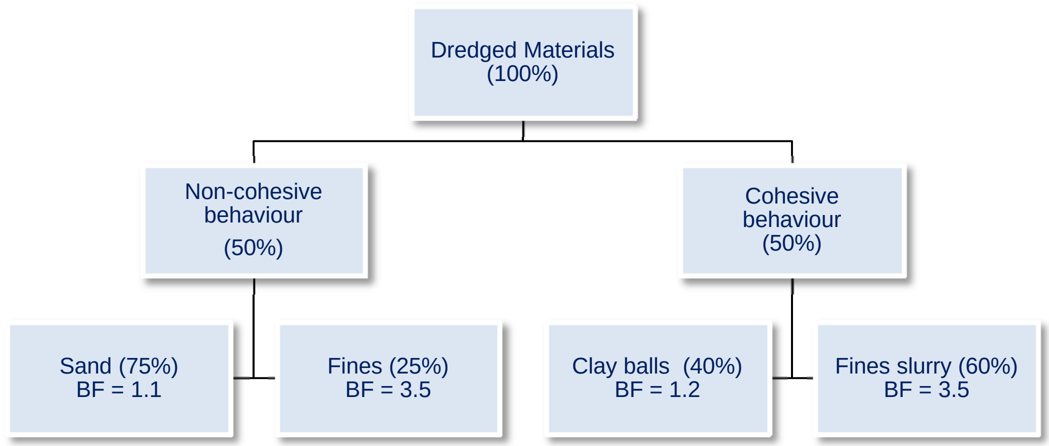

Figure 14 Flow Chart of behaviour of soils as a result of hydraulic dredging (excludes Quaternary marine deposits)

The fines slurry component of the dredged material must be removed from any reclamation area for geotechnical reasons, e.g. by use of a smaller CSD pumping to settling ponds.

Clay balls are not preferred in any above water reclamation and would need to be excluded from above +1 to +2m CD, unless positive support of port facilities are provided such as piles, stone columns, or semi rigid inclusions (AGH-CEP0-EG-REP-0018).

2.4.2 Mechanical Dredging

Materials dredged by BHD will retain much of their in situ soil structure; the material is not fluidised as is the case for hydraulic dredging with a TSHD or CSD.

The stiff to hard clayey and silty materials from the Baxter and Sherwood Formations would form large lumps/blocks. Ground improvement is required to close inter-lump voids and provide sufficient compression of the individual clay pieces. Bulking factors prior to ground improvement could exceed 1.2. Images of clay lumps formed by mechanical dredging are shown in **Figure 15**.

Figure 15 Formation of clay lumps by mechanical dredging

3 GROUND IMPROVEMENT OPTIONS

3.1 General

Ground improvement options have been considered to a preliminary level of detail in within the port reclamation area (Document Ref: AGH-CEP0-EG-REP-0018) and within onshore DMM. However, the selection of a preferred method or combination of methods is subject to a range of factors including ground conditions, design and performance requirements, time available, costs, environmental considerations and the type of structure or facilities being constructed on the improved ground. As such, the costing of ground improvement measures has been excluded from the costs presented herein.

A summary of the main findings of ground improvement investigations completed to date is provided in the following sections.

3.2 Ground Improvement within Port Reclamation Area

The report *Dredging and Reclamation – Ground Improvement* (AGH-CEP0-EG-REP-0018) makes some reasonable assumptions in the assessment of possible ground improvement options. These are listed below:

- the dredging of materials to be beneficially reused within the reclamation area would be undertaken hydraulically with a CSD or mechanically with a BHD;
- the reclamation material would be contained within perimeter bunds constructed of imported granular fill material; and,
- fine slurry can be effectively managed and removed from the port reclamation containment areas.

The report discusses ground improvement techniques considered to be most suited to the Port of Hastings reclamation area. These include the following:

- preload with or without vertical drains;
- vibrocompaction;
- vibroreplacement;
- dynamic replacement;
- semi rigid inclusions (e.g. controlled modulus columns); and,
- deep foundations or piling.

An excerpt of a table in the report discussing possible ground improvement techniques for certain areas, dredging and reclamation scenarios is shown below:

Table 4 Possible Ground Improvement Techniques (AGH-CEP0-EG-REP-0018)

Area	Scenario	Possible Ground Improvement Technique
Containment Bunds	Soft clays removed prior to reclamation.	- Preload surcharge (required over reclamation) - Vibrocompaction of sand fill (extended beneath bund to support structures as required)
Main Reclamation	Fine sand and clay balls placed hydraulically below water, hydraulically placed sand fill above water. Very soft marine clays and slurry removed.	- Preload surcharge with or without vertical drains (drains required depending on mass permeability of compressed clay ball fill) - Vibroreplacement - Semi rigid inclusions - Deep foundations or piling
Main Reclamation	Fine sand and clay balls hydraulically placed below water, fill from BHD or land source spread and compacted using terrestrial earthworks equipment above water. Very soft marine clays and slurry removed.	- Preload surcharge with or without vertical drains (drains required depending on mass permeability of compressed clay ball fill) - Vibroreplacement - Semi rigid inclusions - Deep foundations or piling
Main Reclamation	Fine sand and clay balls hydraulically placed below and above water i.e. fill in top 4 to 5m not engineered and containing low strength clay balls. Very soft marine clays and slurry removed.	- Nominal preload surcharge to close up large intra lump voids plus: - Vibroreplacement - Semi rigid inclusions - Deep foundations or piling

3.3 Ground Improvement within Onshore DMM Areas

The preliminary work assumed that material transported onshore for disposal would be dredged by CSD (with hydraulic transport by pipeline) or by BHD. The characteristics of the dredged material generated by each method are discussed and the most suitable options for ground improvement are recommended.

3.3.1 CSD with Hydraulic Transport

It was assumed that the material discharged from the CSD pipeline would comprise a mixture of sand, clay balls and a volume of clay slurry. The sand and clay balls would settle out relatively quickly and be contained and treated in one area, while the clay slurry would be diverted within return water to separate settlement pond treatment areas.

Options listed for treatment of the clay slurry captured within settlement ponds included:

- discharge into closed cell settlement pond with no treatment ('do nothing option');
- discharge into shallow areas for natural dewatering ('ripening');
- accelerated consolidation (controlled capping layer placement, installation of drainage and application of surcharge load);
- use of admixtures (e.g. cement mixing); and,
- electro osmosis.

The report noted that for the onshore disposal of dredged material, lower performance end uses may apply than for the port reclamation area. It was considered that the loose clayey silty sand and clay balls of varying strength within onshore containment areas could be managed in three possible ways:

1. storage in the containment bunds without any further treatment (do nothing option);
2. removal from containment bunds, spreading into shallow layers, drying, and compaction using conventional compaction equipment. If necessary the properties of the material could be further improved by the addition of lime or cement; and,
3. storage in deeper containment areas (say 3m to 10m deep) and improved using more conventional ground improvement techniques. Options that could be considered suitable for improvement of the dredged materials are listed below:
    - preload surcharge with or without vertical drains;
    - vacuum consolidation;
    - vibroflotation or vibrocompaction;
    - vibroreplacement (stone columns);
    - dynamic compaction;
    - dynamic replacement;
    - rapid impact compaction;

- o impact rolling;
- o deep soil mixing;
- o jet grouting;
- o controlled modulus columns; and,
- o deep foundations or piling.

3.3.2 BHD Dredging

In the consideration of ground improvement options for material dredged with a BHD it was assumed that the dredged material would be end dumped into specific areas for treatment on land. The report concludes that the most likely suitable approach to treatment of BHD dredged materials would be to break up the material, spread it into thin layers and compact it using heavy duty conventional compaction equipment. The process could be repeated in successive lifts subject to the ability of trucks and compaction equipment to traffic over the preceding layers.

4 DREDGING, EXCAVATION AND FILL VOLUMES

4.1 General

Dredging, excavation and fill volumes for the two port concept options under consideration (refer **Section 1.3**) have been estimated by Haskoning Australia in AutoCAD Civil3D based on the ground model developed by the AECOM/GHD JV as part of the Geotechnical Interpretive Report (AGH-CEP0-EG-REP-0009) and shape files supplied by the JV. The shape files are based on all navigable areas being dredged or excavated to a design level of -16.5m CD and all container land areas being filled or, in the case of the Basin Option in some areas being excavated, to a design level +5.5m CD.

Dredging volumes include an overdredging allowance of 0.5m vertically below the design level and 3m horizontally beyond the toelines. Excavation volumes include an over-excavation allowance of 0.5m below the design level within the basin in the Basin Option and an over-excavation allowance of 0.1m for the terminal areas adjacent to the basin.

The dredging volumes include a common allowance for batters of 1V:5H irrespective of material type. In further refinements of the volumes the following batters could be used, as advised by Baggerman Associates:

- Soil Type 1: very soft to firm clays and silts 1V:4H
- Soil Type 2: sand, clayey sand, silty sand typically with fines content 20% to 30% by weight 1V:8H
- Soil Type 3: stiff to hard clays (sandy clay and silty clay) 1V:3H
- Soil Type 4: stiff to hard silts (sandy silt and clayey silt) 1V:3H

The dredging, excavation and fill volumes have been subdivided into the main stages of the port concept options, i.e. Terminal 1 - Stage 1, Terminal 1 - Stage 2 and Terminal 2 (refer **Section 1.3**). The dredging and excavation volumes have also been subdivided into the three main geological units; namely, the Quaternary marine deposits, Baxter Formation and Sherwood Formation, to assist in understanding likely material behaviour due to dredging processes (refer **Section 2.4**).

In the case of the Quaternary marine deposits, distinction is also made between the volume of material situated within the dredging areas and that situated under proposed fill (reclamation) areas. As noted in **Section 2.1.1**, soft Quaternary marine deposits under proposed reclamation areas would need to be removed prior to reclamation to meet required performance criteria for a container terminal. The additional fill material required to replace the soft Quaternary marine deposits under proposed reclamation areas has been accounted for in the estimated fill volume.

All volumes should be regarded as preliminary. All volumes are rounded to one decimal place in million cubic metres (Mm^3).

4.2 Along the Shore Option and Basin Option

4.2.1 Summary of Volumes according to Project Stage and Material Types

The estimated volumes of dredged material and estimated volumes of fill for the Along the Shore Option are set out in **Table 5**. The estimated volumes of dredged and excavated material, and estimated volumes of fill, for the Basin Option, are set out in **Table 6**.

A number of conclusions can be reached based on the volumes presented in **Table 5** and **Table 6**. These are outlined in the following sections.

Table 5 Estimated Volume of Dredged Material by Main Geological Unit and Estimated Volume of Fill – Along the Shore Option

Stage	Estimated Dredged Volume (Mm^3)					Estimated Fill Volume (Mm^3)
	Quaternary Marine Deposits		Baxter Formation	Sherwood Formation	Total	
	within dredge area	under reclamation				
Terminal 1 – Stage 1	1.0	1.6	4.1	-	6.7	3.9
Terminal 1 – Stage 2	0.6	1.2	3.0	-	4.8	2.8
Terminal 2	1.9	4.8	14.8	0.2	21.7	24.6
Ultimate (percentage of dredged)	3.5 (10%)	7.6 (23%)	21.9 (66%)	0.2 (1%)	33.2 (100%)	31.3

Notes:

1. The estimated total fill volume of $31.3Mm^3$ is made up of $23.3Mm^3$ within the terminal area and $8.0Mm^3$ landward of the terminal area (mostly beyond Terminal 1 – Stage 2).
2. All volumes are preliminary and represent in situ volumes including overdredging.

Table 6 Estimated Volumes of Dredged and Excavated Material by Main Geological Unit and Estimated Volume of Fill – Basin Option

Stage	Estimated Dredged and Excavation Volume (Mm^3)								Estimated Fill Volume (Mm^3)
	Quaternary Marine Deposits		Baxter Formation		Sherwood Formation		Total		
	within dredge / excavation areas	under reclamation	dredged	excavated	dredged	excavated	dredged	excavated	
Terminal 1 – Stage 1	1.0	1.6	4.1	-	-	-	6.7	-	3.9
Terminal 1 – Stage 2	0.6	1.2	3.0	-	-	-	4.8	-	2.8
Terminal 2	2.7	0.5	13.2	26.4	0.6	7.2	16.3	34.3	1.6
Ultimate (percentage of dredged or excavated)	4.3[3]	3.3	20.3 (73%)	26.4 (77%)	0.6 (2%)	7.1 (21%)	27.8 (100%)	34.3 (100%)	8.3
	see Note 1								

Notes:
1. It has been assumed that the majority of the Quaternary marine deposits would be removed by dredging (around 90%). Accordingly, the Quaternary marine deposits would make up about 25% of the total dredging volume and about 2% of the total excavation volume.
2. All volumes are preliminary and represent in situ volumes including overdredging/over-excavation.
3. This volume includes $0.6Mm^3$ of Quaternary material within the terminal area excavation which is not of marine origin.
4. The split between 'dredged' and 'excavated' volumes is defined by a line drawn along the approximate edge of foreshore vegetation. Removal of material within the basin landward of this line was considered to be carried out by excavation methods (i.e. behind a bund to prevent flooding of the basin during excavation). Removal of material seaward of this line was considered to be carried out by dredging methods.

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4.2.2 Total Volumes of Dredging and Excavation

The Along the Shore Option and Basin Option are equivalent schemes for Terminal 1 – Stage 1 and Terminal 1 – Stage 2. In addition, removal of all material in these stages is by dredging. Total dredging volumes are $6.7Mm^3$ and $4.8Mm^3$ for Terminal 1 – Stage 1 and Terminal 1 – Stage 2 respectively.

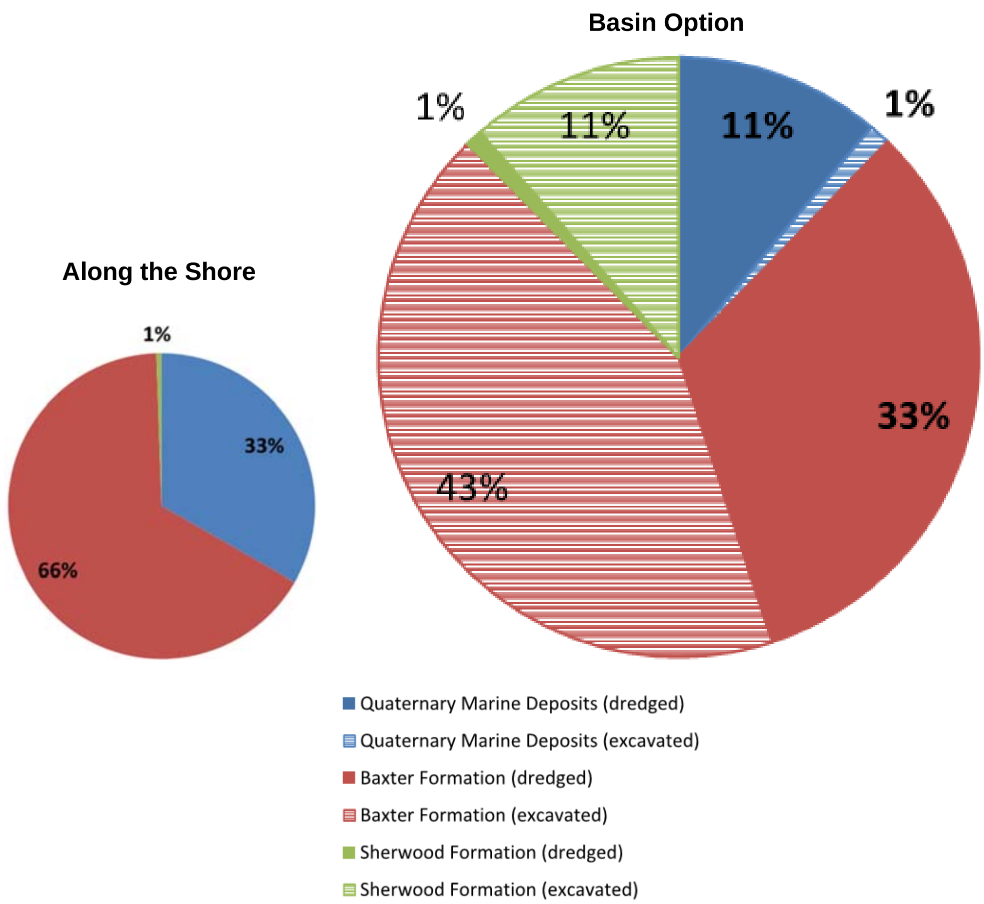
The dredging volume for the Terminal 2 stage of the Along the Shore Option is significantly greater than for the Terminal 2 stage of the Basin Option, $21.7Mm^3$ compared to $16.3Mm^3$, assuming the basin in the Basin Option is excavated rather than dredged. The feasibility of creating the basin by excavation will be influenced by further groundwater studies.

The total combined dredging and excavation volumes for Terminal 1 – Stage1, Terminal 1 – Stage 2 and Terminal 2 are significantly greater for the Basin Option ($62.1Mm^3$) than for the Along the Shore Option ($33.2Mm^3$), due to the large excavation in the Basin Option to create the basin.

4.2.3 Breakdown of Dredging and Excavation Volumes by Material Type

In the Along the Shore Option, the total dredging volume of $33.2Mm^3$ comprises about two thirds Baxter Formation ($21.9Mm^3$) and one third Quaternary marine deposits ($11.1Mm^3$). There is negligible dredging of the Sherwood Formation in this Option. This is illustrated in the pie chart below (refer **Figure 16**).

In the Basin Option, the dominant material type for dredging and excavation is again the Baxter Formation (about 75%). Quaternary marine deposits account for about 12% of the total dredging and excavation volume. The Sherwood Formation becomes more significant in the Basin Option, due to its existence at depth in the basin footprint, accounting for about 12% of the total dredging and excavation volume. The above breakdown is illustrated in the pie chart below (refer **Figure 16**).



Note: pie charts are sized in proportion to total dredging/excavation volumes

Figure 16 Breakdown of Dredging and Excavation volumes by material type

4.2.4 Quaternary Marine Deposits

Removal of Quaternary marine deposits is a significant part of the project task for the Along the Shore Option, comprising about one third of the total material to be removed (11.1Mm^3 out of 33.2Mm^3). The majority of the Quaternary marine deposits to be removed in this Option, about 70%, is located under proposed reclamation areas.

The quantity of Quaternary marine deposits to be removed in the Basin Option is less than for the Along the Shore Option (7.6Mm^3 compared to 11.1Mm^3). This is largely due to the reduced reclamation area in the Basin Option.

4.2.5 Fill Volumes

The total fill volume in the Along the Shore Option is significantly greater than for the Basin Option (31.3Mm^3 compared to 8.3Mm^3). This is by virtue of the significant reclamation in the Along the Shore Option in the Terminal 2 stage to provide the terminal area, whereas the terminal is developed over existing land in the Basin Option (refer also to Note 1 under **Table 5**).

5 SCENARIOS AND MATERIAL FLOW CHARTS

5.1 General

There are numerous factors at play in developing strategies for dredging, reclamation and dredged material management (DMM), for example:

- two port concept options – the Along the Shore Option and Basin Option;
- at least three stages of development, probably a minimum of four, in each of the port concept options;
- three main geological units to be dredged and excavated – Quaternary marine deposits, Baxter Formation and Sherwood Formation, and within these units numerous soil types;
- a range of possible disposal locations for DMM material – to land, within Western Port, and beyond Western Port;
- variable behaviour of the soil types due to dredging processes;
- beneficial reuse opportunities for dredged and excavated materials;
- a range of possible work methods for dredging, e.g. refer **Table 1**, and for excavation;
- different methods for ground improvement;
- estimated costs, including mobilisation and demobilisation costs, and unit rates for dredging and for excavation;
- a range of environmental and social factors that influence the strategies; which may be thought of as the approvals risk associated with the various strategies or components of the strategies. It is noted that there are no contamination issues of a material nature and that acid sulfate soils issues are likely to be minor and readily manageable.

It follows from the above that it is necessary, if possible, to try to organise a logical simplified approach to identification of strategies for dredging, reclamation and dredged material management. This involves establishing the primary purpose of the project, and identifying those factors that drive the outcomes and those that are secondary or are a consequence of other factors.

The primary purpose of the project is to provide improved shipping access and land for container terminal development. For a number of reasons it is considered that the fundamental factor is the source of reclamation material to create the land for the terminal. A number of scenarios can be considered:

- Scenario 1: reclamation material sourced from port capital dredging/excavation;
- Scenario 2: reclamation material sourced from land, e.g. from the SUZ1 land or a commercial quarry;
- Scenario 3: reclamation material sourced from offshore; and,
- Scenario 4: reclamation material sourced from a mix of the above.

The relationships between dredging, reclamation and DMM for each of the above four Scenarios are depicted graphically in the flow charts in **Figure 17**, **Figure 18**, **Figure 19** and **Figure 20**.

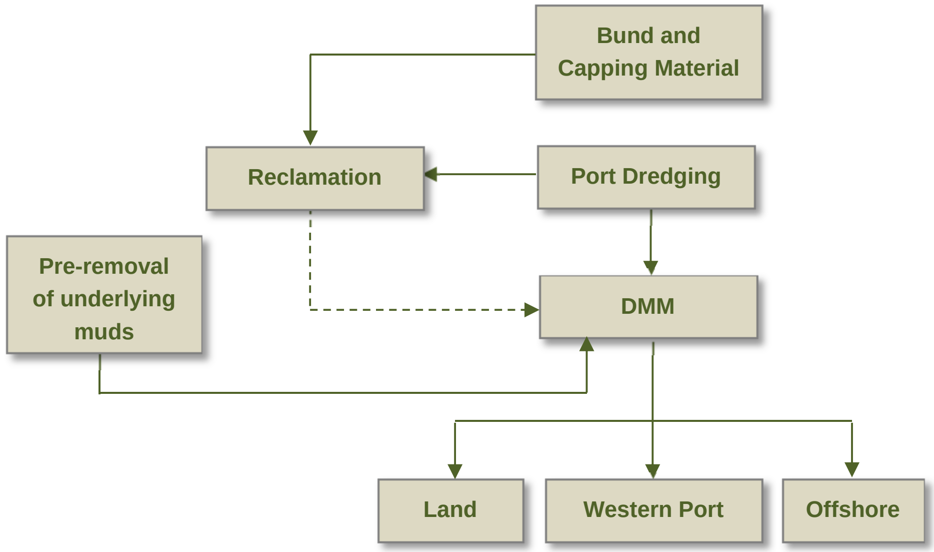


Figure 17 Flow Chart for Scenario 1 – Reclamation material sourced from port capital dredging/excavation

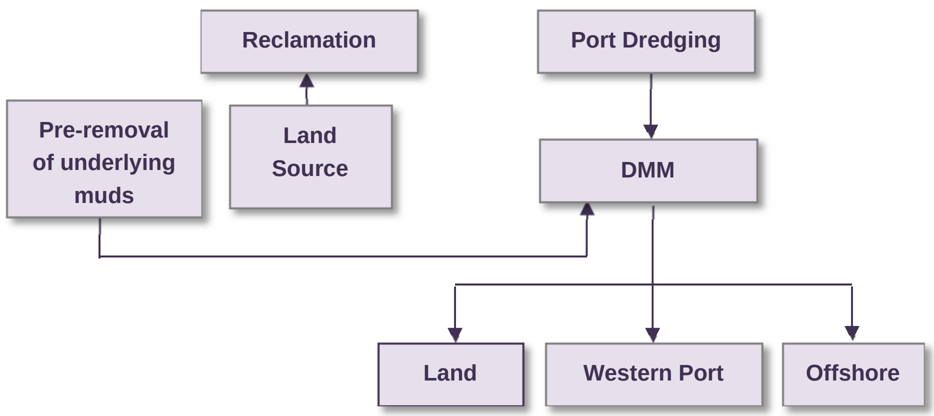


Figure 18 Flow Chart for Scenario 2 – Reclamation material sourced from land (SUZ1/quarry)

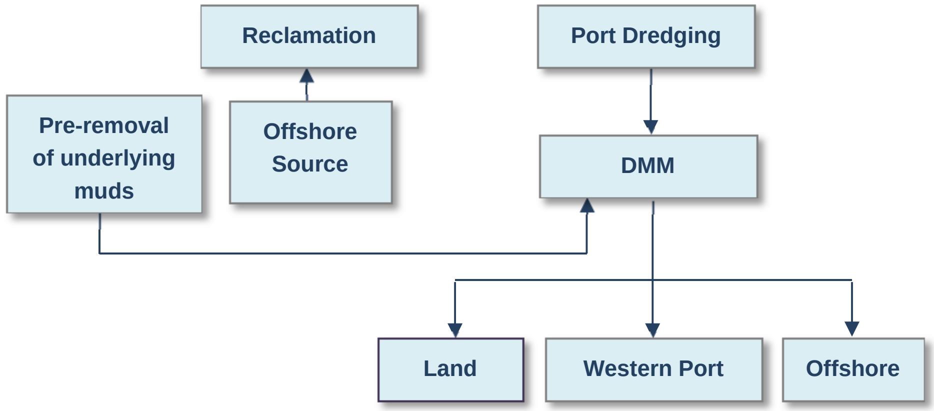


Figure 19 Flow Chart for Scenario 3 – Reclamation material sourced from offshore

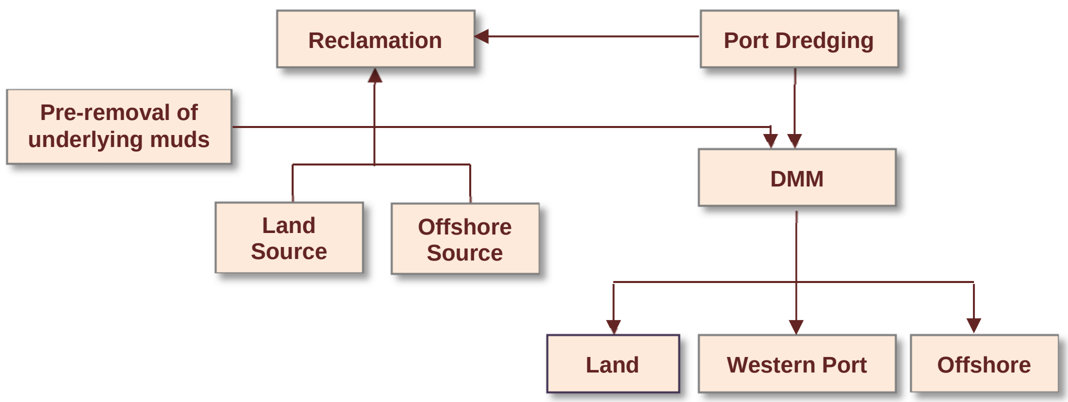


Figure 20 Flow Chart for Scenario 4 – Reclamation material sourced from a mix of port dredging, land and offshore

An important consideration in assessment of strategies is the staging of the project. For this reason the discussion that follows is approached on a stage by stage basis.

The following sections present some Rough Order of Magnitude (ROM) costs for certain work methods, based on unit rate and mobilisation/demobilisation cost estimates prepared by Baggerman Associates. Note that the ROM costs are used simply for comparative purposes and may exclude some common items between work methods. Unit rates are based on net dredging volumes and therefore any volumes presented in the cost tables are net volumes excluding overdredging. Calculations to support the ROM costs are provided in **Appendix A**.

For comparative purposes, graphs showing the variation of dredging unit rates and production rates between work methods provided by Baggerman Associates are provided as **Figure 21** and **Figure 22**.

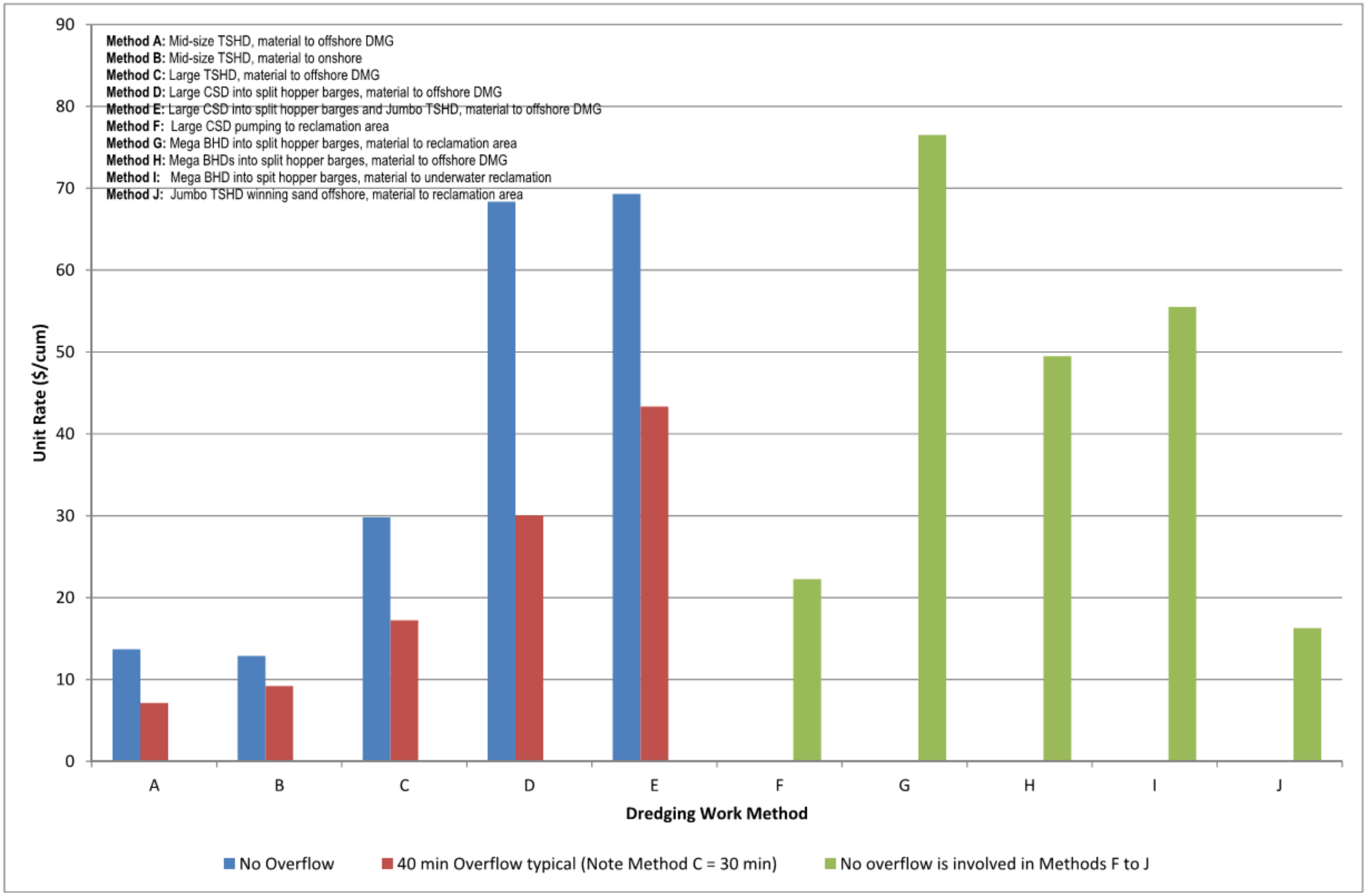


Figure 21 Unit rates for various dredging methods

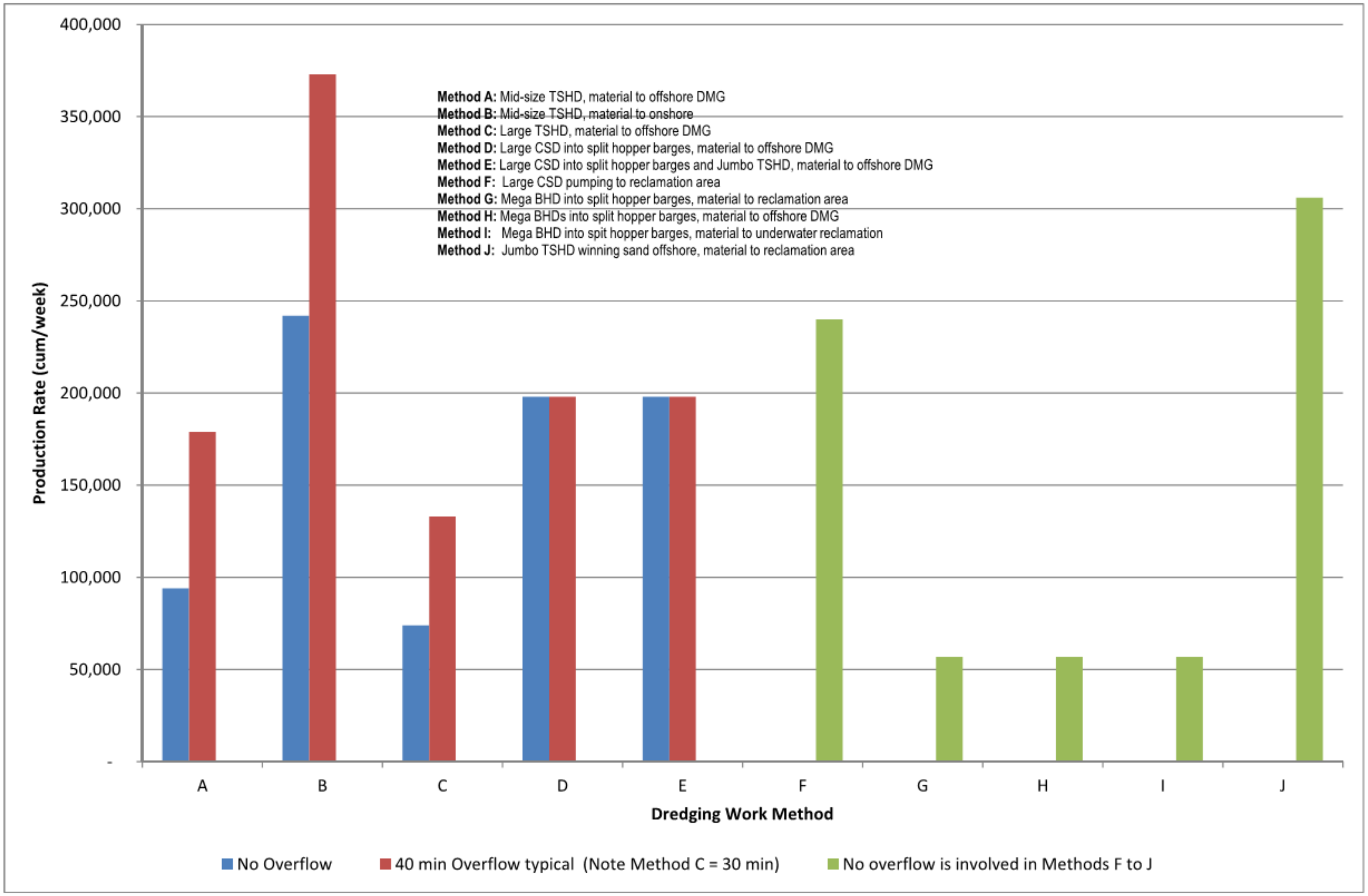


Figure 22 Production rates for various dredging methods

5.2 Terminal 1 – Stage 1 Development

5.2.1 Quantified Material Flow Charts for Scenarios 1-4

The quantified material flow charts for Terminal 1 – Stage 1 for Scenarios 1-4 are shown in **Figure 23** based on hydraulic dredging[6]. The same quantified flow charts would apply for both the Along the Shore Option and Basin Option, which are identical for Terminal 1 – Stage 1. Quantification of in situ volumes including overdredging is from **Table 5** / **Table 6**. The relative quantities of sand, clay balls, and fines slurry from the Baxter/Sherwood formation volumes are based on the behaviour of soils during hydraulic dredging as set out in **Figure 14**. The volume of Quaternary marine deposits within the dredging footprint has been assumed to comprise 30% fines and 70% sand, based on available data.

A number of common themes and differentiating factors arise for Scenarios 1-4, as discussed in the following sections.

Scenario 1 – Reclamation material sourced from port capital dredging

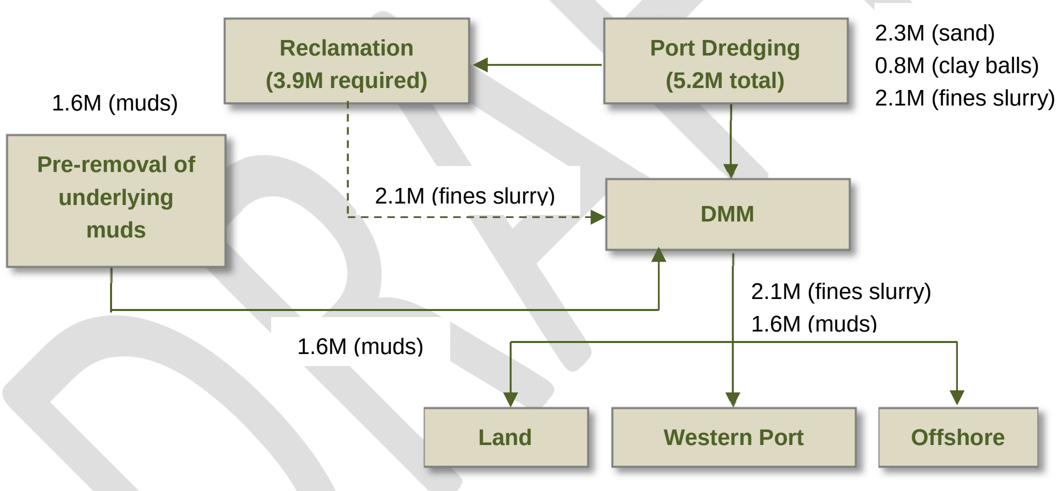
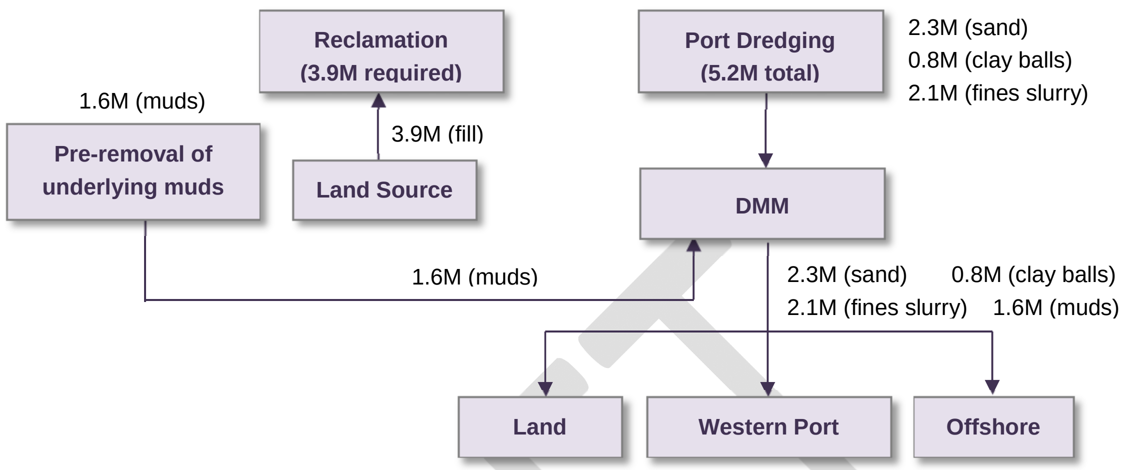


Figure 23 Quantified material flow charts for Terminal 1 – Stage 1 for Scenarios 1-4

[6] Hydraulic dredging has been adopted for illustration purposes since, as will be shown, this form of dredging has a significantly lower cost than mechanical dredging. Factors other than cost may ultimately influence the selection of hydraulic dredging versus mechanical dredging.

Scenario 2 – Reclamation material sourced from land (SUZ1/quarry)



Scenario 3 – Reclamation material sourced from offshore

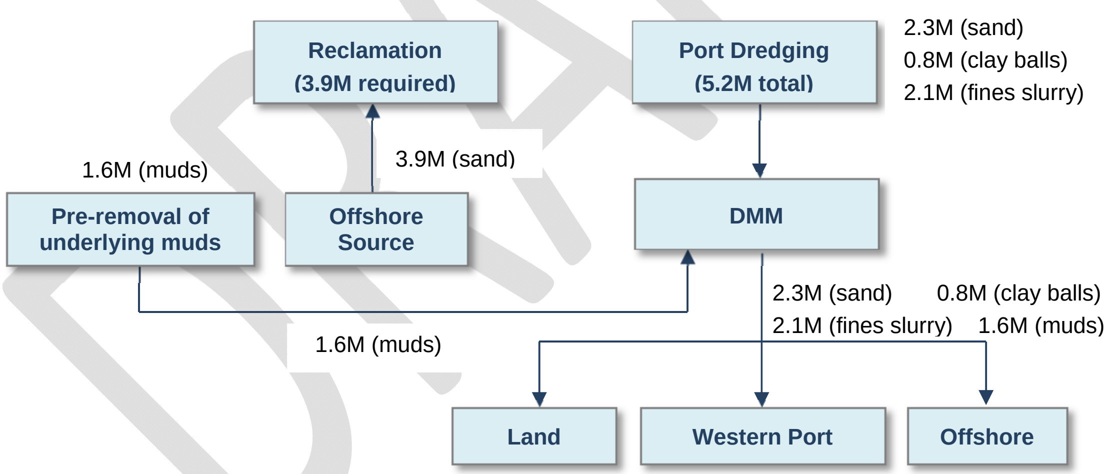


Figure 23 Quantified material flow charts for Terminal 1 – Stage 1 for Scenarios 1-4 (continued)

Scenario 4 – Reclamation material sourced from a mix of the above

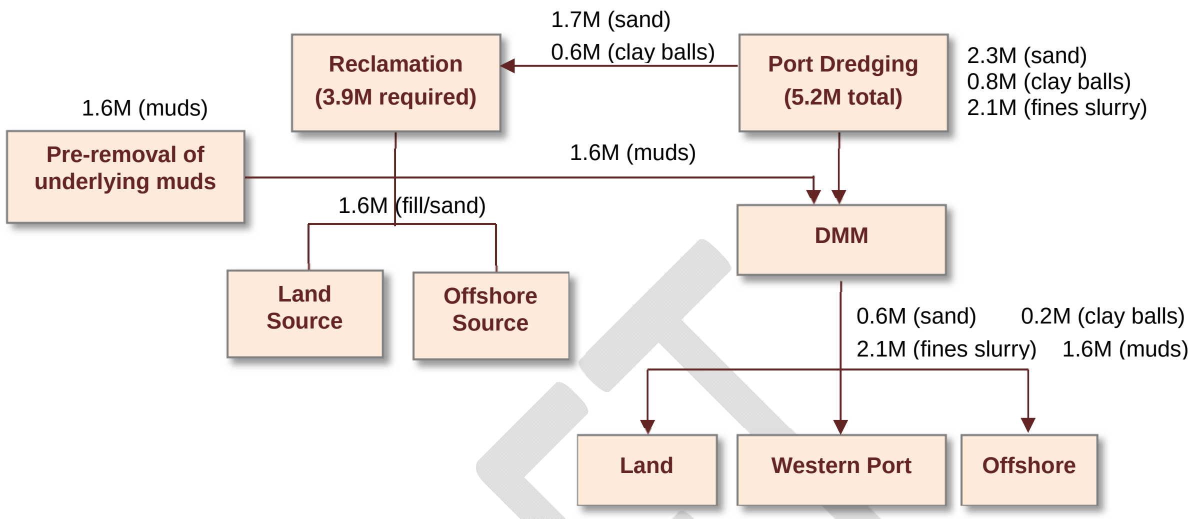


Figure 23 Quantified material flow charts for Terminal 1 – Stage 1 for Scenarios 1-4 (continued)

5.2.2 Pre-Removal of Muds (Quaternary Marine Deposits) Underlying the Reclamation

As noted earlier, muds (Quaternary marine deposits) underlying the reclamation area must be removed prior to reclamation, for geotechnical reasons. This is common with all Scenarios 1-4.

Baggerman Associates considered a number of possible work methods that may be suited to this activity, which involves dredging and disposal of 1.6Mm^3 including overdredging (refer **Table 5** / **Table 6**).

- Method A: Mid-size, shallow draft TSHD to offshore DMG;
- Method D: Large CSD into split hopper barges to offshore DMG;
- Method F: Large CSD pumping to onshore;
- Method G: Mega BHD into split hopper barges to onshore;
- Method H: Mega BHD into split hopper barges to offshore DMG.

Table 7 sets out the full mobilisation and demobilisation costs, and unit rates, for the different work methods. In practice mobilisation and demobilisation costs would be spread among the other dredging tasks in Terminal 1 – Stage 1 if the plant was suitable for these tasks (total 6.7Mm^3 dredging in Terminal 1 – Stage 1, refer **Table 5** / **Table 6**).

Table 7 also sets out for comparative purposes the approximate total cost of dredging 1.6Mm^3 (1.4Mm^3 net) if the mobilisation/demobilisation costs are spread, which can be the case for Methods D, F, G and H but not for Method A (Method A is not suited to dredging the remaining material in Terminal 1 – Stage 1 (Baxter Formation) and therefore mobilisation/demobilisation costs have not been spread for this method).

Table 7 Rough Order of Magnitude (ROM) Costs associated with Pre-Removal of Muds Underlying the Reclamation

Work Method	Total Mob/Demob ($M)	Spread Mob/Demob ($M)	Other Costs ($M)	Unit Rate ($/m^3)	Dredging Volume (Net Mm^3)	Comparative approx. Total Cost ($M)
A	8.9	8.9	-	7 - 14	1.4	19 - 29
D	33.1	7.9	-	30 - 69	1.4	50 - 105
F	23.9	5.7	-	23	1.4	38
G	38.0	9.1	8 (see Note 1)	77	1.4	125
H	34.1	8.1	-	50	1.4	78

Notes:

1. Other costs associated with Method G are for the installation and removal of an unloading dock, and for roads and bunds. A saving of $1.7M could be realised if self-propelled bottom discharge hopper barges are used as an alternative to split hopper barges.
2. Unit rate ranges correspond to'40 minute overflow' and 'no overflow' where applicable.
3. Unit rates are applied to the net in situ dredging volumes (i.e. excluding overdredging).

The information in **Table 7** suggests the following:

- one of the lower cost methods for disposal of the muds would be the use of a Large CSD pumping the material to onshore (Method F)[7]. A land disposal method would also be expected to have a lower approvals risk compared to a method involving establishment of a DMG. The potential disadvantage of use of a CSD pumping the material to onshore is the area required for settling ponds. Based on an in situ volume of 1.6Mm^3, a bulking factor of 2 (HAS-CEP-0-HY-REP-0030), and an average fill height in the settling ponds of say 4m, the total area of land required would be up to about 100 hectares (ha), or about 1km x 1km, measured as a square. This area would represent 3 to 4% of the SUZ1;
- another lower cost method for disposal of the muds would be to an offshore DMG, either by a mid-size, shallow draft TSHD (Method A) or a Large CSD loading split hopper barges (Method D). Use of a mid-size TSHD would make the pre-removal of the muds independent of the main port dredging (since the mid-size TSHD could not effectively dredge the stiff to hard Baxter Formation), however draft restrictions in nearshore areas will limit the volume of material that will be able to be dredged. Use of a Mega BHD loading split hopper barges for disposal to an offshore DMG (Method H) would be more expensive than using a mid-size TSHD and comparable to the Large CSD (subject to the duration of overflow that is allowed);
- use of a Mega BHD loading split hopper barges for disposal to onshore (Method G) would be expected to have a lower approvals risk (like the Large CSD pumping to onshore) and would involve less use of the SUZ1 land for disposal (due to a lower bulking factor) but is considerably more expensive than use of a Large CSD by a factor of about three.

[7] It is suggested this would also be the case for a smaller CSD.

Selection of the work method for pre-removal of the muds under the reclamation is likely to be influenced by the work method adopted for the main port dredging.

5.2.3 Source of Material for Reclamation

This matter is the fundamental difference between Scenarios 1-4.

Scenario 1

In Scenario 1 the reclamation material is sourced from the port capital dredging/excavation. In Terminal 1 – Stage 1 the ability to place dredged material in the reclamation area is restricted by the existence of the Old Tyabb Reclamation (which is proposed to be retained, with ground improvement in this area achieved by preload surcharge and vertical drains). Two further factors also restrict the ability to place the dredged material in the reclamation area:

- the construction of a bund, which must be constructed with imported material rather than dredged material as the dredged material is unsuitable;
- the restriction on the elevation to which dredged material can be placed (level of +1 to +2m CD) due to the need to provide a sand capping over the dredged material, associated with ground improvement (to address clay balls or clay lumps at depth).

The above restrictions mean that of the total reclamation volume requirement in Terminal 1 – Stage 1 of 3.9Mm^3 only approximately 2.3Mm^3 is available for placement of dredged material.

In effect there is no ‘pure’ Scenario 1, due to the problematic nature of the dredged material.

Baggerman Associates considered two possible work methods for disposal of port dredging material into the reclamation (Scenario 1).

- Method F: Large CSD pumping to reclamation
- Method I: Mega BHD into split hopper barges to reclamation

Table 8 sets out a cost comparison for two cases which adopt Method F and Method I separately as a basis. The costs exclude dredging and disposal of the Quaternary marine deposits under the reclamation area, which are common.

The information in **Table 8** suggests that, of the two options considered, use of a Large CSD pumping port dredging material to the reclamation is likely to have a significantly lower cost than use of a Mega BHD. Accordingly, use of a Large CSD pumping to the reclamation would be more attractive unless there is a compelling reason against hydraulic dredging, e.g. a greater ground improvement cost within the reclamation or unacceptable impact on the land from residual DMM material (excess to reclamation requirements) pumped to land.

Based on adoption of preload surcharge and vertical drains for ground improvement, the cost differential in **Table 8** is unlikely to be eroded by additional ground improvement costs

for the hydraulically placed material. The impact on the SUZ1 land of hydraulically placed DMM material may however be a significant differentiating issue (refer **Section 5.2.4**).

Table 8 Rough Order of Magnitude (ROM) Costs associated with Scenario 1 (Terminal 1 – Stage 1)

Item	Mob / Demob ($M)	Unit Rate ($/m^3)	Volume (Net Mm^3)	Amount ($M)^
Case 1 – Main Dredging by Large CSD				
Bund construction (Reclamation Area & DMM Area)	-	25	1.51	37.5
CSD to Reclamation Area	23.9	22.25	3.94	111.6
CSD to DMM Area	-	22.25	0.61	13.6
TSHD winning offshore sand for upper fill layer	26.6	16.3	1.43	49.9
			Case 1 Total	**212.6**
Case 2 – Main Dredging by Mega BHD				
Bund construction (Reclamation Area)	-	25	0.18	4.5
BHD into split hopper barges to Reclamation Area	18.1	55.5	2.27	144.1
BHD into split hopper barges to DMM Area*	27.9*	76.5	2.28	202.3
TSHD winning offshore sand for upper fill layer	26.6	16.3	1.43	49.9
			Case 2 Total	**400.8**

^ Excludes pre-removal of Quaternary marine deposit and ground improvement costs.

* A saving of $1.7M could be realised if self-propelled bottom discharge hopper barges are used as an alternative to split hopper barges.

<u>Scenarios 2 and 3</u>

Scenarios 2 and 3 involve winning reclamation material from a land source and an offshore source respectively. A desktop investigation has indicated that sand is likely to be available in the offshore area (HAS-CEP0-HY-REP-0019). Sand is available on land from commercial quarries within 100km from Hastings (HAS-CEP0-HY-REP-0027). There would appear to be limited quantities of sand with low fines content available from within the SUZ1 (HAS-CEP0-HY-REP-0027)[8].

Baggerman Associates considered a work method for winning sand from offshore using a Jumbo TSHD. Rough Order of Magnitude (ROM) costs for mobilisation and demobilisation, and dredging unit rate, are $26.6M and $16.3/m^3 respectively. These costs, when considered in the context of the volume of reclamation fill required (3.9Mm^3 giving an

[8] Nevertheless, due to the proximity of this source further studies should examine the material more closely.

average unit cost of $23/m^3), are likely to be comparable with land sources (Scenario 2)[9]. Accordingly, from a cost point of view, the discussion below is applicable for Scenario 2 as well as for Scenario 3.

When the reclamation material is supplied from an offshore source or a land source, the port dredging material becomes wholly DMM material. Work methods for dredging and disposal of this material are essentially the same as those outlined in **Section 5.2.2** for the pre-removal of muds under the reclamation except for Method A which is not suitable since the small TSHD is not able to effectively dredge the stiff to hard Baxter Formation.

It is of interest to compare the costs for Scenario 2/3 and Scenario 1. These are set out in **Table 9**. The costs exclude dredging and disposal of the muds under the reclamation area, which are common to all scenarios. It should be noted that assumed upper and lower bound unit rates are provided for a CSD pumping into split hopper barges based on 'no overflow' and '40 min. overflow' operational conditions. The adopted overflow duration is subject to further environmental assessment.

It is evident that the cost of Scenario 3 (and thus Scenario 2) is similar to the lower of the two costs for Scenario 1, within about $30 to $50M. Given that it would be expected the ground improvement costs for Scenario 2/3 (sand reclamation over water) would be significantly less than for Scenario 1 (where clay balls are included in the reclamation over water) the differences in cost would be reduced further; thus Scenario 2/3 may indeed be a lower cost overall. However, the costs of disposing port dredging material to an offshore DMG using a Large CSD pumping into split hopper barges is sensitive to the amount of overflow that is permitted and are significantly more than the lower bound costs for Scenario 1 if no overflow is allowed.

[9] Investigation of sand sources from several commercial quarries within HAS-CEP0-HY-REP-0027 indicated that supply and delivery costs ranged from $17/tonne to $35/tonne, which for a sand density of 1.5 t/m^3 corresponds to $26/m^3 to $53/m^3.

Table 9 Rough Order of Magnitude (ROM) Costs associated with Scenario 2/3 (Terminal 1 – Stage 1)

Item	Mob / Demob ($M)	Unit Rate ($/m^3)	Volume (Net Mm^3)	Amount ($M)^
Scenario 2/3 Case 1 – Port Dredging Material to DMM Area				
TSHD winning offshore sand for Reclamation Area	26.6	16.3	3.88	89.8
Bund construction	-	25	1.19	29.8
CSD to DMM Area	23.89	22.25	4.55	125.1
			Case 1 Total	**244.7**
Scenario 2/3 Case 2 – Port Dredging Material to Offshore DMG				
TSHD winning offshore sand for Reclamation Area	26.6	16.3	3.88	89.8
CSD into split hopper barges to Offshore DMG (40min overflow) or	33.1	30.05	4.55	169.8
CSD into split hopper barges to Offshore DMG (no overflow)	33.1	68.35	4.55	344.1
			Case 2 Total (40min overflow)	**259.6**
			Case 2 Total (no overflow)	**433.9**
Scenario 1				
From Table 8 (Case 1)				212.6
From Table 8 (Case 2)				400.8

^excludes pre-removal of Quaternary marine deposit and ground improvement costs.

Scenario 4

This scenario has already been addressed by Scenario 1 as an insufficient volume of suitable reclamation material exists within the dredging footprint and the reclamation volume needs to be supplemented by sand won from offshore (or onshore). That is, the required reclamation volume is obtained from a mix of material sources as per Scenario 4.

5.2.4 Onshore Land Area Required for Settling Ponds for DMM Material

Material unsuitable for incorporation into the reclamation (DMM material) comprises, generally speaking, the Quaternary marine deposits under the proposed reclamation, the fines slurry from hydraulic dredging of Baxter Formation and excess fines from the sandy materials exhibiting non-cohesive behaviour (refer **Figure 14**). In addition, due to the restricted volume available in the Terminal 1 – Stage 1 reclamation area, a proportion of the sand and clay balls from the port dredging would also become DMM material.

Total quantities of the above materials in Terminal 1 – Stage 1, measured in situ, are approximately 4.5Mm^3. Based on application of the bulking factors in **Table 3**, the bulked volume as a result of hydraulic dredging would be approximately 11Mm^3.

Based on an average fill height in the settling ponds of say 4m the total area required for the settling ponds, excluding bunds, would be approximately 275ha. Allowing for bunds and associated return water drainage systems, it is suggested that a nominal area of 300ha be adopted.

If considered as a square area, 300ha would have dimensions of around 1.7km x 1.7km. As a guide to the relative magnitude of this area on the SUZ1 site, the dimensions of 1.7km x 1.7km have been superimposed on the site together with the Terminal 1 – Stage 1 concept plan prepared by AECOM/GHD JV, as shown in **Figure 24**. The area would represent approximately 10% of the entire SUZ1, ideally it would be located close to the dredging area to reduce pumping distance and costs.

The area required for placement of DMM material would be significantly reduced if mechanical rather than hydraulic dredging was employed, by about 50%, but the cost would be significantly greater as shown in **Table 8**.

If all the dredging material became DMM material (Scenario 2/3) the total area required for settling ponds, bunds and drainage systems would increase to about 380ha or approximately 13% of the entire SUZ1.

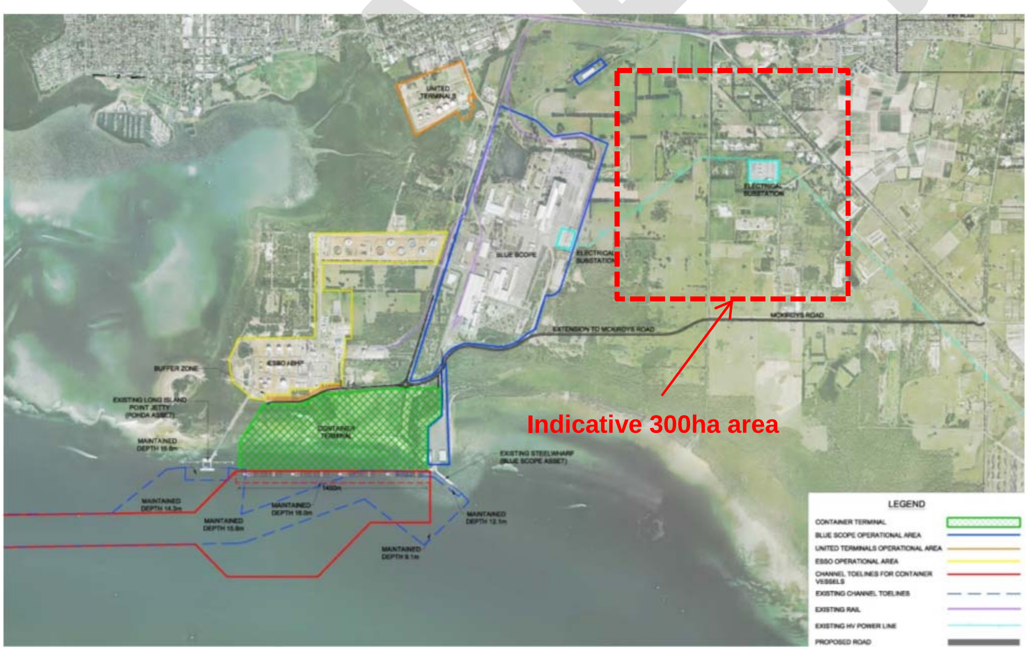


Figure 24 Area of 300ha (1.7km x 1.7km) shown superimposed on SUZ1 together with Terminal 1 – Stage 1 concept plan

5.2.5 Concluding Remarks

The following can be concluded in relation to Terminal 1 – Stage 1:

- there are a number of methods available for pre-removal of the muds (Quaternary marine deposits) below the reclamation area. Costs for disposal to land and for disposal to sea are likely to be comparable, however the cost of some hydraulic dredging methods for sea disposal is sensitive to the amount of overflow that is permitted;
- for disposal of dredged material on land or at an offshore DMG, use of hydraulic dredging (Large CSD) could be significantly lower in cost than use of mechanical dredging (Jumbo BHD), however the cost of hydraulic dredging methods for sea disposal is sensitive to the amount of overflow that is permitted;
- the area required on land for disposal of dredged material by hydraulic dredging is about two times that required for disposal of material by mechanical dredging. If all the port dredging material was disposed of to land, the total land area required would be about 380ha or approximately 13% of the entire SUZ1;
- the dredged material from the port is not suitable for reclamation without incorporation of sand from an offshore source and/or land source for purposes such as containment bunds, fill behind the quay wall and ground improvement; and,
- construction of the reclamation solely using sand sourced from offshore and/or from land, with all port dredged material disposed of as DMM material, is likely to have a comparable cost to options which aim to include port dredged material into the reclamation, however the cost of some hydraulic methods for sea disposal is sensitive to the amount of overflow that is permitted.

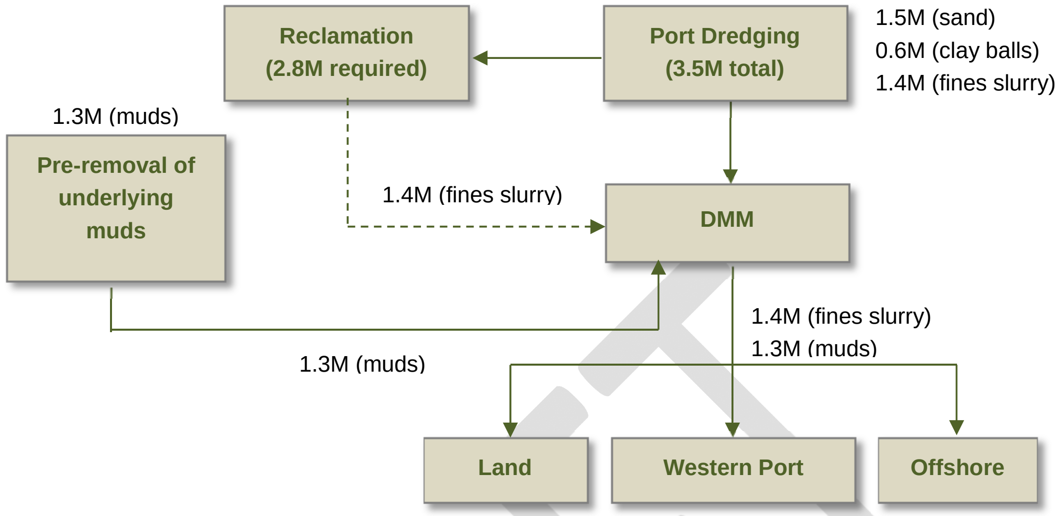
5.3 Terminal 1 – Stage 2 Development

5.3.1 Quantified Material Flow Charts for Scenarios 1-4

The quantified material flow charts for Terminal 1 – Stage 2 for Scenarios 1-4 are shown in **Figure 25** based on hydraulic dredging[10]. The same quantified flow charts would apply for both the Along the Shore Option and Basin Option, which are identical for Terminal 1 – Stage 2. Quantification of in situ volumes including overdredging is from **Table 5** / **Table 6**. The relative quantities of sand, clay balls and fines slurry from the Baxter/Sherwood formation volumes are based on the behaviour of soils during hydraulic dredging as set out in **Figure 14**. The volume of Quaternary marine deposits within the dredging footprint has been assumed to comprise 30% fines and 70% sand, based on available data.

[10] Hydraulic dredging has been adopted for illustration purposes since, as will be shown, this form of dredging has a significantly lower cost than mechanical dredging. Factors other than cost may ultimately influence the selection of hydraulic dredging versus mechanical dredging.

Scenario 1 – Reclamation material sourced from port capital dredging



Scenario 2 – Reclamation material sourced from land (SUZ1/quarry)

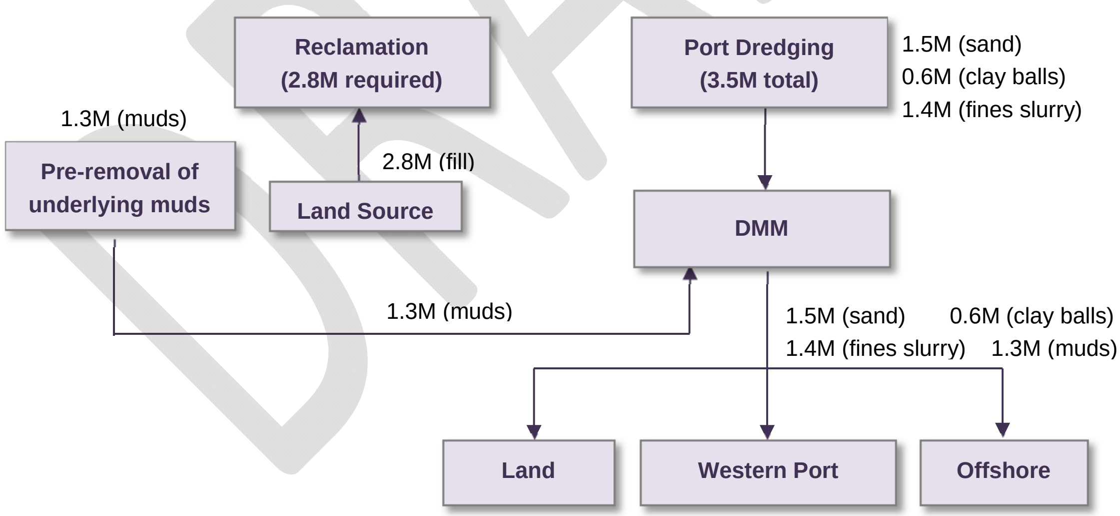


Figure 25 Quantified material flow charts for Terminal 1 – Stage 2 for Scenarios 1-4

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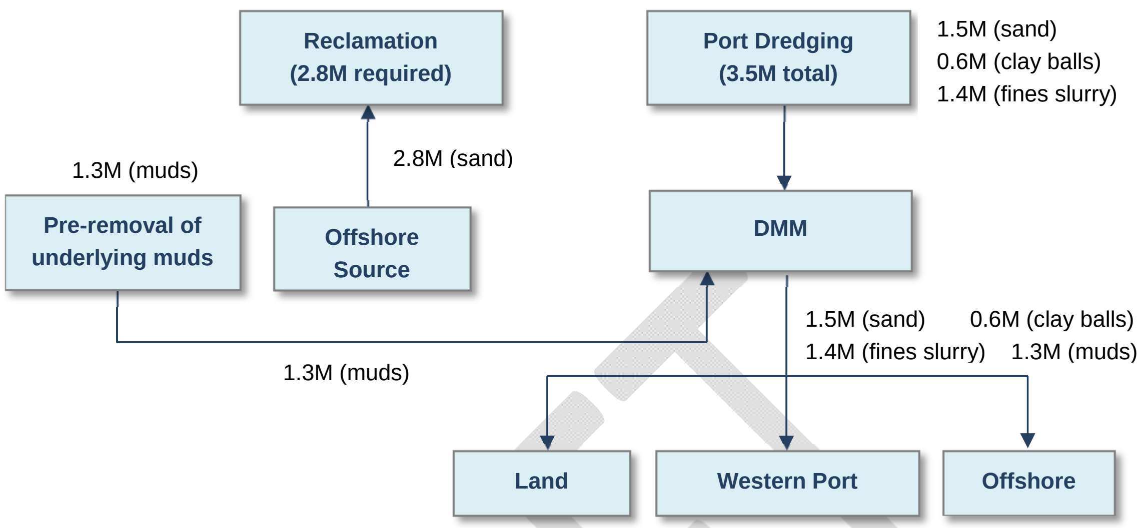
Scenario 3 – Reclamation material sourced from offshore



Scenario 4 – Reclamation material sourced from a mix of the above

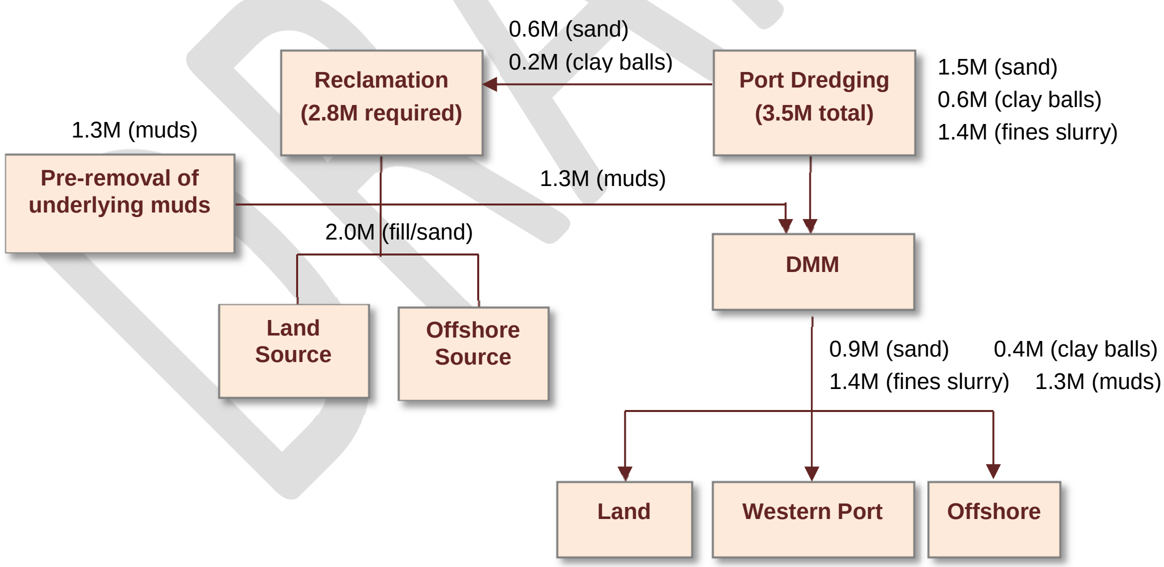


Figure 25 Quantified material flow charts for Terminal 1 – Stage 2 for Scenarios 1-4 (continued)

5.3.2 Discussion

The situation with Terminal 1 – Stage 2 is very similar to Terminal 1 – Stage 1, except that the various dredging volumes and the reclamation volumes are somewhat lower, accordingly:

- similar work methods would apply for pre-removal of the muds (Quaternary marine deposits) underlying the reclamation;
- there is again no 'pure' Scenario 1 due to the problematic nature of the dredged material; it is necessary to utilise sand from an offshore source (Scenario 3) and/or land source (Scenario 2) for purposes such as containment bunds, fill behind the quay wall and ground improvement.

Table 10 and **Table 12** sets out the cost comparison for Scenario 1 and Scenario 2/3. Again the costs exclude dredging and disposal of muds under the reclamation area which are common to all scenarios. As was the case for Terminal 1 – Stage 1, the cost for Scenario 3 (and thus Scenario 2) are similar to the lower range of costs for Scenario 1.

Table 10 Rough Order of Magnitude (ROM) Costs associated with Scenario 1 (Terminal 1 – Stage 2)

Item	Mob / Demob ($M)	Unit Rate ($/m^3)	Volume (Net Mm^3)	Amount ($M)^
Case 1 – Main Dredging by Large CSD				
Bund construction (Reclamation Area and DMM Area)	-	25	0.99	24.8
CSD to Reclamation Area	23.9	22.25	1.46	56.4
CSD to DMM Area	-	22.25	1.89	42.1
TSHD winning offshore sand for upper fill layer	26.6	16.3	1.80	55.9
			Case 1 Total	**179.2**
Case 2 – Main Dredging by Mega BHD				
Bund construction (Reclamation Area)	-	25	0.14	3.5
BHD into split hopper barges to Reclamation Area	18.1	55.5	0.84	64.7
BHD into split hopper barges to DMM Area	27.9*	76.5	2.51	219.9
TSHD winning offshore sand for upper fill layer	26.6	16.3	1.80	55.9
			Case 2 Total	**344.0**

^ Excludes pre-removal of Quaternary marine deposit and ground improvement costs.

* A saving of $1.7M could be realised if self-propelled bottom discharge hopper barges are used as an alternative to split hopper barges.

Table 11 Rough Order of Magnitude (ROM) Costs associated with Scenario 2/3 (Terminal 1 – Stage 2)

Item	Mob / Demob ($M)	Unit Rate ($/m^3)	Volume (Net Mm^3)	Amount ($M)^
Scenario 2/3 Case 1 – Port Dredging Material to DMM Area				
TSHD winning offshore sand for Reclamation Area	26.6	16.3	2.78	71.9
Bund construction	-	25	1.01	25.3
CSD to DMM Area	23.89	22.25	3.35	98.4
			Case 1 Total	**195.6**
Scenario 2/3 Case 2 – Port Dredging Material to Offshore DMG				
TSHD winning offshore sand for Reclamation Area	26.6	16.3	2.78	71.9
CSD into split hopper barges to Offshore DMG (40min overflow) or	33.1	30.05	3.35	133.8
CSD into split hopper barges to Offshore DMG (no overflow)	33.1	68.35	3.35	262.1
			Case 2 Total (40min overflow)	**205.7**
			Case 2 Total (no overflow)	**334.0**
Scenario 1				
From Table 10 (Case 1)				179.2
From Table 10 (Case 2)				344.0

^ Excludes pre-removal of Quaternary marine deposit and ground improvement costs.

If all dredging material became DMM material (Scenario 2/3) and the material was pumped to onshore the total area required for settling ponds, bunds and drainage systems, based on a fill height in the settling ponds of say 4m, would be about 280ha. If considered as a square area, 280ha would have dimensions of around 1.7km x 1.7km and would represent about 9% of the entire SUZ1.

Scenario 4 has already been addressed by Scenario 1 as an insufficient volume of suitable reclamation material exists within the dredging footprint and the reclamation volume needs to be supplemented by sand won from offshore (or onshore). That is, the required reclamation volume is obtained from a mix of material sources as per Scenario 4.

Similar concluding remarks apply to Terminal 1 – Stage 2 as for Terminal 1 – Stage 1 (refer **Section 5.2.5**),

5.4 Terminal 2 – Along the Shore Option

5.4.1 Quantified Material Flow Charts for Scenarios 1-4

The quantified material flow charts for the Terminal 2 stage of the development, for the Along the Shore Option, are shown in **Figure 26**, based on hydraulic dredging[11]. Quantification of in situ volumes including overdredging is from **Table 5**. The relative quantities of sand, clay balls and fines slurry from the Baxter/Sherwood formation volumes are based on the behaviour of soils during dredging as set out in **Figure 14**. The volume of Quaternary marine deposits within the dredging footprint has been assumed to comprise 30% fines and 70% sand, based on available data.

In practice, the balance of the development represented by Terminal 2 would be undertaken in a number of stages which are unknown at this point in time. Accordingly, comments of a general nature only are made below.

Scenario 1 – Reclamation material sourced from port capital dredging

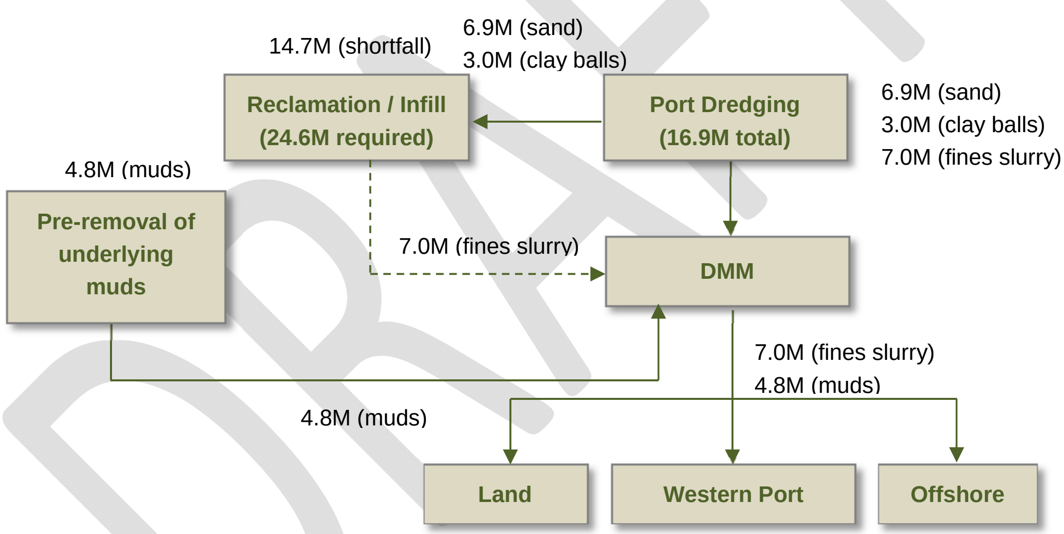
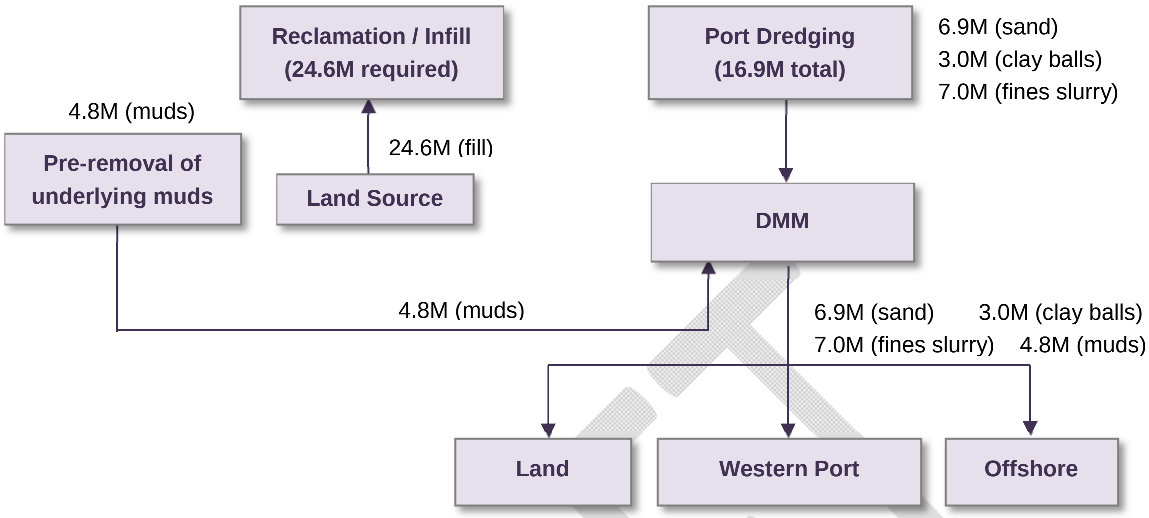


Figure 26 Quantified material flow charts for Terminal 2 for Scenarios 1-4 (Along the Shore Option)

[11] Hydraulic dredging has been adopted for illustration purposes since, as will be shown, this form of dredging has a significantly lower cost than mechanical dredging. Factors other than cost may ultimately influence the selection of hydraulic dredging versus mechanical dredging.

Scenario 2 – Reclamation material sourced from land (SUZ1/quarry)



Scenario 3 – Reclamation material sourced from offshore

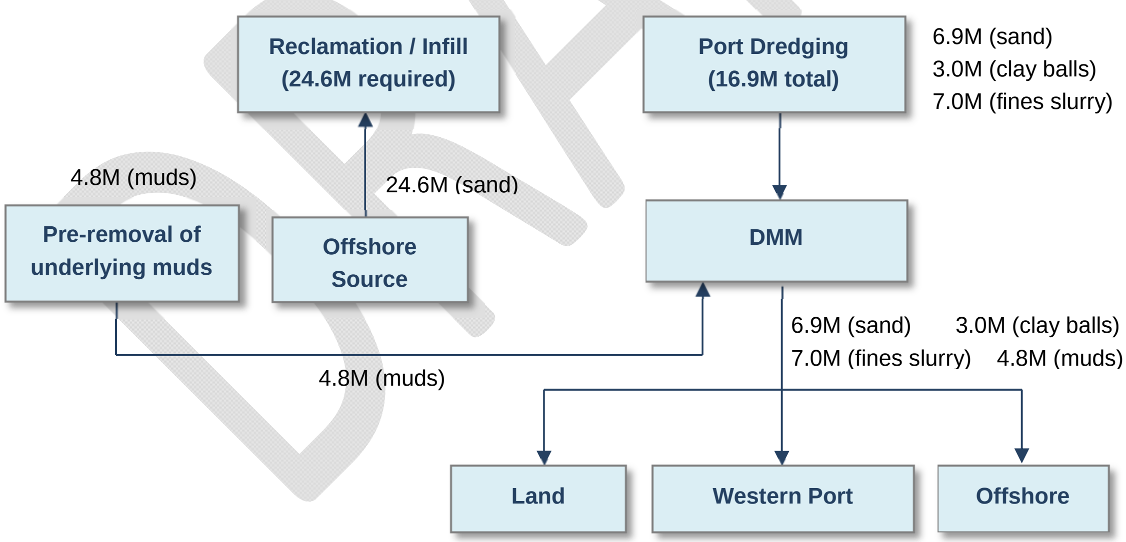


Figure 26 Quantified material flow charts for Terminal 2 for Scenarios 1-4 (Along the Shore Option) (continued)

Scenario 4 – Reclamation material sourced from a mix of the above

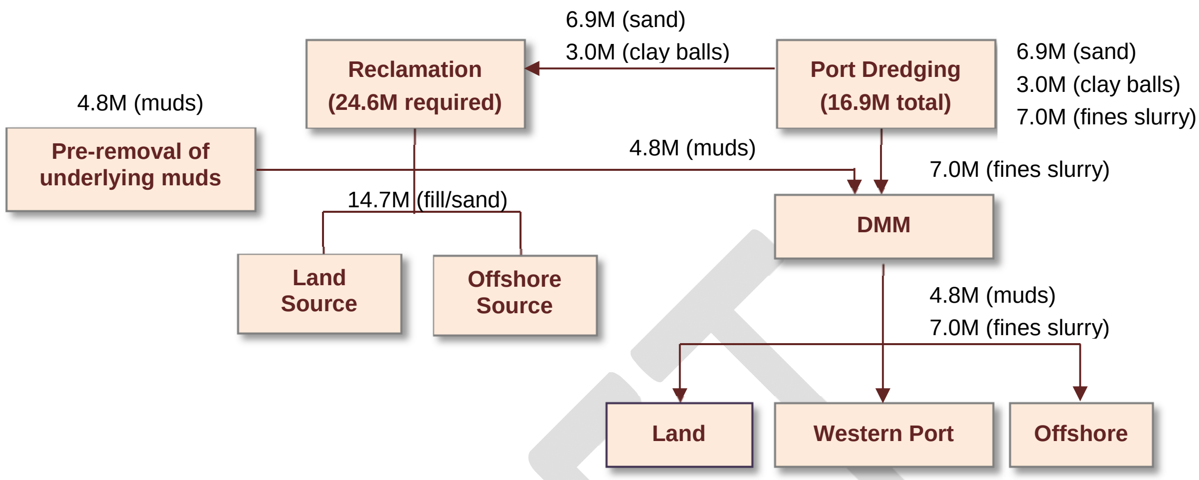


Figure 26 Quantified material flow charts for Terminal 2 for Scenarios 1-4 (Along the Shore Option) (continued)

5.4.2 Discussion

In the case of the Along the Shore Option, considering the Terminal 2 stage:

- similar work methods would apply for the pre-removal of the muds (Quaternary marine deposits) underlying the reclamation as was the case for Terminal 1 – Stage 1 and Terminal 1 – Stage 2 (refer **Section 5.2.2** for discussion of Terminal 1 – Stage 1);
- all of the sand and clay balls generated by the port dredging could be included in the reclamation;
- a source of additional fill would be required to complete the reclamation. A proportion of this additional fill would need to comprise sand from an offshore source (Scenario 3) and/or a land source for purposes such as containment bunds, fill behind the quarry wall and ground improvement.

Table 12 and **Table 13** set out the range of costs for Scenario 1 and Scenario 2/3 considering the Terminal 2 stage. Again the costs exclude dredging and disposal of the muds under the reclamation area which are common to all scenarios.

The results in **Table 13** suggest that Scenario 1 may start to become more attractive when the Terminal 2 stage is considered, but it is noted that the costs in **Table 13** exclude ground improvement which are likely to be significantly more expensive for Scenario 1 due to the problematic nature of the port dredged materials compared to Scenario 2/3 which includes reclamation wholly from a sand source.

Table 12 Rough Order of Magnitude (ROM) Costs associated with Scenario 1 (Terminal 2, Along the Shore Option)

Item	Mob / Demob ($M)	Unit Rate ($/m^3)	Volume (Net Mm^3)	Amount ($M)^
Case 1 – Main Dredging by Large CSD				
Bund construction (Reclamation Area and DMM Area)	-	25	2.66	66.5
CSD to Reclamation Area	23.9	22.25	15.88	377.2
TSHD winning offshore sand	26.6	16.3	14.1	256.4
			Case 1 Total	**700.1**
Case 2 – Main Dredging by Mega BHD				
Bund construction (Reclamation Area)	-	25	0.39	9.8
BHD into split hopper barges to Reclamation Area	18.1	55.5	15.88	899.4
TSHD winning offshore sand	26.6	16.3	8.54	165.8
			Case 2 Total	**1075.0**

^ Excludes pre-removal of Quaternary marine deposit and ground improvement costs.

Table 13 Rough Order of Magnitude (ROM) Costs associated with Scenario 2/3 (Terminal 2, Along the Shore Option)

Item	Mob / Demob ($M)	Unit Rate ($/m^3)	Volume (Net Mm^3)	Amount ($M)^
Scenario 2/3 Case 1 – Port Dredging Material to DMM Area				
TSHD winning offshore sand for Reclamation Area	26.6	16.3	24.42	424.7
Bund construction (DMM Area)	-	25	2.85	71.3
CSD to DMM Area	23.89	22.25	15.88	377.2
			Case 1 Total	**873.2**
Scenario 2/3 Case 2 – Port Dredging Material to Offshore DMG				
TSHD winning offshore sand for Reclamation Area	26.6	16.3	24.42	424.7
CSD into split hopper barges to Offshore DMG (40min overflow) or	33.1	30.05	15.88	510.3
CSD into split hopper barges to Offshore DMG (no overflow)	33.1	68.35	15.88	1118.5
			Case 2 Total (40min overflow)	**935.0**
			Case 2 Total (no overflow)	**1543.2**
Scenario 1				
From Table 12 (Case 1)				700.1
From Table 12 (Case 2)				1075.0

^ Excludes pre-removal of Quaternary marine deposit and ground improvement costs.

If all the dredged material became DMM material (Scenario 2/3) and the material was pumped to onshore, the total area for settling ponds, bunds and drainage systems, based on a full height in the settling ponds of say 4m, would be about 1,200ha. If considered as a square area, the 1,200ha would have dimensions of around 3.5km x 3.5km and would represent about 40% of the entire SUZ1.

Scenario 4 has already been addressed by Scenario 1 as an insufficient volume of suitable reclamation material exists within the dredging footprint and the reclamation volume needs to be supplemented by sand won from offshore (or onshore). That is, the required reclamation volume is obtained from a mix of material sources as per Scenario 4.

5.5 Terminal 2 – Basin Option

5.5.1 Quantified Material Flow Charts for Scenarios 1-4

The quantified material flow charts for the Terminal 2 stage, for the Basin Option, are shown in **Figure 27**, based on dredging being undertaken by hydraulic methods[12]. Quantification of in situ volumes including overdredging and over-excavation is from **Table 6**. The relative quantities of sand, clay balls and fines slurry from the Baxter/Sherwood formation volumes are based on the behaviour of soils during dredging as set out in **Figure 14**. The volume of Quaternary marine deposits within the dredging footprint has been assumed to comprise 30% fines and 70% sand, based on available data.

In practice, the balance of the development represented by Terminal 2 would be undertaken in a number of stages which are unknown at this point in time. As such, comments of a general nature only are made below.

Scenario 1 – Reclamation material sourced from port capital dredging

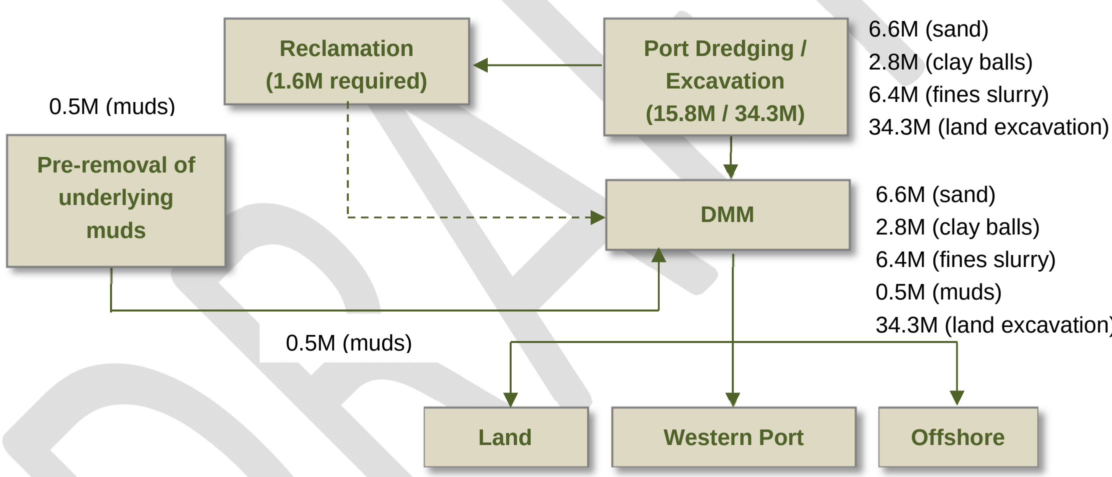
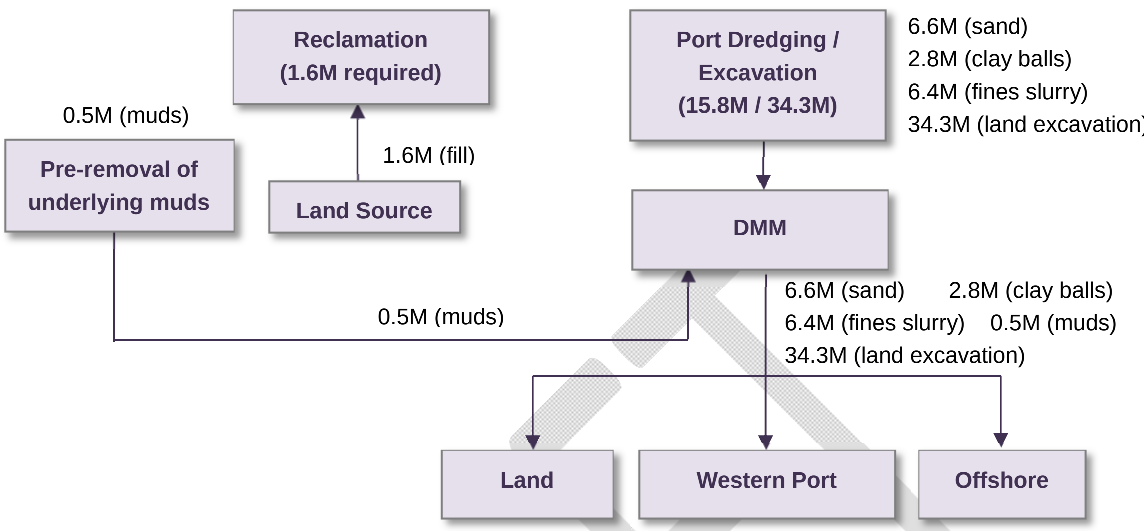


Figure 27 Quantified material flow charts for Terminal 2 for Scenarios 1-4 (Basin Option)

[12] Hydraulic dredging has been adopted for illustration purposes since, as will be shown, this form of dredging has a significantly lower cost than mechanical dredging. Factors other than cost may ultimately influence the selection of hydraulic dredging versus mechanical dredging.

Scenario 2 – Reclamation material sourced from land (SUZ1/quarry)



Scenario 3 – Reclamation material sourced from offshore

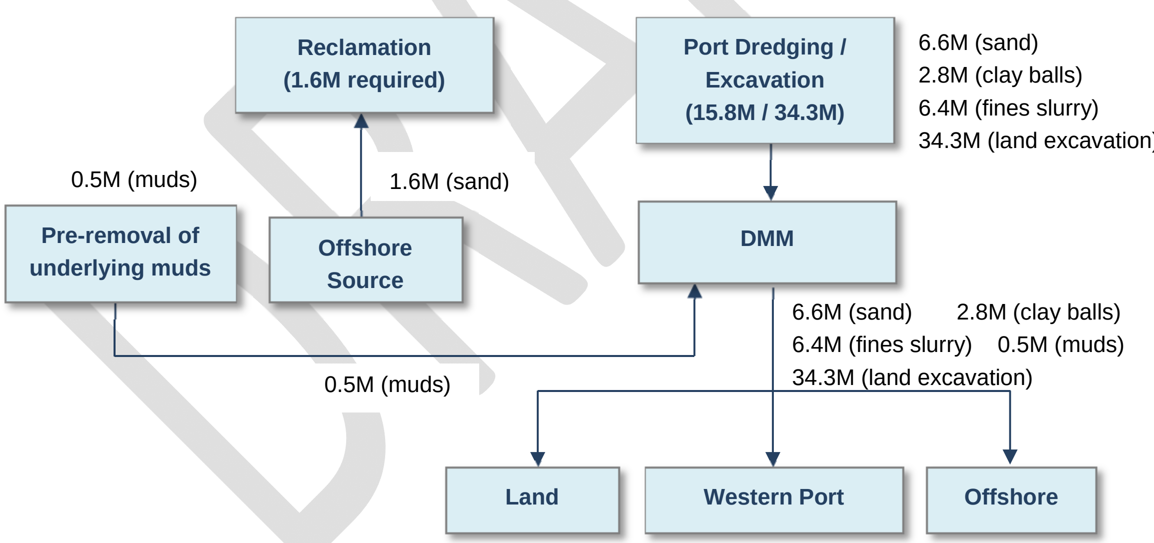


Figure 27 Quantified material flow charts for Terminal 2 for Scenarios 1-4 (Basin Option) (Continued)

Scenario 4 – Reclamation material sourced from a mix of the above

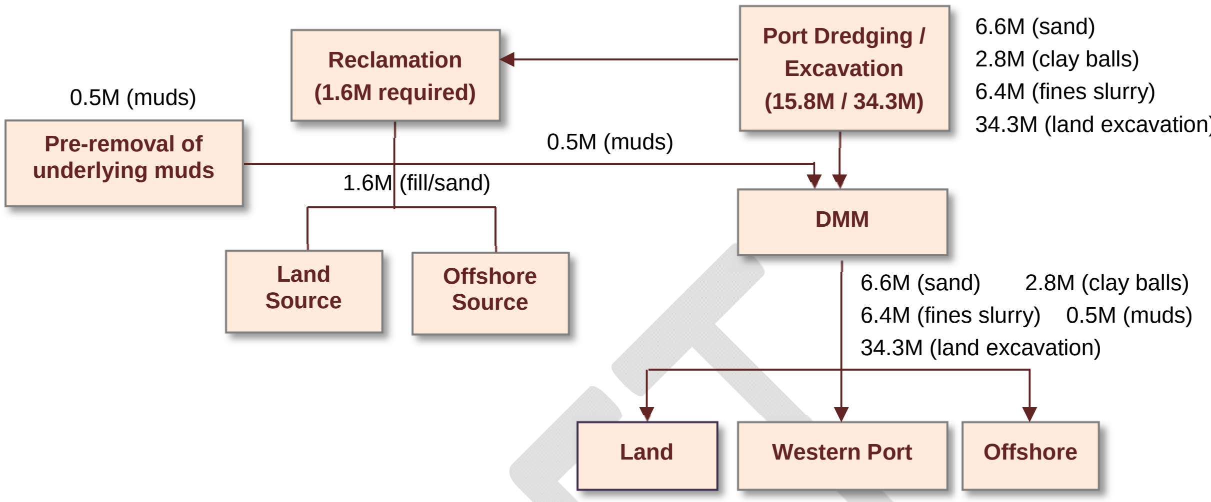


Figure 27 Quantified material flow charts for Terminal 2 for Scenarios 1-4 (Basin Option) (Continued)

5.5.2 Discussion

It is apparent from the flow charts in Error! Reference source not found. that:

- there is minimal reclamation in the Terminal 2 stage of development for the Basin Option (1.6Mm^3);
- all dredging material would essentially became DMM material;
- there is a major volume of excavated material from land (34.3Mm^3) made up of two parts, excavation for the land terminal (14.4Mm^3) and excavation for the basin (19.9Mm^3) which involves excavation below the water table;
- the major volume of excavation could likely be managed to accommodate the minor reclamation requirement, if required.

A significant proportion of the costs associated with the Terminal 2 stage of development for the Basin Option would be the cost of excavation, in particular the cost of excavation of the basin below the water table. There is currently limited information available on groundwater conditions and behaviour to inform development of costs for the basin excavation. A preliminary rate for excavation of $15/m^3 has been adopted for costing purposes[13]. This equates to a cost of around $500M for the basin/terminal excavation volume of 34.3M.

Table 14 sets out the range of costs of the dredging component of the Basin Option based on two main options for disposal of dredged material, disposal to land (either by hydraulic dredging or mechanical dredging) and disposal to an offshore DMG (either by hydraulic dredging or mechanical dredging). It is possible to use the costs in **Table 14** to identify the

[13] This excludes the cost of quay walls and associated anchoring along the perimeter of the basin area.

breakeven costs necessary for excavation in order to roughly match the range of costs for the Along the Shore Option.

The following can be concluded:

- hydraulic dredging methods are potentially more cost effective than mechanical methods for both disposal to land and to an offshore DMG, however the cost of hydraulic dredging methods for sea disposal is sensitive to the amount of overflow that is permitted;
- the costs of disposal to land and disposal to an offshore DMG are likely to be comparable if the additional costs of ground improvement associated with land disposal are considered, and,
- comparison of the cost of hydraulic dredging methods with lower bound costs for the Along the Shore option indicate the excavation costs for the Basin Option would need to be in the order of \$6/m^3 to \$20/m^3 for the Basin Option costs to roughly match the costs of the Terminal 2 stage for the Along the Shore Option. The preliminary rate of \$15/m^3 adopted for excavation (as noted above) falls within this range.

Table 14 Rough Order of Magnitude (ROM) Costs associated with the Dredging Component of the Basin Option (Terminal 2)

Item	Mob / Demob ($M)	Unit Rate ($/m^3)	Volume (Net Mm^3)	Amount ($M)^
Disposal to Land - Large CSD pumping to onshore bunded area				
Bund construction (Reclamation and DMM Area)	-	25	2.28	57.0
CSD to Reclamation Area	23.9	22.25	15.01	357.9
			Total	**414.9**
Disposal to Land – Mega BHD into split hopper barges to onshore				
BHD into split hopper barges to DMM Area	50.3*	76.5	15.01	1198.6
			Total	**1198.6**
Disposal to Offshore DMG – Large CSD into split hopper barges				
CSD into split hopper barges to Offshore DMG (40min overflow) or	33.1	30.05	15.01	484.2
CSD into split hopper barges to Offshore DMG (no overflow)	33.1	68.35	15.01	1059.0
			Total (40min overflow)	**484.2**
			Total (no overflow)	**1059.0**
Disposal to Offshore DMG – Mega BHD into split hopper barges				
BHD into split hopper barges to Offshore DMG	34.1	49.5	15.01	777.1
			Total	**777.1**

^ Excludes pre-removal of Quaternary marine deposit and ground improvement costs.

* A saving of $1.7M could be realised if self-propelled bottom discharge hopper barges are used as an alternative to split hopper barges.

If all the dredged material was pumped to onshore, the total area for settling ponds, bunds and drainage systems, based on a full height in the settling ponds of say 4m, would be about 900ha. If considered as a square area, the 900ha would have dimensions of around 3.0km x 3.0km and would represent about 30% of the entire SUZ1.

6 REALISTIC STRATEGIES FOR DREDGING, RECLAMATION AND DMM

6.1 General

The following sections summarise what are considered to be realistic strategies for dredging, reclamation and dredged material management according to the main stages of the project. Consideration is given to both the Along the Shore Option and Basin Option.

6.2 Terminal 1 – Stage 1 and Terminal 1 – Stage 2 Development

It is useful to consider Terminal 1 – Stage 1 and Terminal 1 – Stage 2 of the project together since the outcomes are similar. The two stages are also equivalent for the Along the Shore Option and Basin Option.

From the cost and technical points of view, and minimising the impacts of DMM on the SUZ1 land, the suggested strategy would be:

- use of a Jumbo TSHD to win sand from offshore for reclamation;
- use of a Large CSD loading split hopper barges for disposal of port dredged material at an offshore DMG; and,
- identification of opportunities to incorporate locally excavated material from the SUZ1 within the reclamation where material is suitable, and subject to costs.

This strategy has an elevated approvals risk since there are no approvals in place for offshore sand extraction and there is no established offshore DMG. The cost of the strategy is also sensitive to the amount of overflow which would be permitted from the barges. For this reason it is suggested that a strategy with a lower approvals risk also be developed. This would involve an 'all land solution' reclamation using a combination of dredged material and sand from a land source (for those areas of the reclamation where dredged material is unsuitable) and disposal of the balance of the dredged material on the SUZ1 land. There are two options for disposal of dredged material to the SUZ1 land:

- Large CSD pumping to a bunded area, which is lower cost but requires a larger land area;
- Jumbo BHD into split hopper barges and unloading at a dock for distribution by a road system, which requires less land (about 50% less) but is significantly higher cost (difference of several $100M).

Pumping dredged material to the SUZ1 land is unlikely to be sustainable over the ongoing stages of the project due to the land area required. This is particularly the case if the Basin Option is adopted for the longer term port concept since less land area would be available in this case.

6.3 Terminal 2 Stage of the Development

As noted earlier, in practice the balance of the development represented by Terminal 2 would be undertaken in a number of stages which are unknown at this point in time. Accordingly, comments of a general nature only are made below for the Along the Shore Option and Basin Option.

Comments for the Terminal 2 stage of the Along the Shore Option include:

- the quantity of suitable dredged material (i.e. sand and clay balls) is not sufficient to satisfy reclamation requirements and additional fill would be required from an offshore source (Scenario 3) and/or a land source (Scenario 2) for purposes such as containment bunds, fill behind the quarry wall and ground improvement;
- disposal of DMM material on land would occupy a significant proportion of the SUZ1 (up to 40%), and is not sustainable for future land development as this would create significant areas of sterilised land requiring ground improvement.

Comments for the Terminal 2 stage of the Basin Option include:

- a significant volume of excavated material (34.3Mm^3) from the creation of the basin and lowering of adjacent terminal area would be available to satisfy the minor reclamation or filling requirements of the Terminal 2 stage and could potentially be used as reclamation material for earlier stages (Terminal 1 – Stage 1 and Terminal 1 – Stage 2);
- the costs of disposal of dredged material to land and disposal to an offshore DMG are likely to be comparable, however disposal to land would occupy a significant portion of the SUZ1 (up to 30%) which is problematic as discussed above;
- excavation costs for the Basin Option would need to be in the order of \$6/m^3 to \$20/m^3 for the Basin Option costs to roughly match the costs of the Terminal 2 stage for the Along the Shore Option.

Given that the range of breakeven excavation costs for the Basin Option against the Along the Shore Option are not unreasonably high or low and other cost differentials associated with ground improvement, quay wall construction and terminal development are yet to be incorporated, it is recommended that both options should continue to be developed in parallel until full development costs are better understood and project staging beyond Terminal 1 – Stage 2 is defined.

7 RECOMMENDATIONS FOR FURTHER WORK

Further refinement of port development options and their associated dredging, reclamation and DMM strategies is required to provide greater certainty going forward. Recommendations for further work include:

- plume modelling and environmental impact assessment to assist in refinement of work method selection and/or duration of allowable overflow;
- development of conceptual layouts for reclamation and DMM bunded areas and return water management;
- further investigation (including field studies) of potential DMG sites within Western Port and in Bass Strait;
- further investigation (including field studies) of offshore sand availability;
- assessment of whether additional geotechnical investigation is required within the basin and adjacent terminal area in the Basin Option;
- additional groundwater investigations to assist in determining work methods, costs and impact assessment for the Basin Option;
- development of staging for Terminal 2 development;
- preparation of work methods and costs for land-based excavation (Basin Option);
- further development of ground improvement schemes for reclamation and DMM material and costing; and,
- preparation of all-inclusive costs for various port development options and strategies with the benefit of the above work.

APPENDIX A – ROUGH ORDER OF MAGNITUDE COST CALCULATIONS

ALONG THE SHORE OPTION - BULKING CALCULATIONS

Stage	Gross Dredging Volumes				Reclamation Volume	Net Dredging Volumes			
	Q3 (under fill)	Q3 (dredge area)	Remaining Material	Total		Q3 (under fill)	Q3 (dredge area)	Remaining Material	Total
Terminal 1 - Stage 1	1,562,925	1,023,335	4,132,326	6,718,586	3,880,580	1,383,737	1,023,335	3,526,728	5,933,800
Terminal 1 - Stage 2	1,242,406	551,607	2,982,011	4,776,024	2,781,139	1,073,004	551,607	2,796,174	4,420,785
Terminal 2	4,809,017	1,863,497	15,001,284	21,673,798	16,608,968	3,918,136	1,863,497	14,019,405	19,801,038
Total	*7,614,347*	*3,438,439*	*22,115,621*	*33,168,407*	*23,270,686*	*6,374,877*	*3,438,439*	*20,342,307*	*30,155,623*

Terminal 1 - Stage 1 Bulking			**Terminal 1 - Stage 2 Bulking**			**Terminal 2 Bulking**		
Q3 (underfill)	1,562,925	cum	Q3 (underfill)	1,242,406	cum	Q3 (underfill)	4,809,017	cum
Bulking Factor	2	(slurry)	Bulking Factor	2	(slurry)	Bulking Factor	2	(slurry)
Bulked Slurry Volume	3,125,849	cum	Bulked Slurry Volume	2,484,811	cum	Bulked Slurry Volume	9,618,034	cum
Q3 (dredge area)	1,023,335	cum	Q3 (dredge area)	551,607	cum	Q3 (dredge area)	1,863,497	cum
Fines	307,001	cum (30% fines)	Fines	165,482	cum (30% fines)	Fines	559,049	cum (30% fines)
Bulking Factor	3.5	(slurry)	Bulking Factor	3.5	(slurry)	Bulking Factor	3.5	(slurry)
Bulked Slurry Volume	1,074,502	cum	Bulked Slurry Volume	579,187	cum	Bulked Slurry Volume	1,956,672	cum
Sand	716,335	cum (70% sand)	Sand	386,125	cum (70% sand)	Sand	1,304,448	cum (70% sand)
Bulking Factor	1.1	(sand)	Bulking Factor	1.1	(sand)	Bulking Factor	1.1	(sand)
Bulked Sand Volume	787,968	cum	Bulked Sand Volume	424,737	cum	Bulked Sand Volume	1,434,893	cum
Remaining Material	4,132,326	cum	Remaining Material	2,982,011	cum	Remaining Material	15,001,284	cum
Cohesive	2,066,163	cum (50% cohesive)	Cohesive	1,491,006	cum (50% cohesive)	Cohesive	7,500,642	cum (50% cohesive)
Clay Balls	826,465	cum (40% clay balls)	Clay Balls	596,402	cum (40% clay balls)	Clay Balls	3,000,257	cum (40% clay balls)
Bulking Factor	1.2	(clay balls)	Bulking Factor	1.2	(clay balls)	Bulking Factor	1.2	(clay balls)
Bulked Clay Balls Volume	991,758	cum	Bulked Clay Balls Volume	715,683	cum	Bulked Clay Balls Volume	3,600,308	cum
Slurry	1,239,698	cum (60% slurry)	Slurry	894,603	cum (60% slurry)	Slurry	4,500,385	cum (60% slurry)
Bulking Factor	3.5	(slurry)	Bulking Factor	3.5	(slurry)	Bulking Factor	3.5	(slurry)
Bulked Slurry Volume	4,338,942	cum	Bulked Slurry Volume	3,131,112	cum	Bulked Slurry Volume	15,751,348	cum
Non-Cohesive	2,066,163	cum (50% non-cohesive)	Non-Cohesive	1,491,006	cum (50% non-cohesive)	Non-Cohesive	7,500,642	cum (50% non-cohesive)
Fines	516,541	cum (25% fines)	Fines	372,751	cum (25% fines)	Fines	1,875,161	cum (25% fines)
Bulking Factor	3.5	(slurry)	Bulking Factor	3.5	(slurry)	Bulking Factor	3.5	(slurry)
Bulked Slurry Volume	1,807,893	cum	Bulked Slurry Volume	1,304,630	cum	Bulked Slurry Volume	6,563,062	cum
Sand	1,549,622	cum (75% sand)	Sand	1,118,254	cum (75% sand)	Sand	5,625,482	cum (75% sand)
Bulking Factor	1.1	(sand)	Bulking Factor	1.1	(sand)	Bulking Factor	1.1	(sand)
Bulked Sand Volume	1,704,584	cum	Bulked Sand Volume	1,230,080	cum	Bulked Sand Volume	6,188,030	cum
Total Bulked Slurry Volume	10,347,186	cum	Total Bulked Slurry Volume	7,499,740	cum	Total Bulked Slurry Volume	33,889,116	cum
Total Bulked Sand Volume	2,492,552	cum	Total Bulked Sand Volume	1,654,817	cum	Total Bulked Sand Volume	7,622,922	cum
Total Bulked Clay Balls Volume	991,758	cum	Total Bulked Clay Balls Volume	715,683	cum	Total Bulked Clay Balls Volume	3,600,308	cum
Useable Bulked Reclamation Volume	**3,484,311**	**cum (Sand and Clay Balls)**	**Useable Bulked Reclamation Volume**	**2,370,500**	**cum (Sand and Clay Balls)**	**Useable Bulked Reclamation Volume**	**11,223,231**	**cum (Sand and Clay Balls)**
Reclamation Requirement	**3,880,580**	**cum**	**Reclamation Requirement**	**2,781,139**	**cum**	**Reclamation Requirement**	**16,608,968**	**cum**
Reclamation Shortfall	396,269	cum	Reclamation Shortfall	410,639	cum	Reclamation Shortfall	5,385,738	cum

Gross Q3 (underfill) volume	1,562,925	cum (in situ)	Gross Q3 (underfill) volume	1,242,406	cum (in situ)	Gross Q3 (underfill) volume	4,809,017	cum (in situ)
Gross clay balls volume	826,465	cum (in situ)	Gross clay balls volume	596,402	cum (in situ)	Gross clay balls volume	3,000,257	cum (in situ)
Gross fines slurry volume	2,063,239	cum (in situ)	Gross fines slurry volume	1,432,837	cum (in situ)	Gross fines slurry volume	6,934,595	cum (in situ)
Gross sand volume	2,265,957	cum (in situ)	Gross sand volume	1,504,379	cum (in situ)	Gross sand volume	6,929,929	cum (in situ)

Net Q3 (underfill) volume	1,383,737	cum (in situ)	Net Q3 (underfill) volume	1,073,004	cum (in situ)	Net Q3 (underfill) volume	3,918,136	cum (in situ)
Net clay balls volume	705,346	cum (in situ)	Net clay balls volume	559,235	cum (in situ)	Net clay balls volume	2,803,881	cum (in situ)
Net fines slurry volume	1,805,860	cum (in situ)	Net fines slurry volume	1,353,856	cum (in situ)	Net fines slurry volume	6,517,296	cum (in situ)
Net sand volume	2,038,858	cum (in situ)	Net sand volume	1,434,690	cum (in situ)	Net sand volume	6,561,725	cum (in situ)

Total Bulked Volume	13,831,496	cum	Total Bulked Volume	9,870,239	cum	Total Bulked Volume	45,112,346	cum
Land Area	**346**	**ha (4m placement height)**	**Land Area**	**247**	**ha (4m placement height)**	**Land Area**	**1,128**	**ha (4m placement height)**
SUZ1	3000	ha	SUZ1	3000	ha	SUZ1	3000	ha
% SUZ1	**12%**		**% SUZ1**	**8%**		**% SUZ1**	**38%**	

BASIN OPTION - BULKING CALCULATIONS

Stage	Gross Dredging Volumes				Reclamation/Fill Volume	Net Dredging Volumes			
	Q3 (under fill)	Q3 (dredge area)	Remaining Material	Total		Q3 (under fill)	Q3 (dredge area)	Remaining Material	Total
Terminal 1 - Stage 1	1,562,925	1,023,335	4,132,824	6,719,084	3,880,580	1,383,737	1,023,335	3,527,226	5,934,298
Terminal 1 - Stage 2	1,242,406	551,607	2,982,011	4,776,024	2,725,790	1,073,004	551,607	2,796,174	4,420,785
Terminal 2	503,833	1,998,175	13,768,677	16,270,685	1,640,675	441,914	1,998,175	13,014,483	15,454,572
Total	*3,309,163*	*3,573,117*	*20,883,512*	*27,765,792*	*8,247,044*	*2,898,655*	*3,573,117*	*19,337,883*	*25,809,655*

Terminal 1 - Stage 1 Bulking			**Terminal 1 - Stage 2 Bulking**			**Terminal 2 Bulking**		
Q3 (underfill)	1,562,925	cum	Q3 (underfill)	1,242,406	cum	Q3 (underfill)	503,833	cum
Bulking Factor	2	(slurry)	Bulking Factor	2	(slurry)	Bulking Factor	2	(slurry)
Bulked Slurry Volume	3,125,849	cum	Bulked Slurry Volume	2,484,811	cum	Bulked Slurry Volume	1,007,666	cum
Q3 (dredge area)	1,023,335	cum	Q3 (dredge area)	551,607	cum	Q3 (dredge area)	1,998,175	cum
Fines	307,001	cum (30% fines)	Fines	165,482	cum (30% fines)	Fines	599,453	cum (30% fines)
Bulking Factor	3.5	(slurry)	Bulking Factor	3.5	(slurry)	Bulking Factor	3.5	(slurry)
Bulked Slurry Volume	1,074,502	cum	Bulked Slurry Volume	579,187	cum	Bulked Slurry Volume	2,098,084	cum
Sand	716,335	cum (70% sand)	Sand	386,125	cum (70% sand)	Sand	1,398,723	cum (70% sand)
Bulking Factor	1.1	(sand)	Bulking Factor	1.1	(sand)	Bulking Factor	1.1	(sand)
Bulked Sand Volume	787,968	cum	Bulked Sand Volume	424,737	cum	Bulked Sand Volume	1,538,595	cum
Remaining Material	4,132,824	cum	Remaining Material	2,982,011	cum	Remaining Material	13,768,677	cum
Cohesive	2,066,412	cum (50% cohesive)	Cohesive	1,491,006	cum (50% cohesive)	Cohesive	6,884,339	cum (50% cohesive)
Clay Balls	826,565	cum (40% clay balls)	Clay Balls	596,402	cum (40% clay balls)	Clay Balls	2,753,735	cum (40% clay balls)
Bulking Factor	1.2	(clay balls)	Bulking Factor	1.2	(clay balls)	Bulking Factor	1.2	(clay balls)
Bulked Clay Balls Volume	991,878	cum	Bulked Clay Balls Volume	715,683	cum	Bulked Clay Balls Volume	3,304,482	cum
Slurry	1,239,847	cum (60% slurry)	Slurry	894,603	cum (60% slurry)	Slurry	4,130,603	cum (60% slurry)
Bulking Factor	3.5	(slurry)	Bulking Factor	3.5	(slurry)	Bulking Factor	3.5	(slurry)
Bulked Slurry Volume	4,339,465	cum	Bulked Slurry Volume	3,131,112	cum	Bulked Slurry Volume	14,457,111	cum
Non-Cohesive	2,066,412	cum (50% non-cohesive)	Non-Cohesive	1,491,006	cum (50% non-cohesive)	Non-Cohesive	6,884,339	cum (50% non-cohesive)
Fines	516,603	cum (25% fines)	Fines	372,751	cum (25% fines)	Fines	1,721,085	cum (25% fines)
Bulking Factor	3.5	(slurry)	Bulking Factor	3.5	(slurry)	Bulking Factor	3.5	(slurry)
Bulked Slurry Volume	1,808,111	cum	Bulked Slurry Volume	1,304,630	cum	Bulked Slurry Volume	6,023,796	cum
Sand	1,549,809	cum (75% sand)	Sand	1,118,254	cum (75% sand)	Sand	5,163,254	cum (75% sand)
Bulking Factor	1.1	(sand)	Bulking Factor	1.1	(sand)	Bulking Factor	1.1	(sand)
Bulked Sand Volume	1,704,790	cum	Bulked Sand Volume	1,230,080	cum	Bulked Sand Volume	5,679,579	cum
Total Bulked Slurry Volume	10,347,926	cum	Total Bulked Slurry Volume	7,499,740	cum	Total Bulked Slurry Volume	23,586,657	cum
Total Bulked Sand Volume	2,492,758	cum	Total Bulked Sand Volume	1,654,817	cum	Total Bulked Sand Volume	7,218,174	cum
Total Bulked Clay Balls Volume	991,878	cum	Total Bulked Clay Balls Volume	715,683	cum	Total Bulked Clay Balls Volume	3,304,482	cum
Useable Bulked Reclamation Volume	**3,484,636**	**cum (Sand and Clay Balls)**	**Useable Bulked Reclamation Volume**	**2,370,500**	**cum (Sand and Clay Balls)**	**Useable Bulked Reclamation Volume**	**10,522,656**	**cum (Sand and Clay Balls)**
Reclamation Requirement	**3,880,580**	**cum**	**Reclamation Requirement**	**2,725,790**	**cum**	**Onshore Fill Requirement**	**1,640,675**	**cum**
Reclamation Shortfall	395,944	cum	Reclamation Shortfall	355,290	cum	Onshore Fill Surplus	8,881,981	cum

Gross Q3 (underfill) volume	1,562,925	cum (in situ)	Gross Q3 (underfill) volume	1,242,406	cum (in situ)	Gross Q3 (underfill) volume	503,833	cum (in situ)
Gross clay balls volume	826,565	cum (in situ)	Gross clay balls volume	596,402	cum (in situ)	Gross clay balls volume	2,753,735	cum (in situ)
Gross fines slurry volume	2,063,451	cum (in situ)	Gross fines slurry volume	1,432,837	cum (in situ)	Gross fines slurry volume	6,451,140	cum (in situ)
Gross sand volume	2,266,144	cum (in situ)	Gross sand volume	1,504,379	cum (in situ)	Gross sand volume	6,561,976	cum (in situ)

Net Q3 (underfill) volume	1,383,737	cum (in situ)	Net Q3 (underfill) volume	1,073,004	cum (in situ)	Net Q3 (underfill) volume	441,914	cum (in situ)
Net clay balls volume	705,445	cum (in situ)	Net clay balls volume	559,235	cum (in situ)	Net clay balls volume	2,602,897	cum (in situ)
Net fines slurry volume	1,806,072	cum (in situ)	Net fines slurry volume	1,353,856	cum (in situ)	Net fines slurry volume	6,130,608	cum (in situ)
Net sand volume	2,039,044	cum (in situ)	Net sand volume	1,434,690	cum (in situ)	Net sand volume	6,279,154	cum (in situ)

Total Bulked Volume	13,832,562	cum	Total Bulked Volume	9,870,239	cum	Total Bulked Volume	34,109,313	cum
Land Area	**346**	**ha (4m placement height)**	**Land Area**	**247**	**ha (4m placement height)**	**Land Area**	**853**	**ha (4m placement height)**
SUZ1	3000	ha	SUZ1	3000	ha	SUZ1	3000	ha
% SUZ1	**12%**		**% SUZ1**	**8%**		**% SUZ1**	**28%**	

SCENARIO 1 COSTING OPTIONS: TERMINAL 1 - STAGE 1

Reclamation Volume	3,880,580	cum	(assume incl. bund + reclamation fill)
Dredged Material (all DMM)			

Net Q3 (underfill) volume	1,383,737	cum
Net clay balls volume	705,346	cum
Net fines slurry volume	1,805,860	cum
Net sand volume	2,038,858	cum

Gross Q3 (underfill) volume	1,562,925	cum
Gross clay balls volume	826,465	cum
Gross fines slurry volume	2,063,239	cum
Gross sand volume	2,265,957	cum

Case 1 - Main Dredging by Large CSD

CSD pumping to Reclamation Area (Baggerman Method F)

Mob/Demob (CSD)		23.89	M	(incl. small CSD for slimes)
Bund Construction (reclam and settlement pond area)		37.12	M	(1.51M m3 bund volume @ $25/m3)
Unit Rate		22.25	per cum	(incl. small CSD for slimes)
Material Volume (net)		3,944,312	cum	(volume of net dredging required to achieve vol. of sand/clay balls in reclam.)
Cost	**$**	**148.8**	**M**	**(plus ground improvement costs)**

CSD pumping to DMM Bunded Area (Baggerman Method F)

Unit Rate		22.25	per cum	
Material Volume (net)		605,751	cum	(remaining net volume of port dredging)
Cost	**$**	**13.5**	**M**	**(plus ground improvement costs)**

Bund volume (reclam only)	0.18	M cum	(900m3/m length around 1,990m perimeter of reclamation)
Reclamation Vol. (excl. bunds)	3.70	M cum	
Useable Reclam Material Vol. (gross)	3,092,422	cum	(sand + clay balls, assume consolidated back to in situ density)
4m sand fill depth in Q3 underfill area	1,433,500	cum	
Remaining reclamation volume	2.27	M cum	(filled with sand and clay ball matrix, remainder to onshore bunded area)
Remainder from offshore sand source	1.43	M cum	

TSHD winning offshore sand for upper fill layer (Baggerman Method J)

Mob/Demob (TSHD)	$	26.60	M
Unit Rate	$	16.30	per cum
Offshore sand volume (net)		1.43	M cum
Cost	**$**	**50.0**	**M**

COMBINED TOTAL COST (Case 1)	**$**	**212.2**	**M**	**(plus ground improvement costs)**

Case 2 - Main Dredging by Mega BHD

BHD loading hopper barges for bottom dumping in reclamation (Baggerman Method I)

Mob/Demob (BHD and barges)		18.1	M	
Bund construction volume (reclam area)		0.18	M cum	(90m3/m length around 1,990m perimeter of reclamation)
Bund construction cost (reclam area)		4.5	M	(@ $25/m3)
Unit Rate	$	55.50	per cum	
Material Volume (net)		2.27	M cum	(assume in situ quantity of material is unchanged with BHD dredging)
Cost		**148.5**	**M**	**(plus ground improvement costs)**

BHD loading hopper barges to onshore placement area (Baggerman Method G)

Mob/Demob (BHD and barges)		19.9	M	(extra in addition to mob/demob for bottom dumping, 38M-18.1M=19.9M)
Hopper unloading dock install/remove		6.0	M	
Distribution network (roads and bunds)		2.0	M	
Unit Rate	$	76.50	per cum	
Material Volume (net)		2.28	M cum	
Cost		**202.5**	**M**	**(plus ground improvement costs)**

TSHD winning offshore sand for upper fill layer (Baggerman Method J)

Mob/Demob (TSHD)	$	26.60	M
Unit Rate	$	16.30	per cum
Offshore sand volume (net)		1.43	M cum
Cost	**$**	**50.0**	**M**

COMBINED TOTAL COST (Case 2)	**400.9**	**M**	**(plus ground improvement costs)**

Bulked Volumes - All Stage 1 Material to Land

Bulked Volumes to DMM Land Area:		BF	
Q3 (underfill)	3,125,849	2	
Clay Balls	991,758.24	1.2	
Fines Slurry	7,221,336.68	3.5	
Sand	2,492,552.43	1.1	
Total Bulked Volume	**13,831,496**	**cum**	
Land Area	**346**	**ha**	(4m placement height)
Side Length	**1.9**	**km**	(assume square)
Perimeter	**7.4**	**km**	
No. Internal Bunds	**4**		(500m spacing)
Bund Volume	**1.19**	**M cum**	(90m3/m for perimeter bunds, 70m3/m for internal bunds)
SUZ1	3000	ha	
% SUZ1	**12%**		

Bulked Volumes - Part of Stage 1 Material to Reclam Area and remainder to Land

Reclam volume filled with dredged material	2.27	M cum	
Bulked Volumes to DMM Land Area:		BF	
Q3 (underfill)	3,125,849	2	
Clay Balls	264,404	1.2	
Fines Slurry	7,221,336.68	3.5	
Sand	664,517	1.1	
Total Bulked Volume	**11,276,106**	**cum**	
Land Area	**282**	**ha**	(4m placement height)
Side Length	**1.7**	**km**	(assume square)
Perimeter	**6.7**	**km**	
No. Internal Bunds	**4**		(500m spacing)
Bund Volume	**1.07**	**M cum**	(90m3/m for perimeter bunds, 70m3/m for internal bunds)
SUZ1	3000	ha	
% SUZ1	**9%**		

SCENARIO 1 COSTING OPTIONS: TERMINAL 1 - STAGE 2

Reclamation Volume	2,781,139	cum	(assume incl. bund + reclamation fill)
Dredged Material (all DMM)			
Net Q3 (underfill) volume	1,073,004	cum	
Net clay balls volume	559,235	cum	
Net fines slurry volume	1,353,856	cum	
Net sand volume	1,434,690	cum	

Gross Q3 (underfill) volume	1,242,406	cum
Gross clay balls volume	596,402	cum
Gross fines slurry volume	1,432,837	cum
Gross sand volume	1,504,379	cum

Case 1 - Main Dredging by Large CSD

CSD pumping to Reclamation Area (Baggerman Method F)

Mob/Demob (CSD)		23.89	M	(incl. small CSD for slimes)
Bund Construction Volume (reclam and settlement pond)		0.99	M cum	(90m3/m length around 1,560m perimeter reclam and onshore bunded volume below)
Bund Construction (reclam and settlement pond area)		24.79	M	(@ $25/m3)
Unit Rate		22.25	per cum	(incl. small CSD for slimes)
Material Volume (net)		1,462,091	cum	(volume of net dredging required to achieve vol. of sand/clay balls in reclam.)
Cost	**$**	**81.2**	**M**	**(plus ground improvement costs)**

CSD pumping to DMM Bunded Area (Baggerman Method F)

Unit Rate		22.25	per cum	
Material Volume (net)		1,885,690	cum	(remaining net volume of port dredging)
Cost	**$**	**42.0**	**M**	**(plus ground improvement costs)**

Bund volume (reclam only)	0.14	M cum	(90m3/m length around 1,560m perimeter of reclamation)
Reclamation Vol. (excl. bunds)	2.64	M cum	
Useable Reclam Material Vol. (gross)	2,100,781	cum	(sand + clay balls, assume consolidated back to in situ density)
4m sand fill depth over reclamation area	1,800,036	cum	
Remaining reclamation volume	0.84	M cum	(filled with sand and clay ball matrix, remainder to onshore bunded area)
Remainder from offshore sand source	1.80	M cum	

TSHD winning offshore sand for upper fill layer (Baggerman Method J)

Mob/Demob (TSHD)	$	26.60	M
Unit Rate	$	16.30	per cum
Offshore sand volume (net)		1.80	M cum
Cost	**$**	**55.9**	**M**

COMBINED TOTAL COST (Case 1)	**$**	**179.1**	**M**	**(plus ground improvement costs)**

Case 2 - Main Dredging by Mega BHD

BHD loading hopper barges for bottom dumping in reclamation (Baggerman Method I)

Mob/Demob (BHD and barges)		18.1	M	
Bund construction volume (reclam area)		0.14	M cum	(90m3/m length around 1,560m perimeter of reclamation)
Bund construction cost (reclam area)		3.5	M	(@ $25/m3)
Unit Rate	$	55.50	per cum	
Material Volume (net)		0.84	M cum	(assume in situ quantity of material is unchanged with BHD dredging)
Cost		**68.3**	**M**	**(plus ground improvement costs)**

BHD loading hopper barges to onshore placement area (Baggerman Method G)

Mob/Demob (BHD and barges)		19.9	M	(extra in addition to mob/demob for bottom dumping, 38M-18.1M=19.9M)
Hopper unloading dock install/remove		6.0	M	
Distribution network (roads and bunds)		2.0	M	
Unit Rate	$	76.50	per cum	
Material Volume (net)		2.51	M cum	
Cost		**219.7**	**M**	**(plus ground improvement costs)**

TSHD winning offshore sand for upper fill layer (Baggerman Method J)

Mob/Demob (TSHD)	$	26.60	M
Unit Rate	$	16.30	per cum
Offshore sand volume (net)		1.80	M cum
Cost	**$**	**55.9**	**M**

COMBINED TOTAL COST (Case 2)	**343.9**	**M**	**(plus ground improvement costs)**

Bulked Volumes - All Stage 2 Material to Land

Bulked Volumes to DMM Land Area:		BF	
Q3 (underfill)	2,484,811	2	
Clay Balls	715,683	1.2	
Fines Slurry	5,014,929	3.5	
Sand	1,654,817	1.1	
Total Bulked Volume	**9,870,239**	**cum**	
Land Area	**247**	**ha**	(4m placement height)
Side Length	**1.6**	**km**	(assume square)
Perimeter	**6.3**	**km**	
No. Internal Bunds	**4**		(500m spacing)
Bund Volume	**1.01**	**M cum**	(90m3/m for perimeter bunds, 70m3/m for internal bunds)
SUZ1	3000	ha	
% SUZ1	**8%**		

Bulked Volumes - Part of Stage 2 Material to Reclam Area and remainder to Land

Reclam volume filled with dredged material	0.84	M cum	
Bulked Volumes to DMM Land Area:		BF	
Q3 (underfill)	2,484,811	2	
Clay Balls	429,277	1.2	
Fines Slurry	5,014,929	3.5	
Sand	992,583	1.1	
Total Bulked Volume	**8,921,599**	**cum**	
Land Area	**223**	**ha**	(4m placement height)
Side Length	**1.5**	**km**	(assume square)
Perimeter	**6.0**	**km**	
No. Internal Bunds	**3**		(500m spacing)
Bund Volume	**0.85**	**M cum**	(90m3/m for perimeter bunds, 70m3/m for internal bunds)
SUZ1	3000	ha	
% SUZ1	**7%**		

SCENARIO 1 COSTING OPTIONS: ALONG THE SHORE - TERMINAL 2

Reclamation Volume 24,420,620 cum (assume incl. bund + reclamation fill + infill volume)

Dredged Material (all DMM)

Net Q3 (underfill) volume	3,918,136	cum
Net clay balls volume	2,803,881	cum
Net fines slurry volume	6,517,296	cum
Net sand volume	6,561,725	cum
Net excavation volume	-	cum

Gross Q3 (underfill) volume	4,809,017	cum
Gross clay balls volume	3,000,257	cum
Gross fines slurry volume	6,934,595	cum
Gross sand volume	6,929,929	cum
Gross excavation volume	-	cum

Case 1 - Main Dredging by Large CSD

CSD pumping to Reclamation Area (Baggerman Method F)

Mob/Demob (CSD)		23.89	M	(incl. small CSD for slimes)
Bund Construction Volume (reclam and settlement pond)		2.66	M cum	(90m3/m length around 4,360m perimeter reclam and onshore bunded volume below)
Bund Construction (reclam and settlement pond area)		66.57	M	(@ $25/m3)
Unit Rate		22.25	per cum	(incl. small CSD for slimes)
Material Volume (net)		15,882,902	cum	(all port dredging volume pumped into reclamation/infill area)
Cost	**$**	**443.9**	**M**	**(plus ground improvement costs)**

CSD pumping to DMM Bunded Area (Baggerman Method F)

Unit Rate		22.25	per cum	
Material Volume (net)		-	cum	(all port dredging volume pumped into reclamation/infill area)
Cost	**$**	**-**	**M**	**(plus ground improvement costs)**

Bund volume (reclam only)	0.39	M cum	(90m3/m length around 4,360m perimeter of reclamation)
Reclamation Vol. (excl. bunds)	24.03	M cum	
Useable Reclam Material Vol. (gross)	9,930,186	cum	(sand + clay balls, assume consolidated back to in situ density)
4m sand fill depth over reclamation area	7,127,048	cum	
Remaining reclamation volume	16.90	M cum	(filled with sand and clay ball matrix, remainder with other material sourced from offshore/onshore)
Remainder from offshore sand source	14.10	M cum	

TSHD winning offshore sand for upper fill layer (Baggerman Method J)

Mob/Demob (TSHD)	$	26.60	M
Unit Rate	$	16.30	per cum
Offshore sand volume (net)		14.10	M cum
Cost	**$**	**256.4**	**M**

COMBINED TOTAL COST (Case 1)	**$**	**700.3**	**M**	**(plus ground improvement costs)**

Case 2 - Main Dredging by Mega BHD

BHD loading hopper barges for bottom dumping in reclamation (Baggerman Method I)

Mob/Demob (BHD and barges)		18.1	M	
Bund construction volume (reclam area)		0.39	M cum	(90m3/m length around 4,360m perimeter of reclamation)
Bund construction cost (reclam area)		9.8	M	(@ $25/m3)
Unit Rate	$	55.50	per cum	
Material Volume (net)		15.9	M cum	(assume in situ quantity of material is unchanged with BHD dredging)
Cost		**909.4**	**M**	**(plus ground improvement costs)**

BHD loading hopper barges to onshore placement area (Baggerman Method G)

Mob/Demob (BHD and barges)		0.0	M	
Hopper unloading dock install/remove		0.0	M	
Distribution network (roads and bunds)		0.0	M	
Unit Rate	$	76.50	per cum	
Material Volume (net)		-	M cum	(all port dredging volume placed into reclamation/infill area)
Cost		**-**	**M**	**(plus ground improvement costs)**

TSHD winning offshore sand for upper fill layer (Baggerman Method J)

Mob/Demob (TSHD)	$	26.60	M
Unit Rate	$	16.30	per cum
Offshore sand volume (net)		8.54	M cum
Cost	**$**	**165.8**	**M**

COMBINED TOTAL COST (Case 2)	**1,075.2**	**M**	**(plus ground improvement costs)**

Bulked Volumes - All Terminal 2 Material to Land

Bulked Volumes to DMM Land Area:		BF	
Q3 (underfill)	9,618,034	2	
Clay Balls	3,600,308	1.2	
Fines Slurry	24,271,082	3.5	
Sand	7,622,922	1.1	
Total Bulked Volume	**45,112,346**	**cum**	
Land Area	**1,128**	**ha**	(4m placement height)
Side Length	**3.4**	**km**	(assume square)
Perimeter	**13.4**	**km**	
No. Internal Bunds	**7**		(500m spacing)
Bund Volume	**2.85**	**M cum**	(90m3/m for perimeter bunds, 70m3/m for internal bunds)
SUZ1	3000	ha	
% SUZ1	**38%**		

Bulked Volumes - Part of Terminal 2 Material to Reclam Area and remainder to Land

Reclam volume filled with dredged material	9.9	M cum	
Bulked Volumes to DMM Land Area:		BF	
Q3 (underfill)	9,618,034	2	
Clay Balls	-	1.2	
Fines Slurry	24,271,081.80	3.5	
Sand	-	1.1	
Total Bulked Volume	**33,889,116**	**cum**	
Land Area	**847**	**ha**	(4m placement height)
Side Length	**2.9**	**km**	(assume square)
Perimeter	**11.6**	**km**	

No. Internal Bunds	**6**		(500m spacing)
Bund Volume	**2.27**	**M cum**	(90m3/m for perimeter bunds, 70m3/m for internal bunds)
SUZ1	3000	ha	
% SUZ1	**28%**		

SCENARIO 3 COSTING OPTIONS: TERMINAL 1 - STAGE 1

Reclamation Volume	3,880,580	cum	(assume incl. bund + reclamation fill)
Dredged Material (all DMM)			

Net Q3 (underfill) volume	1,383,737	cum
Net clay balls volume	705,346	cum
Net fines slurry volume	1,805,860	cum
Net sand volume	2,038,858	cum

Gross Q3 (underfill) volume	1,562,925	cum
Gross clay balls volume	826,465	cum
Gross fines slurry volume	2,063,239	cum
Gross sand volume	2,265,957	cum

Case 1/2 - TSHD Winning Offshore Sand

Jumbo TSHD winning offshore sand and pumping into reclamation (Baggerman Method J)

Mob/demob	$ 26.60	M	
Unit Rate	$ 16.30	per cum	
Offshore sand volume (net)	3,880,580	cum	(assume incl. bund + reclamation fill)
Cost	**$ 89.9**	**M**	

Case 1 - Port Dredging Material to DMM Area

Best Case: Large CSD pumping to onshore bunded area (Baggerman Method F)

Mob/demob	23.89	M	
Bund Volume (DMM Area)	1.19	M cum	
Bund Construction	29.75	M	(@ $25/m3)
Unit Rate	22.25	per cum	
DMM Material Volume (net)	4,550,063	cum	(excl. Q3 material underfill)
Cost	**$ 154.9**	**M**	**(plus ground improvement costs)**

Case 2 - Port Dredging Material to Offshore DMG

Worst Case: Large CSD pumping into split hopper barges for transit to offshore DMG (Baggerman Method D)

Mob/demob	33.1	M	
Unit Rate (40 min overflow)	30.05	per cum	
Unit Rate (no overflow)	68.35	per cum	
DMM Material Volume (net)	4,550,063	cum	(excl. Q3 material underfill)
Cost (40min overflow)	**$ 169.8**	**M**	
Cost (no overflow)	**$ 344.1**	**M**	

COMBINED TOTAL COST (Case 1)	**$ 244.7**	**M**	**(plus ground improvement costs)**
COMBINED TOTAL COST (Case 2, 40min overflow)	**$ 259.7**	**M**	
COMBINED TOTAL COST (Case 2, no overflow)	**$ 434.0**	**M**	

Bulked Volumes - All Stage 1 Material to Land

Bulked Volumes to DMM Land Area:		BF	
Q3 (underfill)	3,125,849	2	
Clay Balls	991,758.24	1.2	
Fines Slurry	7,221,336.68	3.5	
Sand	2,492,552.43	1.1	
Total Bulked Volume	**13,831,496**	**cum**	
Land Area	**346**	**ha**	(4m placement height)
Side Length	**1.9**	**km**	(assume square)
Perimeter	**7.4**	**km**	
No. Internal Bunds	**4**		(500m spacing)
Bund Volume	**1.19**	**M cum**	(90m3/m for perimeter bunds, 70m3/m for internal bunds)
SUZ1	3000	ha	
% SUZ1	**12%**		

SCENARIO 3 COSTING OPTIONS: TERMINAL 1 - STAGE 2

Reclamation Volume 2,781,139 cum (assume incl. bund + reclamation fill)

Dredged Material (all DMM)

Net Q3 (underfill) volume	1,073,004	cum
Net clay balls volume	559,235	cum
Net fines slurry volume	1,353,856	cum
Net sand volume	1,434,690	cum

Gross Q3 (underfill) volume	1,242,406	cum
Gross clay balls volume	596,402	cum
Gross fines slurry volume	1,432,837	cum
Gross sand volume	1,504,379	cum

Case 1/2 - TSHD Winning Offshore Sand

Jumbo TSHD winning offshore sand and pumping into reclamation (Baggerman Method J)

Mob/demob	$	26.60	M	
Unit Rate	$	16.30	per cum	
Offshore sand volume (net)		2,781,139	cum	(assume incl. bund + reclamation fill)
Cost	**$**	**71.9**	**M**	

Case 1 - Port Dredging Material to DMM Area

Best Case: Large CSD pumping to onshore bunded area (Baggerman Method F)

Mob/demob		23.89	M	
Bund Construction Volume		1.01	M cum	(247ha, 6.3km perimeter x 90m3/m, 4 x 1.6km x 70m3/m internal bunds)
Bund Construction Cost		25.13	M	(@ $25/m3)
Unit Rate		22.25	per cum	
DMM Material Volume (net)		3,347,781	cum	(excl. Q3 material underfill)
Cost	**$**	**123.5**	**M**	**(plus ground improvement costs)**

Case 2 - Port Dredging Material to Offshore DMG

Worst Case: Large CSD pumping into split hopper barges for transit to offshore DMG (Baggerman Method D)

Mob/demob		33.1	M	
Unit Rate (40 min overflow)		30.05	per cum	
Unit Rate (no overflow)		68.35	per cum	
DMM Material Volume (net)		3,347,781	cum	(excl. Q3 material underfill)
Cost (40min overflow)	**$**	**133.7**	**M**	
Cost (no overflow)	**$**	**261.9**	**M**	

COMBINED TOTAL COST (Case 1)	**$**	**195.4**	**M**	**(plus ground improvement costs)**
COMBINED TOTAL COST (Case 2, 40min overflow)	**$**	**205.6**	**M**	
COMBINED TOTAL COST (Case 2, no overflow)	**$**	**333.9**	**M**	

Bulked Volumes - All Stage 2 Material to Land

Bulked Volumes to DMM Land Area:		BF	
Q3 (underfill)	2,484,811	2	
Clay Balls	715,682.64	1.2	
Fines Slurry	5,014,928.71	3.5	
Sand	1,654,816.93	1.1	
Total Bulked Volume	**9,870,239**	**cum**	
Land Area	**247**	**ha**	(4m placement height)
Side Length	**1.6**	**km**	(assume square)
Perimeter	**6.3**	**km**	
No. Internal Bunds	**4**		(500m spacing)
Bund Volume	**1.01**	**M cum**	(90m3/m for perimeter bunds, 70m3/m for internal bunds)
SUZ1	3000	ha	
% SUZ1	**8%**		

SCENARIO 3 COSTING OPTIONS: ALONG THE SHORE - TERMINAL 2

Reclamation Volume 24,420,620 cum (assume incl. bund + reclamation fill + infill volume)

Dredged Material (all DMM)

Net Q3 (underfill) volume	3,918,136	cum
Net clay balls volume	2,803,881	cum
Net fines slurry volume	6,517,296	cum
Net sand volume	6,561,725	cum
Net excavation volume	-	cum

Gross Q3 (underfill) volume	4,809,017	cum
Gross clay balls volume	3,000,257	cum
Gross fines slurry volume	6,934,595	cum
Gross sand volume	6,929,929	cum
Gross excavation volume	-	cum

Case 1/2 - TSHD Winning Offshore Sand

Jumbo TSHD winning offshore sand and pumping into reclamation (Baggerman Method J)

Mob/demob	$ 26.60	M	
Unit Rate	$ 16.30	per cum	
Offshore sand volume (net)	24,420,620	cum	(assume incl. bund + reclamation fill)
Cost	**$ 424.7**	**M**	

Case 1 - Port Dredging Material to DMM Area

Best Case: Large CSD pumping to onshore bunded area (Baggerman Method F)

Mob/demob	23.89	M	
Bund Construction Volume	2.85	M cum	(1128ha, 13.4km perimeter x 90m3/m, 7 x 3.4km x 70m3/m internal bunds)
Bund Construction Cost	71.36	M	(@ $25/m3)
Unit Rate	22.25	per cum	
DMM Material Volume (net)	15,882,902	cum	(excl. Q3 material underfill)
Cost	**$ 448.6**	**M**	**(plus ground improvement costs)**

Case 2 - Port Dredging Material to Offshore DMG

Worst Case: Large CSD pumping into split hopper barges for transit to offshore DMG (Baggerman Method D)

Mob/demob	33.1	M	
Unit Rate (40 min overflow)	30.05	per cum	
Unit Rate (no overflow)	68.35	per cum	
DMM Material Volume (net)	15,882,902	cum	(excl. Q3 material underfill)
Cost (40min overflow)	**$ 510.4**	**M**	
Cost (no overflow)	**$ 1,118.7**	**M**	

COMBINED TOTAL COST (Case 1)	**$ 873.3**	**M**	**(plus ground improvement costs)**
COMBINED TOTAL COST (Case 2, 40min overflow)	**$ 935.0**	**M**	
COMBINED TOTAL COST (Case 2, no overflow)	**$ 1,543.4**	**M**	

Bulked Volumes - All Balance Material to Land

Bulked Volumes to DMM Land Area:

		BF	
Q3 (underfill)	9,618,034	2	
Clay Balls	3,600,308.16	1.2	
Fines Slurry	24,271,081.80	3.5	
Sand	7,622,922.34	1.1	
Total Bulked Volume	**45,112,346**	**cum**	
Land Area	**1,128**	**ha**	(4m placement height)
Side Length	**3.4**	**km**	(assume square)
Perimeter	**13.4**	**km**	
No. Internal Bunds	**7**		(500m spacing)
Bund Volume	**2.85**	**M cum**	(90m3/m for perimeter bunds, 70m3/m for internal bunds)
SUZ1	3000	ha	
% SUZ1	**38%**		

BASIN OPTION COSTING OPTIONS: TERMINAL 2

Reclamation Volume	1,640,675	cum	(assume incl. bund + reclamation fill)
Dredged Material (all DMM)			

Net Q3 (underfill) volume	441,914	cum
Net clay balls volume	2,602,897	cum
Net fines slurry volume	6,130,608	cum
Net sand volume	6,279,154	cum

Gross Q3 (underfill) volume	503,833	cum
Gross clay balls volume	2,753,735	cum
Gross fines slurry volume	6,451,140	cum
Gross sand volume	6,561,976	cum

Disposal to Land - Large CSD pumping to onshore bunded area (Baggerman Method F)

Mob/demob	23.89	M	
Bund Construction Volume	2.28	M cum	(853ha, 11.7km perimeter x 90m3/m, 6 x 2.9km x 70m3/m internal bunds)
Bund Construction Cost	56.94	M	(@ $25/m3)
Unit Rate	22.25	per cum	(rate excl. slimes pumping with small CSD, subtract $5.15/m3 from $24.60/m3)
DMM Material Volume (net)	15,012,658	cum	(excl. Q3 material underfill)
Cost	**$ 414.9**	**M**	**(plus ground improvement costs)**

Disposal to Land - Mega BHD into split hopper barges to onshore (Baggerman Method G)

Mob/demob (BHD and barges)	38.0	M	
Hopper unloading dock install/remove	6.0	M	
Distribution network (roads and bunds)	6.3	M	(prorata Baggerman cost for 4.75Mm3)
Unit Rate	$ 76.50	per cum	
Material Volume (net)	15,012,658	M cum	(excl. Q3 material underfill)
Cost	**1,198.8**	**M**	**(plus ground improvement costs)**

Disposal to Offshore DMG - Large CSD into split hopper barges (Baggerman Method D)

Mob/demob	33.1	M	
Unit Rate (40 min overflow)	30.05	per cum	
Unit Rate (no overflow)	68.35	per cum	
DMM Material Volume (net)	15,012,658	cum	(excl. Q3 material underfill)
Cost (40min overflow)	**$ 484.2**	**M**	
Cost (no overflow)	**$ 1,059.2**	**M**	

Disposal to Offshore DMG - Mega BHD into split hopper barges (Baggerman Method H)

Mob/demob	34.1	M	
Unit Rate	49.5	per cum	
DMM Material Volume (net)	15,012,658	cum	(excl. Q3 material underfill)
Cost	**$ 777.2**	**M**	

Bulked Volumes - All Terminal 2 Dredged Material to Land

Bulked Volumes to DMM Land Area:		BF	
Q3 (underfill)	1,007,666	2	
Clay Balls	3,304,482.48	1.2	
Fines Slurry	22,578,990.79	3.5	
Sand	7,218,174.01	1.1	
Total Bulked Volume	**34,109,313**	**cum**	
Land Area	**853**	**ha**	(4m placement height)
Side Length	**2.9**	**km**	(assume square)
Perimeter	**11.7**	**km**	
No. Internal Bunds	**6**		(500m spacing)
Bund Volume	**2.28**	**M cum**	(90m3/m for perimeter bunds, 70m3/m for internal bunds)
SUZ1	3000	ha	
% SUZ1	**28%**		