APPENDIX I

Comprehensive beneficial reuse assessment

APPENDIX I

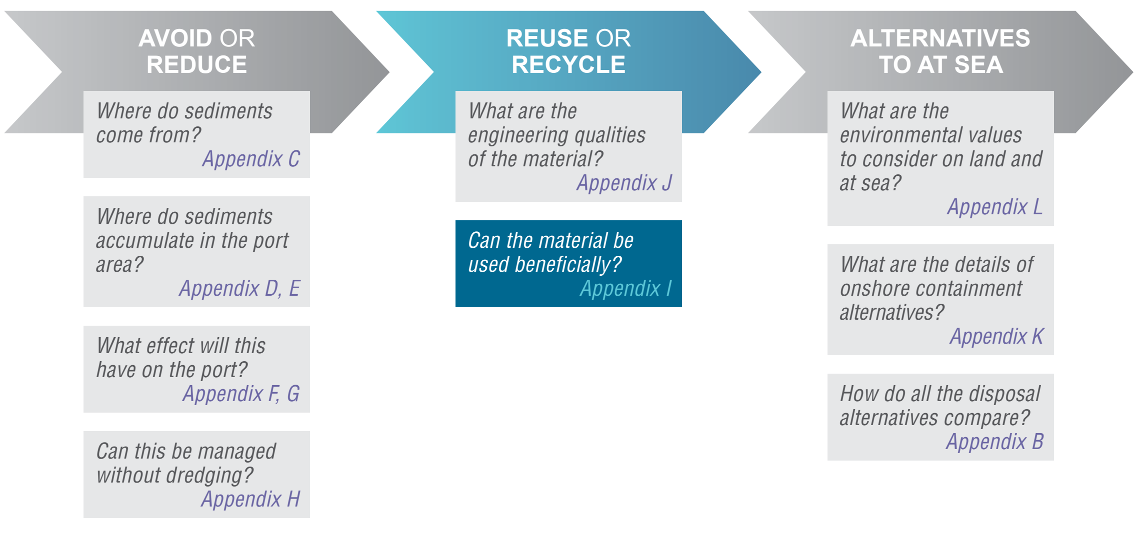
Comprehensive beneficial reuse assessment

SYNOPSIS

Independent technical specialist

Advisian | **25 July 2016**

Hay Point sustainable sediment management assessment approach



Purpose of study:

To undertake a comprehensive analysis of potential beneficial reuse options for the Port of Hay Point maintenance dredge material.

Broad study approach:

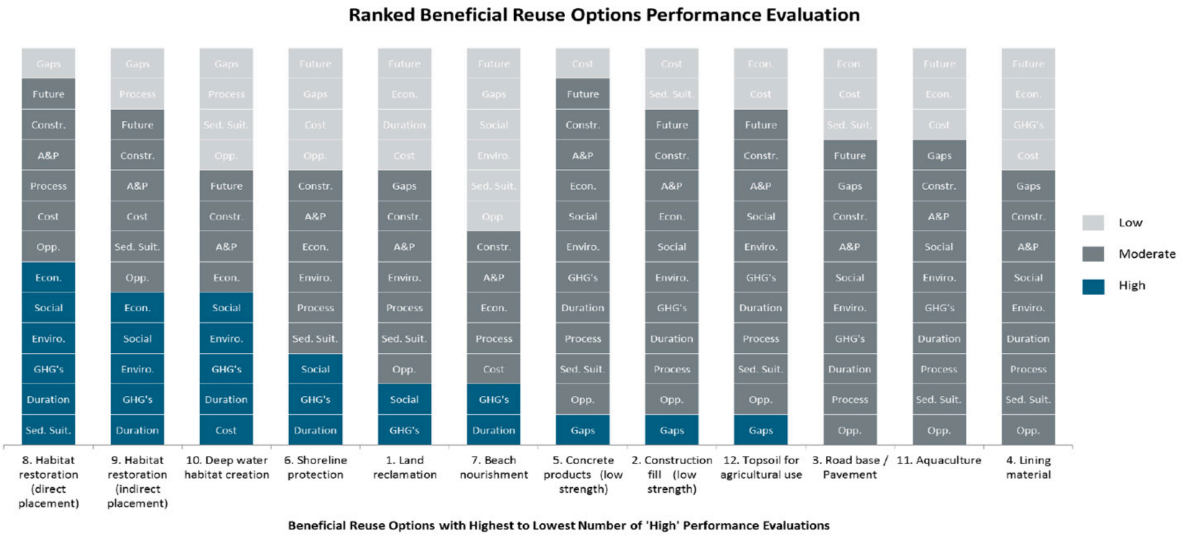
This study summarises and utilises the outcomes of the Marine Sediment Properties Assessment undertaken at the Port of Hay Point (refer SSMA – Appendix J).

A multi-disciplinary team was brought together to identify a range of potential beneficial reuse options for Port of Hay Point maintenance dredge material. Twelve reuse options were identified for further analysis. Reuse options were then analysed and compared using a number of defined performance criteria including:

- Sediment Properties
- Material Suitability
- Opportunity
- Cost
- Process
- Duration
- GHG emissions
- Environmental Implications
- Social Implications
- Economic Implications
- Approvals and Permits
- Constraints
- Knowledge Gaps
- Future Considerations

Key findings:

Outcomes of the comprehensive analysis are presented graphically below:



In terms of how the various reuse options compared, further summary information is provided below:

Beach Nourishment, Shoreline Protection – beach nourishment was the lowest performing reuse option assessed. This is due mainly to the material being predominately fine silts and clays which is unsuitable for beach nourishment purposes. Similar outcomes were obtained for shoreline protection, but additionally there is no foreseeable need for shoreline protection in the Hay Point area or greater Mackay region.

Low Strength Concrete Products, Low Strength Construction Fill, Road Base – all had very high cost implications, with the only high performing criteria relating to fewer knowledge gaps (or comparatively good understanding) of the process in developing the end-use products. Importantly, no immediate demand exists and these products would not be suitable in a competitive market.

Topsoil, Aquaculture and Lining Material – all had very high cost implications, the only high performing criteria relating to fewer knowledge gaps (or comparatively good understanding) of the process in developing the end-use products. Importantly, no immediate demand exists and these products would not be suitable in a competitive market.

Land Reclamation – although costly, land reclamation could be achieved, but the consequential development would support only low load bearing uses, such us as recreational parks or carparks.

Habitat Restoration (direct, indirect, deep-water) – habitat restoration had the greatest number of high performing criteria. The downfalls predominately related to the gaps in knowledge in both i) using dredged maintenance material for habitat restoration and ii) feasible opportunities in the region. It is noted that deep-water habitat creation and possible indirect habitat restoration are not expected to be supported in the GBRWHA.

Conclusions:

- Although no on-land beneficial reuses were identified, many of these reuses would require the construction of an on-land containment facility to store and dry the material for reprocessing. It would be prudent to include an analysis of on-land containment facilities or structures when assessing disposal options.
- Land reclamation, although costly and not suitable for port related uses, is worthy of assessing as a potential disposal option, as the land use plans of both the Port of Hay Point and Port of Mackay include potential future land reclamations.
- Direct habitat restoration has merit as a beneficial reuse, although it is acknowledged that considerable additional scientific research and a thorough feasibility assessment would be necessary before the option can be considered viable.

Comprehensive Beneficial Reuse Assessment

Port of Hay Point - Sustainable Sediment Management Assessment for Navigational Maintenance

25 July 2016

Level 31, 12 Creek Street
Brisbane QLD 4000
Australia

301310-09537-002

www.**advisian**.com

Advisian
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Project No: 301310-09537-002 – Comprehensive Beneficial Reuse Assessment: Port of Hay Point

Rev	Description	Author	Review	Advisian Approval	Date
Rev 0	Issued for use	L Stalley	B Boylson	B Boylson	25 July 2016

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Executive Summary

North Queensland Bulk Ports Corporation Limited (NQBP) has commenced work on a long-term strategic assessment for ongoing management of marine sediments at the Port of Hay Point. To support this project, NQBP commissioned Advisian to undertake a comprehensive investigation of options for the beneficial reuse of marine sediments that naturally accumulate in the navigational areas of the Port of Hay Point.

The beneficial reuse investigations were undertaken in two main stages:

1. Sediment properties investigations

2. Beneficial reuse options identification and analysis.

There is currently approximately 200,000m^3 of material to be dredged from the port for maintenance of depth in the port's operational areas, and it is expected that maintenance dredging of this quantum will be required every five years for the foreseeable future. The majority of the material to be dredged is fine clay/silt material (60%), mixed with sand (36%) and small amounts of gravel material (4%). Given the mixture of sediment type, dominated by fine material, which has accumulated in relatively confined areas, it is considered that it would be impractical to separate sediment types during dredging for alternate beneficial reuse options.

Analysis of the geotechnical properties of the material to be dredged indicates:

- Sediment is likely to contain high plasticity clay
- Sediment to be dredged is likely to have very high moisture content, and therefore significant effort would be required to dry out the sediment as may be required for various reuse options
- Sediments to be dredged are likely to have very low to medium compressibility and have some potential to swell and shrink

Sediments to be dredged are likely to be potential acid sulfate soils (PASS); however, they contain sufficient acid neutralising capacity to buffer inherent acidity to negligible concentrations and as such are unlikely to require ASS treatment, albeit that this is dependent on the management measures required for reuse. The material to be dredged is free of contamination and therefore suitable for ocean placement.

The primary considerations of analysis are the properties of the sediment to be dredged (Sed. Suit.). Other considerations included demand (Opp.), conceptual cost (Cost) and greenhouse gas emissions (GHG's), confidence in beneficial reuse process (Process), duration from construction to use (Duration), environmental (Enviro.) and socio-economic (Social and Econ.) implications, environmental approvals (A&P), constraints (Constr.), knowledge gaps (requiring research) (Gaps) and longevity of the beneficial reuse option (Future). A summary of the comparative analysis for each of the options identified is provided in Figure 1.

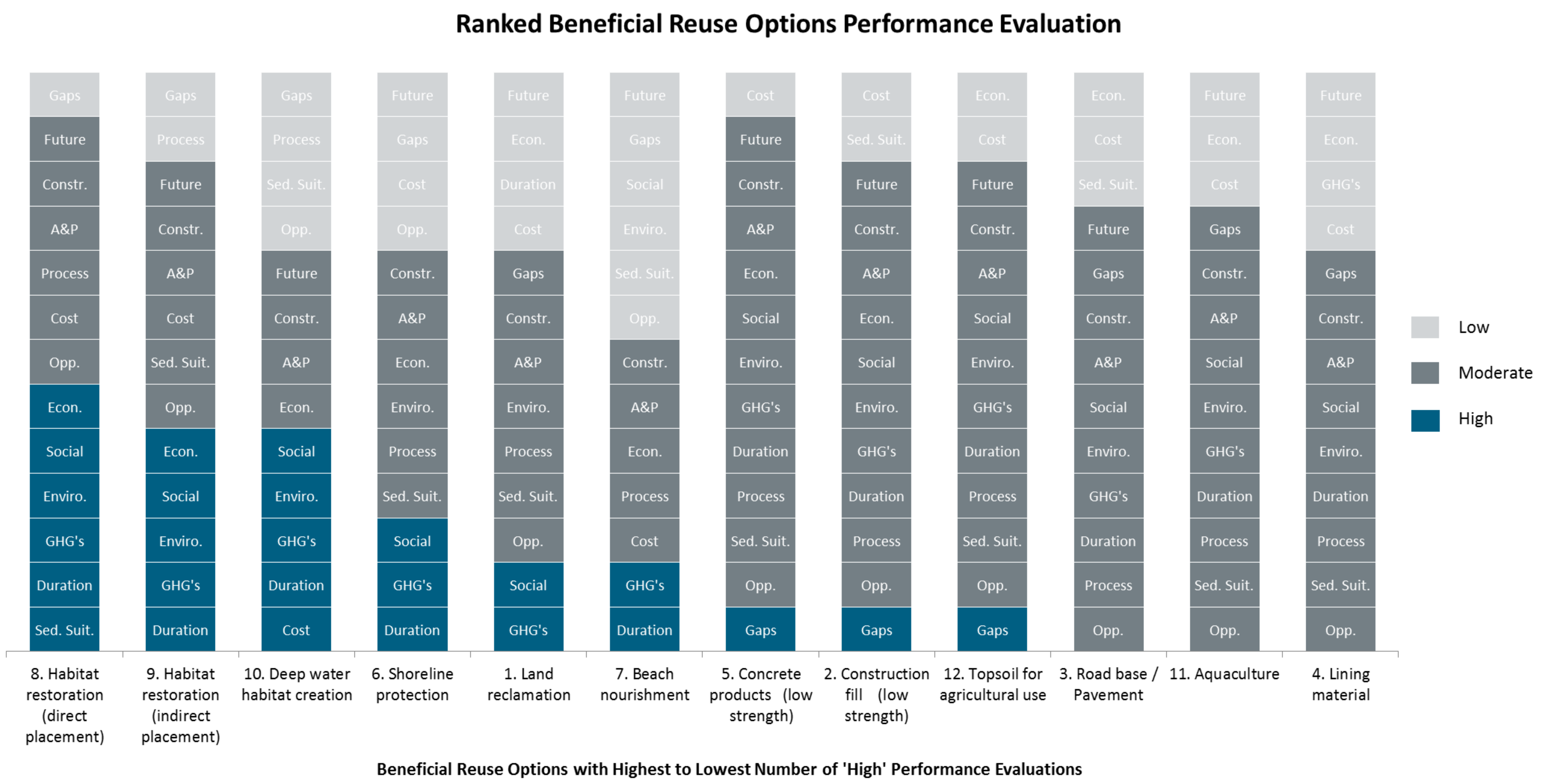


Figure 1 Beneficial reuse options performance summary

Comparative analysis of the potential reuse options shows that:

- None of the options have a clear existing demand for the reuse of sediment material that would require minimal infrastructure needs. For most options, a potential demand exists requiring infrastructure construction, while for three options (shoreline protection, beach nourishment and deep water habitat creation) no substantive demand for the dredge material was identified.
- All but one of the options were assessed as having low to moderate sediment suitability performance, indicating the material would require some or significant treatment , processing and/or additives. Only for the habitat restoration (direct placement) option was it likely the sediment material could be utilised without treatment or additives.
- Most of the options were of low performance with respect to cost (more than $17million in a five year period) with three options of moderate performance (between $10million and $17million in a five year period). Only the option of deep water habitat creation, which has costs similar to traditional offshore placement (less than $10million in a five year period), is considered to be high performance with respect cost.
- For most of the options, the proposed process is sound; however, there are few examples of the reuse being applied in environments similar to the Port of Hay Point using maintenance dredge material. Two of the 'recycle as environmental enhancement' options (habitat restoration using indirect placement and deep water habitat creation) were considered to be mostly unproven for maintenance dredge material such as that of Hay Point.
- The options for use that did not require intermediate storage, with placement directly to the environment were generally of high performance with respect duration, due to their taking less than one year to function as the final use. The exception to this is reclamation, which, due to likely extended dewatering times was rated as low performance (i.e. greater than 3 years to construct and function as the proposed final use). The remaining options required onshore placement, with each option being rated as moderate i.e. 1 to 3 years to construct and treated in preparation for proposed final use.
- The options that did not require intermediate storage were of high performance (less than 2500t CO_2 equivalent) with respect greenhouse gas emissions. The options that required onshore placement were of moderate performance (between 2500t and 5000t CO_2 equivalent), with the exception of the liner materials option which was of low performance (greater than 5000t CO_2 equivalent) due to the long transport distance required for the end product.
- Most of the options were rated as being of moderate performance with respect environmental implications i.e. potential nuisance or harm issues identified, but for the most part are considered manageable. The three options for recycling dredge material as an environmental enhancement were all rated as high performance, due to the net benefit opportunities that exist for positive environmental outcomes with each of the options. The beach nourishment option was rated as being of low performance due to potential for nuisance or harm issues unlikely to be easily managed, particularly water quality impacts near the placement location.
- The three options for recycling dredge material as an environmental enhancement, along with the reclamation and shoreline protection options were all rated as high performance due to the potential for positive social opportunities for local communities. The remaining options were rated as moderate performance, as they are likely to have social effects that are for the

most part manageable, with the exception of the beach nourishment option, which was rated as low performance, due to the lack of compatibility of dredge sediments with local beaches causing negative social impacts that are unlikely to be easily managed.

- Two of the options for recycling dredge material as an environmental enhancement (habitat restoration options) were rated as high performance due to positive economic opportunities for enhancing community capability, including involvement in development of the project and opportunities associated with development of fisheries habitat. The engineering reuses of road base and liner material, and aquaculture and topsoil for agricultural uses were all rated as low performance, due to the likely need for subsidisation for the use to be acceptable. The land reclamation option was also rated as low performance, due to the reduction in availability of areas to develop for port uses. The remaining options were rated as moderate performance, as they may provide limited economic opportunities for enhancing port or community capability.
- For the construction fill, concrete products and topsoil for agriculture options there are few knowledge gaps and less than one year of further work would be required to progress the option. Conversely, each of the three options for recycling dredge material as an environmental enhancement, along with the shoreline protection and beach nourishment options would likely require greater than three years of further research to address knowledge gaps, particularly with respect confirmation of the demand for the use and suitability of the material and placement strategy. The remaining options would likely require one to three years of further research to address multiple knowledge gaps.
- A number of options were considered to have a single, or limited application, including reclamation, liner materials, shoreline protection, beach nourishment and aquaculture facilities options. The remaining options may cater for immediate needs and have some scope in the short term to address maintenance dredging needs, with the ongoing use needing regular assessment. None of the options were considered to provide a clear long term solution for the Port of Hay Point.

The analysis indicates that, while there are a number of options for beneficial reuse that may be feasible, in consideration of all of the aspects relevant to the use, there is no clear preferred beneficial reuse option for maintenance dredge material. For all of the options, further investigation regarding demand is required.

Three reuse options ranked well on the number of 'high' performance evaluation criteria, namely habitat restoration through direct placement, which ranked highest, followed in equal second position by habitat restoration through indirect placement, and deep water habitat creation. These options all involve placement direct to the environment, short duration and relatively low costs. All three options scored 'low' for knowledge gaps, indicating there are multiple or complex knowledge gaps requiring significant research work to progress these options. If a suitable placement area is available the habitat restoration through direct placement option potentially offers environmental benefits, likely to be socially acceptable, and provides the prospect of a collaborative environmental research project. However, the availability of suitable areas for mangrove rehabilitation may limit the option as a long term solution. There may be an opportunity to implement this option as a pilot program in the Sandringham Bay area, with the involvement of local stakeholders (e.g. fisheries, reef catchment, research bodies) to assess suitability for future beneficial reuse.

There are a number of reuse options where the majority of performance criteria were scored moderate, with only one or two low performance criteria, namely concrete products (low strength), construction fill (low strength) and topsoil for agriculture. This finding may be interpreted as these options having few unknowns or constraints to their implementation. These options all involve the construction of an onshore management area and potential long term treatment. If an onshore placement area were constructed this may create the potential for six of the beneficial options to be realized (construction fill (low strength), road base / pavement, lining material, concrete products (low strength), aquaculture and topsoil for agriculture). Subject to user demand for an end product, a single reuse option or combination of reuse options is possible once the material is placed onshore, enabling portions of the material to be directed to different reuse as demand arises.

1 Introduction

North Queensland Bulk Ports Corporation Limited (NQBP) is a port authority under the *Transport Infrastructure Act 1994*, for the seaport facilities at Hay Point, Mackay, Abbot Point, Weipa and Maryborough.

The Port of Hay Point is situated on the central Queensland coast, approximately 40 kilometres by road south of Mackay. The port comprises two separate coal export terminals: Dalrymple Bay Coal Terminal (DBCT) which is leased from the Queensland Government by DBCT Management Pty Ltd and the Hay Point Coal Terminal (HPCT) which is owned by BHP Billiton Mitsubishi Alliance and operated by Hay Point Services. The port lies within the Great Barrier Reef World Heritage Area (GBRWHA) but is excluded from the Great Barrier Reef Marine Park (GBRMP), with the exception of part of the port's departure path (Figure 1-1).

NQBP has commenced work on a long-term strategic assessment for ongoing management of marine sediments at the Port of Hay Point, known as the *Port of Hay Point – Sustainable Sediment Management Assessment for Navigational Maintenance (SSM Project)*. To support this project, NQBP commissioned Advisian to undertake a comprehensive investigation of options for the beneficial reuse of marine sediments that naturally accumulate in the navigational areas of the Port of Hay Point.

The beneficial reuse investigations were undertaken in two main stages:

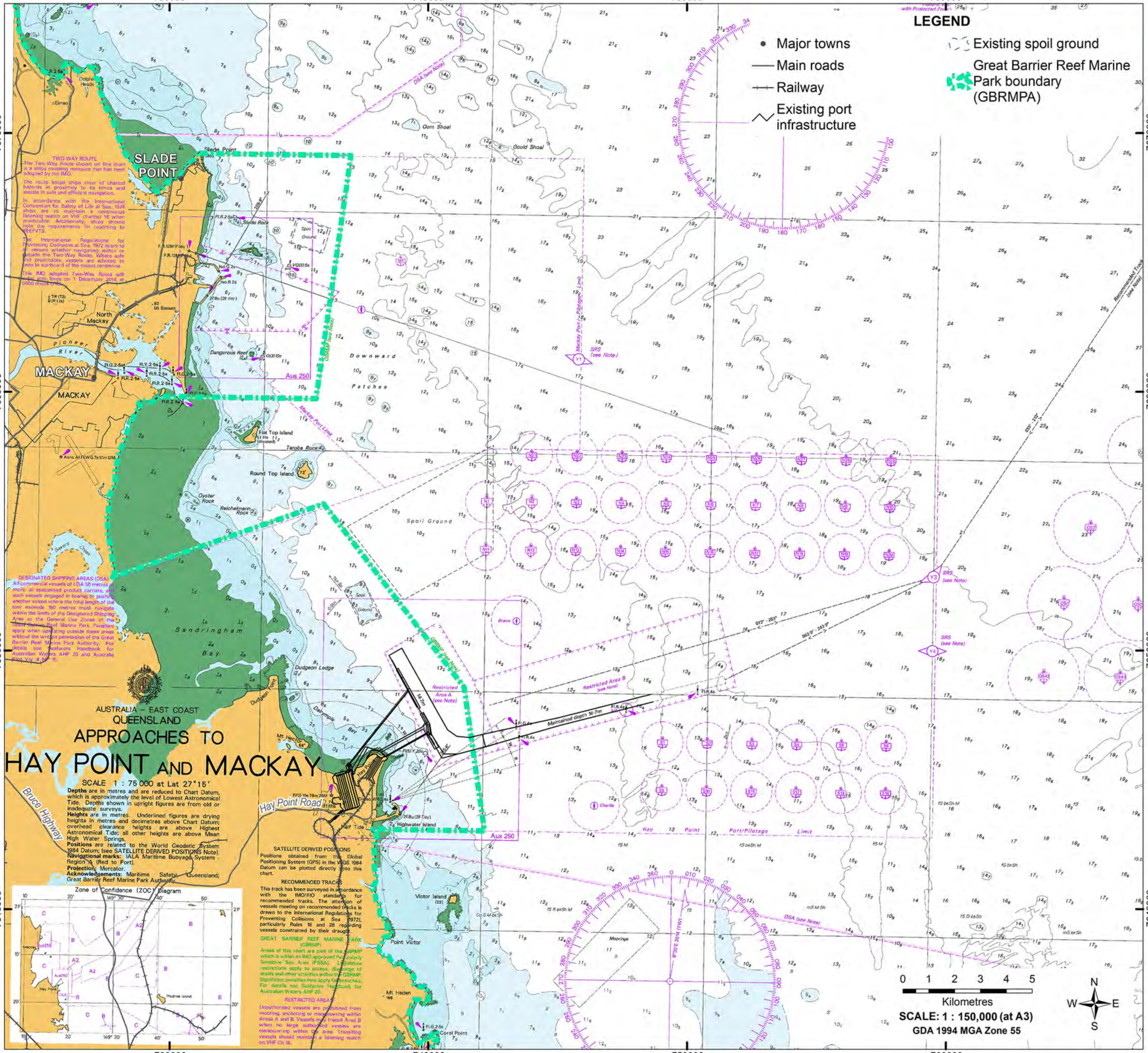
1. Sediment properties investigations

2. Beneficial reuse options identification and analysis.

The first stage included the evaluation, assessment and documentation of the engineering properties of maintenance material sediments within the navigational infrastructure of the Port of Hay Point. These investigations are described in detail in Appendix A, and summarised in Section 2 below.

The sediment properties investigations provide the basis for identification of potential beneficial reuse options, along with subsequent analysis. Following identification of beneficial reuse options, the analysis compares the range of options at conceptual level, considering processes, potential constraints and implications, approvals, conceptual costs and greenhouse gas emissions, along with knowledge gaps and future considerations. The method used for the analysis is described in Section 3, and the analysis is reported in Section 4.

The beneficial reuse investigations draw on other investigations undertaken for NQBP as part of the SSM Project, including bathymetric analysis and modelling undertaken to determine maintenance dredging requirements (amongst other things).



Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China

Source information:
Infrastructure - Extracted from drawing 223510-A20-DW-M-001(M) supplied by Aurecon 2012/09/26
Main Roads - Department of Main Roads 2009
Great Barrier Reef Marine Park - GBRMPA 20 March 2012
Seafarer® GeoTIFF A00249 - Australian Hydrographic Office 2016

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BENEFICIAL REUSE ASSESSMENT
PORT OF HAY POINT

Figure 1-1
Locality Map

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2 Sediment properties

2.1 Sediment investigations

Targeted sediment properties investigations were undertaken in March 2016. The purpose of the investigations was to identify and classify marine sediment materials that require dredging within the navigational areas of the Port of Hay Point, and investigate their acid generating capacity and geotechnical properties for consideration of potential reuse options.

Sediments were sampled at 16 locations within Port of Hay Point navigational areas, including inner and outer departure paths, apron areas and DBCT berth pockets (Figure 2-1). The number of sampling locations selected was in general accordance with requirements for a pilot study outlined in the National Assessment Guidelines for Dredging (NAGD, 2009). A detailed description of the sediment properties investigations is provided in Appendix A, and a summary of the key findings is provided here.

2.1.1 Geotechnical results

The geotechnical laboratory testing determined the properties and enabled characterisation of the sediment material. These properties and characteristics, detailed in Appendix A and outlined below, assist to define the suitability of material for various reuse options.

The properties below are described in relation to the general results range for the test to indicate where the sediment characteristics lie in relation to other materials.

2.1.1.1 Material Description

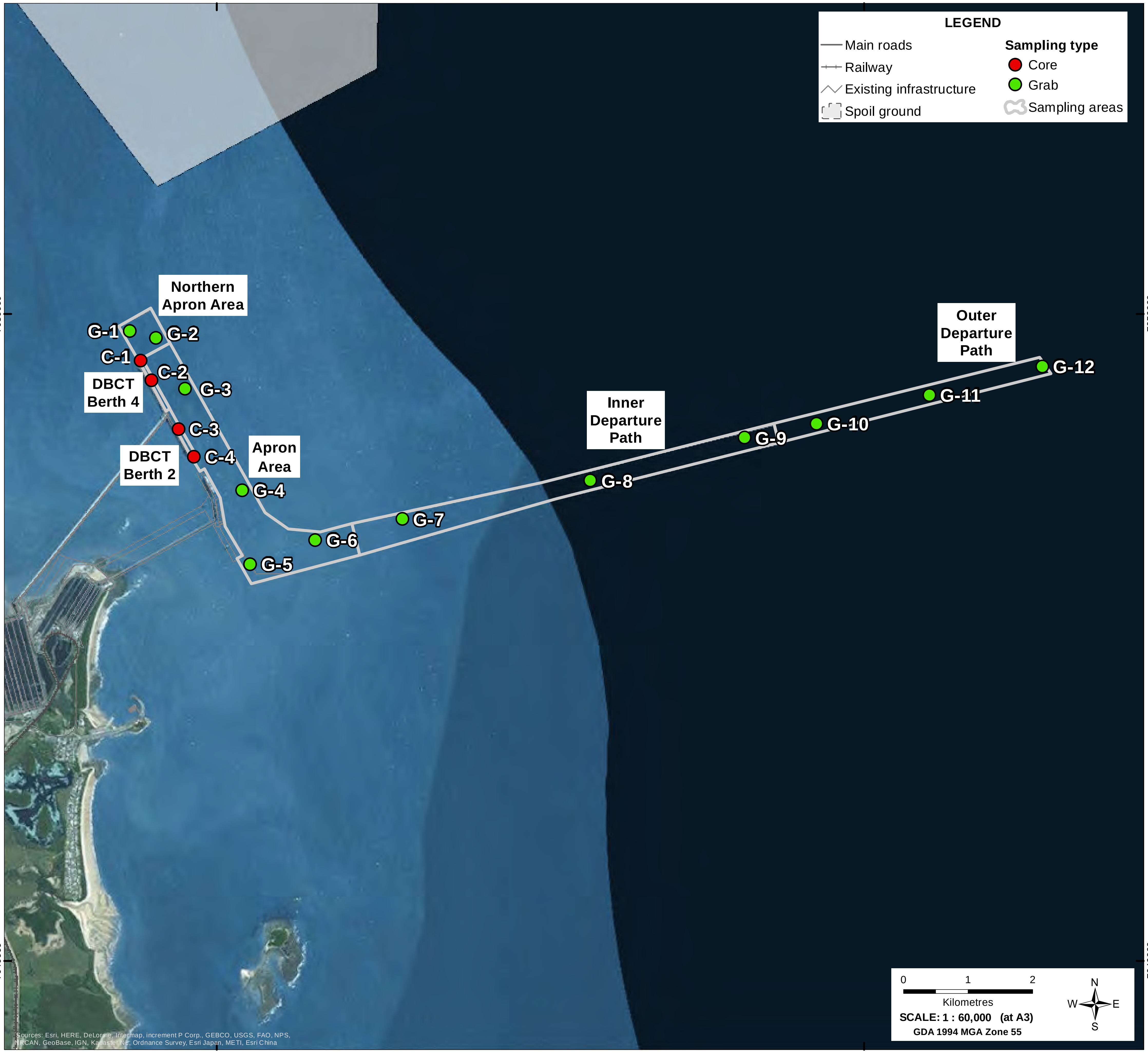
The sediment materials encountered are described as silty clays and clayey and silty sands, dark grey in colour.

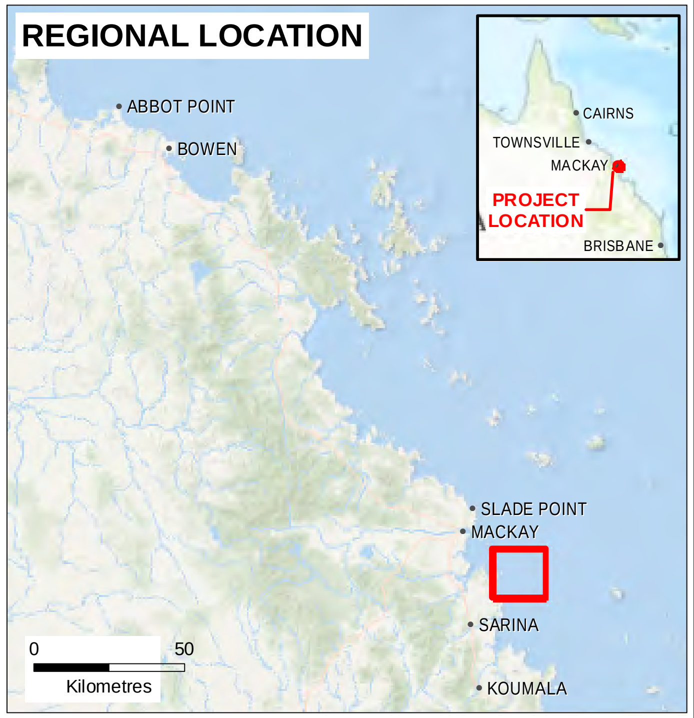
2.1.1.2 Particle Size Distribution

The Particle Size Distribution (PSD) for the combined samples of the dredge sediment material[1] consisted of:

- Clay/Silt 60% (<0.075mm dia.)
- Sand 36% (0.075mm to 4.8mm dia.)
- Gravel 4% (>4.8mm dia.)

[1] Soil type as defined by particle size under the Unified Soil Classification System.





Source information:
Infrastructure - Extracted from drawing 223510-A20-DW-M-001(M) supplied by Aurecon 2012/09/26
Main Roads - Department of Main Roads 2009
Great Barrier Reef Marine Park - Commonwealth of Australia 2013
Great Barrier Coast Marine Park - Department of Environment and Resource Management 2011
Seafarer® GeoTIFF A00823 - Australian Hydrographic Office 2016

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BENEFICIAL REUSE ASSESSMENT
PORT OF HAY POINT

Figure 2-1
Sampling Locations

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As illustrated in Figure 2-2, the PSD is dominated by the fine clay/silt and sand portions with coarse material (gravel) almost absent. This unbalanced distribution of fine particle size means the sediment material is considered poorly graded.

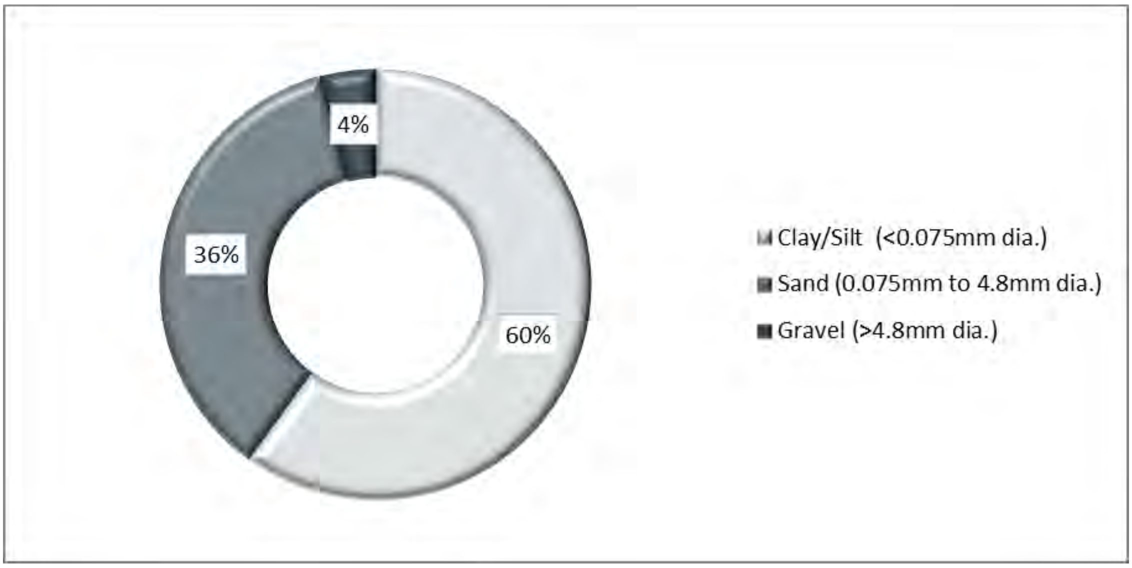


Figure 2-2 Particle Size Distribution for combined samples of dredge sediment material

2.1.1.3 Moisture content

Moisture content results for the samples varied between approximately 84% and 160% for the fine grained sediment material, and between approximately 19% and 49% for the coarse grained sediment material. The fine grain sediment materials (located in the berth pocket and apron areas) had very high moisture content, typical of fine marine sediments, whilst the departure path area samples, had coarser grained material, fewer voids to retain moisture and consequently had lower moisture content. General optimum moisture content for pavement material or general earthworks ranges between 5 and 20%. Hence the sediment material is considered to exhibit extremely high moisture content.

2.1.1.4 Atterberg limits

Atterberg liquid and plastic limit tests are designed to reflect the influence of water content, grain size and mineral composition on mechanical behaviour of clays and silts. These tests indicated that fine grained material (berth pockets and apron areas) is indicative of low to high plasticity clay, with the average result indicating high plasticity.

2.1.1.5 Plasticity Index

Plasticity Index (PI) is the range of moisture content at which a soil material remains plastic (exhibits plastic properties) before becoming a liquid. The samples of fine grained sediment material tested are indicative of low to high plasticity clays with PI for the samples ranging from 14% to 72%. For all samples tested, the moisture contents were found to be higher than the corresponding liquid limits, indicating the sediments are very wet and soft, fine grained materials.

High PI% is associated with the silty clay material and lower PI% and 'not plastic' results were found for the locations sampled with higher sand content.

2.1.1.6 Linear shrinkage

Linear shrinkage results (ranging from 5.5% to 22%) indicate a potential for swelling in fine grained materials, most of which were above the critical potential for expansion limit of 8%. This is supported by oedometer tests, which recorded swelling at less than 160kPa loading. Less than 5% is a generally acceptable linear shrinkage result for materials in applications where the swelling or expansive potential for clay is important. The high proportion of fines (silt and clay) in the sediment material results in high potential for swelling of the reuse material.

2.1.1.7 Density test

Particle density tests were undertaken on 16 samples of the recovered sediment. The recorded densities ranged between 2.53 t/m^3 and 2.67 t/m^3 with an average value of 2.61 t/m^3. These values are typical of silty clay and silty sand materials.

2.1.1.8 Strength and consolidation

Strength and consolidation tests were undertaken on samples of remoulded and moisture conditioned sediments of silty sand (departure path area) in order to provide indicative parameters for material following reworking and field placement. The silty clay material (berth area) has very poor strength and consolidation properties such that the results would not be measurable by the test methods undertaken. Direct shear tests and consolidated undrained triaxial tests from the departure path area (locations G9 and G11) results range from 0kPa to 5kPa effective cohesion and between 30 and 33 degrees friction angle. Generally the sediment material in the departure path area has very poor cohesion, and a high friction angle typical for a sand material.

2.1.1.9 Permeability

Permeability is the ability for moisture to move through the spaces or cracks between pores in material. Where permeability is low, movement of moisture is restricted and thus, a build-up of pressure can occur quickly. This pore pressure can lead to cracking and breakdown the material structure.

The constant head test results on the sand recorded permeabilities of 2.4 x 10^{-5}ms^{-1} and 2.8 x 10^{-5} ms^{-1} for samples from G-9 and G-11 (in the departure path) respectively. These permeabilities are typical of sand materials.

For the clay samples, measured permeabilities are 3.3 x 10^{-11} ms^{-1} and 9.3 x 10^{-11} ms^{-1} for samples from C-2 and C-3 (in berth areas) respectively. These permeabilities are typical of clay materials.

2.1.1.10 Cement laboratory testing

X-ray Diffraction and X-ray Fluorescence tests were undertaken on two samples, one in the berth areas (silty clay) and a second in the inner departure path area (sand). The tests indicated that the sample from the berth areas may be used to form a binding agent by the introduction and mixing of an alkaline geopolymer hardener chemical. The tests indicated that the sample from the inner departure path areas cannot be used as a binding agent; however it may form the body matter in a useful material with the introduction of a binding agent.

2.1.1.11 Interpretation

Interpretation of the general properties and general range of the sediment material characteristics outlined above enables matching to a potentially corresponding beneficial reuse option or options. The appropriateness of sediment material characteristics to meet a particular reuse option's requirements ranges from suitable to potentially suitable (with treatment and processing) to entirely unsuitable. The suitability of specific sediment material properties is considered against each individual potential reuse and analysed in sections 4.2, 4.3 and 4.4.

2.1.2 Geochemical results

The presence of potential acid sulfate soils (PASS) was assessed using the chromium suite of analysis (S_{CR}) as recommended for use in PASS assessment by the most recent guidelines, *Queensland Acid Sulfate Soil Technical Manual – Soil Management Guideline* (Dear *et al*., 2002). Analysis was also undertaken of a range of salinity parameters and organic matter.

Based on the PASS analysis, samples comprised of fine textured material (i.e. silts and silty clays) and generally located in the apron and berth pocket areas was PASS. Samples comprised of coarser textured material (i.e. sands) and generally located in the departure path, were not PASS.

Although the fine textured samples are PASS, these contained adequate Acid Neturalising Capacity (ANC) to buffer inherent acidity to negligible concentrations. This indicates that the sediments are unlikely to require ASS treatment through neutralisation using lime.

All samples are considered extremely saline according to Rayment and Lyons (2011) salinity ratings, with Total Soluble Salts ranging from 9490 to 50600 mg/kg, and electrical conductivity ranging from 2920 to 15600 μS/cm. Higher levels of salinity were reported for samples with fine texture collected from berth pockets and apron areas, compared to the samples with sandier texture collected from the departure path.

Low levels of organic material were reported for all samples analysed, with the highest levels (i.e. 1-2%) reported for finer textured samples. Levels of organic matter in course texture samples (primarily located in the departure path) were lower than the laboratory quantification limit.

2.2 Maintenance dredging requirements

NQBP engaged RoyalHaskoningDHV (RHDHV, 2016a) to undertake bathymetric analysis and modelling in order to determine the current maintenance dredging requirements at the Port of Hay Point. The analysis identified total current maintenance dredging requirements based on the comparison of the most recent hydrographic data captured in October 2015 with design depth as shown in Table 2-1.

Table 2-1 Summary of current maintenance dredging requirements

Dredge area	Approximate volume (m^3)
Dalrymple Bay Coal Terminal berths 1 & 2	80,020
Dalrymple Bay Coal Terminal berths 3 & 4	59,770
Hay Point Coal Terminal berths	6,700
Apron areas	48,550
Departure path areas	10,734
Total	**205,774**

In consideration of potential future maintenance dredging requirements, NQBP commissioned RHDHV to develop a predictive tool to assist decision making (RHDHV, 2016b). The analysis found that regular ongoing siltation is likely to occur only in berths and in some parts of the apron, while siltation associated with tropical cyclones may occur across all areas of the port.

Due to limitations in data availability (and particularly data associated with the impacts on erosion or accretion during tropical cyclones) the predictive model typically takes a conservative approach in the prediction of volumes above design depth that may require maintenance dredging. RHDHV (2016b) identifies separate predictions for siltation with or without the occurrence of tropical cyclones. Based on the assumption that the current volume of material (Table 2-1) is dredged to design depth or existing bed level (whichever is lower) the predictive model identifies total siltation volumes at five years subsequent of approximately 216,000 and 265,000m^3 for scenarios without or with a tropical cyclone respectively. The model predicts that the vast majority (greater than 98%) of the siltation will occur in the berths and parts of the apron areas.

Based on historical maintenance dredging frequency and volumes, NQBP considers it reasonable to assume that maintenance dredging may be required to remove approximately 200,000m^3 from navigational areas of the port about every five years. It is considered likely that the majority of the maintenance dredging will be required in the berths, with some in apron areas, and very little in departure path areas.

2.3 Implications for potential beneficial reuse

The properties of the sediment to be dredged along with the current and predicted future maintenance dredging requirements are key consideration for identification and analysis of potential beneficial reuse of the sediment. An approximation of the amount of each sediment type (fine, sand and gravel) that currently require dredging from each of the main port areas is represented in Table 2-2 and Figure 2-3. These representations have been derived in consideration of the PSD results from sediment properties analysis and the current maintenance dredging requirements described above.

Table 2-2 Approximation of sediment type in each dredge area

Dredge area	Volume of material based on texture (PSD) (m^3)			Total
	Fine	Sand	Gravel	
Berths 1 & 2	58948.1	21071.9	0	80020
Berths 3 & 4	30183.9	25103.4	4482.8	59770
Apron areas	28887.3	16911.6	2751.2	48550
Departure path areas	1019.7	9517.5	196.8	10734
Total	119038.9	72604.4	7430.7	**199074**

Note that the calculations provided in Table 2-2 and Figure 2-3 do not include the dredge volume associated with the Hay Point Coal Terminal berths, as no sediment sampling was undertaken to characterise the type of sediment in this area.

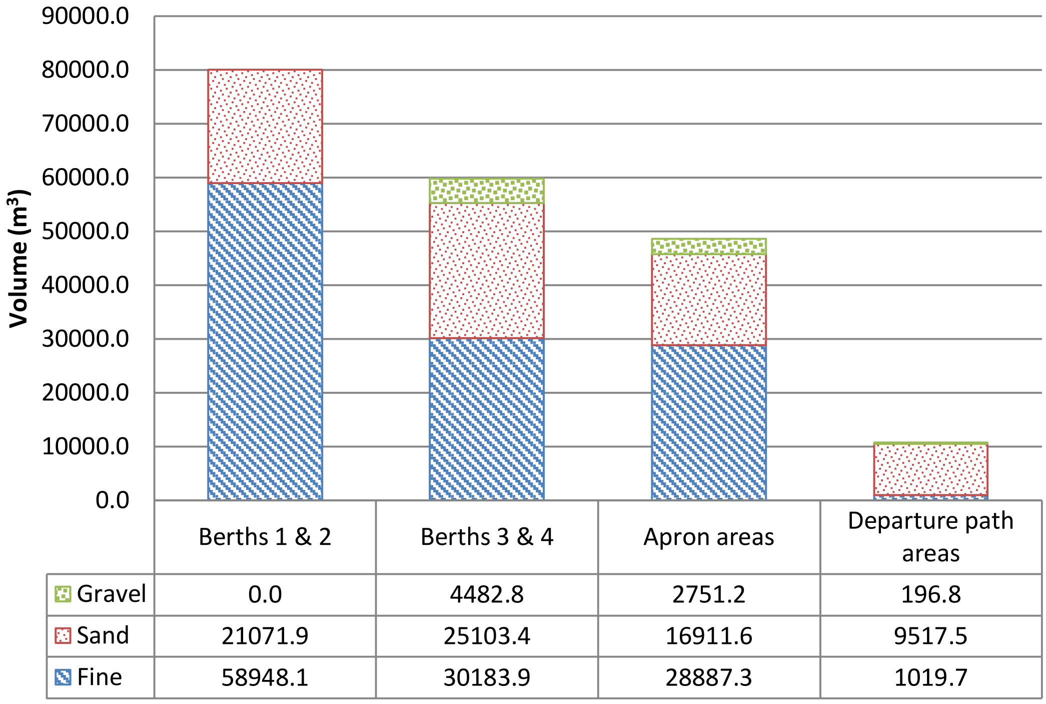


Figure 2-3 Approximation of sediment type in each dredge area

Given the predictions of future maintenance dredging requirements described above, it is considered likely that the volumetric split of material per dredge area and sediment type will be similar for future maintenance dredging i.e. the vast majority of material to be dredged from the berths and apron areas, the majority of which will be fine material.

The majority of material to be dredged is a mixture of sediment type, dominated by fine material, which has accumulated in relatively confined areas, within which it would likely be impractical to separate sediment types during dredging. The volume of sand located with the departure path areas is not of sufficient quantity to warrant targeted dredging to support a beneficial use separate from that of the remaining material. As such, it is considered unlikely that selective dredging of material for alternate beneficial reuse options (e.g. managing sand material for one use, separate from fine material for another use) will be feasible. There may be some opportunity within a reuse option, to maximise the proportion of sand versus fine material dredged and placed or vice versa through dredge management activities.

The geotechnical properties of the material to be dredged are considered in further detail in the discussion of potential beneficial reuse options below, with the key implications for the majority of the sediment (fines) likely to be encountered through dredging summarised below:

- Sediment is likely to contain high plasticity clay
- Sediment to be dredged is likely to have very high moisture content, and therefore significant effort would be required to dry out the sediment as may be required for various reuse options
- Sediments to be dredged are likely to have very low to medium compressibility and have some potential to swell
- Sediments may be able to be used to form a binding agent (e.g. in products including concrete, bricks and stabilised engineering fill material) by the introduction and mixing of an alkaline geopolymer hardener chemical.

With respect geochemical properties, whilst the sediments to be dredged are likely to be PASS, they contain sufficient ANC to buffer inherent acidity to negligible concentrations and as such are unlikely to require ASS treatment. Nonetheless PASS management may require consideration depending on the process associated with beneficial reuse options (e.g. should the process require separation of dredged sediment material, potentially separating material associated with the ANC (such as shell material) from the PASS). Previous sediment characterisation studies undertaken for NQBP (PACE, 2013) have concluded that material to be dredged from navigational areas is free of contamination and therefore suitable for ocean placement. As such, in terms of sediment characteristics, the consideration of potential beneficial reuse options assumes that material is not contaminated.

3 Analysis method

The second stage of investigations comprised two phases, being:

1. Identification of potential beneficial reuse options
2. Analysis of the opportunity, potential feasibility and achievability of the options in the context of the Port of Hay Point.

A description of the considerations for analysis is provided below, followed by description of the methods of analysis.

3.1 Relevant considerations

3.1.1 Primary considerations

The primary considerations of analysis were the properties of the sediment to be dredged and the current and likely future maintenance dredging requirements.

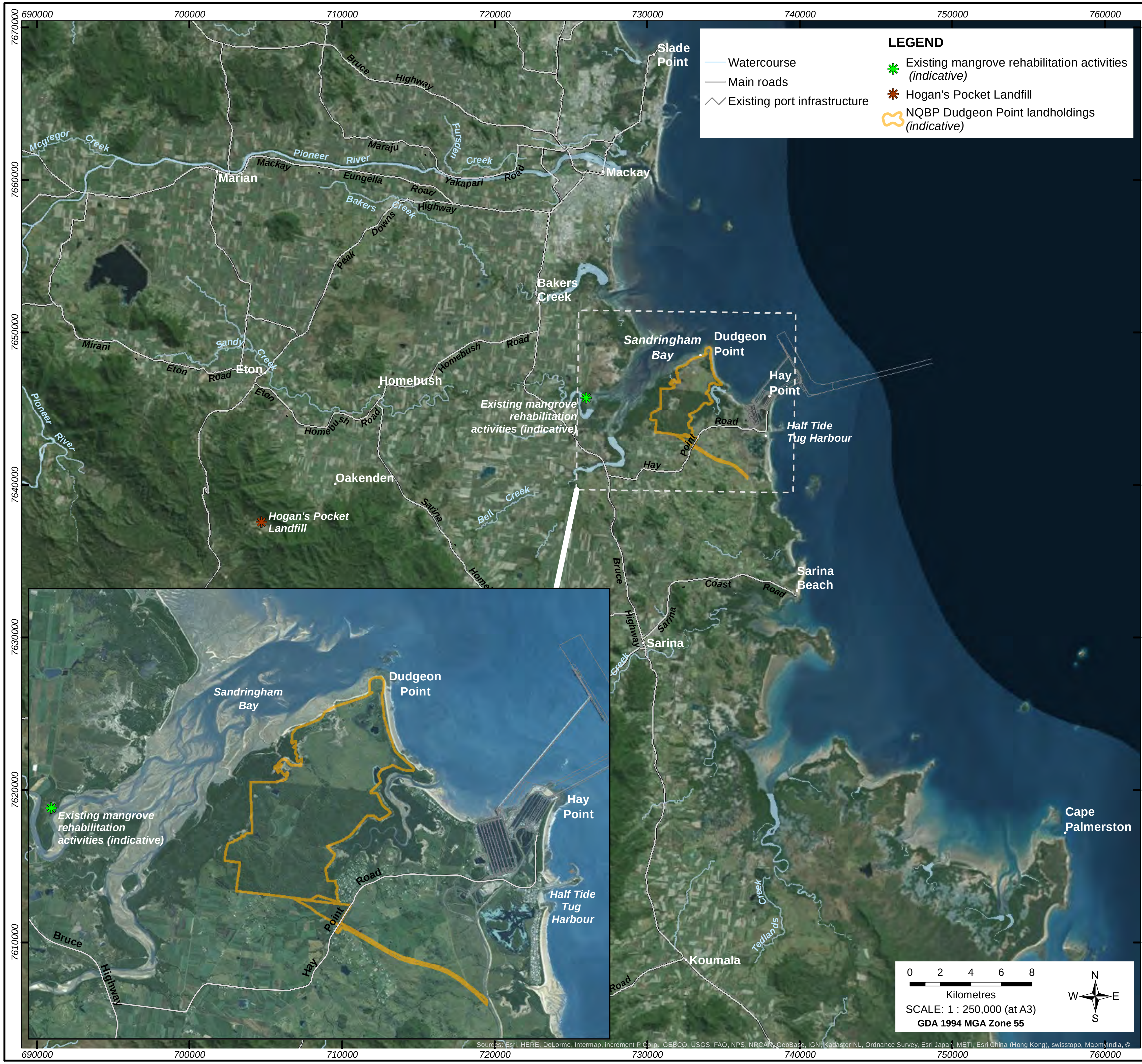
While the basis of the analysis is that the maintenance dredge material is delivered in a wet state to a reuse area which is not defined in a geographical space, it is considered reasonable for the analysis to provide some consideration of regional context i.e. potential beneficial reuse options may be limited by the location of the potential downstream beneficial use relative to the maintenance dredge areas. Figure 3-1 shows the port areas in the regional context which was considered in the beneficial reuse analysis.

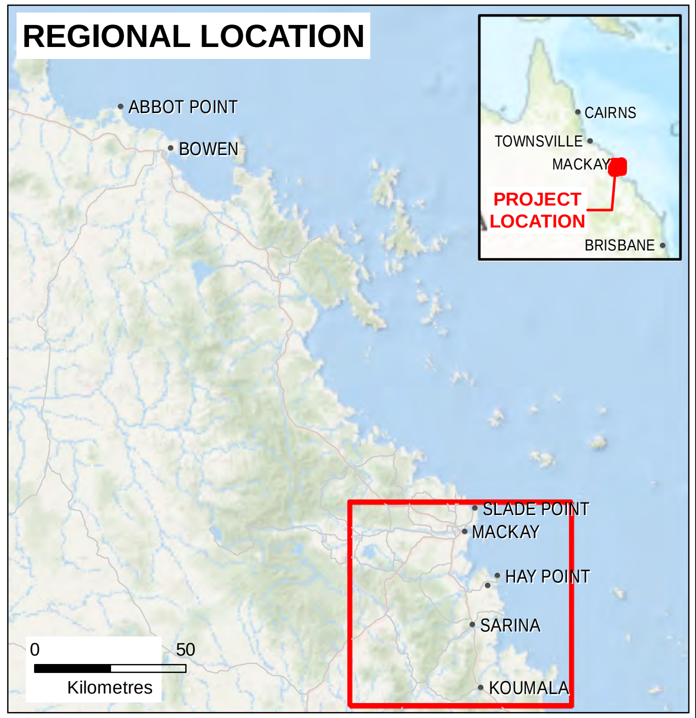
3.1.2 Other considerations

3.1.2.1 Dredge and dredge material placement method

One of the key assumptions identified by NQBP to apply to the beneficial reuse analysis was the assumption that dredged material is delivered to a reuse area (not defined in geographical space) in a wet state. Nonetheless it is notable that the potential feasibility of beneficial reuse options depends heavily on the cycle from dredging to end use. Dredging and placement methods affect the ability to successfully reuse the material. Some options may be enabled directly by the dredge used (e.g. they may be delivered directly to their final location by the dredge).

To provide context to the potential beneficial reuse options analysis, this section outlines the main dredging and placement methods that were considered, firstly through discussion of the overall 'route' to beneficial reuse, and secondly through discussion of specific dredge and placement methods. This is largely drawn from the Permanent International Association of Navigational Congresses (PIANC) publication *Dredged material as a resource: Options and Constraints* (PIANC, 2009).





Source information:
Infrastructure - Extracted from drawing 223510-A20-DW-M-001(M) supplied by Aurecon 2012/09/26
Main Roads - Department of Main Roads 2009
Watercourse Queensland - State of Queensland (Department of Natural Resources and Mines) 2016

REV	DATE	REVISION DESCRIPTION	DRN	CHK	ENG	CHK ENG	APPD
A	24/06/2016	Issued for information	KM	AK	WB		

Advisian WorleyParsons Group

North Queensland Bulk Ports Corporation

NORTH QUEENSLAND BULK PORTS CORPORATION

BENEFICIAL REUSE ASSESSMENT
PORT OF HAY POINT

Figure 3-1
Regional Context

Figure: 301310-09537-00-GM-SKT-0002 Rev: A

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Implications of beneficial reuse route

There are a number of potential approaches which may be used in taking dredged material towards a beneficial reuse, including direct use, treatment and intermediate storage.

Direct Use

Direct use options involve the direct use of dredge material without the need for treatment and / or storage. The dredged material may be used directly for uses such as embankment construction, land reclamation or habitat restoration or creation.

Capital dredging with cutter suction dredgers, backhoes, grab or bucket ladder dredgers often produces dredged material consisting of materials such as rock, stones, sand and consolidated clay. The material can be pumped through a pipeline to the place of use, or into barges for transport direct to the required location.

Maintenance dredging with suction dredgers (predominantly trailer suction hopper dredgers) typically produces material consisting of loose gravel, sand and mud. The material is transported in the trailer to the area of use. The material is either deposited through hatches at the bottom of the ship, dumped by method of split hopper dumping, pumped through a floating pipe or rainbowed[2].

Hydraulic dredging (i.e. using cutter suction or trailer suction hopper dredgers) typically results in the dredged material containing a large proportion of water, which may not be desirable in certain applications of reuse. Use of a bucket dredger typically sees less water entrainment than hydraulic dredging, with the dredged material loaded by the bucket dredge into a barge which then transports the material to the place of reuse.

Treatment prior to use

For dredged material not directly meeting the potential reuse criteria, a number of treatment techniques may be applied, depending typically on the sediment properties and desired reuse.

Treatment techniques designed to meet geotechnical requirements include physical techniques such as dewatering and separation. Treatment techniques designed to meet environmental requirements may include chemical, biological or thermal treatment (e.g. bioremediation, immobilisation and thermal oxidation), which are most commonly applied to contaminated sediments. A combination of several techniques might be necessary to meet reuse requirements in a treatment chain; which typically commences with material dewatering.

Intermediate storage

Intermediate storage between dredging and use might be necessary due to logistical reasons such as:

- Different timing between dredging and use due to planning or environmental reasons
- Difference in production rate of the dredging activity and the capacity and rate of demand for the use.

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[2] Discharge from the dredge into the air, depositing the dredge material on the water surface

- Difference in capacity of dredging and treatment, as the rate of treatment is generally an order of magnitude lower than the production rate of the dredging plant
- To create homogeneity of the input of dredged material, as certain treatment processes such as mechanical separation need homogenous inflows for proper operation.

Intermediate storage may also be useful as it may allow more detailed characterisation of the dredged material before use.

Implications of dredge and placement method

Dredging method

The dredge method chosen may enable some treatment of sediments during dredging, and as such has implications for the potential feasibility of reuse options available.

A trailer suction hopper dredger may allow for some separation of dredge material during the dredging operation based on grain size. If a mixture of coarser material (sand and gravel) and fines is dredged, a large proportion of the fines can be washed out with the overflow while dredging. The coarser material settles in the hopper while the fines, together with the process water leave the hopper through funnels or weirs in the hopper. This may enable the separation of sands from finer material, of which the sands may have greater reuse potential (e.g. for beach nourishment); however this type of dredging (overflow dredging) creates greater levels of turbidity in the dredge areas, which may be less desirable.

Placement method

Specific placement methods are sometimes specified for certain types of reuse such as:

- Diffusers: Diffusers may be required for certain uses to reduce the velocity of the dredged material discharge stream. Diffusers limit the suspension of material and may enable coverage of an area with a homogeneous layer of sediments.
- Rainbowing: For reuse situation where access for direct unloading might be difficult, the placement may be executed using a front discharge from the dredge into the air, depositing the dredge material on the water surface. This may be useful for beneficial reuse options in shallow areas where the placement of a floating pipeline is problematic.
- Seabed placement: Direct placement of material on the seabed from a pipeline or via a diffuser may be undertaken to reduce turbidity through the water column.

Dredge, placement and reuse logistics

The matching of dredging, placement and reuse logistics is a significant consideration in the successful development of a beneficial reuse project. Several logistical issues warrant consideration:

- Timing: Ideally the schedule for dredging and reuse are matched, such that they may be planned and organised concurrently. If direct matching is not possible, intermediate storage may be necessary.

- Operational aspects: In order to match dredging and reuse, operational aspects of both activities need consideration, such as production rate and time span of delivery. Treatment and direct use routes may impose limits on the dredging operation, e.g. due to limited capacity for treatment or settling/consolidation times in reuse areas.

3.1.2.2 Environmental approval requirements

Environmental approval requirements are considered in the analysis of each of the beneficial reuse options. As there are likely to be common environmental approval requirements across each of the options, a summary of key approvals is provided in Table 3-1. For each approval identified in Table 3-1, an indication is given as to whether it is likely to apply to the 'dredging and placement', 'onshore reuse' or 'offshore reuse' components of beneficial reuse options (discussed in Section 4). Offshore reuse includes works in the tidal zone.

The approvals required for the beneficial reuse of dredged material will ultimately depend on the detailed project scope of works, timing and strategy for approval obtainment and the position of the Australian and Queensland Governments with respect the works.

Table 3-1 Potential environmental approvals required

Approval	Legislation and administering authority	Potential trigger / activity covered	Potentially applicable reuse component
Approval for a controlled action	Environment Protection and Biodiversity Conservation Act 1999 Australian Government Department of the Environment	Potential for significant impact on: ▪ World Heritage properties ▪ National Heritage places ▪ listed threatened species and communities ▪ listed migratory species ▪ Great Barrier Reef Marine Park ▪ Commonwealth marine areas	Dredging and Placement Onshore reuse Offshore reuse
Approval for activities within the Great Barrier Reef Marine Park	Great Barrier Reef Marine Park Act 1975 Great Barrier Reef Marine Park Authority (GBRMPA)	Activities within the Great Barrier Reef Marine Park	Dredging and Placement Offshore reuse

Approval	Legislation and administering authority	Potential trigger / activity covered	Potentially applicable reuse component
Land owner's consent for works on State-owned land	Sustainable Planning Act 2009 (SP Act 2009) Queensland Department of Natural Resources and Mines (DNRM)	Works on lots owned by the State	Dredging and placement Onshore reuse Offshore reuse
Resource allocation for quarry material	SP Act/Forestry Act 1959 Queensland Department of Agriculture and Fisheries (DAF) and / or Queensland Department of Environment and Heritage Protection (DEHP)	Works on lots owned by the State that involve interference with quarry material (seabed or earthworks)	Dredging and placement Onshore reuse Offshore reuse
Port Development Approval and Material Change of Use where a use is inconsistent with the Land Use Plan	SP Act 2009 *Transport Infrastructure Act 1994* (TI Act) and relevant code: Port of Hay Point Land Use Plan NQBP Minister under the TI Act	Works in strategic port land (onshore and offshore lots) for the beneficial reuse project	Dredging and placement Onshore reuse Offshore reuse
Material Change of Use and Operational Works under the Local Government Planning Scheme	SP Act 2009 and planning scheme of the Mackay Regional Council (MRC) MRC	Works in the local government area that are inconsistent with the designation of the planning scheme and / or require approval under the scheme	Dredging and placement Onshore reuse Offshore reuse
Operational Work - Tidal works	SP Act 2009, SP Regulation 2009 *Coastal Protection and*	Works in tidal waters for the beneficial reuse	Dredging and placement

Approval	Legislation and administering authority	Potential trigger / activity covered	Potentially applicable reuse component
	Management Act 1995 Referral agency: Queensland State Assessment and Referral Agency (SARA) Technical advice: DEHP, Maritime Safety Queensland (MSQ)	project	Offshore reuse
Operational work - removal, damage or destruction of marine plants	SP Act 2009 Fisheries Act 1994 Referral agency: SARA Technical advice: DAF	Works in tidal waters potentially involving the removal, damage or destruction of marine plants	Dredging and placement Offshore reuse
Amendment of existing Material Change of Use (MCU) for Environmentally Relevant Activity (ERA) 16 – extractive and screening activities - dredging	SP Act 2009 SP Regulation *Environmental Protection Act 1994* (EP Act 1994) Referral agency: SARA Technical advice: DEHP	Dredging in offshore lots	Dredging and placement
Amendment of current Environmental Authority for ERA 16 - extractive and screening activities - dredging	EP Act 1994 DEHP	Dredging in areas previously approved, with subsequent beneficial reuse	Dredging and placement
Operational work - Clearing native vegetation	SP Act 2009 Vegetation Management Act 1999 Referral agency: SARA Technical advice: DNRM	Clearing of native vegetation.	Dredging and placement Onshore reuse
Operational work – High impact earthworks in a	SP Act 2009 Referral agency: SARA Technical advice:	Earthworks in and near wetland protection areas	Dredging and placement

Approval	Legislation and administering authority	Potential trigger / activity covered	Potentially applicable reuse component
wetland protection area	DEHP		Onshore reuse Offshore reuse
Tampering with animal breeding places	*Nature Conservation Act 1994* (NC Act 1994) Nature Conservation (Administration) Regulation 2006 DEHP	Tampering with native animal breeding places during clearing and grubbing activities.	Dredging and placement Onshore reuse Offshore reuse

3.2 Options identification

Following completion of the sediment properties investigations, the sediment properties assessment report (Appendix A), was provided to a multi-disciplinary team to identify potential reuse options for the material. The team was also provided with basic details of the current and likely future dredging requirements.

The team consisted of a blend of local, international and specific dredging and materials use experience including:

- Jan Matthe (Advisian Director Ports and Marine Terminals) with over 20 years of engineering and contracting experience in the marine and coastal sector, including as dredging lead for dredging and reclamation projects
- Jaap van Thiel de Vries (Boskalis Ecoshape management team Senior Engineer) of global maritime service company Royal Boskalis Westminister N.V., which has extensive experience in dredging and dredged material management. Jaap is involved in coordination of Boskalis' 'Building with Nature' program, which seeks to enable sustainable marine infrastructure development, while at the same time creating opportunities for nature and society.
- Russell Genrich (Wagner Earth Friendly Concrete Research and Development Laboratory Manager) of building materials company Wagners, which has wide experience with varied applications of most types of construction material including stabilised soils, production of cements, processing of flyash and ground granulated blast furnace slag
- Greg Holz (Advisian Principal Soil Scientist) with over 40 years of experience in soil science, including numerous soil suitability assessments for agriculture (cane farming) in the Mackay region
- Joe Hixson, (Advisian Lead Geotechnical Engineer) with around 20 years of experience in geotechnical engineering and engineering geology for civil infrastructure and development schemes

- Luke Stalley (Advisian Principal Consultant) with over 20 years of experience as a civil/environmental engineer in planning, design and construction of major infrastructure projects
- Bill Boylson (Advisian Senior Consultant) with around 15 years of experience as an environmental engineer particularly in the planning, development, environmental impacts assessment, approvals and management of Queensland ports and marine projects

The team reviewed the sediment properties report, considered the maintenance dredging requirements and associated implications for beneficial reuse, drew on international literature (such as publications of PIANC relevant to beneficial reuse of dredged material) and considered global and local examples of reuse of dredge material. Based on this information the team developed a list of reuse and recycling options that warranted further analysis.

3.3 Options analysis

The primary and other considerations described above informed the analysis undertaken for each of the options identified. The analysis of each option includes a discussion of the individual features, processes or characteristics related to the option to enable comparison. The description of each option is organised to include:

- Description of the beneficial reuse activity that may be applicable
- Description of the specific opportunity that may be applicable to the Port of Hay Point, including the core assumptions of the analysis (e.g. location of the beneficial reuse)
- Discussion of the suitability of the sediments to the beneficial reuse opportunity
- Description of the process required to realise the opportunity, typically with delineation between dredging and placement, and infrastructure and management requirements
- Identification of the potential constraints to successful delivery of the opportunity
- Identification of the potential implications (environmental, commercial, socio-economic) of execution of the opportunity
- Summary of the environmental approvals likely to be required to enable the opportunity
- Quantification at a conceptual level of costs and greenhouse gas emissions that may be associated with the execution of the opportunity
- Identification of existing key knowledge gaps with respect to execution of the beneficial reuse opportunity
- Identification of future considerations for the opportunity (e.g. does it provide a long-term reuse option).

As each opportunity may have numerous alternative configurations (including alternative dredging and/or processing method and location), for each option the analysis focuses on what is considered to be a reasonable and practicable configuration to achieve the beneficial reuse outcomes of that option.

3.3.1 Sediment suitability

As part of the assessment for each of the proposed reuse opportunities an analysis of the sediment suitability was undertaken, based upon properties determined from results of the laboratory testing of the samples. The sediment was subsequently categorised as:

- Likely suitable
- Potentially suitable with treatment/processing
- Not likely to be suitable
- Not applicable (irrelevant or no negative or positive impact upon the reuse)

The suitability categories have been considered for each of the of the properties including: material colour, particle size distribution, moisture content, plasticity index, linear shrinkage, density test, strength and consolidation, permeability, cement laboratory testing, PASS, salinity and organic material. The consideration of relevant material properties and sediment suitability for each individual reuse option is discussed in the respective analysis sections and this work has informed option comparison described in sections 4.2, 4.3 and 4.4. The suitability of the properties and characteristics of the sediment material for the ultimately selected beneficial reuse option will require confirmation as part of the detailed planning and design.

3.3.2 Cost and greenhouse gas emissions estimates

Cost and greenhouse gas emissions estimations have been developed on the basis of conceptual reuse option information for the purpose of comparison between options. The estimate information provided in Appendix B and C are not an indication of any option's feasibility but are a preliminary cost and greenhouse gas emissions estimate of the key activities required for each.

It is notable that quantification of conceptual cost and greenhouse gas emissions associated with each option is based on assessment of dredge material use from a single maintenance dredging campaign. For a number of options, infrastructure that is developed for the initial campaign may be used for subsequent campaigns, and therefore this initial cost of infrastructure, may provide long-term use. This is identified for each option where relevant in the description of future considerations.

Identification of a conceptual cost and estimation of potential greenhouse gas emissions for each of the options requires the delineation of boundaries of the assessment, effectively to identify what and where the final beneficial reuse product is for the purposes of assessment. There are numerous alternatives and sub-options associated with each of the potential beneficial reuse options identified, both in terms of downstream processing applications and geographical location of the downstream beneficial reuse. As such, it is considered reasonable for the purposes of comparative analysis to use the delivery of the dredged material (following processing if relevant) to the beneficial reuse location (detailed in the relevant process description) as the boundary of the assessment, e.g. for road base this includes delivery to the assumed point of use as described in the road base process description.

Cost Estimate

The basis of the conceptual cost estimate is pricing of the key activities associated with the offshore and onshore tasks for all 12 beneficial reuse options. The conceptual cost estimate is indicative, and enables a high-level comparison of various beneficial use options. Assumptions for vessels, plant and equipment, sailing distance, production rates, local condition and unit rates have been considered in the development of the estimate. It is noteworthy that some pump-ashore, treatment, processing, monitoring and transport to end user options are more complex and have a longer duration than others, and this has been taken into account where relevant. The vessel mobilization, demobilization and production rate costs were estimated with the assistance of Tender Manager, Boskalis Australia Pty Ltd. A detailed breakdown of the cost estimate, and assumptions is provided in Appendix B.

No allowance has been made in the cost estimate for items including, project management, administration, design ,approvals, specialist engineering or scientific studies, access road to intermediate storage location or any contingency. The preliminary cost estimate does not consider any cost recovery should opportunistic uses be identified where the end user may pay for the reuse material providing an income stream.

Greenhouse gas emissions estimate

The basis of the greenhouse gas emissions calculation is estimation of the emissions associated with all 12 beneficial reuse options, expressed as tonnes of CO_2 equivalent. Assumptions for the vessels, plant and equipment, fuel type, fuel consumption, installed power, utilisation and total hours of operation have been considered in the development of the emission calculations. The emission factors have been referenced from the National Greenhouse and Energy Reporting (NGER) Scope 1 - National Green House Account Factors 2015. A detailed list of assumptions, activity data and emission calculations are provided in Appendix C.

3.3.3 Performance summary

In consideration of each of the aspects of analysis described above, and to facilitate presentation of the qualitative comparison of the options (using a consistent basis), a performance evaluation key was developed in consultation with NQBP, as shown in Table 3-2.

This key was utilised to develop a summary of performance for each option. This summary is included in the analysis for each option in sections 4.2, 4.3 and 4.4. The summary analysis is aggregated to enable easy comparison between the options at Section 5, Conclusions.

Table 3-2 Performance evaluation key

Performance Criteria	High Performance	Moderate Performance	Low Performance
Opportunity	The is an existing demand in a location accessible to the Port of Hay Point, requiring minimal infrastructure needs	Potentially a demand reasonably accessible to the Port of Hay Point, requiring infrastructure construction	No demand identified, poor access to the Port of Hay Point, requiring extensive infrastructure construction
Sediment suitability	Reuse option well suited to the dredge material. Requires no additives or treatment (other than dewatering if necessary)	Reuse option potentially suited to the dredge material. Requires treatment, processing and/or additives to make material suitable	Reuse option poorly suited to the dredge material. Requires substantial treatment, processing and/or additives to make material suitable; or treatment to a suitable level is considered unachievable
Cost	Less than $10M in a 5 year period	$10M to $17M in a 5 year period	More than $17M in a 5 year period
Process	The proposed process is well understood and clearly demonstrated in similar environments to the Port of Hay Point using maintenance dredge material	The proposed process is sound but there are few examples of it being applied in environments similar to the port of Hay Point using maintenance dredge material	The proposed process is mostly unproven
Duration	Less than 1 year to construct and function as the proposed final use	1 to 3 years to construct and function as the proposed final use	Greater than 3 years to construct and function as the proposed final use
Greenhouse Gas Emissions (GHGs)	< 2500t CO_2 equivalent in 5 year period	>2500t and <5000t CO_2 equivalent	>5000t CO_2 equivalent
Environmental Implications	Net benefit opportunities exist for positive environmental outcomes, with manageable nuisance of harm issues	Nuisance or harm issues identified, but for the most part are considered manageable	Nuisance or harm issues unlikely to be easily managed

Performance Criteria	High Performance	Moderate Performance	Low Performance
Social Implications	Positive social opportunities exist for local communities and other key user groups	Social effects for the most part are considered manageable	Negative social impacts are unlikely to be easily managed
Economic Implications	Positive economic opportunities exist enhancing port or community capability	Limited economic opportunities exist enhancing port or community capability	Lost or negative economic opportunities to enhance port or community capability
Approvals and Permits	Recognised approvals pathway, with few management issues identified	Recognised approvals pathway, with significant management issues identified	Not supported but current legislation / policy, or would require high level offset considerations
Constraints	There are few constraints which are for the most part considered manageable	Constraints are identified and there is a degree of uncertainty in the ability to overcome or manage them	Multiple constraints are present that would limit realistic implementation
Knowledge Gaps	There are few knowledge gaps and less than 1 year of further research work would be required to progress the reuse option	There are multiple knowledge gaps and 1-3 years of further research work would be required to progress the reuse option	There are multiple and/or complex knowledge gaps and greater than 3 years of further research work would be required to progress the reuse option
Future considerations	The reuse option provides a long term solution for the Port of Hay Point for a period greater than 10 years	The reuse option would cater for immediate needs and has some scope in the short term (several years), although options would need to be regularly reassessed	The reuse option has only a single or limited application.

4 Beneficial reuse analysis

4.1 Options identified

As identified in Section 3.2, the beneficial reuse analysis team developed a list of reuse and recycling options that warranted further analysis. The potential beneficial reuse options were categorised as 'reuse as an engineering material', 'recycling as an environmental enhancement' or 'reuse in agricultural applications', with the options identified outlined below:

- Reuse of dredge material as an engineering material
  - Land reclamation
  - Construction fill (low strength)
  - Road base
  - Lining material
  - Concrete products (low strength)
  - Shoreline protection
  - Beach nourishment
- Recycle of dredge material as an environmental enhancement
  - Coastal (tidal) habitat restoration including
    - Direct placement
    - Indirect placement
  - Deep water habitat creation
- Reuse of dredge material as an agricultural application
  - Aquaculture
  - Topsoil for agricultural use

Each of these potential beneficial reuse options were taken forward for analysis by the multidisciplinary team, as described in Section 4.2.

4.2 Reuse dredge material as engineering material

The following beneficial reuse options for maintenance dredge material as an engineering material are considered:

- Land reclamation
- Construction fill (low strength)
- Road base /pavement
- Lining material
- Concrete products (low strength)
- Shoreline protection
- Beach nourishment

4.2.1 Land reclamation

4.2.1.1 Activity description

Land reclamation using dredged materials involves filling, raising and protecting an area that is otherwise periodically or permanently submerged. Reclamation usually involves construction of a perimeter enclosure around the reclamation area, which, depending on dredged material types and location, incorporates protection against erosion by waves and currents. In sheltered locations (e.g. estuarine waters with small tidal range), erosion protection may be unnecessary if the dredged material is coarse enough to form a stable slope which will adequately resist erosion.

The most common method of perimeter enclosure involves the construction of an embankment with the seaward face typically incorporating some form of erosion protection e.g. graded rock or concrete revetment. For some uses, (e.g. development of adjacent wharf facilities), the enclosure may require a vertical face, which may be achieved through use of steel sheet piling or caisson construction.

It is possible to use coarse or fine material for land reclamation; however, fine material typically requires a long time to adequately drain and consolidate, and the strength achieved for land reclaimed with fine material is likely to be low. As such, the use of fine grained material in reclamation is usually restricted to uses where the imposed loads are small, e.g. recreational uses, such as parks, while land required for industrial development usually requires sand or coarser material (PIANC, 1992).

The Port of Brisbane has undertaken land reclamation works over a number of years using both capital and maintenance dredging material, where suitable dredged material is pumped into containment paddocks within the reclamation area. Work is ongoing for the development of a further 230 hectares of port land at Fisherman Island at the mouth of the Brisbane River.

4.2.1.2 Opportunity

The masterplan for the Port of Hay Point (*Draft Final Port of Hay Point Ten Year Development Master Plan* (Aurecon, 2012)) contemplates a small reclamation area (approximately six hectares (ha)) within the Half Tide Tug Harbour, which is located to the south of Hay Point (Figure 3-1). An extract of the masterplan for the tug harbour is shown in Figure 4-1. The reclamation area within the master plan was identified in order to accommodate heavy lift of materials to support future port development. It is notable that the intensity and extent of proposed development at the Port of Hay Point has reduced significantly since the composition of the masterplan, and as such the need for land (and associated reclamation) in the tug harbour may be different from that identified in the master plan.

The Half Tide Tug Harbour currently provides shelter for five tugs and two lines launches which provide services for the ships utilising the Port of Hay Point berths. A public boat ramp is positioned in the South Western corner of the Harbour and there is an area available for small vessels to anchor outside the security area (Maritime Safety Queensland, 2016).

The land use plan for the Port of Mackay, located approximately 20km to the north of Hay Point, identifies proposed future strategic port land, including a small reclamation area (approximately

16ha) adjacent to the existing north harbour wall (Figure 4-2). The reclamation area within the land use plan was identified in order to accommodate heavy lift of materials, including break bulk cargo, to support future port operations.

It is not presently known if other opportunities or needs for future reclamation at or near the Port of Hay Point exist. It is considered that reclamation within, or in the vicinity of the Half Tide Tug Harbour is the most likely to occur of the opportunities identified, and as such the analysis below is based on the assumption of reclamation occurring within this area. Given that the dredged material is primarily fine grained, the end use of the reclamation area is assumed to be restricted to one where the imposed loads are small (e.g. car parking associated with community boat ramp use), and this is the basis of the analysis below. It is notable that the demand for reclamation identified with the Port of Hay Point master planning and Port of Mackay land use planning is primarily for small areas of land with heavy load-bearing port operations capability.

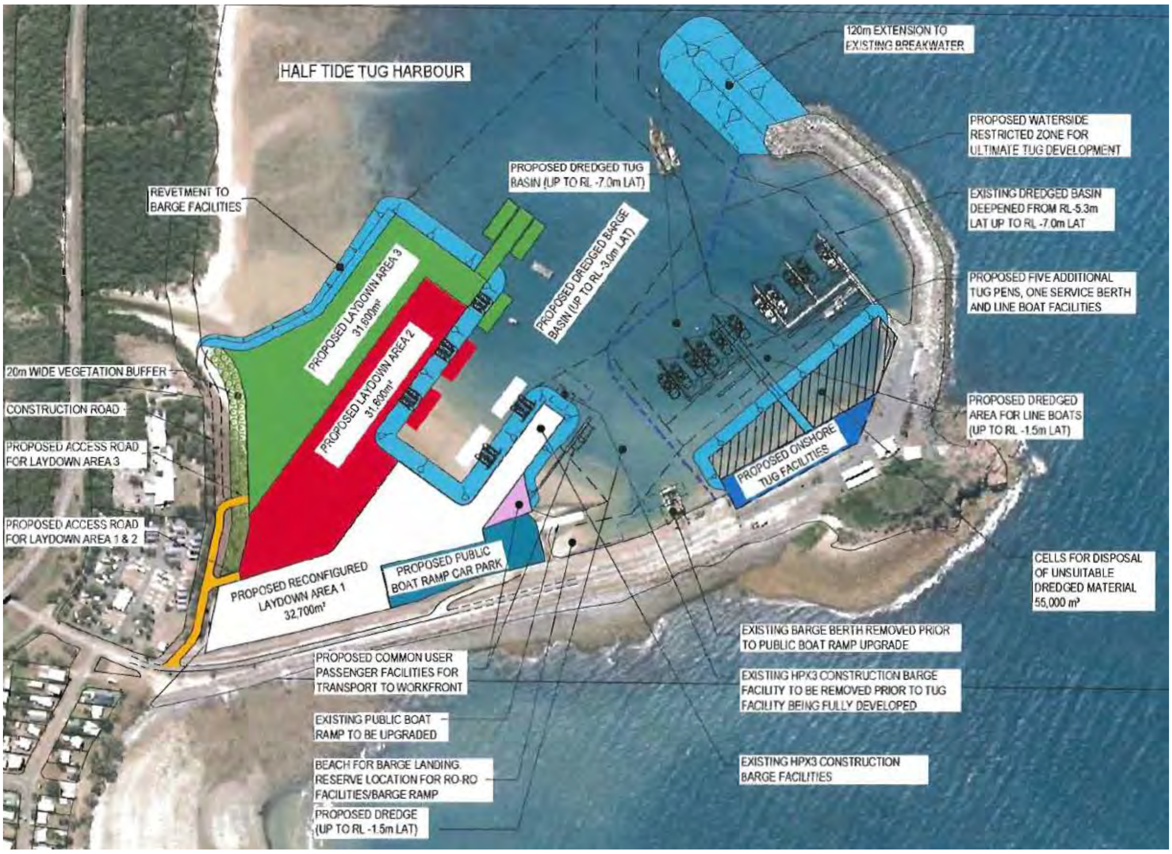

Figure 4-1 Port of Hay Point Ten Year Development Master Plan, Half Tide Tug Harbour (Aurecon, 2012)

Figure 4-2 Port of Mackay Land Use Plan, Proposed Future Strategic Port Land (NQBP, 2009)

4.2.1.3 Suitability of Hay Point sediments

Sandy or coarse material is preferred for reclamation where the created land must have sufficient strength for construction purposes. Fine material typically requires a long time to consolidate, which may be accelerated by surcharging or 'wick drains', however the final strength achieved may still be low. As such, land created with fine material may be limited to recreational purposes such as parks, or uses where imposed loads will be small. As described in Section 2.3, it is considered that there is limited opportunity for the selective dredging of fine and coarse materials within the berth and apron areas.

As part of the assessment of the proposed land reclamation (low load-bearing) reuse opportunity described above, the sediment suitability, based upon properties determined from results of laboratory testing of the samples, is outlined in Table 4-1 (suitability categories as per Section 3.3.1).

Table 4-1 Suitability of dredge sediment for proposed low load-bearing land reclamation reuse

Sediment Material Property	Suitability
Geotechnical	
Material colour	n/a
Particle Size Distribution	Potentially suitable with treatment/processing
Moisture content	Potentially suitable with treatment/processing
Plasticity Index	Likely suitable
Linear Shrinkage	Likely suitable
Density test	Likely suitable
Strength and Consolidation	Likely suitable
Permeability	Likely suitable
Geochemical	
PASS	Likely suitable
Salinity	Likely suitable
Organic Material	Likely suitable
Other	
Cement laboratory testing	n/a

The volumes to be dredged are small; however, may be suitable for a small reclamation project, not having future heavy load requirements. Treatment of the dredge material for other uses, including construction fill and concrete products is discussed in sections 4.2.2 and 4.2.5 respectively.

4.2.1.4 Process description

Dredging and placement

Dredge material would be dredged and transported to the reclamation site. Various types of dredging equipment may be used to develop land reclamation, including a Trailing Suction Hopper Dredge, Backhoe or Cutter Suction Dredge. Trailing Suction Hopper Dredges typically have significant draft, meaning that dredged material may need to be pumped to the reclamation area through a pipeline. Depending on vessel, material and reclamation location, booster stations may be required to deliver material to the reclamation area. A Backhoe dredge can excavate in-situ material and place it on barges that transport the material towards the reclamation area. A Cutter Suction Dredge may also be used to dredge and pipe the dredge material to the reclamation area; albeit that use of this type of dredge would require a very long pipeline. Use of both the Cutter Suction Dredge and Backhoe Dredge options would be likely to cause interference with port navigation, due to limited manoeuvrability and time taken to dredge. As such, it is considered likely that a Trailing Suction Hopper Dredge would be the most appropriate dredge type for this beneficial reuse option, and this forms part of the basis of the analysis below.

Given that the dredge 'Brisbane' is based in Queensland and has historically been used for maintenance dredging at the Port of Hay Point, it is considered reasonable to assume that the 'Brisbane', or a similar dredge may be used for future dredging, and as such, this forms the basis for analysis below. The 'Brisbane' has the facility to pump out its hoppers through a nozzle mounted on the bow into a pipeline; however, there are a number of operational considerations for pump out to a reclamation area, including:

- The distance which the dredged material can be pumped and how close the dredge can get to the discharge point (pipeline) into the reclamation area
- Provision of the infrastructure for the pump-out and clear access for the dredge to pick up the pump-out point.

Infrastructure required to facilitate the pump-out could be permanent or temporary, and would include a pipeline (potentially a combination of floating and submerged pipeline, along with a pump out coupling), and a mooring system for the dredge during pump-out.

As noted previously, Trailing Suction Hopper Dredges have significant draft, which affects how closely they may approach shore, and consequently the pumping distance required to a potential reclamation area in the Half Tide Tug Harbour (or vicinity thereof). The design depths of the swing basin and tug berths in the Half Tide Tug Harbour are 5.6m and 6.1m below Lowest Astronomical Tide (LAT) respectively. Navigational maintenance dredging within the tug harbour is not regularly undertaken outside of the port operations areas, and may be approximately 1m below LAT, and less moving towards shore. A dredge such as the 'Brisbane' has a draft of 6.25m, and with allowance of under keel clearance of 1m, the fully-laden dredge would be limited to where water depths are 7.25m. It is understood that the 'Brisbane' has a maximum guaranteed pumping distance of 1.5km, noting that the distance from the eastern end of Hay Point Coal Terminal berths to the Half Tide Tug Harbour is some 2.5 to 3km. These constraints can be dealt with to some degree through dredging management techniques such as programming of dredging, such that pump-out does not occur on low tides and short loading of the dredge so that it doesn't achieve maximum draft; however use of these techniques affect the efficiency of the dredging operation.

For the purposes of the analysis it has been assumed that the Trailing Suction Hopper Dredge will travel approximately 5km from the dredging area to access the pump-out point, approximately 1.5km from the reclamation location, with pipeline installed to transfer material from that point into the reclamation area. Mooring and pump-out facilities will be required; however it is assumed that no booster pumping station is required for pump-out to the reclamation area.

The dredge is assumed to operate almost continuously i.e. typically 24 hours a day, seven days a week with minimal downtime and the dredge campaign would last approximately 5 weeks.

Infrastructure and management requirements

The volume of a reclamation area required to accommodate the dredged material need account for the in-situ volume of the dredged material, bulking of the dredge material (which may increase the volume of material to be managed initially by around three times) and retention of water in the reclamation area, sufficient that discharge from the reclamation area of that water is of acceptable water quality. While the extent of demand for land within the tug harbor area is unclear, based on an assumption of material to be dredged for one campaign (200,000m^3) being placed on average 3m deep in an area within or adjacent to the tug harbour, the area that may be occupied by dredge material may be approximately 200,000m^2 (e.g. an area of 20ha, 200m wide and 1000m long, depth between 0m to 6m (average 3m) to accommodate the bulked dredge material (approximately 600,000m^3)). An estimated 6m high outer wall is anticipated to be required to cope with the large tidal range.

As the material to be dredged is predominately fine-grained, and the Half Tide Tug Harbour is subject to waves and currents, enclosure of the reclamation area would be required to be developed to provide protection against erosion. Depending on the proposed use of the reclamation area, this enclosure would likely incorporate graded rock or concrete revetment, steel sheet piling or caisson construction, or a combination of these. Given that use of the reclaimed land would be restricted those where imposed loads are small, it is considered likely that graded rock or concrete revetment would be suitable protection for the area. Based upon the assumed dimensions (200m wide and 1000m long) it is estimated that an outer wall of approximately 7,200m^2 face area, will require rock armouring.

Construction of the perimeter embankment would require importation of rock material from outside of the port area. For the purposes of analysis, the volume of material requiring importation to create the embankment is estimated to be approximately 16,200m^3, which is assumed to be brought to site on trucks from a location within the Mackay region (approximately 75km round trip). The rock wall would require an internal liner, geofabric or similar, to contain the fine sediment material within the perimeter embankment. Construction of the reclamation area will require the use of earthworks plant and machinery (such as large excavators greater than 40 tonne). For the purposes of analysis, it is assumed that construction of the perimeter embankment may take approximately 52 weeks.

The dredged material is disposed and trapped in the enclosed reclamation area and would dewater to the sea. Dewatering would need to be managed such that impacts to water quality in the vicinity of the reclamation area are kept within acceptable limits. This may require management of the location of the dredge spoil placement inlet point relative to the dewatering discharge location.

Monitoring and management effort would be required during construction of the reclamation area and placement of the dredge material until it is effectively dewatered. As described previously, the fine material is likely to take a long time (potentially greater than three years) to drain and consolidate, such that it is available for subsequent use.

4.2.1.5 Potential constraints

Potential constraints associated with this option include:

- Land created is unlikely to have suitable strength for industrial (heavy load-bearing applications)
- Demand for reclaimed land of low strength within or adjacent the Half Tide Tug Harbour, or elsewhere in the region is considered likely to be substantially less than 20ha of land identified as potentially being created through reclamation using maintenance dredge material
- Construction of the perimeter enclosure for the reclamation requires an estimated 16,200m^3 of suitable rock, access to which in the local area may be difficult
- Dewatering needs to be managed to avoid potential impacts of discharge water quality (entrained fined material), in the vicinity of the reclamation area
- Rock sea wall will need geofabric or HDPE internal liner (or similar) installed to retain fines material and avoid fine sediment being ‘leached’ through voids between rocks to adjacent marine environment
- Limited area within the tug harbour or otherwise in the vicinity of the port requiring reclamation, and as such the use in unlikely to meet long term maintenance dredging needs
- Dredging and placement will cause some constraints to navigation, as dredge will be required to traverse multiple navigation areas (aprons and channels) to reach discharge pipeline
- Sea and weather conditions may affect operability of the supporting infrastructure, particularly pipeline to the reclamation area
- Potential acid sulphate soils, while unlikely to be an significant issue, will require consideration and potentially management during reclamation
- Location of a reclamation area and determination of the placement approach (e.g. pipeline route) will be constrained by existing uses (port and community users)
- Area to be reclaimed is within the GBRWHA, and as such development of land here may be subject to particular community and regulatory agency scrutiny
- Land access including native title related issues may be an issue depending on the reclamation location

4.2.1.6 Potential implications

Potential implications of this option, considering potential environmental, commercial and socio-economic outcomes include:

- Creation of land within the port area that may be suitable for community uses e.g. car parking associated with boat ramp, which may provide a positive socio-economic outcome
- Creation of land within the port area with limited suitability for port uses (low-load uses only) may reduce area available for future port uses, including heavy load-bearing land uses and port support operations (tug and other support vessel areas)
- Reclamation will cause a small reduction in the extent of the GBRWHA, and will cause some (manageable) impacts to water quality in areas adjacent to the dredging and reclamation areas

- Construction of the reclamation area will cause temporary loss of amenity to the local community, particularly that of Half Tide Beach and boat ramp users, and will also affect commercial users (tug operations and port operation support).

4.2.1.7 Approvals

Approvals associated with dredging and placement and offshore reuse (as identified in Table 3-1) will be required for the construction and operation of this option. Depending on how material is sourced to construct the project (e.g. the perimeter embankment), approvals associated with onshore reuse may also be required.

The recently introduced *Sustainable Ports Development Act 2015* identifies the ports of Hay Point and Mackay as priority ports, and stipulates that material generated from capital dredging of these areas must be beneficially reused (as a condition of any approval), which may include use as land reclamation. Whilst potential approval of maintenance dredging is not subject to this condition, it is considered that the beneficial use of maintenance dredge material for land reclamation is not inconsistent with existing Queensland Government legislation and policy.

4.2.1.8 Costs

A summary breakdown of the estimated costs associated with construction and operation of the land reclamation options is provided in Table 4-2. The costs are based on the assumed process description described above, with further detailed assumptions provided in Appendix B.

Depending on the location of the concept (dredge method, distance from dredging zone and water depth for accessibility), it is estimated that costs will be approximately \$90/m^3 measured in situ.

Table 4-2 Land reclamation summary cost estimate table

Key activity	Land reclamation
Offshore	
Trailing Suction Hopper Dredge mobilisation and demobilisation	$5,000,000
Pipeline mobilisation and demobilisation	$5,000,000
Workboat	$500,000
Dredge and pump to placement location	$2,000,000
Reclamation area	
Construction of reclamation area including rock armour	$4,320,000

Key activity	Land reclamation
Processing material, including dewatering	$1,000,000
Monitoring and management	$250,000
Total	**$18,070,000**

4.2.1.9 Greenhouse gas emissions

The estimated Green House Gas emissions associated with the land reclamation option is 1,505 tonnes of CO_2 equivalent. The estimated emissions are based on the assumed process description describe above, with further detailed assumptions provided in Appendix C.

4.2.1.10 Knowledge gaps

If a reclamation option was to be further pursued, key areas where additional information would be required include:

- Demand for land for port and/or community processes
- Coastal dynamics and processes specific to the proposed location of the reclamation and dredge pump-out areas to enable design of fit-for-purpose structures, including consideration of siting, erosion protection requirements and dewatering discharge location
- Availability of suitable construction materials for the perimeter embankment
- Detailed design including consideration of dredging, placement, construction and ultimate use of the reclamation area.

4.2.1.11 Future considerations

As described above, the dredged material may enable reclamation of an area of approximately 20ha, in the tug harbour or immediate vicinity, albeit that the immediate need for such a large area for low load-bearing purposes is considered unlikely. It may be that this area can be expanded over time; however, without there being a sufficient existing or likely future need for low load-bearing lands within the immediate area of the port, it is considered unlikely that this option would provide beyond a single or otherwise limited application for the use of dredge material.

4.2.1.12 Performance summary

A summary of the performance of the land reclamation option based on the use of the performance criteria described in Section 3.3.3 is provided in Table 4-3.

Table 4-3 Land reclamation performance summary

Performance Criteria	Land reclamation performance
Opportunity	**Moderate:** Potentially a demand reasonably accessible to the Port of Hay Point, requiring infrastructure construction
Sediment suitability	**Moderate:** Reuse option potentially suited to the dredge material. Requires treatment, processing and/or additives to make material suitable
Cost	**Low:** More than $17M in a 5 year period
Process	**Moderate:** The proposed process is sound but there are few examples of it being applied in environments similar to the port of Hay Point using maintenance dredge material
Duration	**Low:** Greater than 3 years to construct and function as the proposed final use
GHGs	**High:** $<$ 2500t CO_2 equivalent in 5 year period
Environmental Implications	**Moderate:** Nuisance or harm issues identified, but for the most part are considered manageable
Social Implications	**High:** Positive social opportunities exist for local communities and other key user groups
Economic Implications	**Low:** Lost or negative economic opportunities to enhance port or community capability
Approvals and Permits	**Moderate:** Recognised approvals pathway, with significant management issues identified
Constraints	**Moderate:** Constraints are identified and there is a degree of uncertainty in the ability to overcome or manage them
Knowledge Gaps	**Moderate:** There are multiple knowledge gaps and 1-3 years of further research work would be required to progress the reuse option
Future considerations	**Low:** The reuse option has only a single or limited application.

4.2.2 Construction fill

4.2.2.1 Activity description

In some circumstances, dredged material may be used as a construction fill for various purposes. This is most likely to be a beneficial use where the dredged material has superior physical qualities compared to soils at the construction site (e.g. the replacement of weak soils with sand that may be derived from dredging). Fine-grained soils do not have the necessary physical properties for industrial fill in most civil works projects, though they may be suitable for other applications such as parks (PIANC, 1992).

Typically, dredged material consists of a mixture of sand and clay fractions, which requires separation through dredging or at the placement site. Dredged material, such as sand or gravel, may be used as construction fill for higher strength applications (e.g. beneath pavement or foundations), although screening and the addition of imported materials is typically necessary to achieve the desired grading. Dewatering is typically required, given high water content of dredged material, and desalination may be required depending on the construction use.

4.2.2.2 Opportunity

The potential opportunity identified is that dredged material from the Port of Hay Point may be used as low strength construction fill material. This may include use as a low performance general construction fill, including land improvement where the quality of existing land is not adequate for anticipated use or where the land elevation is subject to flooding. Currently there is no identified need or end user for the type or quantity of the dredge sediment low strength construction fill material in the Mackay region. Use in other construction related opportunities as road base / pavement, lining material or in concrete products is discussed in sections 4.2.3, 4.2.4 and 4.2.5 respectively.

As described in Section 4.2.1, sandy material is more likely to be suitable for load bearing purposes, while fine (silt and clay) material will require a long time to consolidate and the final compaction and strength achieved will still be low. As noted previously, there is likely to be limited opportunity for the selective dredging of fine and coarse materials. Given this, and the need to process material in order for it to have some application as a construction fill, the opportunity requires onshore placement of dredged material. Onshore placement and processing for use as a general low strength construction fill is the focus of the analysis below.

The analysis assumes that onshore placement may be undertaken at Dudgeon Point (as shown on Figure 3-1), as this land is owned by NQBP, is reasonably proximate to the dredging area, and is likely to be of sufficient size to accommodate onshore placement. Dredged material, once processed may then be utilised on-site at Dudgeon Point or transported from Dudgeon Point to construction sites in the Mackay region for use as low strength construction fill.

4.2.2.3 Suitability of Hay Point sediments

Well graded (particle size distribution), sandy or coarse material is preferred for construction fill to have sufficient strength for construction purposes. The fine sediment material with higher clay content is subject to swelling (high plasticity index) and cracking (high linear shrinkage) and a low final strength. The sediment material will require dewatering to achieve moisture content to enable optimum compaction (density, strength and consolidation) to be achieved. The use of fine material for construction fill purposes is likely to be be limited to bulk fill and uses where imposed loads will be small. As described in Section 2.3, it is considered that there is limited opportunity for the selective dredging of fine and coarse materials within the berth and apron areas.

The high fines (silt and clay) content and accompanying low strength characteristics of the sediment material determines it is only able to be used for low strength and low load bearing construction fill uses or alternatively as a low proportion (<20% approximately) component of a manufactured construction fill. The dredge sediment material's construction fill performance characteristics can be enhanced with the addition of imported materials to improve the particle size distribution, material grading and swell/shrinkage characteristics by adding particle shapes and sizes with superior properties. Utilising the sediment material as a minor component potentially enables the manufacture a construction fill material that will achieve better compaction, higher strength to be used in different layers of an engineered pavement. Generally construction fill is spoil material able to be reused in is current state, The need to treat and potentially process dredge sediment to enhance its characteristics to make it suitable for construction fill for uses other than low strength/low load bearing decreases this alternative's cost competitiveness.

Utilisation of the treated dredge sediment materials reclaimed from the onshore management area, with some minimal processing involving screening and blending to produce a low strength fill was considered the most likely to be feasible of the construction fill options, and as such, is the subject of analysis below.

As part of the assessment of the proposed low strength, low load bearing construction fill reuse opportunity described above, the sediment suitability, based upon properties determined from results of the laboratory testing of the samples, is outlined in Table 4-4 (suitability categories as per Section 3.3.1).

Table 4-4 Suitability of dredge sediment for proposed construction fill (low strength) reuse

Sediment Material Property	Suitability
Geotechnical	
Material colour	n/a
Particle Size Distribution	Potentially suitable with treatment
Moisture content	Potentially suitable with treatment
Plasticity Index	Potentially suitable with treatment
Linear Shrinkage	Potentially suitable with treatment
Density test	Potentially suitable with treatment
Strength and Consolidation	Potentially suitable with treatment/processing

Sediment Material Property	Suitability
Permeability	Likely suitable
Geochemical	
PASS	Likely suitable
Salinity	Likely suitable
Organic Material	Likely suitable
Other	
Cement laboratory testing	n/a

The volumes to be dredged are small and the sediment material requires treatment to improve its suitability. Reuse may be suitable for a construction fill project, particularly an area not having future heavy load requirements such as a laydown area.

4.2.2.4 Process description

Dredging and placement

Dredge material would be dredged and transported to the onshore placement site. As described for the land reclamation option, various types of dredging equipment may be used to dredge and place sediment material onshore, including a Trailing Suction Hopper Dredge, Backhoe and Cutter Suction Dredge; however, due to the superior manoeuvrability of the Trailing Suction Hopper Dredge this is considered the most appropriate dredge type for this beneficial reuse option, and this forms part of the basis of the analysis below.

Also, and as described for the land reclamation option above, it is considered reasonable to assume dredging and onshore placement using the dredge 'Brisbane' or similar as the basis for analysis. Operational considerations for pump out to an onshore placement area are similar to those for the land reclamation option, and need to contemplate:

- The distance which the dredged material can be pumped and how close the dredge can get to the discharge point (pipeline) into the bunded area
- Provision of the infrastructure for the pump-out and clear access of dredge to pick up the pump-out point.

Infrastructure required to facilitate the pump-out could be permanent or temporary, and would include a pipeline (potentially a combination of floating and submerged pipeline, along with a pump out coupling) and a mooring system for the dredge during pump-out. It is considered that pump-out infrastructure would be more likely to be permanent for onshore placement than reclamation, as onshore placement is more likely to provide a longer term beneficial reuse opportunity than reclamation.

Similar to the operational limitations associated with the land reclamation option, a dredge such as the 'Brisbane' would be draft-limited in terms of how close it could approach the Dudgeon Point shore during low tide when fully-laden with dredged material. It is likely that it could approach to within 1.5 and 2km, while the maximum guaranteed pumping distance of such a dredge is understood to be 1.5km. As described for the land reclamation option, these constraints can be dealt with to some degree through dredging management techniques such as programming of dredging, such that pump-out does not occur on low tides and short loading of the dredge so that it doesn't achieve maximum draft; however use of these techniques affect the efficiency of the dredging operation.

For the purposes of the analysis it has been assumed that the Trailing Suction Hopper Dredge will travel approximately 5km from the dredging area to access the pump-out point, approximately 1.5km from the onshore placement location at Dudgeon Point, with pipeline installed to transfer material from that point into the reclamation area. Mooring and pump-out facilities will be required; however it is assumed that no booster pumping station is required for pump-out to the onshore placement area.

The dredge is assumed to operate almost continuously i.e. typically 24 hours a day, seven days a week with minimal downtime and the dredge campaign would last approximately 5 weeks.

Infrastructure and management requirements

Dredge material would be transported to the onshore placement location for intermediate storage and processing. The configuration of an onshore placement facility at Dudgeon Point is constrained by:

- Extent of available and suitable land, including topographical and environmental constraints
- Volume of the placement area required for handling and treatment of material, including whether the placement area is used for a single or multiple maintenance dredging campaigns
- Need for the intake to be as close as possible to a dredge pump-out point, and for a suitable marine discharge outlet point.

Similar to the description of dredged material volume needing consideration for the land reclamation option, sizing of the onshore placement area needs consider the in-situ volume of dredged material, bulking of that material (potentially by three times) and sufficient retention of water, such that water discharged from the area to the marine environment is of acceptable quality.

The topography of NQBP land holding at Dudgeon Point is such that the low lying and relatively flat areas most suitable for onshore placement are located in the north-eastern portion, adjacent to potential pump-out locations.

In order that the onshore placement area may be reused for multiple dredging campaigns (i.e. to accept approximately 200,000m^3 of material every five years) it has been assumed that the depth of placement of the dredged material would be between 0.5 and 1m. As such, the area of land required to support onshore placement would be approximately 50ha.

The area may be divided into multiple adjacent and cascading (two or three) ponds to enable multiple entry points and / or sufficient flow path so that discharge water is of acceptable quality.

Bund walls will need to be constructed around the area of the ponds using clay material (if available) or a liner, depending on site conditions. For the purposes of analysis it has been assumed that approximately 27,000m^3 of material will be required to construct the ponds, using some material sourced from on-site, but with the majority assumed to be imported from off-site sources (delivered by truck). It is estimated that construction would be undertaken over a period of approximately 12 weeks using earthworks machinery including excavators, loaders and trucks.

Placement of the dredge material in thin layers minimises to some extent the ongoing dewatering management requirements to enable construction fill development in the placement area. Nonetheless it is assumed for the purposes of analysis that some management is required to enhance dewatering, which includes the use of earthworks machinery (dozer and excavator) for enhancement of ambient drying through improvement of surface drainage. Following placement, machinery use would be intermittent over a period of approximately three years, to meet dewatering and construction fill development requirements. It is assumed that limited screening, blending and mixing, and no desalination is required, given the general low-value, low strength construction fill use proposed.

The marine discharge point, which is assumed to be to the west of Dudgeon Point into Sandringham Bay, would require ongoing monitoring and management during the dredging, placement and dewatering activities. For the purposes of analysis it is assumed that construction fill (low strength) would be delivered to the Mackay city area requiring an approximately 75km round trip from Dudgeon Point, with excavators, loaders and trucks used for loadout.

4.2.2.5 Potential constraints

Potential constraints associated with this option include:

- The majority of the material (fines) has limited usefulness in construction applications, and the demand for low strength construction fill within the region is not clear
- Dredge material as source of construction fill will be opportunistic only i.e. not a continuous source of material
- Construction of the bunds for the onshore placement ponds requires 27,000m^3 of material, much of which may require importation, and access to this material may be difficult
- Rainfall levels in the region will influence the speed at which dewatering may occur
- Infrastructure development would need to consider potential impact of extreme events, including for pump-out and onshore infrastructure
- Limited information regarding existing conditions on site (including geotechnical conditions, potential for seepage from ponds and suitability of material that may be locally sourced) which will affect engineering design
- Sea and weather conditions may affect operability of the supporting infrastructure, particularly pipeline to the onshore placement area
- Potential acid sulphate soils, while unlikely to be an issue, will require consideration and potentially management during placement, particularly if separation of potentially acid forming material from acid neutralising capacity material occurs during processing
- Construction and operation of the placement area may require improvement of access to Dudgeon Point, and will increase traffic on local roads.

4.2.2.6 Potential implications

Potential implications of this option, considering potential environmental, commercial and socio-economic outcomes include:

- Development of a potential source of construction fill (low strength) in the region
- Onshore placement may cause temporary sterilisation of land at Dudgeon
- Onshore placement will cause some (manageable) impacts to water quality in areas adjacent to the dredging and marine discharge areas
- Onshore placement may cause some (manageable) impacts to migratory shorebird habitat in Sandringham Bay (adjacent Dudgeon Point)
- Construction and operation of the onshore placement area will cause temporary and intermittent loss of amenity to the local community, through increases in local traffic, particularly along Bally Keel Road and the area of Alligator Creek

4.2.2.7 Approvals

Approvals associated with dredging and placement and onshore reuse (as identified in Table 3-1) will be required for the construction and operation of this option.

The recently introduced *Sustainable Ports Development Act 2015* identifies the ports of Hay Point and Mackay as priority ports, and stipulates that material generated from capital dredging of these areas must be beneficially reused (as a condition of any approval), which may include use as construction fill. Whilst potential approval of maintenance dredging is not subject to this condition, it is considered that the beneficial use of maintenance dredge material for construction fill is not inconsistent with existing Queensland Government legislation and policy.

4.2.2.8 Costs

A summary breakdown of the estimated costs associated with construction and operation of the construction fill (low strength) options is provided in Table 4-5. The costs are based on the assumed process description described above, with further detailed assumptions provided in Appendix B.

Depending on the location of the concept (dredge method, distance from dredging zone and water depth for accessibility), it is estimated that costs will be approximately \$104/m^3 measured in situ.

Table 4-5 Construction fill (low strength) summary cost estimate table

Key activity	Construction fill
Offshore	
Trailing Suction Hopper Dredge mobilisation and demobilisation	\$5,000,000

Key activity	Construction fill
Pipeline mobilisation and demobilisation	$5,000,000
Workboat	$340,000
Dredge and pump to placement location	$2,000,000
Onshore	
Dredge management ponds	$4,000,000
Processing material, including dewatering	$500,000
Processing material including limited screening/blending/mixing	$1,000,000
Monitoring and management	$250,000
Transport road transport to construction fill use	$2,700,000
Total	**$20,790,000**

4.2.2.9 Greenhouse gas emissions

The estimated Green House Gas emissions associated with the land reclamation option is 4,921 tonnes of CO_2 equivalent. The estimated emissions are based on the assumed process description describe above, with further detailed assumptions provided in Appendix C.

4.2.2.10 Knowledge gaps

If the construction fill option (low strength) was to be further pursued, key areas where additional information would be required include:

- Demand for low load bearing construction fill
- Availability of suitable construction materials for the bunds, and conditions on site suitable for the construction of ponds
- Site access requirements including potential road upgrades
- Coastal dynamics and processes specific to the proposed location of the dredge pump-out areas to enable design of fit for purpose structures, including mooring requirements and dewatering discharge location
- Detailed design including consideration of dredging, placement, construction and ongoing use of the reclamation area.

4.2.2.11 Future considerations

The dredged material is likely to be able to be dewatered and processed within the assumed five year period between dredging campaigns, and as such, assuming there is a demand for the material so that it may be removed from the onshore placement ponds, the area is likely to be available for ongoing use for onshore placement. The material may provide a form of cost-recovery should opportunistic uses be identified for it.

4.2.2.12 Performance summary

A summary of the performance of the construction fill option based on the use of the performance criteria described in Section 3.3.3 is provided in Table 4-6.

Table 4-6 Construction fill (low strength) performance summary

Performance Criteria	Construction fill performance
Opportunity	**Moderate:** Potentially a demand reasonably accessible to the Port of Hay Point, requiring infrastructure construction
Sediment suitability	**Low:** Reuse option poorly suited to the dredge material. Requires substantial treatment, processing and/or additives to make material suitable, or treatment to a suitable level is considered unachievable
Cost	**Low:** More than $17M in a 5 year period
Process	**Moderate:** The proposed process is sound but there are few examples of it being applied in environments similar to the port of Hay Point using maintenance dredge material
Duration	**Moderate:** 1 to 3 years to construct and function as the proposed final use
GHGs	**Moderate:** >2500t and <5000t CO_2 equivalent
Environmental Implications	**Moderate:** Nuisance or harm issues identified, but for the most part are considered manageable
Social Implications	**Moderate:** Social effects for the most part are considered manageable
Economic Implications	**Moderate:** Limited economic opportunities exist enhancing port or community capability
Approvals and Permits	**Moderate:** Recognised approvals pathway, with significant management issues identified
Constraints	**Moderate:** Constraints are identified and there is a degree of uncertainty in the ability to overcome or manage them

Performance Criteria	Construction fill performance
Knowledge Gaps	**High:** There are few knowledge gaps and less than 1 year of further research work would be required to progress the reuse option
Future considerations	**Moderate:** The reuse option would cater for immediate needs and has some scope in the short term (several years), although options would need to be regularly reassessed

4.2.3 Road base

4.2.3.1 Activity description

Road construction requires large quantities of aggregate, sand and fine (slit and clay) material to make road base course material. The specific characteristics of these constituent materials are combined, placed and compacted to create road pavements. In some circumstances dredged material may be used to supply some, or all of the components required for road base.

4.2.3.2 Opportunity

The dredge material potentially provides a source of sand, fine and some gravel (aggregate) materials for road sub-base construction in the Mackay region. This opportunity relies on onshore placement of the dredge material (as described for construction fill above), followed by processing.

Market demand for the dredge sediment as road base material is likely to be low because of the time and cost needed to blend the mostly fine dredge material with other sources of aggregate and fine material to meet pavement specifications. Established commercial quarry operations in the Mackay region supply road base materials in accordance with Queensland Department of Transport and Main Roads (TMR) specifications at around \$65/m^3 to \$75/m^3[3], significantly less expensive than producing road base materials from the dredge sediment material. In order to use dredge material as a component for road base material it will require several years of storage followed by treatment, processing and screening, along with the addition of other imported materials which will add to the cost of production. There may exist opportunities for private road construction applications if the end user is willing to accept dredge sediment as a low performance road base material and NQBP were willing to provide it at a substantially subsidised cost rate.

4.2.3.3 Suitability of Hay Point sediments

The performance characteristics of a road pavement are directly related to the different strength and properties of the base course materials. The potential opportunity of reusing dredge material in road base relies upon the material properties meeting the requirement of road pavement specifications. The TMR technical specifications for pavements are adopted as the road industry standard. To be acceptable for road construction in accordance with the TMR specification, material properties are required to meet stringent requirements verified by compliance testing. The key sediment material properties have been compared with the TMR Specification (MRTSO5) requirements for typical mid-range base course gravel Type 2.3 sub base[3], along with other essential properties described in Table 4-7.

[3] TMR Specification MRTS05 Unbound Pavements July 2015, Table 7.2.3 Fines component properties – Type 2, Table 7.2.4.A- particle size distribution envelopes – Type 2 – Grading C&K

Table 4-7 Comparison of road base/pavement requirements and sediment material properties

Material Property	Requirement	Sediment material results
MRTSO5 Specification Properties		
Particle Size Distribution – Gravel	between 30% and 55%	4%
Particle Size Distribution – Sand	between 12% and 30%	36%
Particle Size Distribution – Clay/Silt	between 5% and 5%	60%
Plasticity Index	maximum 8%	ranges between 14% and 72%
Liquid Limit	maximum 28%	ranges between 29% and 108%
Linear Shrinkage	maximum 4.5%	ranges between 5.5% and 22%
Other Properties		
Moisture Content	typically between 5% and 20%	Sand 19% to 49% Silt/Clay 84% to 160%
Salinity	>0.250% TSS high risk[4]	Ranges between 0.009% to 0.506%

From comparison with the criteria in Table 4-7, the dredge sediment material tested does not meet the requirements for the example road base specification, along with moisture content and salinity in any of the material properties criteria.

The dredge material particle size distribution is dominated by the fine clay/silt and sand portions with coarse material (gravel) almost absent. This unbalanced distribution of fine particle size means the sediment material is considered poorly graded and unsuitable for road base/pavement.

The liquid limit and plastic limit tests are designed to reflect the influence of water content, grain size and mineral composition on mechanical behaviour of clays and silts. These tests found that fine grained material (berth pockets and apron areas) is indicative of low to high plasticity clay, with the average result indicating high plasticity. Linear shrinkage results (ranging from 5.5% to 22%) indicate a potential for swelling in fine grained materials, most of which were above the critical potential for expansion limit of 8%. The fine sediment material's high plasticity and high potential for swelling make the material unsuitable for road base/pavement material.

The moisture content is important to determine the amount of effort required to dry out sediment material for various reuse options. The optimum moisture content is the quantity of moisture

[4] Salinity Risk Management Flowchart, Main Roads Western Australia, Document No. 6706/02/133, 2013.

within the material under standard compaction provides the maximum dry density the material can achieve, which would be targeted in the preparation of the sediment material to be used in road base application. Typical optimum moisture content for road base or pavement material ranges between 5% and 15%, and general earthworks up to 20%. The sediment moisture content between 19% and 160% can be characterised as extremely wet and unsuitable for road base/pavement material.

Salinity can shorten the expected lifespan of a road pavement by accelerating the rate of deterioration[5]. If evaporation occurs, salts are further concentrated in the remaining water and/or the salts may become solids in the form of crystals. The type of salt and the conditions under which they crystallise will determine the size and shape of the crystal formed. This in turn determines the amount of pressure exerted on the surrounding material, as the salt makes space for itself within the road pavement. The sediment sample results are extremely saline and places the material in the high risk range for road base/pavements.

The sediment material is potentially suitable for use as a road base/pavement material with a significant amount of treatment and processing to improve its properties. The sediment will require dewatering to achieve moisture content to enable optimum compaction (density, strength and consolidation) to be achieved. Treatment to achieve desalination though leaching by a repeated process of rainfall and 'turning over' the material over a period of years will reduce the salinity levels. After dewatering and desalination the sediment material can be processed by screening, blending and mixing with other imported material to manufacture a base material to meet specified properties requirements. It is likely that even with treatment and processing the sediment material will be a constituent part of a low specification road base/pavement material, unless blended in small proportions (<10% to 20%) with large quantities of high grade materials.

As part of the assessment of the proposed road base/pavement reuse opportunity described above, the sediment suitability, based upon properties determined from results of the laboratory testing of the samples, is outlined in Table 4-8 (suitability categories as per Section 3.3.1).

Table 4-8 Suitability of dredge sediment for proposed road base/pavement reuse

Sediment Material Property	Suitability
Geotechnical	
Material colour	n/a
Particle Size Distribution	Potentially suitable with treatment/processing
Moisture content	Potentially suitable with treatment/processing
Plasticity Index	Potentially suitable with treatment/processing
Linear Shrinkage	Potentially suitable with treatment/processing
Density test	Potentially suitable with treatment/processing

[5] Salinity Risk management Flowchart, Main Roads Western Australia, Document No. 6706/02/133, 2013

Sediment Material Property	Suitability
Strength and Consolidation	Potentially suitable with treatment/processing
Permeability	n/a
Geochemical	
PASS	Likely suitable
Salinity	Potentially suitable with treatment/processing
Organic Material	Likely suitable
Other	
Cement laboratory testing	n/a

The sediment material has poor properties for the construction of road base/pavement. It requires extensive treatment (dewatering and desalination) and processing (screening, blending, mixing) with other materials to manufacture a material where the sediment material is a minor constituent to meet the road pavement specification. However if the treated and process material is blended with suitable material it may be acceptable for a private road construction when the owner is willing to accept the lower performance material and it would be suitable for light traffic volume and light vehicle situation such as an access truck not used by heavy vehicles (duel axel trucks).

4.2.3.4 Process description

Dredging and placement

The dredging and placement requirements for this option are as identified for construction fill at Section 4.2.2.4.

Infrastructure and management requirements

In addition to the onshore infrastructure and management requirements identified for construction fill at Section 4.2.2.4, material to be used for road base requires more intensive treatment to desalinate the material, and more extensive processing to separate and / or mix material suitable for road base.

The high salt level will be reduced by exposure to rainfall to achieving leaching of the salts and periodic ‘mixing and turning over’ the store material by an excavator over an extended period of time (up to three years).

The material will need to be extracted for the storage pond and sorted into various particle sizes be a screening plant. The materials is stockpiles by particle size and can then be batched, and if necessary blended with imported material, to create a road base material to achieve the required particle size distribution and properties.

For the purposes of analysis it is assumed that road base would be delivered to the Mackay city area requiring an approximately 75km round trip.

Relevant standards

The industry standard for road construction materials in Queensland is the Queensland TMR Specification Category 5: Pavements, Sub grade and Surfacing. These specifications are universally used by State Government, Local Government and private sector for road and pavement construction. The specifications relevant to beneficial reuse and a road base or pavement material include:

- MRTS05 Unbound Pavements (July 2015)
- MRTS35 Recycled Materials for Pavements (April 2016)
- MRTS39 Lean Mix Concrete Sub Base for Pavements (Jan 2015).

4.2.3.5 Potential constraints

Potential constraints associated with this option include:

- Complex process of mixing, treatment, extraction, processing by screening, stockpiling and then blending and batching with imported material to manufacture road base material
- Stringent TMR road pavement specifications and compliance testing likely required by end user
- Production of road base from the dredge material is more process intensive than other methods of road base production, and as such the cost of supply will likely need to be subsidised by NQBP to create demand
- Dredge material as source of road base will be opportunistic only i.e. not a continuous source of material
- Construction of the bunds for the onshore placement ponds requires 27,000m^3 of material, much of which may require importation, and access to this material may be difficult
- Rainfall levels in the region will impact the speed at which dewatering may occur
- Infrastructure development would need to consider potential impact of extreme events, including for pump-out and onshore infrastructure
- Limited information regarding existing conditions on site (including geotechnical conditions, potential for seepage from ponds and suitability of material that may be locally sourced) which will affect engineering design
- Sea and weather conditions may affect operability of the supporting infrastructure, particularly pipeline to the onshore placement area
- Potential acid sulphate soils, while unlikely to be an issue, will require consideration and potentially management during placement, particularly if separation of potentially acid forming material from acid neutralising capacity material occurs during processing
- Construction and operation of the placement area will require improvement of access to Dudgeon Point, and will increase traffic on local roads

4.2.3.6 Potential implications

Potential implications of this option, considering potential environmental, commercial and socio-economic outcomes include:

- Development of a potential source of road base in the region, albeit that it would be unlikely cost competitive without subsidisation
- Onshore placement may cause temporary sterilisation of land at Dudgeon
- Onshore placement will cause some (manageable) impacts to water quality in areas adjacent to the dredging and marine discharge areas
- Onshore placement may cause some (manageable) impacts to migratory shorebird habitat in Sandringham Bay (adjacent Dudgeon Point)
- Construction and operation of the onshore placement area will cause temporary and intermittent loss of amenity to the local community, through increases in local traffic, particularly along Bally Keel Road and the area of Alligator Creek

4.2.3.7 Approvals

Approvals associated with dredging and placement and onshore reuse (as identified in Table 3-1) will be required for the construction and operation of this option.

The recently introduced *Sustainable Ports Development Act 2015* identifies the ports of Hay Point and Mackay as priority ports, and stipulates that material generated from capital dredging of these areas must be beneficially reused (as a condition of any approval), which may include use as road base. Whilst potential approval of maintenance dredging is not subject to this condition, it is considered that the beneficial use of maintenance dredge material for road base is not inconsistent with existing Queensland Government legislation and policy.

4.2.3.8 Costs

A summary breakdown of the estimated costs associated with construction and operation of the road base option is provided in Table 4-9. The costs are based on the assumed process description described above, with further detailed assumptions provided in Appendix B.

Depending on the location of the concept (dredge method, distance from dredging zone and water depth for accessibility), it is estimated that costs will be approximately \$113/m^3 measured in situ.

Table 4-9 Road base summary cost estimate table

Key activity	Road base
Offshore	
Trailing Suction Hopper Dredge mobilisation and demobilisation	\$5,000,000

Key activity	Road base
Pipeline mobilisation and demobilisation	$5,000,000
Workboat	$340,000
Dredge and pump to placement location	$2,000,000
Onshore	
Dredge management ponds	$4,000,000
Processing material, including dewatering and desalination	$1,000,000
Processing material including extensive screening/blending/mixing	$2,000,000
Monitoring and management	$500,000
Transport road transport to road base use	$2,700,000
Total	**$22,540,000**

4.2.3.9 Greenhouse gas emissions

The estimated Green House Gas emissions associated with the road base / pavement materials option is 4,921 tonnes of CO_2 equivalent. The estimated emissions are based on the assumed process description describe above, with further detailed assumptions provided in Appendix C.

4.2.3.10 Knowledge gaps

If the road base option was to be further pursued, key areas where additional information would be required include:

- Demand for road base and improved understanding of comparative cost of production
- Coastal dynamics and processes specific to the proposal location of the dredge pump-out areas to enable design of fit for purpose structures, including mooring requirements and dewatering discharge location
- Availability of suitable construction materials for the bunds, and conditions on site suitable for the construction of ponds
- Detailed design including consideration of dredging, placement, construction and ongoing use of the reclamation area
- Site access requirements including potential road upgrades.

4.2.3.11 Future considerations

The dredged material is likely to be able to be dewatered and processed within the assumed five year period between dredging campaigns, and as such, assuming there is a demand for the material so that it may be removed from the onshore placement ponds, the area is likely to be available for ongoing use for onshore placement. The availability of a local project willing to use the dredge material as road base and availability of significant less expensive TMR registered quarry sources makes production establishment and operation likely to be cost prohibitive.

4.2.3.12 Performance summary

A summary of the performance of the road base option based on the use of the performance criteria described in Section 3.3.3 is provided in Table 4-10.

Table 4-10 Road base performance summary

Performance Criteria	Road base performance
Opportunity	**Moderate:** Potentially a demand reasonably accessible to the Port of Hay Point, requiring infrastructure construction
Sediment suitability	**Low:** Reuse option poorly suited to the dredge material. Requires substantial treatment, processing and/or additives to make material suitable,or treatment to a suitable level is considered unachievable
Cost	**Low:** More than $17M in a 5 year period
Process	**Moderate:** The proposed process is sound but there are few examples of it being applied in environments similar to the port of Hay Point using maintenance dredge material
Duration	**Moderate:** 1 to 3 years to construct and function as the proposed final use
GHGs	**Moderate:** >2500t and <5000t CO_2 equivalent
Environmental Implications	**Moderate:** Nuisance or harm issues identified, but for the most part are considered manageable
Social Implications	**Moderate:** Social effects for the most part are considered manageable
Economic Implications	**Low:** Lost or negative economic opportunities to enhance port or community capability
Approvals and Permits	**Moderate:** Recognised approvals pathway, with significant management issues identified
Constraints	**Moderate:** Constraints are identified and there is a degree of uncertainty in the ability to overcome or manage them

Performance Criteria	Road base performance
Knowledge Gaps	**Moderate:** There are multiple knowledge gaps and 1-3 years of further research work would be required to progress the reuse option
Future considerations	**Moderate:** The reuse option would cater for immediate needs and has some scope in the short term (several years), although options would need to be regularly reassessed

4.2.4 Lining material

4.2.4.1 Activity description

Dredged material, once processed may be used as a liner in confined disposal facilities (CDFs). Liners are often used to reduce the release of leachate from CDFs containing contaminated materials. Leachate may be produced by several potential sources including gravity drainage of the original pore water and ponded water, inflow of groundwater, and infiltration of rainwater. Leachate generation and transport in a CDF thus depend on many site-specific and sediment-specific factors.

Liner systems function to minimize contaminant release into the environment by controlling leachate pathways. Liners not only serve to physically isolate the sediments from lateral dikes and foundation materials, but they also function to reduce contaminant migration by employing low-permeability materials to retard the passage of water that may contain contaminants. Figure 4-3 and Figure 4-4 shows CDFs without and with a typical liner system respectively.

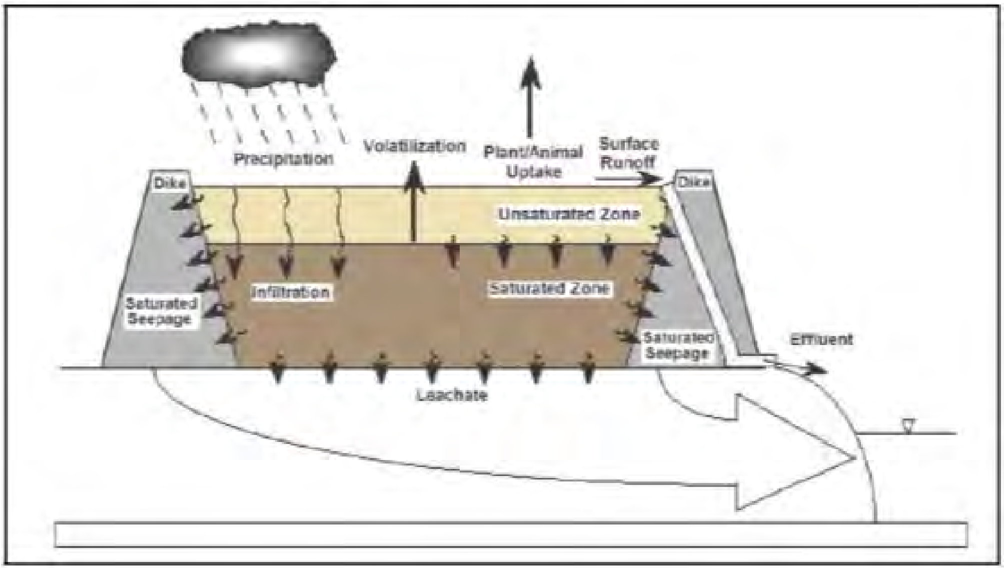

Figure 4-3 Potential contaminant loss pathways for CDFs without a leachate control system

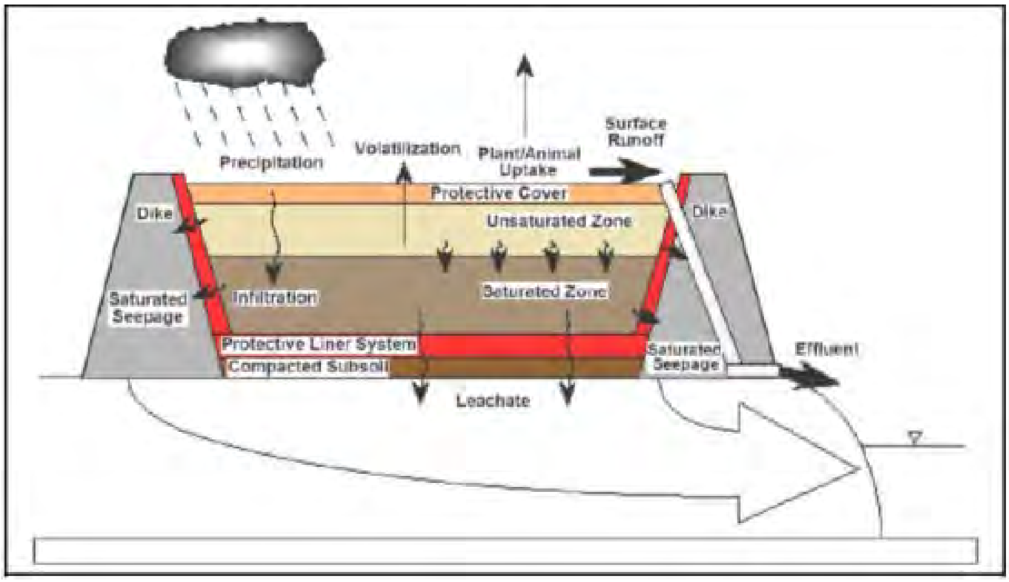

Figure 4-4 Potential contaminant loss pathways for CDFs with a leachate control system

4.2.4.2 Opportunity

The fine component of the dredge material is considered likely to have appropriate characteristics to be used as lining material for a CDF, such as the Mackay Regional Council CDF, located at Hogan's Pocket, as shown in Figure 3-1. This opportunity relies on onshore placement of the dredge material (as described for construction fill above), followed by processing.

4.2.4.3 Suitability of Hay Point sediments

The USACE Dredging Operations and Environmental Research (DOER) Technical Note ERDC TN-DOER-R6 (USACE, 2004) provides detailed guidance for the liner design for CDF Leachate Control.

Detailed consideration would need to be given to the flux retardation properties of the dredge material if to be used as a liner. Attention would also need to be given to chemical compatibility of the liner materials with the leachate. Chemical degradation of liner systems can result from interactions of the contaminants and/or the water in the leachate with the liner system, potentially leading to defects in the liner and increased leakage rates for leachate transport.

One of the most important design parameters influencing liner material selection is hydraulic conductivity. Soil and dredged material liners should provide a field hydraulic conductivity of $1x10^{-8}$ to $1x10^{-5}$ cm/s or less when compacted. Clean dredged fine-grained material when allowed to settle and condense, dredged from rivers and harbors can reach permeabilities as low as 10^{-7} to 10^{-10} cm/s (Giroud et al. 1997,Schroeder et al. 1994). By most standards, this range of liner permeability is acceptable for service as hydraulic barriers. Additional reductions in hydraulic conductivity may be realized through modification of clean dredged material with additives, use of clay layers, or employment of geosynthetic materials and composite liner systems. Liners and their underlying soils must also possess sufficient strength after compaction to support themselves and the overlying materials without failure.

The clay samples, measured permeabilities are 3.3 x 10^{-11} m/s and 9.3 x 10^{-11} m/s for samples from berth area (C-2 and C-3) respectively. These permeabilities are typical of clay materials and are suitable to meet the permeability criteria outlined above to be acceptable for use a hydraulic barriers in a lining material.

As part of the assessment of the proposed lining material reuse opportunity described above, the sediment suitability, based upon properties determined from results of the laboratory testing of the samples, is outlined in Table 4-11 (suitability categories as per Section 3.3.1).

Table 4-11 Suitability of dredge sediment for proposed lining material reuse

Sediment Material Property	Suitability
Geotechnical	
Material colour	n/a
Particle Size Distribution	Potentially suitable with treatment/processing
Moisture content	Potentially suitable with treatment/processing
Plasticity Index	Potentially suitable with treatment/processing
Linear Shrinkage	Potentially suitable with treatment/processing
Density test	Potentially suitable with treatment/processing
Strength and Consolidation	Potentially suitable with treatment/processing
Permeability	Likely suitable
Geochemical	
PASS	Likely suitable
Salinity	Likely suitable
Organic Material	Likely suitable
Other	
Cement laboratory testing	n/a

The volumes to be dredged are small; however, due to high fine clay and silt content a potentially large quantity of lining material suitable for a CDF may be produced. There is currently one major landfill owned by the Mackay Regional Council at Hogan's Pocket. Liner material requirements for this facility are unknown. The dredge sediment material would require treatment and processing to improve its suitability as a lining material.

4.2.4.4 Process description

Dredging and placement

A hydraulically placed clean fine dredge material liner may be an economical solution; however given the distance from the dredge area to the nearest CDF at Hogan's Pocket, this direct placement option is not possible (approximately 40km distance from the dredge area at significant elevation above sea level). A potential solution would be for material to be first pumped on land to an intermediate storage location, dewatered and then trucked to the CDF. As such, the dredging and placement requirements for this option are as identified for construction fill at Section 4.2.2.4.

Infrastructure and management requirements

In addition to the onshore infrastructure and management requirements identified for construction fill at Section 4.2.2.4, material to be used for CDF liner material is likely to require more extensive processing to separate and / or mix material suitable for a liner.

The dewatered sediment material will need to be extracted for the storage pond and sorted into various particle sizes be a screening plant. The material is stockpiled by particle size and can then be batched, and if necessary blended with imported material, to create a liner material to achieve the required properties. The processing to separate the fine material for use as a lining material would produce a waste steam of unsuitable larger particle material that would need to be managed separately.

For the purposes of analysis it is assumed that liner material would be delivered to the Hogan's Pocket landfill requiring an approximately 130km round trip.

Relevant standards

A number of standards may be relevant to the evaluation of the suitability of the dredged material as a liner for a CDF:

- ASTM D6141-97 (ASTM 1997) provides guidance for evaluation of clay portions of geosynthetic clay liners
- ASTM D2487-00 (ASTM 2000a) is used to classify engineering properties of soils based on particle size and organic matter content.
- ASTM D4318-00 (ASTM 2000d) and EM 1110-2-1906 (USACE 1970) Provides water contents at which a fine-grained soil or sediment changes from a semisolid to a plastic solid and from a plastic solid to a semiliquid.

4.2.4.5 Potential constraints

Potential constraints associated with this option include:

- Complex process of mixing, treatment, extraction, processing by screening, stockpiling and then potential blending and batching with imported material to manufacture liner material

- Production of liner from the dredge material may be more process intensive than other methods of liner production, and as such the cost of supply will likely need to be subsidised by NQBP to create demand
- Likely to be a limited requirement for liner material in the region, and as such, dredged material as source of liner material will be opportunistic only i.e. not a continuous source of, or demand for material
- Construction of the bunds for the onshore placement ponds requires 27,000m^3 of material, much of which may require importation, and access to this material may be difficult
- Rainfall levels in the region will impact the speed at which dewatering may occur
- Infrastructure development would need to consider potential impact of extreme events, including for pump-out and onshore infrastructure
- Limited information regarding existing conditions on site (including geotechnical conditions, potential for seepage from ponds and suitability of material that may be locally sourced) which will affect engineering design
- Sea and weather conditions may affect operability of the supporting infrastructure, particularly pipeline to the onshore placement area
- Potential acid sulphate soils, while unlikely to be an issue, will require consideration and potentially management during placement, particularly if separation of potentially acid forming material from acid neutralising capacity material occurs during processing
- Construction and operation of the placement area will require improvement of access to Dudgeon Point, and will increase traffic on local roads

4.2.4.6 Potential implications

Potential implications of this option, considering potential environmental, commercial and socio-economic outcomes include:

- Development of a potential source of liner material in the region, albeit that it would be unlikely cost competitive without subsidisation
- Onshore placement may cause temporary sterilisation of land at Dudgeon
- Onshore placement will cause some (manageable) impacts to water quality in areas adjacent to the dredging and marine discharge areas
- Onshore placement may cause some (manageable) impacts to migratory shorebird habitat in Sandringham Bay (adjacent Dudgeon Point)
- Construction and operation of the onshore placement area will cause temporary and intermittent loss of amenity to the local community, through increases in local traffic, particularly along Bally Keel Road and the area of Alligator Creek.

4.2.4.7 Approvals

Approvals associated with dredging and placement and onshore reuse (as identified in Table 3-1) will be required for the construction and operation of this option.

The recently introduced *Sustainable Ports Development Act 2015* identifies the ports of Hay Point and Mackay as priority ports, and stipulates that material generated from capital dredging of these areas must be beneficially reused (as a condition of any approval), which may include use as liner. Whilst potential approval of maintenance dredging is not subject to this condition, it is considered that the beneficial use of maintenance dredge material for liner is not inconsistent with existing Queensland Government legislation and policy.

4.2.4.8 Costs

A summary breakdown of the estimated costs associated with construction and operation of the liner material option is provided in Table 4-12. The costs are based on the assumed process description described above, with further detailed assumptions provided in Appendix B.

Depending on the location of the concept (dredge method, distance from dredging zone and water depth for accessibility), it is estimated that costs will be approximately \$118/m^3 measured in situ.

Table 4-12 Liner material summary cost estimate table

Key activity	Liner material
Offshore	
Trailing Suction Hopper Dredge mobilisation and demobilisation	$5,000,000
Pipeline mobilisation and demobilisation	$5,000,000
Workboat	$340,000
Dredge and pump to placement location	$2,000,000
Onshore	
Dredge management ponds	$4,000,000
Processing material, including dewatering	$500,000
Processing material including extensive screening/blending/mixing	$2,000,000
Monitoring and management	$500,000
Transport road transport to liner material use	$4,200,000
Total	**$23,540,000**

4.2.4.9 Greenhouse gas emissions

The estimated Green House Gas emissions associated with the lining material option is 6,146 tonnes of CO_2 equivalent. The estimated emissions are based on the assumed process description describe above, with further detailed assumptions provided in Appendix C.

4.2.4.10 Knowledge gaps

If the liner material option was to be further pursued, key areas where additional information would be required include:

- Requirements for liner material of CDFs in the region, and the potential for dredged material to be suitable for the specific use
- Demand for liner and improved understanding of comparative cost of production
- Coastal dynamics and processes specific to the proposal location of the dredge pump-out areas to enable design of fit for purpose structures, including mooring requirements and dewatering discharge location
- Availability of suitable construction materials for the bunds, and conditions on site suitable for the construction of ponds
- Detailed design including consideration of dredging, placement, construction and ongoing use of the reclamation area
- Site access requirements including potential road upgrades

4.2.4.11 Future considerations

The dredged material is likely to be able to be dewatered and processed within the assumed five year period between dredging campaigns, and as such, assuming there is a demand for the material so that it may be removed from the onshore placement ponds, the area is likely to be available for ongoing use for onshore placement.

It is considered that the volume of fine grained sediment that may be derived from the dredging area would be sufficient for the creation of a liner system for a CDF, depending on the specifications and ongoing requirements of the CDF e.g. a CDF of 200m by 200m with a 1m thick liner, would require approximately 40,000 m^3 of liner material. It is unclear whether there would be demand for the material, and particularly ongoing demand to provide a long term solution for receipt of dredged material.

4.2.4.12 Performance summary

A summary of the performance of the liner material option based on the use of the performance criteria described in Section 3.3.3 is provided in Table 4-13.

Table 4-13: Liner material performance summary

Performance Criteria	Liner material performance
Opportunity	**Moderate:** Potentially a demand reasonably accessible to the Port of Hay Point, requiring infrastructure construction
Sediment suitability	**Moderate:** Reuse option potentially suited to the dredge material. Requires treatment, processing and/or additives to make material suitable
Cost	**Low:** More than $17M in a 5 year period
Process	**Moderate:** The proposed process is sound but there are few examples of it being applied in environments similar to the port of Hay Point using maintenance dredge material
Duration	**Moderate:** 1 to 3 years to construct and function as the proposed final use
GHGs	**Low:** >5000t CO_2 equivalent
Environmental Implications	**Moderate:** Nuisance or harm issues identified, but for the most part are considered manageable
Social Implications	**Moderate:** Social effects for the most part are considered manageable
Economic Implications	**Low:** Lost or negative economic opportunities to enhance port or community capability
Approvals and Permits	**Moderate:** Recognised approvals pathway, with significant management issues identified
Constraints	**Moderate:** Constraints are identified and there is a degree of uncertainty in the ability to overcome or manage them
Knowledge Gaps	**Moderate:** There are multiple knowledge gaps and 1-3 years of further research work would be required to progress the reuse option
Future considerations	**Low:** The reuse option has only a single or limited application

4.2.5 Concrete products

4.2.5.1 Activity description

Dredged sediment material may potentially be reused in the production of a range of concrete products including:

- Bricks, blocks and pavers
- Low strength concrete (<5MPa) flowable fill type concrete as a sub-base for construction pads and pavements or as back fill for trenches. This low strength sub-base layer may be used beneath an engineered pavement with higher strength such as quarry supplied well graded and highly specified base course material tested/verified or a rigid pavement concrete slab and engineered foundations

4.2.5.2 Opportunity

Two different process courses were considered for utilising the dredge material in combination with a binder for reuse as a component of concrete products as follows:

- Portland cement binder based treatment
- Geopolymer binder based treatment

Either process course relies on onshore placement and treatment of the dredge material (as described for construction fill above), followed by processing.

High end use of the sand material in concrete products (bricks, blocks and pavers) would require significant processing, producing waste from unsuitable material and be expensive relative to the market for sand supply. To meet the stringent material specifications for manufacturing concrete construction products the dredge material would require

- Selective dredging to target the sand which is not practical given the low proportions and small quantities available
- Treatment of sand to remove the chlorides (salt) which will otherwise affect mix strength properties
- Treatment to remove internally held salt which will migrate and become a cause of efflorescence (crystalline surface salt deposit, whitish in appearance) on the finished masonry surface which is visually unacceptable in architectural applications
- Processing to avoid clay particles that will swell and shrink with wetting and drying. This characteristic affects the workability of the mix when manufacturing bricks, blocks or pavers and requires more water to be added which will reduce the strength of the mix and the final product
- Avoidance of coloured fines, as colour is important in concrete products as the dark grey colour of sediment material will be reflected in the final product and may leach out or concentrate in areas blemishing appearance which will be unacceptable for end users

This reuse of dredge material sediment in manufacture of concrete products (bricks, blocks, pavers) is unsuitable due to the material's properties and is unable to be cost competitive in this market sector, and as such, is not considered further in this analysis.

4.2.5.3 Suitability of Hay Point sediments

Analyses of the sediment samples (described in Section 2.1) showed marked differences in properties between the two samples:

- Sediment from the departure path areas was almost pure sand (>99% quartz). This material would only find use as an alternative source of normal fine sand in concrete and concrete products. The silt and relatively high level of chlorides present would need to be dewatered and washed before general use in concrete would be permitted. This fine sand would typically be used at a rate of 200kg/m^3 of concrete (or less than 10% by weight).
- Sediment from the berth areas has some sand, but relatively high clay content. This would interfere with its use in concrete; however, these clays can undergo stabilisation through an ion exchange mechanism with a calcium bearing material (e.g. lime or Portland cement). By altering the level of Portland cement added (approximately between 2% and 5%) the final product could be used for the lowest strength trench flowable backfill, up to the low-performance sub-base fill material described above.

The Portland cement approach would be the simplest treatment of the fine sediment material. However, Portland cement is an expensive additive (bulk cement costs approximately $200/t in major Queensland centres, including Mackay) and its manufacture is a large source of carbon emissions. The geopolymer process would generate lower carbon emissions (the binder generates more than 80% lower carbon emissions during manufacture), however the high water content in the fine sediments would be problematic. The material would need to be dewatered and dried before use. Ideally to get the most benefit in a geopolymeric product, the fine sediment material would need to be heated to approximately 750°C to improve reactivity, which is an expensive and impractical alternative to Portland cement additive option.

Sediment materials with any salt content are unsuitable for manufacturing concrete used in structural applications as the steel reinforcing is susceptible to physical and chemical attack by salt which may cause concrete spalling, cracking and crumbling, reducing its load bearing strength for the purpose it was designed. The clay particles in the sediment will swell and shrink with wetting and drying. This characteristic affects the workability of the mix when manufacturing concrete and requires more water to be added which will reduce the strength of the mix and the final concrete, and also makes the sediment unsuitable for structural concrete.

Utilisation of the Portland cement approach to produce a low strength (less than 5Mpa), low-performance flowable fill material (which may be used for trench backfill, and sub-base course) was considered the most likely to be feasible of the concrete products options, and as such, is the subject of analysis below.

As part of the assessment of the proposed concrete products (low strength) reuse opportunity described above, the sediment suitability, based upon properties determined from results of the laboratory testing of the samples, is outlined in Table 4-14 (suitability categories as per Section 3.3.1).

Table 4-14 Suitability of dredge sediment for proposed concrete products (low strength) reuse

Sediment Material Property	Suitability
Geotechnical	
Material colour	n/a
Particle Size Distribution	Potentially suitable with treatment/processing
Moisture content	Potentially suitable with treatment/processing
Plasticity Index	Potentially suitable with treatment/processing
Linear Shrinkage	Potentially suitable with treatment/processing
Density test	Potentially suitable with treatment/processing
Strength and Consolidation	Potentially suitable with treatment/processing
Permeability	Likely suitable
Geochemical	
PASS	Likely suitable
Salinity	Likely suitable (non-structural concrete only)
Organic Material	Likely suitable
Other	
Cement laboratory testing	n/a

The sediment material requires treatment and processing to improve its suitability for potential use as a low performance, low strength concrete product. Reuse as a low strength backfill or sub-base course material would require mixing with small percentage of Portland cement (2% to 5%) dependant on mix design. A large civil earthworks construction project would be required to utilise 200,000m^3 (or 33,333 standard concrete trucks of 6m^3 capacity each) of low strength concrete in a sub–base construction fill application.

4.2.5.4 Process description

Dredging and placement

The dredging and placement requirements for this option are as identified for construction fill at Section 4.2.2.4.

Infrastructure and management requirements

Material to be used for concrete products will require to be placed onshore in a sediment material treatment area and undergo similar treatment (dewatering) as that identified for construction fill at Section 4.2.2.4. A shorter storage period in the treatment area may be desirable as a 'wetter' sediment enhances the flowability of the low strength concrete mix. Addition and blending of Portland cement to manufacture a low performance, low strength flowable fill concrete would require the installation and operation of a pug mill to continuously mix sediment material to achieve a thoroughly mixed and homogeneous product. The pug mill would include a cement silo, clean water supply and a conveyor system all operated by a diesel engine, Ideally the sediment material would be reclaimed from the treatment area at a time when the material's moisture content is close to optimum to run the pug mill 'wetter' so large quantities of water are not required to be added to flow and place the final low strength concrete mix.

The conveyor system would be used to elevate and load the mixture into a fleet of tip trucks or concrete agitator trucks for delivery to the end user. Tip trucks could be used for bulk placement and transport over short distances (<5km) or agitator trucks for transport over longer distances, with agitator truck chutes being suited to more precise placement such as trench backfill.

For the purposes of analysis it is assumed that the low strength concrete product would be delivered to the Mackay city region requiring an approximately 75km round trip.

Relevant standards

Australian Standards relevant to the concrete products under consideration include:

- AS3700 "Masonry Structures"
- AS 1379 "Specification and supply of concrete"
- Queensland Department of Transport and Main Roads Specification Category 5: Pavements, Sub grade and Surfacing: MRTS39 "Lean Mix Concrete Sub-base for Pavements (Jan 2015)"

4.2.5.5 Potential constraints

Potential constraints associated with this option include:

- Given that sediment is dredged periodically at relatively low volumes (approximately 200,000m^3 every five years), it is considered unlikely that supply would be large or consistent enough to justify development of a new concrete products business specifically for the dredge material.
- Production of concrete products from the dredge material may be more process intensive than other methods of production and may not be supported by demand
- Construction of the bunds for the onshore placement ponds requires 27,000m^3 of material, much of which may require importation, and access to this material may be difficult
- Rainfall levels in the region will impact the speed at which dewatering may occur
- Infrastructure development would need to consider potential impact of extreme events, including for pump-out and onshore infrastructure

- Limited information regarding existing conditions on site (including geotechnical conditions, potential for seepage from ponds and suitability of material that may be locally sourced) which will affect engineering design
- Sea and weather conditions may affect operability of the supporting infrastructure, particularly pipeline to the onshore placement area
- Potential acid sulphate soils, while unlikely to be an issue, will require consideration and potentially management during placement, particularly if separation of potentially acid forming material from acid neutralising capacity material occurs during processing
- Construction and operation of the placement area will require improvement of access to Dudgeon Point, and will increase traffic on local roads
- The addition of Portland cement will increase the strength characteristics of the flowable fill sub-base material. Generally the addition of more Portland cement results in a higher strength concrete material. However, the sediment material will never achieve high strength as a concrete, due to high content of fines (silt and clay) unable to bind as aggregates would.
- The high expense of the Portland cement as an additive limits its cost effectiveness to typically between 2% and 5% by weight.

4.2.5.6 Potential implications

Potential implications of this option, considering potential environmental, commercial and socio-economic outcomes include:

- Development of a potential source of low-performance, low strength flowable fill sub-base material in the region, albeit that it would likely only be able to supplement requirements of an existing business, or be useful for applications on port land
- Onshore placement may cause temporary sterilisation of land at Dudgeon Point
- Onshore placement will cause some (manageable) impacts to water quality in areas adjacent to the dredging and marine discharge areas
- Onshore placement may cause some (manageable) impacts to migratory shorebird habitat in Sandringham Bay (adjacent Dudgeon Point)
- Construction and operation of the onshore placement area will cause temporary and intermittent loss of amenity to the local community, through increases in local traffic, particularly along Bally Keel Road and the area of Alligator Creek.

4.2.5.7 Approvals

Approvals associated with dredging and placement and onshore reuse (as identified in Table 3-1) will be required for the construction and operation of this option.

The recently introduced *Sustainable Ports Development Act 2015* identifies the ports of Hay Point and Mackay as priority ports, and stipulates that material generated from capital dredging of these areas must be beneficially reused (as a condition of any approval), which may include use as concrete products. Whilst potential approval of maintenance dredging is not subject to this condition, it is considered that the beneficial use of maintenance dredge material for concrete products is not inconsistent with existing Queensland Government legislation and policy.

4.2.5.8 Costs

A summary breakdown of the estimated costs associated with construction and operation of the concrete products (low strength) option is provided in Table 4-15. The costs are based on the assumed process description described above, with further detailed assumptions provided in Appendix B.

Depending on the location of the concept (dredge method, distance from dredging zone and water depth for accessibility), it is estimated that costs will be approximately $122/m^3$ measured in situ.

Table 4-15 Concrete products (low strength) summary cost estimate table

Key activity	Concrete products
Offshore	
Trailing Suction Hopper Dredge mobilisation and demobilisation	$5,000,000
Pipeline mobilisation and demobilisation	$5,000,000
Workboat	$340,000
Dredge and pump to placement location	$2,000,000
Onshore	
Dredge management ponds	$4,000,000
Processing material, including dewatering	$500,000
Processing material in a pug mill	$450,000
Processing additive Portland cement (3.5%)	$3,250,000
Monitoring and management	$250,000
Transport road transport to concrete products use	$2,700,000
Total	**$24,490,000**

4.2.5.9 Greenhouse gas emissions

The estimated Green House Gas emissions associated with the concrete products option is 4,921 tonnes of CO_2 equivalent. The estimated emissions are based on the assumed process description describe above, with further detailed assumptions provided in Appendix C.

4.2.5.10 Knowledge gaps

If the concrete products option was to be further pursued, key areas where additional information would be required include:

- Demand for concrete products (particularly low-performance, low strength sub-base flowable fill material) and improved understanding of comparative cost of production
- Obtain samples of the dredge sediment material to prepare trial mixes to see how specific mixes react. Test blends of various proportions of Portland cement, flyash and lime to determine optimum mix design for performance characteristics and cost.
- Coastal dynamics and processes specific to the proposal location of the dredge pump-out areas to enable design of fit for purpose structures, including mooring requirements and dewatering discharge location
- Availability of suitable construction materials for the bunds, and conditions on site suitable for the construction of ponds
- Detailed design including consideration of dredging, placement, construction and ongoing use of the reclamation area
- Site access requirements including potential road upgrades

4.2.5.11 Future considerations

The dredged material is likely to be able to be dewatered and processed within the assumed five year period between dredging campaigns, and as such, assuming there is a demand for the material so that it may be removed from the onshore placement ponds, the area is likely to be available for ongoing use for onshore placement.

As noted above, production of mid-performance flowable fill material from the dredged material is unlikely to support a new business given high relative costs and limitations to supply (limited dredge quantities); however it may be used opportunistically for port or other uses in the vicinity of the port.

4.2.5.12 Performance summary

A summary of the performance of the concrete products (low strength) option based on the use of the performance criteria described in Section 3.3.3 is provided in Table 4-16.

Table 4-16: Concrete products (low strength) performance summary

Performance Criteria	Concrete products performance
Opportunity	**Moderate:** Potentially a demand reasonably accessible to the Port of Hay Point, requiring infrastructure construction
Sediment suitability	**Moderate:** Reuse option potentially suited to the dredge material. Requires treatment, processing and/or additives to make material suitable

Performance Criteria	Concrete products performance
Cost	**Low:** More than $17M in a 5 year period
Process	**Moderate:** The proposed process is sound but there are few examples of it being applied in environments similar to the port of Hay Point using maintenance dredge material
Duration	**Moderate:** 1 to 3 years to construct and function as the proposed final use
GHGs	**Moderate:** >2500t and <5000t CO_2 equivalent
Environmental Implications	**Moderate:** Nuisance or harm issues identified, but for the most part are considered manageable
Social Implications	**Moderate:** Social effects for the most part are considered manageable
Economic Implications	**Moderate:** Limited economic opportunities exist enhancing port or community capability
Approvals and Permits	**Moderate:** Recognised approvals pathway, with significant management issues identified
Constraints	**Moderate:** Constraints are identified and there is a degree of uncertainty in the ability to overcome or manage them
Knowledge Gaps	**High:** There are few knowledge gaps and less than 1 year of further research work would be required to progress the reuse option
Future considerations	**Moderate:** The reuse option would cater for immediate needs and has some scope in the short term (several years), although options would need to be regularly reassessed

4.2.6 Shoreline protection

4.2.6.1 Activity description

Dredged material (including sand, clay and rock) may be used to provide shoreline protection to compensate for erosion. This may include the placement of material to protect low lying areas from erosion, or the use of offshore berms to modify the local wave climate.

4.2.6.2 Opportunity

Coastal erosion may occur in the estuaries around Hay Point including in areas where mangrove dieback has occurred (discussed in detail in Section 4.3.1), as mangroves may provide a natural protection against erosion from wave action, tidal and (partially) high flow currents in the estuaries. No specific demand for shoreline protection has been identified; however it is noted that potential minor areas of erosion that may require shoreline protection has previously been identified at McEwen's Beach (RMC, 2012) and beaches to the north of the mouth of Bakers Creek (EPA, 2005). For the purposes of analysis it has been assumed that shoreline protection may be applied offshore, and in the Sandringham Bay area (approximately 10km west of the dredge area).

A number of shoreline protection options may be utilised:

- Direct placement on the banks of waterways to protect low lying land against wave action, where coarser material will remain where placed on the bank
- Placement in geotextile bags / tubes, above and/or underwater to prevent further erosion

Placement in geobags / geotubes

Geotubes and bags exist in different shapes and forms and can be used in different design applications to prevent erosion. Figure 4-5 and Figure 4-6 shows various applications for geobags and geotubes respectively:

- Revetments
- Groynes
- Artificial reefs
- Slope buttressing
- Temporary protection dykes
- Offshore breakwaters
- Containment dykes

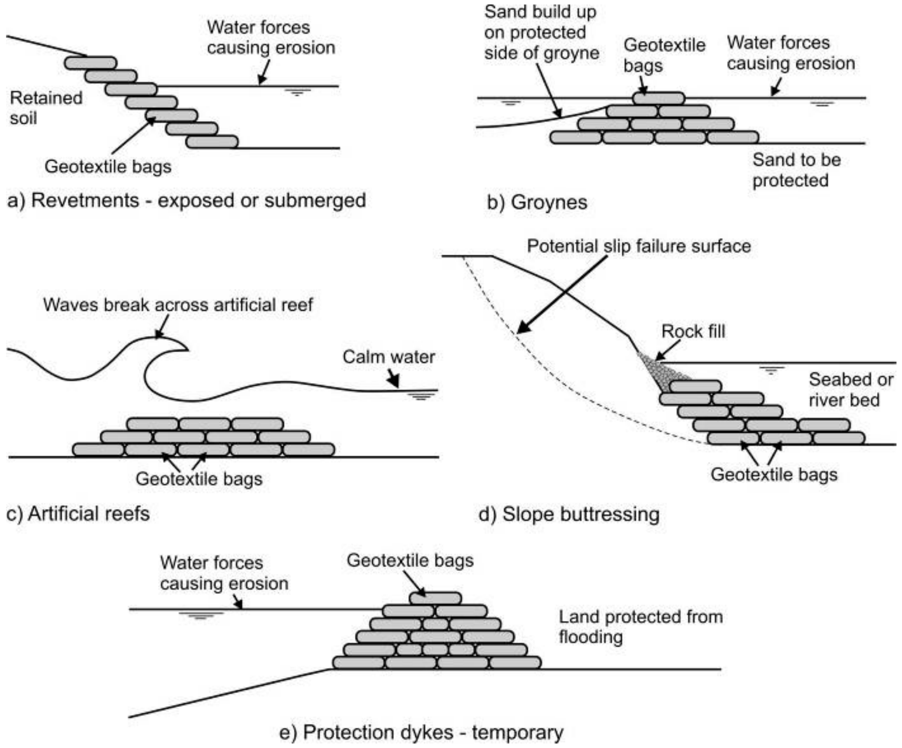

Figure 4-5 Geobag applications, source: Pilarczyk (2000)

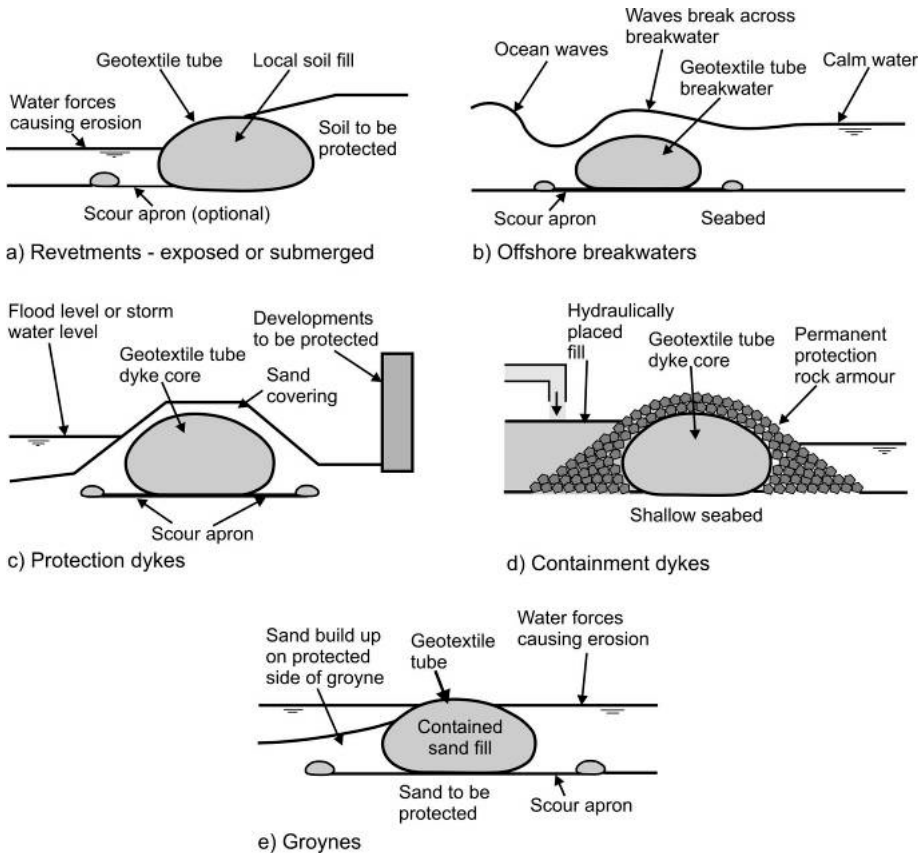

Figure 4-6 Geotube applications, source: Pilarczyk, (2000)

In all of the above cases, the bags and tubes can be filled hydraulically. Bags can be filled hydraulically on a pontoon and placed by crane, and tubes can be filled hydraulically at the placement site from a hopper barge with a pump which liquefies the dredge material in the hopper. This means that the material needs to be handled twice i.e. dredged and transported and then pumped again to place it in the geotube.

Due to the large amount of fine material to be dredged, it is considered that the dredge material is unsuitable for shoreline protection through direct placement; however is suitable for use in geotubes or geobags. The geotextile allows for gradual dewatering of the dredge material and the fines are maintained within the structure of the bag or tube.

The geotubes may be hydraulically filled in a split hopper barge at the dredging site, therefore eliminating the need of transport of the dredge material to the placement site prior to filling and eliminating any plumes resulting from the filling of the bags in the placement site. The tubes are sewn shut once filled, and reinforced with rope ties. Subject to water levels (at high tide) the split hopper barge can place and/or stack the tubes in the placement area (under water). Figure 4-7 illustrates the placement of geotube/geocontainer with a split hopper barge.

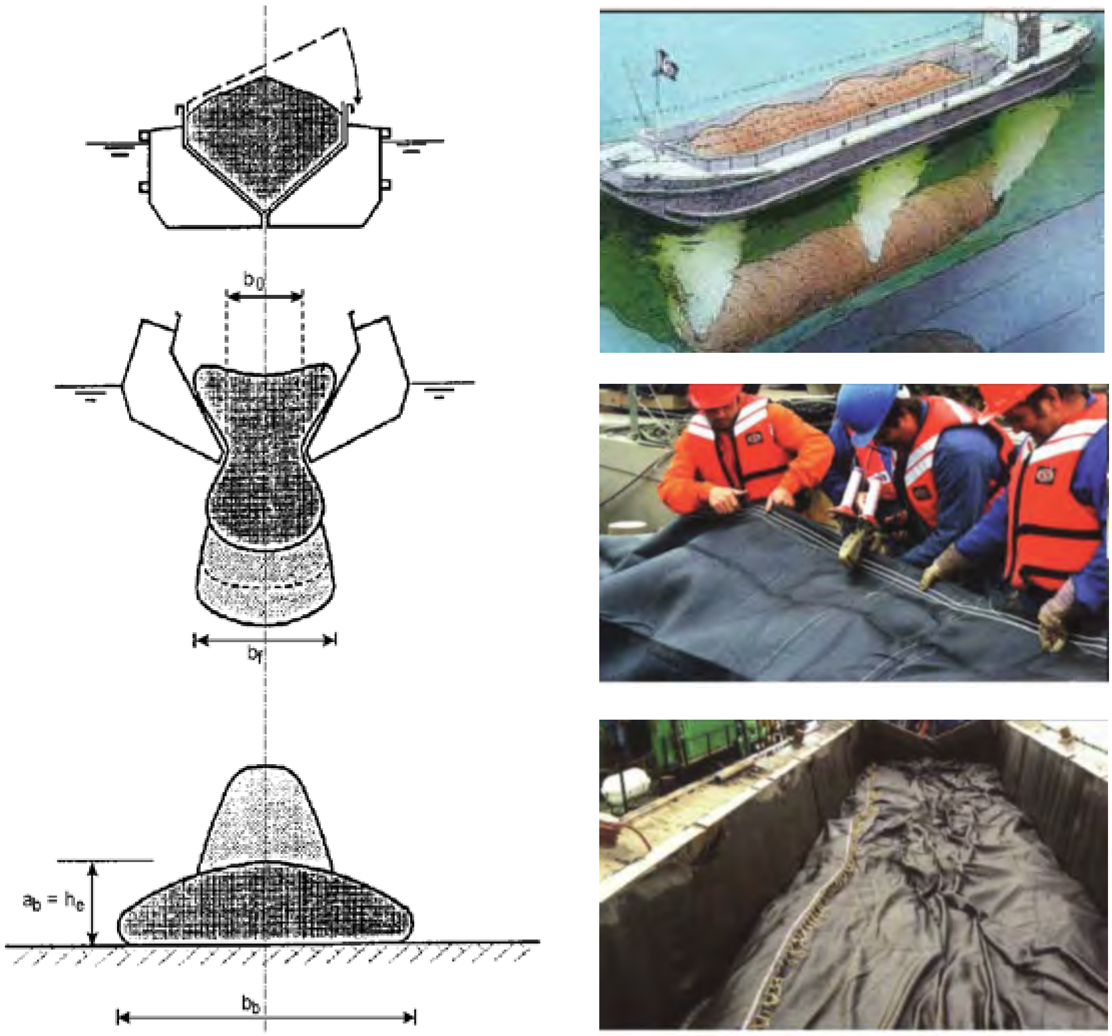

Figure 4-7 Geotube / geocontainer placement, source: TenCate (2016)

4.2.6.3 Suitability of Hay Point sediments

Given that the majority of material is fine-grained it is considered unlikely that direct placement would effectively address coastal erosion issues, as the material would be unlikely to remain in place. As such only the option of placement in geotextile tubes underwater is considered further.

As part of the assessment of the proposed shoreline protection reuse opportunity described above, the sediment suitability, based upon properties determined from results of the laboratory testing of the samples, is outlined in Table 4-17 (suitability categories as per Section 3.3.1).

Table 4-17 Suitability of dredge sediment for proposed shoreline protection (geobags) reuse

Sediment Material Property	Suitability
Geotechnical	
Material colour	n/a
Particle Size Distribution	Likely suitable
Moisture content	Likely suitable
Plasticity Index	Likely suitable
Linear Shrinkage	Likely suitable
Density test	Likely suitable
Strength and Consolidation	Likely suitable
Permeability	Likely suitable
Geochemical	
PASS	Likely suitable
Salinity	Likely suitable
Organic Material	Likely suitable
Other	
Cement laboratory testing	n/a

The proposed sediment material reuse option of placing into geobags to create shoreline protection requires very little if any treatment or processing of the material. Dewatering will assist reduce the volumes of sediment material to be handled and placed directly into geobags.

4.2.6.4 Process description

Dredging and placement

Dredge material would be dredged and transported to the site of shoreline protection works. Given the depth limitations around Sandringham Bay and beaches immediately north of Bakers Creek (i.e. extensive tidal flats exposed during low tides as suggested by Figure 1-1), and the need for dredge manoeuvrability within navigational areas, it is considered that a reasonable dredge configuration for the purposes of analysis is a combination of a Trailing Suction Hopper Dredge (such as the 'Brisbane') with multiple split hopper barges, which would be hydraulically filled at the dredging area, and would transport the dredged material to the placement site.

For the purposes of the analysis it has been assumed that the Trailing Suction Hopper Dredge will load the split hopper barges at the dredging area and the barges will travel approximately 10km to a placement site. Mooring and transfer facilities would be required to enable secure transfer between the Trailing Suction Hopper Dredge and the barges.

The dredge is assumed to operate almost continuously i.e. typically 24 hours a day, seven days a week with minimal downtime and the dredge campaign would last approximately 7 weeks.

4.2.6.5 Potential constraints

Potential constraints associated with this option include:

- Demand for shoreline protection for which the dredge material usage would be suitable is unclear
- Availability of equipment (e.g. appropriate split hopper barges) to execute the works may be limited
- Large tidal range in the region may present significant operational constraints, dependent on the shoreline protection option.
- Sea and weather conditions may affect operability of the configuration, particularly transfer of material from dredge to barge, and placement of geotubes
- Potential acid sulphate soils, may require consideration in development of the shoreline protection concept
- Agreement for access to the land for the proposed works
- Suitable geofabric material able to contain the fine clay/silt material, yet permeable to allow the filled geobag to 'sink' into position.

4.2.6.6 Potential implications

Potential implications of this option, considering potential environmental, commercial and socio-economic outcomes include:

- Provides a potential option to provide potentially cost effective shoreline protection (should demand exist) which may have positive socio-economic, commercial and environmental outcomes

- Placement of structures in the coastal environment may have implications for coastal processes, including sediment dynamics and transport in the local area
- Placement of structures will cause some (manageable) impacts to water quality in areas adjacent to the dredging and placement areas
- Placement of structures near Sandringham Bay and Bakers Creek may cause some (manageable) impacts to migratory shorebird habitat.

4.2.6.7 Approvals

Approvals associated with dredging and placement and offshore reuse (as identified in Table 3-1) will be required for the construction and operation of this option.

The recently introduced *Sustainable Ports Development Act 2015* identifies the ports of Hay Point and Mackay as priority ports, and stipulates that material generated from capital dredging of these areas must be beneficially reused (as a condition of any approval), which may include use as shoreline protection. Whilst potential approval of maintenance dredging is not subject to this condition, it is considered that the beneficial use of maintenance dredge material for shoreline protection is not inconsistent with existing Queensland Government legislation and policy.

4.2.6.8 Costs

A summary breakdown of the estimated costs associated with execution of the shoreline protection option is provided in Table 4-18. The costs are based on the assumed process description described above, with further detailed assumptions provided in Appendix B.

Depending on the location of the concept (dredge method, distance from dredging zone and water depth for accessibility), it is estimated that costs will be approximately \$106/m^3 measured in situ.

Table 4-18 Shoreline protection (geobags) summary cost estimate table

Key activity	Shoreline protection
Offshore	
Trailing Suction Hopper Dredge mobilisation and demobilisation	\$5,000,000
Workboat	\$500,000
Dredge and pump to barge	\$3,000,000
Tug and barge mobilisation and demobilisation	\$3,500,000
Barge mooring facilities	\$1,000,000
Place nearshore with barge, tug and geobags	\$8,000,000

Key activity	Shoreline protection
Monitoring and management	$250,000
Total	**$21,250,000**

4.2.6.9 Greenhouse gas emissions

The estimated Green House Gas emissions associated with the shoreline protection option is 2,083 tonnes of CO_2 equivalent. The estimated emissions are based on the assumed process description describe above, with further detailed assumptions provided in Appendix C.

4.2.6.10 Knowledge gaps

If the shoreline protection option was to be further pursued, key areas where additional information would be required include:

- Demand for shoreline protection in the vicinity of the Hay Point
- Coastal dynamics and processes specific to the proposed location of the shoreline protection areas to enable effective design and implementation
- Availability of suitable equipment to execute the works
- Detailed design including consideration of dredging, dredge material transfer and placement.

4.2.6.11 Future considerations

This option for beneficial reuse of dredged material is heavily constrained by demand. While the quantity of material to be dredged per campaign may be suitable for this option (i.e. typically dredge material quantities of 100,000-300,000 m^3 are required to make this option work) dependent on the need for shoreline protection, it is considered likely that reuse would only have a single or limited application.

4.2.6.12 Performance summary

A summary of the performance of the shoreline protection option based on the use of the performance criteria described in Section 3.3.3 is provided in Table 4-19.

Table 4-19: Shoreline protection (geobags) performance summary

Performance Criteria	Shoreline protection performance
Opportunity	**Low:** No demand identified, poor access to the Port of Hay Point, requiring extensive infrastructure construction
Sediment suitability	**Moderate:** Reuse option potentially suited to the dredge material. Requires treatment, processing and/or additives to make material suitable
Cost	**Low:** More than $17M in a 5 year period
Process	**Moderate:** The proposed process is sound but there are few examples of it being applied in environments similar to the port of Hay Point using maintenance dredge material
Duration	**High:** Less than 1 years to construct and function as the proposed final use
GHGs	**High:** < 2500t CO_2 equivalent in 5 year period
Environmental Implications	**Moderate:** Nuisance or harm issues identified, but for the most part are considered manageable
Social Implications	**High:** Positive social opportunities exist for local communities and other key user groups
Economic Implications	**Moderate:** Limited economic opportunities exist enhancing port or community capability
Approvals and Permits	**Moderate:** Recognised approvals pathway, with significant management issues identified
Constraints	**Moderate:** Constraints are identified and there is a degree of uncertainty in the ability to overcome or manage them
Knowledge Gaps	**Low:** There are multiple and/or complex knowledge gaps and greater than 3 years of further research work would be required to progress the reuse option
Future considerations	**Low:** The reuse option has only a single or limited application

4.2.7 Beach nourishment

4.2.7.1 Activity description

Beach nourishment or sand replenishment is a process by which sediment (usually sand) lost through longshore drift or erosion is replaced from sources outside of the eroding beach. A wider beach can reduce storm damage to shoreline by dissipating wave energy and protecting from storm surges and unusually high tides. Beach nourishment is typically a repetitive process, since it does not remove the physical forces that cause erosion, but simply mitigates their effects.

4.2.7.2 Opportunity

The dredge material potentially provides a source of sand and fine materials for beach nourishment in the local vicinity of Hay Point. No demand for beach nourishment has been identified; however as described in Section 4.2.6, potential minor areas of erosion that may benefit from beach nourishment has previously been identified at McEwen's Beach (RMC, 2012) and beaches to the north of the mouth of Bakers Creek. The Mackay Coast Study (EPA, 2005), which studied an area from Bakers Creek to Shoal Point north of Mackay identified a number of areas of active coastal recession that may require management actions. These include parts of Far Beach (between Bakers Creek and the Pioneer River) and the northern section of Harbour Beach (north of the Port of Mackay).

Beaches are typically made up of a number of materials including sand, gravel, pebbles, cobbles, rock or shells. Material on the beaches within the vicinity of the Port of Hay Point that may require management action is likely to comprise of a much sandier material than that identified within the maintenance dredge material (photo of Far Beach shown in Figure 4-8).

Figure 4-8 Far Beach, source: EPA (2005)

For the purposes of analysis it has been assumed that beach nourishment may be applied within approximately 10km of the dredge area i.e. approximate distance to closest areas where some beach nourishment demand may exist. Analysis focuses on the use of dredge material for beach nourishment, rather than potential mudflat nourishment, which is described in Section 4.3.

4.2.7.3 Suitability of Hay Point sediments

Beach nourishment generally requires selective dredging of pure sand. The dredge sediment has a high proportions of fine silt and clay (dark colour) that may not be suitable for placement on beaches in the vicinity of the port. The properties of the fine (clay and silt) material make the sediment placed on a beach potentially more readily susceptible to remobilisation by the large tidal range and fast flowing currents of the Hay Point region.

As part of the assessment of the proposed beach nourishment reuse opportunity described above, the sediment suitability, based upon properties determined from results of the laboratory testing of the samples, is outlined in Table 4-20 (suitability categories as per Section 3.3.1).

Table 4-20 Suitability of dredge sediment for proposed beach nourishment reuse

Sediment Material Property	Suitability
Geotechnical	
Material colour	Not likely to be suitable
Particle Size Distribution	Not likely to be suitable
Moisture content	n/a
Plasticity Index	n/a
Linear Shrinkage	n/a
Density test	n/a
Strength and Consolidation	n/a
Permeability	n/a
Geochemical	
PASS	Likely suitable
Salinity	Likely suitable
Organic Material	Likely suitable
Other	
Cement laboratory testing	n/a

Given that 60% of the sediment material is fine (clay/silt) it is not likely to be suitable for beach nourishment reuse. However, if there is a suitable foreshore location in the Hay Point area that may benefit and has favourable water current patterns, then direct placement of sediment material as beach nourishment is a potential reuse.

4.2.7.4 Process description

Dredging and placement

Dredge material would be dredged and transported to the site of beach nourishment works. Given the depth limitations around Sandringham Bay and beaches immediately north of Bakers Creek (i.e. extensive tidal flats exposed during low tides as suggested by Figure 1-1), and the need for dredge manoeuvrability within navigational areas, it is considered that a reasonable dredge configuration for the purposes of analysis is a combination of a Trailing Suction Hopper Dredge (such as the 'Brisbane') with pump out to the beach requiring nourishment.

Infrastructure required to facilitate the pump-out would likely be temporary, and would include a pipeline (potentially floating, along with a pump out coupling) and a mooring system for the dredge during pump-out. For the purposes of the analysis it has been assumed that the Trailing Suction Hopper Dredge will travel approximately 10km from the dredging area to access the pump-out point. It is likely that a booster pump would be required for the pump-out, given that the dredge is unlikely to be able to moor less than 1.5km from the beach to be nourished.

The dredge is assumed to operate almost continuously i.e. typically 24 hours a day, seven days a week with minimal downtime and the dredge campaign would last approximately 7 weeks.

4.2.7.5 Potential constraints

Potential constraints associated with this option include:

- Demand for beach nourishment for which the dredge material usage would be suitable is not established
- The dark grey colour of the fine sediment material is unlikely to be visually acceptable for reuse on any lighter coloured sandy beach
- Large tidal range in the region may present significant operational constraints, dependent on the beach nourishment option.
- Dredge material placed onshore as beach nourishment is typically eroded by the forces that caused the eroding beach in the first instance. Material is potentially transported elsewhere following placement and may only provide a wider beach temporarily. The dredge material is likely to be highly susceptible to erosion.
- Sea and weather conditions may affect operability of the supporting infrastructure, particularly pipeline to the beach nourishment area
- Potential acid sulphate soils, may require consideration in development of the beach nourishment concept
- Agreement for access to the land for the proposed works.

4.2.7.6 Potential implications

Potential implications of this option, considering potential environmental, commercial and socio-economic outcomes include:

- Given that there is no established demand, it is unlikely that positive socio-economic and commercial outcomes that may typically be associated with beach nourishment would occur
- Placement of the dredge material on sandy beaches may cause a negative community response, given the difference in material types, with dredge material being significantly finer and darker in colour than the existing beach material
- Placement of dredge material in the nearshore coastal environment may have implications for coastal processes, including sediment dynamics and transport in the local area
- Beach nourishment activities particularly pipeline management (including booster pump operation) and placement near Sandringham Bay and Bakers Creek may cause temporary impacts to migratory shorebird habitat
- Utilisation of fine materials for beach nourishment is likely to cause impacts to marine water quality at the placement location, which may cause nuisance that is unlikely to be easily managed

4.2.7.7 Approvals

Approvals associated with dredging and placement and offshore reuse (as identified in Table 3-1) will be required for the construction and operation of this option.

The recently introduced *Sustainable Ports Development Act 2015* identifies the ports of Hay Point and Mackay as priority ports, and stipulates that material generated from capital dredging of these areas must be beneficially reused (as a condition of any approval), with beach nourishment explicitly identified as a beneficial reuse. Whilst potential approval of maintenance dredging is not subject to this condition, it is considered that the beneficial use of maintenance dredge material for beach nourishment is not inconsistent with existing Queensland Government legislation and policy.

4.2.7.8 Costs

A summary breakdown of the estimated costs associated with execution of the beach nourishment option is provided in Table 4-21. The costs are based on the assumed process description described above, with further detailed assumptions provided in Appendix B.

Depending on the location of the concept (dredge method, distance from dredging zone and water depth for accessibility), it is estimated that costs will be approximately $\$80/m^3$ measured in situ.

Table 4-21 Beach nourishment summary cost estimate table

Key activity	Beach nourishment
Offshore	
Trailing Suction Hopper Dredge mobilisation and demobilisation	$5,000,000
Pipeline mobilisation and demobilisation	$7,000,000
Workboat	$500,000
Dredge and pump to placement location	$3,000,000
Monitoring and management	$500,000
Total	**$16,000,000**

4.2.7.9 Greenhouse gas emissions

The estimated Green House Gas emissions associated with the beach nourishment option is 2,173 tonnes of CO_2 equivalent. The estimated emissions are based on the assumed process description describe above, with further detailed assumptions provided in Appendix C.

4.2.7.10 Knowledge gaps

If the beach nourishment option was to be further pursued, key areas where additional information would be required include:

- Demand for beach nourishment using maintenance dredge material in the vicinity of the Hay Point
- Coastal dynamics and processes specific to the proposed location of the beach nourishment to enable effective targeting of placement, and design of pump-out facilities
- Detailed design including consideration of dredging and pump out facilities

4.2.7.11 Future considerations

This option for beneficial reuse of dredged material is heavily constrained by demand. It may have a single or limited application (if at all). It is considered unlikely that dredging would provide a long-term suitable source of material for beach nourishment in the region.

4.2.7.12 Performance summary

A summary of the performance of the beach nourishment option based on the use of the performance criteria described in Section 3.3.3 is provided in Table 4-22.

Table 4-22: Beach nourishment performance summary

Performance Criteria	Beach nourishment performance
Opportunity	**Low:** No demand identified, poor access to the Port of Hay Point, requiring extensive infrastructure construction
Sediment suitability	**Low:** Reuse option poorly suited to the dredge material. Requires substantial treatment, processing and/or additives to make material suitable, or treatment to a suitable level is considered unachievable
Cost	**Moderate:** $10M to $17M in a 5 year period
Process	**Moderate:** The proposed process is sound but there are few examples of it being applied in environments similar to the port of Hay Point using maintenance dredge material
Duration	**High:** Less than 1 years to construct and function as the proposed final use
GHGs	**High:** < 2500t CO_2 equivalent in 5 year period
Environmental Implications	**Low:** Nuisance or harm issues unlikely to be easily managed
Social Implications	**Low:** Negative social impacts are unlikely to be easily managed
Economic Implications	**Moderate:** Limited economic opportunities exist enhancing port or community capability
Approvals and Permits	**Moderate:** Recognised approvals pathway, with significant management issues identified
Constraints	**Moderate:** Constraints are identified and there is a degree of uncertainty in the ability to overcome or manage them
Knowledge Gaps	**Low:** There are multiple and/or complex knowledge gaps and greater than 3 years of further research work would be required to progress the reuse option
Future considerations	**Low:** The reuse option has only a single or limited application

4.3 Recycle dredge material as environmental enhancement

The following beneficial reuse options are considered below where the dredge material placement option seeks to provide environmental enhancement:

- Coastal (tidal) habitat restoration including:
  - Direct placement
  - Indirect placement
- Deep water habitat creation

4.3.1 Coastal habitat restoration

4.3.1.1 Activity description

Direct placement

Maintenance dredge material may be used in the creation of environmental bunds to support the restoration or creation of habitat areas. Coarser material (either dredged or imported to site) can be used to create the bund, and fine dredge material can be deposited behind the bund. The fine material is retained behind the bund and may form new mudflats in which mangrove habitat can be restored or created. There are two potential alternative methods for the use of environmental bunds, being underwater or circular closed offshore bunds.

An underwater bund retains the fine silts and clays behind it to create a new mud flat and associated habitat with the silt-mud sediment as shown on Figure 4-9.

Figure 4-9 Mud flat habitat creation with underwater bund

Similarly, in an offshore shallow water area, coarser material can be used to create a circular closed bund, and fines can be deposited behind the bund to form a mudflat. An example is the 'creation of nature' development in the Ijssel Delta in Holland. This demonstrates how an offshore bunded are may contain silts and clays that can be colonised by vegetation and animal species and become an environmental area (Figure 4-10).

Figure 4-10 Ijssel Delta offshore bund environmental area under construction

Indirect placement

Direct placement of sediment on top of mudflats may alter the benthic community that may take years to recover; however indirect nourishment schemes may provide a lower impact habitat restoration option. The concept of a 'mud motor' is considered, in which (fine) sediment availability in the system is locally increased and natural currents are utilized to transport the sediment to the mudflats and mangroves systems, where natural siltation rates will take place, with which the benthic community can tolerate. The basic principle of the 'mud motor' concept is that dredged material that is supplied to a tidal current can be picked up by that current so that it achieves its maximum transporting capacity. Higher mud concentrations in the currents that feed a mudflat will likely speed up mudflat development processes, while maintaining the desired gradients that are associated with natural mudflat development.

An advantage of indirect nourishment is that soil properties at the anticipated nourishment location will develop from natural siltation processes. Given that the nourished sediment is from the same coastal system, this increases the likelihood of successful habitat restoration.

An example of this method being used is a pilot project in the Port of Harlingen in the Netherlands (Figure 4-11). In this case dredged material is placed and transported by natural processes as a semi-continuous source of sediment (the mud-motor) to nearby salt marshes. The extra input of sediment is expected to lead to the formation and extension of salt marshes, and will yield the following favourable effects for the Port of Harlingen:

- Less recirculation towards the port, hence less maintenance dredging
- Promotion of the growth and stability of salt marshes, improving the Wadden Sea ecosystem
- Stabilizing the foreshore of the dykes, and therefore less maintenance of the dyke

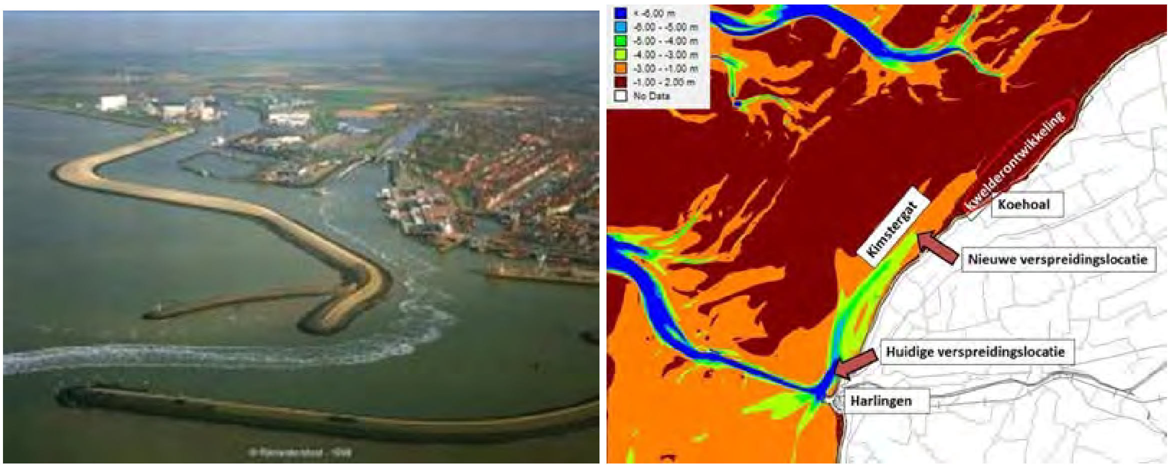

Figure 4-11 Mud motor pilot in Port of Harlingen (The Netherlands)

4.3.1.2 Opportunity

The coastline in a 40 km radius from Hay Point from Shoal Point over Mackay, Bakers Creek, Hay Point to Temple Island consist of a series of headlands with sandy beaches, mudflats and creeks feeding this system with a very shallow coastline.

In the mouths of the main creeks, extensive intertidal mudflats exist. According to Duke el al. (2005), dieback of mangroves was observed up to 2002 which affected greater than 30km^2 of mangroves in at least five adjacent estuaries of the Pioneer River. The mangrove species that were most adversely impacted is *Avicennia Marina*. These investigations suggest that diuron, a broad-spectrum residual herbicide and algaecide, and possibly other agricultural herbicides, were the most likely cause of the severe and widespread mangrove dieback. The extent of the mangrove dieback is shown in the Figure 4-12.

Mudflats provide habitat for worms, small crustaceans such as crabs and burrowing shrimp, and a variety of snails and other molluscs, many of which use broken down organic debris washed into these areas for food. Mudflats also provide feeding areas for birds and fish. With the dieback of mangroves, mudflats are impacted resulting in loss of habitat. The loss of mangroves destabilises the shoreline and may cause erosion and subsequent decline in coastal water quality with increased turbidity, nutrient levels and sediment deposition.

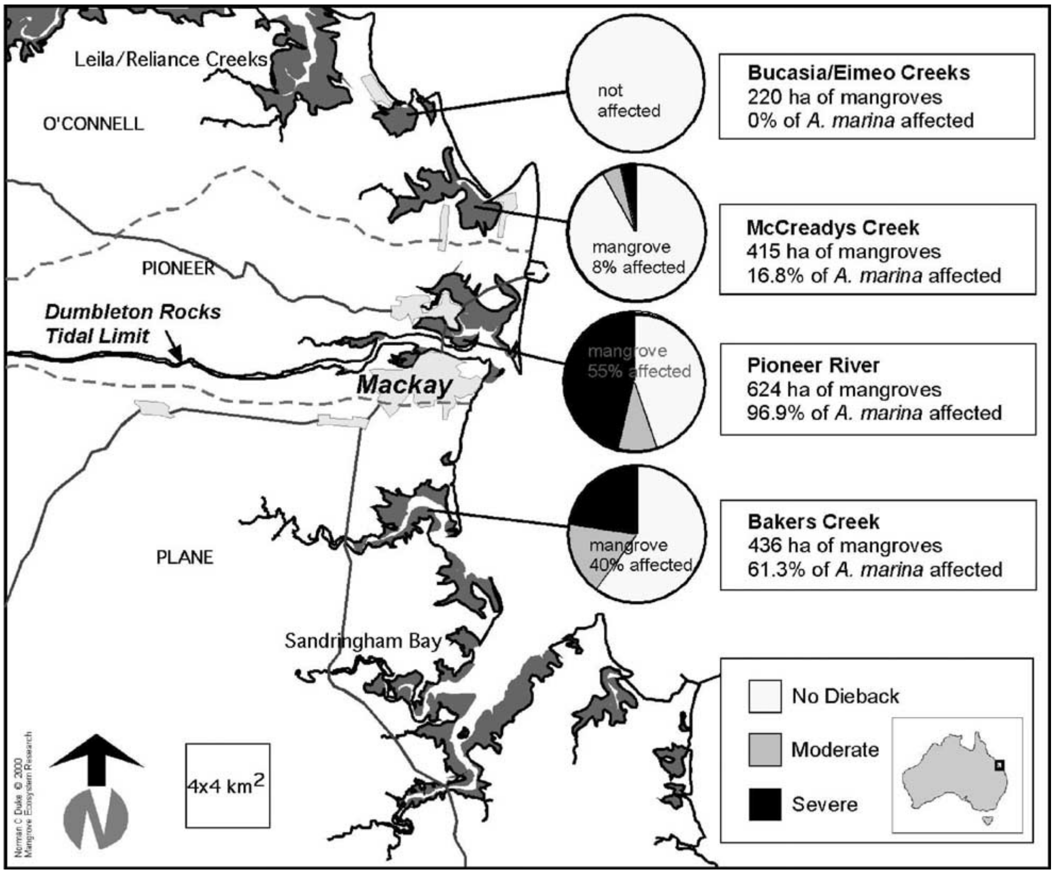

Figure 4-12 Mackay area mangrove habitat loss, Source: Duke et al. (2005)

The region's estuaries directly support several commercial fisheries[6] and contribute significantly to recreational fisheries with fishers spending approximately $42 million annually on this pursuit (Dodds, 2004). Estuaries within the region are highly valued by communities, particularly for recreational fishing and crabbing opportunities. In addition to their economic and social values, mangroves provide ecosystem benefits, including coastal protection functions through which the effects of storm surges and cyclones are reduced (Bridgewater and Cresswell, 1999).

It is notable that there have previously been activities targeted at the rehabilitation of mangroves in Sandringham Bay (Figure 3-1), and for the purposes of the analysis below, it has been assumed that further demand for mangrove habitat rehabilitation for which direct or indirect placement of dredge material may be suitable exists in Sandringham Bay.

The maintenance dredge material may be directly placed, through the development of environmental bunds to restore habitat that has been impacted by catchment runoff in the vicinity of the port. Intertidal mudflat could be created to effectively rehabilitate and cap the mangrove habitat loss area, and create a new clean mangrove habitat for replanting. This is the focus of the direct placement analysis below.

[6] State of the Region 2013 – Reefcatchments.com.au

Alternatively, dredge material may be placed indirectly, through use of natural currents to transport sediment from the discharge point to areas of habitat requiring restoration. This is the focus of the indirect placement analysis below.

4.3.1.3 Suitability of Hay Point sediments

Direct placement

Sandy or coarse material is preferred for environmental bunds to have sufficient strength for construction purposes. The fine sediment material is suitable to backfill behind the main bund.

As part of the assessment of the proposed direct placement habitat restoration opportunity described above, the sediment suitability, based upon properties determined from results of the laboratory testing of the samples, is outlined in Table 4-23 (suitability categories as per Section 3.3.1).

Table 4-23 Suitability of dredge sediment for proposed direct placement habitat restoration reuse

Sediment Material Property	Suitability
Geotechnical	
Material colour	n/a
Particle Size Distribution	Potentially suitable with treatment/processing
Moisture content	Likely suitable
Plasticity Index	Likely suitable
Linear Shrinkage	Likely suitable
Density test	Likely suitable
Strength and Consolidation	Likely suitable
Permeability	Likely suitable
Geochemical	
PASS	Likely suitable
Salinity	Likely suitable
Organic Material	Likely suitable
Other	
Cement laboratory testing	n/a

The sediment material requires little or no processing to improve its suitability for direct placement reuse. Targeted dredging to obtain coarse sand material from the departure path to build the outer bund first would be desirable followed by dredging fine material (berth area) to backfill behind the established bund. The characteristics of the sediment material and the potential impacts (positive and negative) on the foreshore ecosystems would need to be the subject of detailed scientific investigations.

Indirect placement

Habitat restoration through indirect nourishment will require dredging and placement in a suitable nearshore area of material able to be remobilised by currents to transport the sediment material to the target location.

As part of the assessment of the proposed indirect placement habitat restoration reuse opportunity described above, the sediment suitability, based upon properties determined from results of the laboratory testing of the samples, is outlined in Table 4-24 (suitability categories as per Section 3.3.1).

Table 4-24 Suitability of dredge sediment for proposed indirect placement habitat restoration reuse

Sediment Material Property	Suitability
Geotechnical	
Material colour	n/a
Particle Size Distribution	Likely to be suitable
Moisture content	n/a
Plasticity Index	n/a
Linear Shrinkage	n/a
Density test	Likely to be suitable
Strength and Consolidation	n/a
Permeability	n/a
Geochemical	
PASS	Likely suitable
Salinity	Likely suitable
Organic Material	Likely suitable
Other	

Sediment Material Property	Suitability
Cement laboratory testing	n/a

Given that 60% of the sediment material is fine (clay/silt), it is likely to be suitable for remobilisation for habitat restoration by indirect placement. A suitable foreshore location in the Hay Point area would need to be identified and favourable water current patterns utilised, such that indirect placement of sediment material may function appropriately.

4.3.1.4 Process description

Direct placement

Dredge material would be dredged and transported to the site of the direct placement. Construction of the bunds may be undertaken hydraulically through either discharging through the bow coupling to a floating pipeline and spreader pontoon in shallow water for the underwater bund, or by ‘rainbowing’. Given the depth limitations around Sandringham Bay (i.e. extensive tidal flats exposed during low tides as suggested by Figure 1-1), and the need for dredge manoeuvrability within navigational areas, it is considered that a reasonable dredge configuration for the purposes of analysis is a combination of a Trailing Suction Hopper Dredge (such as the ‘Brisbane’) with pump out to the area of the habitat restoration.

Infrastructure required to facilitate the pump-out would likely be temporary, and would include a pipeline (potentially floating, along with a pump out coupling) and a mooring system for the dredge during pump-out. For the purposes of the analysis it has been assumed that the Trailing Suction Hopper Dredge will travel approximately 10km from the dredging area to access the pump-out point. It is likely that a booster pump would be required for the pump-out, given that the dredge is unlikely to be able to moor less than 1.5km from the direct placement area.

The dredge is assumed to operate almost continuously i.e. typically 24 hours a day, seven days a week with minimal downtime and the dredge campaign would last approximately 7 weeks.

Material for the environmental bund may be dredged from the channel areas first and / or to some extent dredged selectively by using overflow to separate the fines in the other areas of dredging (apron and berth areas). If insufficient coarse material is available for use, the environmental bunds may be constructed through the use of imported material, with the dredge material placed behind the bunds subsequently. For the purposes of analysis it has been assumed that the coarse dredge material is available and sufficient for use in development of the environmental bunds.

Indirect placement

Dredge material would be dredged and transported to a discharge location, where material may be transported through natural processes to the location of the rehabilitation area. Given the depth limitations around Sandringham Bay (i.e. extensive tidal flats exposed during low tides as suggested by Figure 1-1), and the need for dredge manoeuvrability within navigational areas, it is considered that a reasonable dredge configuration for the purposes of analysis is a combination of a Trailing Suction Hopper Dredge (such as the ‘Brisbane’) with pump out to the discharge location.

Infrastructure required to facilitate the pump-out would likely be temporary, and would include a pipeline (potentially floating, along with a pump out coupling) and a mooring system for the dredge during pump-out. It is assumed that a booster pump is not required for this option, as dredge placement will utilise natural processes to transport material from the discharge point to the restoration location. It is considered likely that placement of material would be restricted to particular conditions (e.g. tidal state), which would constrain the dredging operations.

For the purposes of the analysis it has been assumed that the Trailing Suction Hopper Dredge will travel approximately 10km from the dredging area to access the discharge point. The dredge is assumed to operate with some constraints to discharge timing and the dredge campaign is assumed to last approximately 7 weeks.

4.3.1.5 Potential constraints

Direct placement

Potential constraints associated with this option include:

- Specific demand for mangrove habitat rehabilitation is unclear
- Large tidal range in the region may present significant operational constraints, dependent on the habitat rehabilitation option.
- Sea and weather conditions may affect operability of the supporting infrastructure, particularly pipeline to the habitat rehabilitation area
- Potential acid sulphate soils, may require consideration in development of the concept
- Agreement for access to the land for the proposed works.

Indirect placement

Potential constraints associated with this option include:

- Specific demand for mangrove habitat rehabilitation is unclear
- Determination of suitable discharge location/s to enable mudflat rehabilitation in a target area may require extensive investigation including consideration of environmental conditions over a long period of time
- Tidal range and sea conditions may dictate when discharge may occur, potentially reducing the efficiency of dredging operations
- Large tidal range in the region may present significant operational constraints, dependent on the habitat rehabilitation option
- Sea and weather conditions may affect operability of the supporting infrastructure, particularly pipeline to the discharge point
- Potential acid sulphate soils, may require consideration in development of the concept

4.3.1.6 Potential implications

Direct placement

Potential implications of this option, considering potential environmental, commercial and socio-economic outcomes include:

- Provides a potential option to address habitat degradation in the area (should sufficient demand in the vicinity of the Hay Point exist) which may have positive socio-economic, commercial and environmental outcomes
- Placement of dredge material in the nearshore coastal environment may have implications for coastal processes, including sediment dynamics and transport in the local area
- Habitat restoration activities, particularly pipeline management (including booster pump operation) and placement near Sandringham Bay and Bakers Creek may cause temporary impacts to migratory shorebird habitat
- Placement of dredge material to create environmental bunds may impact existing benthic community, which will take time to recover

Indirect placement

Potential implications of this option, considering potential environmental, commercial and socio-economic outcomes include:

- Provides a potential option to address habitat degradation in the area (should sufficient demand in the vicinity of the Hay Point exist) which may have positive socio-economic, commercial and environmental outcomes
- Placement of dredge material in the nearshore coastal environment may have implications for coastal processes, including sediment dynamics and transport in the local area
- Dredging and placement activities near Sandringham Bay may cause temporary impacts to migratory shorebird habitat
- Discharge of the dredge material, reliant on transport by natural currents is likely to cause temporary impacts to water quality in the areas of discharge

4.3.1.7 Approvals

Approvals associated with dredging and placement and offshore reuse (as identified in Table 3-1) will be required for the construction and operation of both the direct and indirect placement habitat restoration options.

The recently introduced *Sustainable Ports Development Act 2015* identifies the ports of Hay Point and Mackay as priority ports, and stipulates that material generated from capital dredging of these areas must be beneficially reused (as a condition of any approval). Whilst potential approval of maintenance dredging is not subject to this condition, it is considered that the beneficial use of maintenance dredge material for habitat restoration through either direct or indirect placement is not inconsistent with existing Queensland Government legislation and policy.

4.3.1.8 Costs

Direct placement

A summary breakdown of the estimated costs associated with execution of the direct placement habitat restoration option is provided in Table 4-25. The costs are based on the assumed process description described above, with further detailed assumptions provided in Appendix B.

Depending on the location of the concept (dredge method, distance from dredging zone and water depth for accessibility), it is estimated that costs will be approximately \$80/m^3 measured in situ.

Table 4-25 Direct placement habitat restoration summary cost estimate table

Key activity	Direct placement habitat restoration
Offshore	
Trailing Suction Hopper Dredge mobilisation and demobilisation	\$5,000,000
Pipeline mobilisation and demobilisation	\$7,000,000
Workboat	\$500,000
Dredge and pump to placement location	\$3,000,000
Monitoring and management	\$500,000
Total	**\$16,000,000**

Indirect placement

A summary breakdown of the estimated costs associated with execution of the indirect placement habitat restoration option is provided in Table 4-26. The costs are based on the assumed process description described above, with further detailed assumptions provided in Appendix B.

Depending on the location of the concept (dredge method, distance from dredging zone and water depth for accessibility), it is estimated that costs will be approximately \$69/m^3 measured in situ.

Table 4-26 Indirect placement habitat restoration summary cost estimate table

Key activity	Indirect placement habitat restoration
Offshore	
Trailing Suction Hopper Dredge mobilisation and	\$5,000,000

Key activity	Indirect placement habitat restoration
demobilisation	
Pipeline mobilisation and demobilisation	$5,000,000
Workboat	$340,000
Dredge and pump to placement location	$3,000,000
Monitoring and management	$500,000
Total	**$13,840,000**

4.3.1.9 Greenhouse gas emissions

Direct placement

The estimated Green House Gas emissions associated with the direct placement habitat restoration option is 2,173 tonnes of CO_2 equivalent. The estimated emissions are based on the assumed process description described above, with further detailed assumptions provided in Appendix C.

Indirect placement

The estimated Green House Gas emissions associated with the indirect placement habitat restoration option is 1,674 tonnes of CO_2 equivalent. The estimated emissions are based on the assumed process description described above, with further detailed assumptions provided in Appendix C.

4.3.1.10 Knowledge gaps

A shoreline mangrove rehabilitation project has previously been undertaken in Sandringham Bay by BHP Billiton Mitsubishi Alliance (BMA) in conjunction with Reef Catchments (BMA, 2010). A beneficial reuse project may be able to share knowledge with these proponents, regarding the lessons learned from this earlier project and how best to approach mangrove habitat restoration.

Direct placement

If the direct placement habitat restoration option was to be further pursued, key areas where additional information would be required include:

- Demand for habitat rehabilitation in the vicinity of the Hay Point
- Coastal dynamics and processes specific to the proposed location of the habitat rehabilitation to enable effective targeting of placement, and design of pump-out facilities
- Detailed design including consideration of dredging and pump out facilities

Indirect placement

If the indirect placement habitat restoration option was to be further pursued, key areas where additional information would be required include:

- Demand for habitat rehabilitation in the vicinity of the Hay Point
- Coastal dynamics and processes specific to the proposed location of the dredge material discharge point and of the habitat restoration location (likely including extensive hydrodynamic modelling over a range of conditions) to enable effective targeting of placement, and design of pump-out facilities
- Detailed design including consideration of dredging and pump out facilities.

4.3.1.11 Future considerations

Direct placement

The quantity of maintenance dredge material currently requiring management may be sufficient for a small test direct placement habitat restoration project in shallow water. The rehabilitation areas may be expanded when more material needs to be stored, assuming that further demand for rehabilitation exists. A test case start-up has the advantage that some monitoring is possible and adjustments can be made in the design if needed during subsequent dredging.

Indirect placement

As for the direct placement option, the quantity of maintenance dredge material currently requiring management may be sufficient for a small test project in shallow water; however, detailed investigation would be required of the long-term sediment requirements within the target rehabilitation area/s, to determine whether a long term requirement for the dredge material is likely to exist to support this option as an ongoing beneficial reuse.

Significant additional engineering investigations and analysis (including hydrodynamic modelling) would be required, both of the need for this option, and potential for successful implementation. Consideration would need to be given to how the current and predicted maintenance dredging volumes on a temporal basis relate to the sediment budget delivered to the coastal system.

4.3.1.12 Performance summary

Direct placement

A summary of the performance of the direct placement habitat restoration option based on the use of the performance criteria described in Section 3.3.3 is provided in Table 4-27.

Table 4-27: Direct placement habitat restoration performance summary

Performance Criteria	Direct placement habitat restoration performance
Opportunity	**Moderate:** Potentially a demand reasonably accessible to the Port of Hay Point, requiring infrastructure construction
Sediment suitability	**High:** Reuse option well suited to the dredge material. Requires no additives or treatment (other than dewatering if necessary)
Cost	**Moderate:** \$10M to \$17M in a 5 year period
Process	**Moderate:** The proposed process is sound but there are few examples of it being applied in environments similar to the port of Hay Point using maintenance dredge material
Duration	**High:** Less than 1 years to construct and function as the proposed final use
GHGs	**High:** < 2500t CO_2 equivalent in 5 year period
Environmental Implications	**High:** Net benefit opportunities exist for positive environmental outcomes, with manageable nuisance of harm issues
Social Implications	**High:** Positive social opportunities exist for local communities and other key user groups
Economic Implications	**High:** Positive economic opportunities exist enhancing port or community capability
Approvals and Permits	**Moderate:** Recognised approvals pathway, with significant management issues identified
Constraints	**Moderate:** Constraints are identified and there is a degree of uncertainty in the ability to overcome or manage them
Knowledge Gaps	**Low:** There are multiple and/or complex knowledge gaps and greater than 3 years of further research work would be required to progress the reuse option
Future considerations	**Moderate:** The reuse option would cater for immediate needs and has some scope in the short term (several years), although options would need to be regularly reassessed

Indirect placement

A summary of the performance of the indirect placement habitat restoration option based on the use of the performance criteria described in Section 3.3.3 is provided in Table 4-28.

Table 4-28: Indirect placement habitat restoration performance summary

Performance Criteria	Indirect placement habitat restoration performance
Opportunity	**Moderate:** Potentially a demand reasonably accessible to the Port of Hay Point, requiring infrastructure construction
Sediment suitability	**Moderate:** Reuse option potentially suited to the dredge material. Requires treatment, processing and/or additives to make material suitable
Cost	**Moderate:** $10M to $17M in a 5 year period
Process	**Low:** The proposed process is mostly unproven
Duration	**High:** Less than 1 years to construct and function as the proposed final use
GHGs	**High:** < 2500t CO_2 equivalent in 5 year period
Environmental Implications	**High:** Net benefit opportunities exist for positive environmental outcomes, with manageable nuisance of harm issues
Social Implications	**High:** Positive social opportunities exist for local communities and other key user groups
Economic Implications	**High:** Positive economic opportunities exist enhancing port or community capability
Approvals and Permits	**Moderate:** Recognised approvals pathway, with significant management issues identified
Constraints	**Moderate:** Constraints are identified and there is a degree of uncertainty in the ability to overcome or manage them
Knowledge Gaps	**Low:** There are multiple and/or complex knowledge gaps and greater than 3 years of further research work would be required to progress the reuse option
Future considerations	**Moderate:** The reuse option would cater for immediate needs and has some scope in the short term (several years), although options would need to be regularly reassessed

4.3.2 Deep water habitat creation

4.3.2.1 Activity description

Various habitat may be environmentally enhanced through the use of dredge material including inter-tidal areas (Section 4.3.1). The potential for habitat creation in deeper water is described below.

One of the benefits of deep water habitat creation is ease of access for dredging equipment. An Ecoshape pilot project has been undertaken in the Netherlands (De Jong et al., 2016) in which depth and texture of sand mining locations have been optimized from an ecological perspective (Figure 4-13). The local ecosystem may be enhanced by optimizing water depth and by adding specific bedform features that introduce variations in hydraulic load and consequently biodiversity.

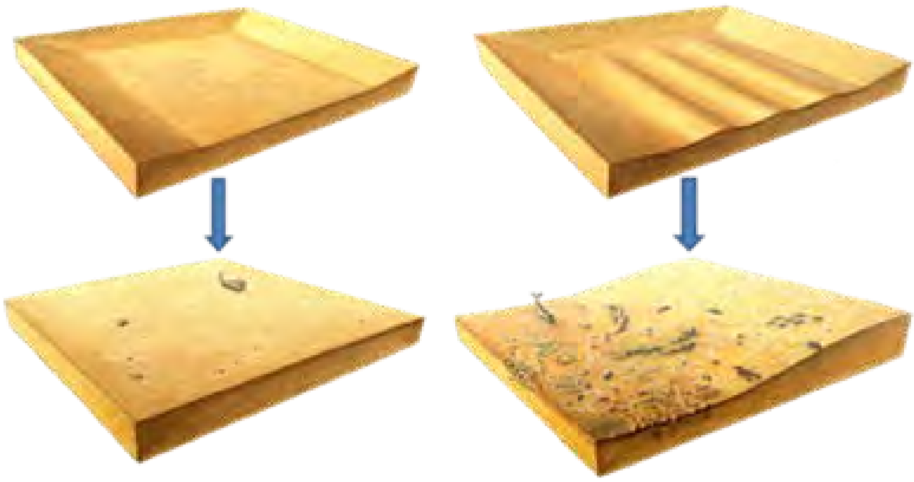

Figure 4-13 Concept of deep water habitat improvement for sand mine areas (De Jong et al., 2016)

In the case study described by De Jong et al. (2016) it was noted that dredging operations for the extraction of sand, typically leave the floor of the extraction area flat, and that the flat seabed did not encourage biodiversity. The pilot project sought to encourage the recolonization, and promote productivity and biodiversity of these deep (up to 20m below the seabed) extraction pits by implementing local seabed landscaping. The pilot project involved selective dredging, leaving behind sand ridges in the designated borrow area. These artificial bedforms are about 700 metres long and 100 metres wide with crests 10 metres high, similar to natural sand waves observed on the North Sea bed. The recolonization of the borrow area has been monitored since 2010. Four to five times more fish have been found inside the pit than outside it, along with greater species richness.

4.3.2.2 Opportunity

Dredge material from Hay Point may be placed in the offshore environment in such a way as to develop features / bedforms that enhance the local habitat, while fitting in with the local environment. The local ecosystem may be enhanced by optimizing water depth and by adding specific bedform features that introduce variations in hydraulic load and consequently biodiversity.

4.3.2.3 Suitability of Hay Point sediments

In the example described above, habitat was created through selective dredging of sand to create bedform features to encourage local habitat. The dredge sediment has a high proportion of fine silt and clay (dark colour) that may not be suitable for habitat creation through placement on the seabed in the vicinity of the port. The properties of the fine (clay and silt) material make the sediment placed on a seabed potentially more readily susceptible to remobilisation.

As part of the assessment of the deep water habitat creation reuse opportunity described above, the sediment suitability, based upon properties determined from results of the laboratory testing of the samples, is outlined in Table 4-29 (suitability categories as per Section 3.3.1).

Table 4-29 Suitability of dredge sediment for proposed deep water habitat creation reuse

Sediment Material Property	Suitability
Geotechnical	
Material colour	Likely to be suitable
Particle Size Distribution	Not likely to be suitable
Moisture content	n/a
Plasticity Index	n/a
Linear Shrinkage	n/a
Density test	n/a
Strength and Consolidation	n/a
Permeability	n/a
Geochemical	
PASS	Likely suitable
Salinity	Likely suitable
Organic Material	Likely suitable
Other	
Cement laboratory testing	n/a

Given that 60% of the sediment material is fine (clay/silt) it is not likely to be suitable for deep water habitat creation reuse; however, if a suitable offshore fisheries habitat location was identified, with sediment characteristics similar to those of the material to be dredged, along with favourable water current patterns, direct placement of sediment material for deep water habitat creation may provide an opportunity for beneficial reuse. Further consideration would be required of the characteristics of the sediment material to be dredged and of the potential placement location, along with the potential impacts (positive and negative) on offshore ecosystems and potential for fisheries development.

4.3.2.4 Process description and key activities

Dredging and placement

Dredge material would be loaded and transported to a deep water habitat creation site where sediments would be placed selectively according to design. Depending on design, dredge material placement can be heterogeneous i.e. spatial spreading of fine and coarse material with height or capping of finer material when desired.

For the purposes of analysis it is assumed that the Trailing Suction Hopper Dredge (such as the 'Brisbane') would undertake the works, with no other infrastructure required.

For the purposes of the analysis it has been assumed that the Trailing Suction Hopper Dredge will travel approximately 7km from the dredging area to the habitat creation site. The dredge is assumed to operate almost continuously i.e. typically 24 hours a day, seven days a week with minimal downtime and the dredge campaign would last four weeks.

4.3.2.5 Potential constraints

Potential constraints associated with this option include:

- Demand for seabed fisheries habitat creation or rehabilitation is unclear
- Significant research effort may be required to demonstrate potential for enhancement of existing habitat through placement of dredge material, in order to achieve regulatory agency acceptance of the option as a beneficial reuse
- Dredge material may not be retained on the seabed floor in the placement location, and as such long term habitat creation may not be possible.

4.3.2.6 Potential implications

Potential implications of this option, considering potential environmental, commercial and socio-economic outcomes include:

- Provides a potential option to develop fisheries habitat in the area which may have positive socio-economic, commercial and environmental outcomes
- Placement of the material on the seafloor will impact existing benthic habitat
- Impacts to water quality similar to offshore placement previously undertaken at the port would be expected

4.3.2.7 Approvals

Approvals associated with dredging and placement and offshore reuse (as identified in Table 3-1) will be required for the construction and operation of this option.

The recently introduced *Sustainable Ports Development Act 2015* identifies the ports of Hay Point and Mackay as priority ports, and stipulates that material generated from capital dredging of these areas must be beneficially reused (as a condition of any approval). Whilst potential approval of maintenance dredging is not subject to this condition, it is considered that the beneficial use of maintenance dredge material for fisheries habitat development is not inconsistent with existing Queensland Government legislation and policy; however it is likely that significant effort would be required to demonstrate the likely benefits that may accrue with this option, for it to be accepted as a beneficial reuse.

4.3.2.8 Costs

A summary breakdown of the estimated costs associated with execution of the deep water habitat creation option is provided in Table 4-30. The costs are based on the assumed process description described above, with further detailed assumptions provided in Appendix B.

Depending on the location of the concept (dredge method, distance from dredging zone and water depth for accessibility), it is estimated that costs will be approximately $\$38/m^3$ measured in situ.

Table 4-30 Deep water habitat creation summary cost estimate table

Key activity	Deep water habitat creation
Offshore	
Trailing Suction Hopper Dredge mobilisation and demobilisation	$5,000,000
Dredge and place to seabed	$2,000,000
Monitoring and management	$500,000
Total	**$7,500,000**

4.3.2.9 Greenhouse gas emissions

The estimated Green House Gas emissions associated with the deep water habitat creation materials option is 1,035 tonnes of CO_2 equivalent. The estimated emissions are based on the assumed process description described above, with further detailed assumptions provided in Appendix C.

4.3.2.10 Knowledge gaps

If the deep water habitat creation option was to be further pursued, key areas where additional information would be required include:

- Demand for fisheries habitat creation in the vicinity of the Hay Point, and the value of existing seabed habitat within the area
- Coastal dynamics and processes specific to the proposed location of the habitat creation area (likely including hydrodynamic modelling over a range of conditions) to enable effective determination of likelihood of success of habitat creation.

4.3.2.11 Future considerations

This quantity of material to be dredged may be sufficient for a pilot project; however the suitability of the options for acceptance of maintenance dredging material on a long term basis would depend on the success of the pilot project, and whether that could be expanded, or replicated across other areas of the sea floor.

4.3.2.12 Performance summary

A summary of the performance of the deep water habitat creation option based on the use of the performance criteria described in Section 3.3.3 is provided in Table 4-31.

Table 4-31 Deep water Habitat creation performance summary

Performance Criteria	Deep water habitat creation performance
Opportunity	**Low:** No demand identified, poor access to the Port of Hay Point, requiring extensive infrastructure construction
Sediment suitability	**Low:** Reuse option poorly suited to the dredge material. Requires substantial treatment, processing and/or additives to make material suitable, or treatment to a suitable level is considered unachievable
Cost	**High:** Less than $10M in a 5 year period
Process	**Low:** The proposed process is mostly unproven
Duration	**High:** Less than 1 years to construct and function as the proposed final use
GHGs	**High:** < 2500t CO_2 equivalent in 5 year period
Environmental Implications	**High:** Net benefit opportunities exist for positive environmental outcomes, with manageable nuisance of harm issues
Social Implications	**High:** Positive social opportunities exist for local communities and other key user groups

Performance Criteria	Deep water habitat creation performance
Economic Implications	**Moderate:** Limited economic opportunities exist enhancing port or community capability
Approvals and Permits	**Moderate:** Recognised approvals pathway, with significant management issues identified
Constraints	**Moderate:** Constraints are identified and there is a degree of uncertainty in the ability to overcome or manage them
Knowledge Gaps	**Low:** There are multiple and/or complex knowledge gaps and greater than 3 years of further research work would be required to progress the reuse option
Future considerations	**Moderate:** The reuse option would cater for immediate needs and has some scope in the short term (several years), although options would need to be regularly reassessed

4.4 Reuse dredge material in agricultural applications

Two agricultural reuse applications were considered in the analysis, namely:

- Aquaculture
- Topsoil for agricultural use

4.4.1 Aquaculture

4.4.1.1 Activity description

Marine, estuarine and freshwater aquaculture activities for production of food and ornamental species are globally expanding industries. Many commercial fisheries throughout the world are in decline and in some regions of the world catching certain species is limited or banned.

Onshore aquaculture impoundments require materials that can be used to create berms that will contain water, ponds with impervious liners, and impoundments within ponds to isolate age or species groups and provide water treatment areas. These needs may be met by the appropriate use of dredged materials.

Dredged materials may be placed in a closed containment area, with ponds created for the commercial production of prawns. This has been done successfully in Texas, USA, where yields have been obtained from 43 to 1,020 lbs of prawn (*Penaeus*) per acre over periods from 15-31 weeks each. Six crops of prawns on two active disposal site (42 and 47 ha) were harvested during 3 years, yielding over 118 tons of prawns (PIANC, 2009).

4.4.1.2 Opportunity

A number of options exist with respect use of dredged material for aquaculture industry development including:

- Use of material as a liner in existing onshore aquaculture facilities, which may be replaced from time to time following harvest
- Development of new aquaculture facilities in the vicinity of the port to utilise dredged material
- Development of new aquaculture facilities in the intertidal and shallow sub-tidal habitat.

Development in the intertidal or shallow subtidal areas would be significantly more challenging (technically, financially and in terms of regulatory approval requirements) than the other options, given that these areas are part of the GBRWHA. Development of new facilities in the vicinity of the port, may be possible; however as this would require development of a new business, the use in dredge material in existing facilities is considered the most likely to be feasible. Notwithstanding this, there is not known to be any existing aquaculture facilities in the Hay Point area and there may not be sufficient demand for material from facilities in the broader Mackay region to support use of the material in existing aquaculture facilities.

4.4.1.3 Suitability of Hay Point sediments

The sediment material potentially could be used for the construction of aquaculture pond embankments for commercial production for seafood. Potentially the fine materials (clay and silt) could be used as liner for the impoundment embankment to retain water in the ponds.

One of the most important design parameters influencing liner material selection is hydraulic conductivity. Soil and dredged material liners should provide a field hydraulic conductivity of 1×10^{-8} to 1×10^{-5} cm/sec or less when compacted. Clean dredged fine-grained material when allowed to settle and condense, dredged from rivers and harbors can reach permeabilities as low as 10^{-7} to 10^{-10} cm/s (Giroud et al. 1997,Schroeder et al. 1994). By most standards, this range of liner permeability is acceptable for service as hydraulic barriers. Additional reductions in hydraulic conductivity may be realized through modification of clean dredged material with additives, use of clay layers, or employment of geosynthetic materials and composite liner systems. Liners and their underlying soils must also possess sufficient strength after compaction to support themselves and the overlying materials without failure.

The clay samples, measured permeabilities are 3.3×10^{-11} m/s and 9.3×10^{-11} m/s for samples from berth area (C-2 and C-3) respectively. These permeabilities are typical of clay materials and are suitable to meet the permeability criteria outlined above to be acceptable for use as hydraulic barriers in a lining material in the embankments of aquaculture ponds.

As part of the assessment of the proposed aquaculture reuse opportunity described above the sediment suitability, based upon properties determined from results of the laboratory testing of the samples, is outlined in Table 4-32.

Table 4-32 Suitability of dredge sediment for proposed aquaculture reuse

Sediment Material Property	Suitability
Geotechnical	
Material colour	n/a
Particle Size Distribution	Potentially suitable with treatment/processing
Moisture content	Potentially suitable with treatment/processing
Plasticity Index	Potentially suitable with treatment/processing
Linear Shrinkage	Potentially suitable with treatment/processing
Density test	Potentially suitable with treatment/processing
Strength and Consolidation	Potentially suitable with treatment/processing
Permeability	Likely suitable
Geochemical	

Sediment Material Property	Suitability
PASS	Likely suitable
Salinity	Likely suitable
Organic Material	Likely suitable
Other	
Cement laboratory testing	n/a

The volumes to be dredged are small, however due to high fine clay and silt content a potentially large quantity of material suitable for lining material and embankment for aquaculture ponds may be produced.

4.4.1.4 Process description

Dredging and placement

The dredging and placement requirements for this option are as identified for construction fill at Section 4.2.2.4.

Infrastructure and management requirements

In addition to the onshore infrastructure and management requirements identified for construction fill at Section 4.2.2.4, material to be used for aquaculture may require more extensive processing to separate and / or mix material suitable for use in aquaculture ponds.

The material will need to be extracted for the storage pond and sorted into various particle sizes by a screening plant. The materials would be stockpiled by particle size and can then be batched, and if necessary blended with imported material, to create material suitable for use in pond embankments, including clay liner for aquaculture facilities.

For the purposes of analysis it is assumed that the material would be delivered to existing aquaculture facilities in the region, requiring an approximately 75km round trip.

4.4.1.5 Potential constraints

Potential constraints associated with this option include:

- Complex process of mixing, treatment, extraction, processing by screening, stockpiling and then potential blending and batching with imported material to manufacture material suitable for use in aquaculture
- Production of material for aquaculture facilities may be more process intensive than other methods of production, and as such the cost of supply may need to be subsidised by NQBP to create demand

- Likely to be a limited requirement for material for aquaculture facilities in the region, and as such, dredged material as source of this material will be opportunistic only i.e. not a continuous source of material
- Construction of the bunds for the onshore placement ponds requires 27,000m^3 of material, much of which may require importation, and access to this material may be difficult
- Rainfall levels in the region will impact the speed at which dewatering may occur
- Infrastructure development would need to consider potential impact of extreme events, including for pump-out and onshore infrastructure
- Limited information regarding existing conditions on site (including geotechnical conditions, potential for seepage from ponds and suitability of material that may be locally sourced) which will affect engineering design
- Sea and weather conditions may affect operability of the supporting infrastructure, particularly pipeline to the onshore placement area
- Potential acid sulphate soils, while unlikely to be an issue, will require consideration and potentially management during placement, particularly if separation of potentially acid forming material from acid neutralising capacity material occurs during processing
- Construction and operation of the placement area will require improvement of access to Dudgeon Point, and will increase traffic on local roads

4.4.1.6 Potential implications

Potential implications of this option, considering potential environmental, commercial and socio-economic outcomes include:

- Development of a potential source of material for use in aquaculture facilities in the region, albeit that it would be unlikely cost competitive without subsidisation
- Onshore placement may cause temporary sterilisation of land at Dudgeon Point
- Onshore placement will cause some (manageable) impacts to water quality in areas adjacent to the dredging and marine discharge areas
- Onshore placement may cause some (manageable) impacts to migratory shorebird habitat in Sandringham Bay (adjacent Dudgeon Point)
- Construction and operation of the onshore placement area will cause temporary and intermittent loss of amenity to the local community, through increases in local traffic, particularly along Bally Keel Road and the area of Alligator Creek.

4.4.1.7 Approvals

Approvals associated with dredging and placement and onshore reuse (as identified in Table 3-1) will be required for the construction and operation of this option.

The recently introduced *Sustainable Ports Development Act 2015* identifies the ports of Hay Point and Mackay as priority ports, and stipulates that material generated from capital dredging of these areas must be beneficially reused (as a condition of any approval), which may include use in aquaculture facilities. Whilst potential approval of maintenance dredging is not subject to this condition, it is considered that the beneficial use of maintenance dredge material for aquaculture facilities is not inconsistent with existing Queensland Government legislation and policy.

While an existing facility would likely have relevant approvals in place, obtainment of regulatory approvals for a new aquaculture facility in the Great Barrier Reef region is likely to be a significant challenge.

4.4.1.8 Costs

A summary breakdown of the estimated costs associated with execution of the aquaculture facilities option is provided in Table 4-33. The costs are based on the assumed process description described above, with further detailed assumptions provided in Appendix B.

Depending on the location of the concept (dredge method, distance from dredging zone and water depth for accessibility), it is estimated that costs will be approximately $110/m^3 measured in situ.

Table 4-33 Aquaculture facilities summary cost estimate table

Key activity	Aquaculture facilities
Offshore	
Trailing Suction Hopper Dredge mobilisation and demobilisation	$5,000,000
Pipeline mobilisation and demobilisation	$5,000,000
Workboat	$340,000
Dredge and pump to placement location	$2,000,000
Onshore	
Dredge management ponds	$4,000,000
Processing material, including dewatering	$500,000
Processing material including extensive screening/blending/mixing	$2,000,000
Monitoring and management	$500,000
Transport road transport to aquaculture use	$2,700,000
Total	**$22,040,000**

4.4.1.9 Greenhouse gas emissions

The estimated Green House Gas emissions associated with the aquaculture facilities option is 4,921 tonnes of CO_2 equivalent. The estimated emissions are based on the assumed process description described above, with further detailed assumptions provided in Appendix C.

4.4.1.10 Knowledge gaps

If the aquaculture facilities option was to be further pursued, key areas where additional information would be required include:

- Demand for material from the aquaculture industry to support the use and improved understanding of comparative cost of production of material currently used
- Coastal dynamics and processes specific to the proposed location of the dredge pump-out areas to enable design of fit for purpose structures, including mooring requirements and dewatering discharge location
- Availability of suitable construction materials for the bunds, and conditions on site suitable for the construction of ponds
- Detailed design including consideration of dredging, placement, construction and ongoing use of the reclamation area
- Site access requirements including potential road upgrades.

4.4.1.11 Future considerations

The dredged material is likely to be able to be dewatered and processed within the assumed five year period between dredging campaigns, and as such, assuming there is a demand for the material so that it may be removed from the onshore placement ponds, the area is likely to be available for ongoing use for onshore placement. Market demand would dictate whether the use provides a long-term beneficial reuse for the dredged material.

4.4.1.12 Performance summary

A summary of the performance of the aquaculture facilities option based on the use of the performance criteria described in Section 3.3.3 is provided in Table 4-34.

Table 4-34 Aquaculture facilities performance summary

Performance Criteria	Aquaculture facilities performance
Opportunity	**Moderate:** Potentially a demand reasonably accessible to the Port of Hay Point, requiring infrastructure construction
Sediment suitability	**Moderate:** Reuse option potentially suited to the dredge material. Requires treatment, processing and/or additives to make material suitable
Cost	**Low:** More than $17M in a 5 year period

Performance Criteria	Aquaculture facilities performance
Process	**Moderate:** The proposed process is sound but there are few examples of it being applied in environments similar to the port of Hay Point using maintenance dredge material
Duration	**Moderate:** 1 to 3 years to construct and function as the proposed final use
GHGs	**Moderate:** >2500t and <5000t CO_2 equivalent
Environmental Implications	**Moderate:** Nuisance or harm issues identified, but for the most part are considered manageable
Social Implications	**Moderate:** Social effects for the most part are considered manageable
Economic Implications	**Low:** Lost or negative economic opportunities to enhance port or community capability
Approvals and Permits	**Moderate:** Recognised approvals pathway, with significant management issues identified
Constraints	**Moderate:** Constraints are identified and there is a degree of uncertainty in the ability to overcome or manage them
Knowledge Gaps	**Moderate:** There are multiple knowledge gaps and 1-3 years of further research work would be required to progress the reuse option
Future considerations	**Low:** The reuse option has only a single or limited application

4.4.2 Topsoil for agricultural use

4.4.2.1 Activity description

Dredged material may be used to improve soil structure for agricultural use. Maintenance dredging in harbors, access channels, and rivers produces mixtures of sand, silt, clay, and organic matter, while the best topsoil is a mixture of sand, silt, clay, and organic matter. As the dredged material comes from coastal areas, attention must be given to salinity, as practically no agricultural species can grow in salty soils and few in brackish soils. Salinity may be reduced naturally by rain or by the dewatering process (PIANC, 1992).

4.4.2.2 Opportunity

The sugar industry in the Mackay region has a history of applying soil additive such as mill mud, fly ash and dunder, therefore, should disposing of the ripened dredge material as a soil additive be considered, the machinery required is commonly available, although the physical properties of the ripened dredge material may be an issue.

It may be possible to use the Hay Point dredge material for agricultural use after dewatering, oxidising and leaching to remove salt. There are two options that may be considered for the reuse of the dredge material for agricultural use:

- Option 1. The dredge material could be deposited in a bunded and drainage controlled area, allowed to ripen[7] and then used in-situ for growing vegetation.
- Option 2. The dredge material that has been deposited in a bunded and drainage controlled area is allowed to ripen and is then excavated and used as a soil additive applied to existing crops that in this area would most likely be sugarcane or possibly pastures.

It is considered that of these options, the most likely feasible as a long-term beneficial reuse, is Option 2, i.e. onshore placement of material, followed by processing, transport and application to soils elsewhere in the region. This option is the focus of analysis below.

4.4.2.3 Suitability of Hay Point sediments

There are low quality sandy soils such as south of Sarina around Koumala (approximately 50km south of Hay Point, refer to Figure 3-1) that are currently used for growing sugar cane that may benefit from additions of clayey material derived from dredging. There may also be opportunities to place material on pastures, particularly if nutrients are added.

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[7] Soil ripening is defined as a pedogenetical process that converts soft, waterlogged and reduced materials into soils (Pons and Zonneveld, 1965). It is comprised of chemical, biological and physical processes. The chemical processes include oxidation of reduced materials in the dredge material and leaching of salts. Biological processes include bioturbation and plant growth while the physical processes mainly include dewatering and changes in bulk density, permeability and structure.

As part of the assessment of the proposed agricultural reuse opportunity described above, the sediment suitability, based upon properties determined from results of the laboratory testing of the samples, is outlined in Table 4-35 (suitability categories as per Section 3.3.1).

Table 4-35 Suitability of dredge sediment for proposed agricultural topsoil reuse

Sediment Material Property	Suitability
Geotechnical	
Material colour	n/a
Particle Size Distribution	Potentially suitable with treatment/processing
Moisture content	Potentially suitable with treatment/processing
Plasticity Index	Potentially suitable with treatment/processing
Linear Shrinkage	Potentially suitable with treatment/processing
Density test	Potentially suitable with treatment/processing
Strength and Consolidation	Potentially suitable with treatment/processing
Permeability	Likely suitable
Geochemical	
PASS	Likely suitable
Salinity	Potentially suitable with treatment/processing
Organic Material	Potentially suitable with treatment/processing
Other	
Cement laboratory testing	n/a

The sediment material requires treatment (dewatering and desalination) and processing (soil ripening, blending, and mixing) to improve its suitability for reuse as agricultural topsoil.

4.4.2.4 Process description

Dredging and placement

The dredging and placement requirements for this option are as identified for construction fill at Section 4.2.2.4.

Infrastructure and management requirements

A review of literature suggests that given the fine textured materials, the depth of the deposited dredge material should be a maximum of 1m to allow dewatering, leaching and oxidising i.e., ripening (van Driel and Nijssen, 1988). A depth of 500mm would promote more rapid ripening. Given the volume of sediment is 200,000m^3 the area needed for ripening would be 50ha if deposited 500mm thick. As such the onshore infrastructure requirements described for the construction fill option, in Section 4.2.2 would be similar for this option. In addition to these requirements, material to be used for agricultural use requires further treatment to desalinate the material, and more extensive processing to separate and / or mix material.

The high salt level will be reduced by exposure to rainfall to achieving leaching of the salts and periodic 'mixing and turning over' the stored material by an excavator over an extended period of time (up to three years).

Halophytes could be planted to increase the rate of ripening when salinity levels in the surface 100-200mm of the dredge material has been reduced to acceptable levels e.g., 2.5 dSm^{-1} (Koropchak et al 2015). Soil amendments such as compost may be beneficial at this stage.

The material will need to be extracted from the storage pond and sorted into various particle sizes by a screening plant. The materials is stockpiled by particle size and can then be batched, and if necessary blended with imported material, to create agricultural soil material to achieve the required particle size distribution and properties.

For the purposes of analysis it is assumed that road base would be delivered to the agricultural facilities in the region requiring an approximately 75km round trip.

The chemical characteristics of the samples analysed to date as described in the sediment properties report (Appendix A) suggest that acidification of the sediments following dredging is unlikely.

4.4.2.5 Potential constraints

Potential constraints associated with this option include:

- Complex process of mixing, treatment, extraction, processing by screening, stockpiling and then blending and batching with imported material to manufacture material suitable for agriculture
- Production of agricultural materials from the dredge material is more process intensive than other methods, and as such the cost of supply will likely need to be subsidised by NQBP to create demand
- Dredge material as source of agricultural material will be opportunistic only i.e. not a continuous source of material
- Construction of the bunds for the onshore placement ponds requires 27,000m^3 of material, much of which may require importation, and access to this material may be difficult
- Rainfall levels in the region will impact the speed at which dewatering may occur

- Infrastructure development would need to consider potential impact of extreme events, including for pump-out and onshore infrastructure
- Limited information regarding existing conditions on site (including geotechnical conditions, potential for seepage from ponds and suitability of material that may be locally sourced) which will affect engineering design
- Sea and weather conditions may affect operability of the supporting infrastructure, particularly pipeline to the onshore placement area
- Potential acid sulphate soils, while unlikely to be an issue, will require consideration and potentially management during placement, particularly if separation of potentially acid forming material from acid neutralising capacity material occurs during processing
- Construction and operation of the placement area will require improvement of access to Dudgeon Point, and will increase traffic on local roads

4.4.2.6 Potential implications

Potential implications of this option, considering potential environmental, commercial and socio-economic outcomes include:

- Development of a potential source of agricultural material in the region, albeit that it would be unlikely cost competitive without subsidisation
- Onshore placement may cause temporary sterilisation of land at Dudgeon
- Onshore placement will cause some (manageable) impacts to water quality in areas adjacent to the dredging and marine discharge areas
- Onshore placement may cause some (manageable) impacts to migratory shorebird habitat in Sandringham Bay (adjacent Dudgeon Point)
- Construction and operation of the onshore placement area will cause temporary and intermittent loss of amenity to the local community, through increases in local traffic, particularly along Bally Keel Road and the area of Alligator Creek.

4.4.2.7 Approvals

Approvals associated with dredging and placement and onshore reuse (as identified in Table 3-1) will be required for the construction and operation of this option.

The recently introduced *Sustainable Ports Development Act 2015* identifies the ports of Hay Point and Mackay as priority ports, and stipulates that material generated from capital dredging of these areas must be beneficially reused (as a condition of any approval), which may include use as agricultural material. Whilst potential approval of maintenance dredging is not subject to this condition, it is considered that the beneficial use of maintenance dredge material for agricultural material is not inconsistent with existing Queensland Government legislation and policy.

4.4.2.8 Costs

A summary breakdown of the estimated costs associated with execution of the agricultural topsoilmaterials option is provided in Table 4-36. The costs are based on the assumed process description described above, with further detailed assumptions provided in Appendix B.

Depending on the location of the concept (dredge method, distance from dredging zone and water depth for accessibility), it is estimated that costs will be approximately $106/m^3$ measured in situ.

Table 4-36 Agricultural topsoil material summary cost estimate table

Key activity	Agricultural material
Offshore	
Trailing Suction Hopper Dredge mobilisation and demobilisation	$5,000,000
Pipeline mobilisation and demobilisation	$5,000,000
Workboat	$340,000
Dredge and pump to placement location	$2,000,000
Onshore	
Dredge management ponds	$4,000,000
Processing material, including dewatering and desalination	$1,000,000
Processing material including limited screening/blending/mixing	$1,000,000
Monitoring and management	$250,000
Transport road transport to agricultural use	$2,700,000
Total	**$21,290,000**

4.4.2.9 Greenhouse gas emissions

The estimated Green House Gas emissions associated with the agricultural materials option is 4,921 tonnes of CO2-equivalent. The estimated emissions are based on the assumed process description described above, with further detailed assumptions provided in Appendix C.

4.4.2.10 Knowledge gaps

If the agricultural materials option was to be further pursued, key areas where additional information would be required include:

- Demand for agricultural materials and improved understanding of comparative cost of production
- Further investigations related to the rate of soil ripening in an onshore placement facility
- Coastal dynamics and processes specific to the proposal location of the dredge pump-out areas to enable design of fit for purpose structures, including mooring requirements and dewatering discharge location
- Availability of suitable construction materials for the bunds, and conditions on site suitable for the construction of ponds
- Detailed design including consideration of dredging, placement, construction and ongoing use of the reclamation area
- Site access requirements including potential road upgrades

4.4.2.11 Future considerations

While further work is required to more accurately estimate the rate of ripening, the current estimate is that dredge material deposited 500mm thick could be ripened and disposed off-site before the subsequent dredging operation (assuming five years between campaigns) i.e., one site of 50 ha would be required and reused for each dredging operation. As such, assuming there is a demand for the material so that it may be removed from the onshore placement ponds, the area is likely to be available for ongoing use for onshore placement.

Prior to use of the dredge material for agricultural purposes it would have to be comprehensively characterised with respect potential contaminants. Other properties such as nutrient content and clay mineralogy would assist in determining the most appropriate use and location for disposal of the materials.

4.4.2.12 Performance summary

A summary of the performance of the agricultural materials option based on the use of the performance criteria described in Section 3.3.3 is provided in Table 4-37.

Table 4-37 Agricultural topsoil material performance summary

Performance Criteria	Agricultural materials performance
Opportunity	**Moderate:** Potentially a demand reasonably accessible to the Port of Hay Point, requiring infrastructure construction
Sediment suitability	**Moderate:** Reuse option potentially suited to the dredge material. Requires treatment, processing and/or additives to make material suitable

Performance Criteria	Agricultural materials performance
Cost	**Low:** More than $17M in a 5 year period
Process	**Moderate:** The proposed process is sound but there are few examples of it being applied in environments similar to the port of Hay Point using maintenance dredge material
Duration	**Moderate:** 1 to 3 years to construct and function as the proposed final use
GHGs	**Moderate:** >2500t and <5000t CO_2 equivalent
Environmental Implications	**Moderate:** Nuisance or harm issues identified, but for the most part are considered manageable
Social Implications	**Moderate:** Social effects for the most part are considered manageable
Economic Implications	**Low:** Lost or negative economic opportunities to enhance port or community capability
Approvals and Permits	**Moderate:** Recognised approvals pathway, with significant management issues identified
Constraints	**Moderate:** Constraints are identified and there is a degree of uncertainty in the ability to overcome or manage them
Knowledge Gaps	**High:** There are few knowledge gaps and less than 1 year of further research work would be required to progress the reuse option
Future considerations	**Moderate:** The reuse option would cater for immediate needs and has some scope in the short term (several years), although options would need to be regularly reassessed

5 Conclusions

Comparison of each of the beneficial reuse options that were analysed is provided in Table 5-1 and Figure 5-1.

Comparative analysis of the potential reuse options shows that:

- None of the options have a clear existing demand for the reuse of sediment material that would require minimal infrastructure needs. For most options, a potential demand exists requiring infrastructure construction, while for three options (shoreline protection, beach nourishment and deep water habitat creation) no substantive demand for the dredge material was identified.
- All but one of the options were assessed as having low to moderate sediment suitability performance, indicating the material would require some or significant treatment, processing and/or additives. Only for the habitat restoration (direct placement) option was it likely the sediment material could be utilised without treatment or additives.
- Most of the options were of low performance with respect to cost (more than $17million in a five year period) with three options of moderate performance (between $10million and $17million in a five year period). Only the option of deep water habitat creation, which has costs similar to traditional offshore placement (less than $10million in a five year period), is considered to be high performance with respect cost. As noted previously, quantification of conceptual cost associated with each option is based on assessment of dredge material use from a single maintenance dredging campaign. For a number of options, particularly those involving intermediate storage, infrastructure that is developed for the initial campaign may be used for subsequent campaigns, and therefore this initial cost of infrastructure, may provide long-term use. For other options, such as beach nourishment, there is unlikely to be a long-term maintenance dredging benefit gained from infrastructure development.
- For most of the options, the proposed process is sound; however, there are few examples of the reuse being applied in environments similar to the Port of Hay Point using maintenance dredge material. Two of the 'recycle as environmental enhancement' options (habitat restoration using indirect placement and deep water habitat creation) were considered to be mostly unproven for maintenance dredge material such as that of Hay Point.
- The options for use that did not require intermediate storage, with placement directly to the environment were generally of high performance with respect duration, due to their taking less than one year to function as the final use. The exception to this is reclamation, which, due to likely extended dewatering times was rated as low performance (i.e. greater than 3 years to construct and function as the proposed final use). The remaining options required onshore placement, with each option being rated as moderate i.e. 1 to 3 years to construct and treated in preparation for proposed final use.
- Similarly the options that did not require intermediate storage were of high performance (less than 2500t CO_2 equivalent) with respect greenhouse gas emissions. The options that required onshore placement were of moderate performance (between 2500t and 5000t CO_2 equivalent), with the exception of the liner materials option which was of low performance (greater than 5000t CO_2 equivalent) due to the long transport distance required for the end product.

Table 5-1 Beneficial reuse options performance summary

Performance Criteria	High Performance	Moderate Performance	Low Performance	Beneficial Reuse Options											
				Reuse Dredge material as an engineering material							Recycle Dredge material as an environmental enhancement			Recycle Dredge material in agricultural application	
				1. Land reclamation	2. Construction fill (low strength)	3. Road base / Pavement	4. Lining material	5. Concrete products (low strength)	6. Shoreline protection	7. Beach nourishment	8. Habitat restoration (direct placement)	9. Habitat restoration (indirect placement)	10. Deep water habitat creation	11. Aquaculture	12. Topsoil for agricultural use
Opportunity	The is an existing demand in a location accessible to the Port of Hay Point, requiring minimal infrastructure needs	Potentially a demand reasonably accessible to the Port of Hay Point, requiring infrastructure construction	No demand identified, poor access to the Port of Hay Point, requiring extensive infrastructure construction	Mod.	Mod.	Mod.	Mod.	Mod.	Low	Low	Mod.	Mod.	Low	Mod.	Mod.
Sediment Suitability	Reuse option well suited to the dredge material. Requires no additives or treatment (other than dewatering if necessary)	Reuse option potentially suited to the dredge material. Requires treatment, processing and/or additives to make material suitable	Reuse option poorly suited to the dredge material. Requires substantial treatment, processing and/or additives to ; or treatment to a suitable level is considered unachievable	Mod.	Low	Low	Mod.	Mod.	Mod.	Low	High	Mod.	Low	Mod.	Mod.
Cost	Less than $10M in a 5 year period	$10M to $17M in a 5 year period	More than $17M in a 5 year period	Low	Low	Low	Low	Low	Low	Mod.	Mod.	Mod.	High	Low	Low
Process	The proposed process is well understood and clearly demonstrated in similar environments to the Port of Hay Point using maintenance dredge material	The proposed process is sound but there are few examples of it being applied in environments similar to the port of Hay Point using maintenance dredge material	The proposed process is mostly unproven	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Low	Low	Mod.	Mod.
Duration	Less than 1 years to construct and function as the proposed final use	1 to 3 years to construct and function as the proposed final use	Greater than 3 years to construct and function as the proposed final use	Low	Mod.	Mod.	Mod.	Mod.	High	High	High	High	High	Mod.	Mod.
GHG emissions	< 2500t CO_2 equivalent	>2500t and <5000t CO_2 equivalent	>5000t CO_2 equivalent	High	Mod.	Mod.	Low	Mod.	High	High	High	High	High	Mod.	Mod.
Environmental Implications	Net benefit opportunities exist for positive environmental outcomes, with manageable nuisance of harm issues	Nuisance or harm issues identified, but for the most part are considered manageable	Nuisance or harm issues unlikely to be easily managed	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Low	High	High	High	Mod.	Mod.
Social Implications	Positive social opportunities exist for local communities and other key user groups	Social effects for the most part are considered manageable	Negative social impacts are unlikely to be easily managed	High	Mod.	Mod.	Mod.	Mod.	High	Low	High	High	High	Mod.	Mod.
Economic Implications	Positive economic opportunities exist enhancing port or community capability	Limited economic opportunities exist enhancing port or community capability	Lost or negative economic opportunities to enhance port or community capability	Low	Mod.	Low	Low	Mod.	Mod.	Mod.	High	High	Mod.	Low	Low
Approvals and Permits	Recognised approvals pathway, with few management issues identified	Recognised approvals pathway, with significant management issues identified	Not supported but current legislation / policy, or would require high level offset considerations	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.
Constraints	There are few constraints which are for the most part considered manageable	Constraints are identified and there is a degree of uncertainty in the ability to overcome or manage them	Multiple constraints are present that would limit realistic implementation	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.
Knowledge Gaps	There are few knowledge gaps and less than 1 year of further research work would be required to progress the reuse option	There are multiple knowledge gaps and 1-3 years of further research work would be required to progress the reuse option	There are multiple and/or complex knowledge gaps and greater than 3 years of further research work would be required to progress the reuse option	Mod.	High	Mod.	Mod.	High	Low	Low	Low	Low	Low	Mod.	High
Future considerations	The reuse option provides a long term solution for the Port of Hay Point for a period greater than 10 years	The reuse option would cater for immediate needs and has some scope in the short term (several years), although options would need to be regularly reassessed	The reuse option has only a single or limited application.	Low	Mod.	Mod.	Low	Mod.	Low	Low	Mod.	Mod.	Mod.	Low	Mod.

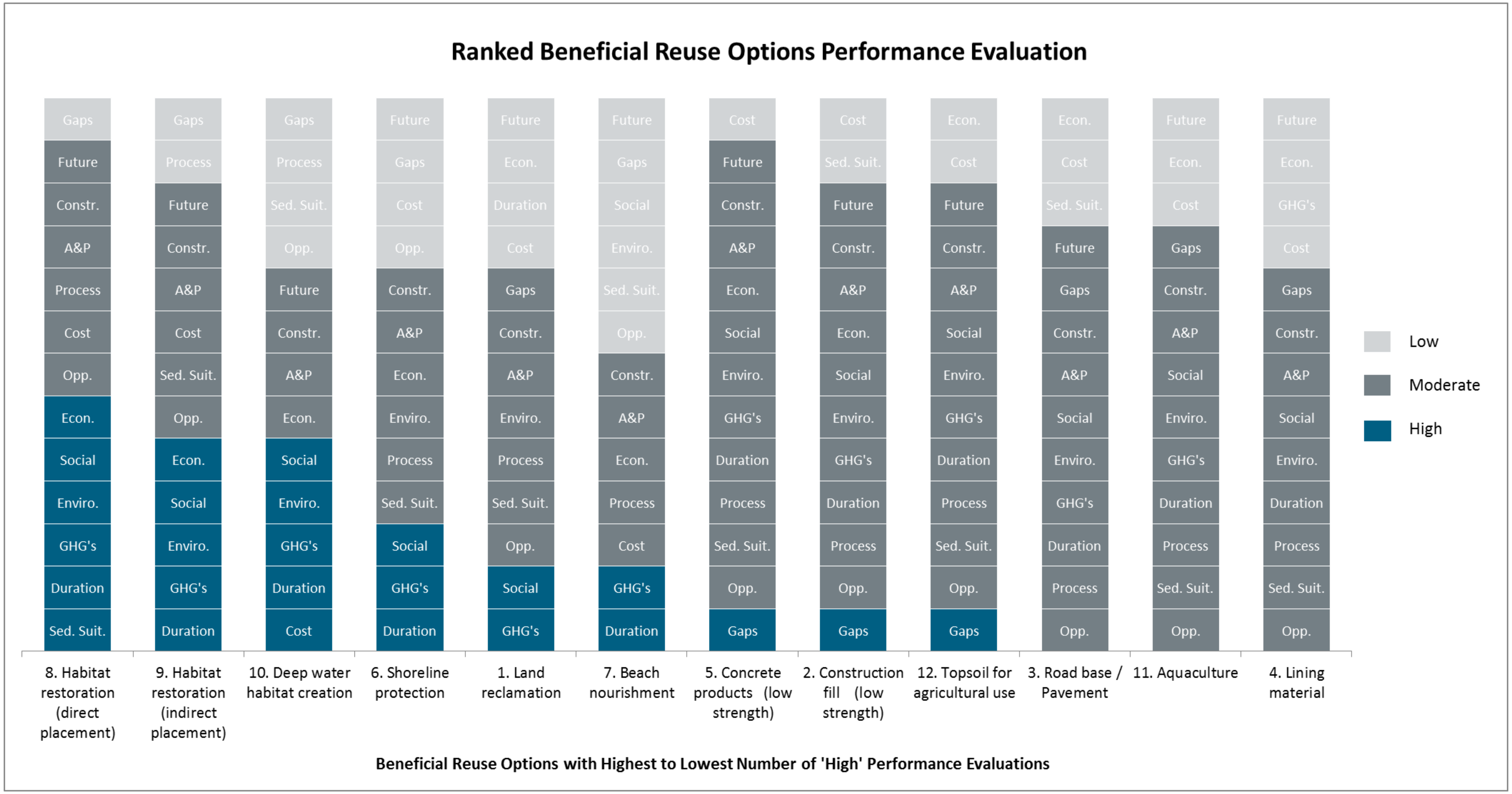


Figure 5-1 Beneficial reuse options performance evaluation

- Most of the options were rated as being of moderate performance with respect environmental implications i.e. potential nuisance or harm issues identified, but for the most part are considered manageable. The three options for recycling dredge material as an environmental enhancement were all rated as high performance, due to the net benefit opportunities that exist for positive environmental outcomes with each of the options. The beach nourishment option was rated as being of low performance due to potential for nuisance or harm issues unlikely to be easily managed, particularly water quality impacts near the placement location.
- The three options for recycling dredge material as an environmental enhancement, along with the reclamation and shoreline protection options were all rated as high performance due to the potential for positive social opportunities for local communities. The remaining options were rated as moderate performance, as they are likely to have social effects that are for the most part manageable, with the exception of the beach nourishment option, which was rated as low performance, due to the lack of compatibility of dredge sediments with local beaches causing negative social impacts that are unlikely to be easily managed.
- Two of the options for recycling dredge material as an environmental enhancement (habitat restoration options) were rated as high performance due to positive economic opportunities for enhancing community capability, including involvement in development of the project and opportunities associated with development of fisheries habitat. The engineering reuses of road base and liner material, and aquaculture and topsoil for agricultural uses were all rated as low performance, due to the likely need for subsidisation for the use to be acceptable. The land reclamation option was also rated as low performance, due to the reduction in availability of areas to develop for port uses. The remaining options were rated as moderate performance, as they may provide limited economic opportunities for enhancing port or community capability.
- For all options, there is a recognized approvals pathway with significant management issues identified.
- For all options, constraints are identified and there is a degree of uncertainty in the ability to overcome or manage them.
- For the construction fill (low strength) , concrete products (low strength) and topsoil for agriculture options there are few knowledge gaps and less than one year of further work would be required to progress the option. Conversely, each of the three options for recycling dredge material as an environmental enhancement along with the shoreline protection and beach nourishment options would likely require greater than three years of further research to address knowledge gaps, particularly with respect confirmation of the demand for the use and suitability of the material and placement strategy. The remaining options would likely require one to three years of further research to address multiple knowledge gaps.
- A number of options were considered to have a single, or limited application, including reclamation, liner materials, shoreline protection, beach nourishment and aquaculture facilities options. The remaining options may cater for immediate needs and have some scope in the short term to address maintenance dredging needs, with the ongoing use needing regular assessment. None of the options were considered to provide a clear long term solution for the Port of Hay Point.

The analysis indicates that, while there are a number of options for beneficial reuse that may be feasible, in consideration of all of the aspects relevant to the use, there is no clear preferred beneficial reuse for maintenance dredge material. For all of the options, further investigation regarding demand is required.

Three reuse options ranked well on the number of 'high' performance evaluation criteria, namely habitat restoration through direct placement, which ranked highest, followed in equal second position by habitat restoration through indirect placement, and deep water habitat creation. These options all involve placement direct to the environment, short duration and relatively low costs. All three options scored 'low' for knowledge gaps, indicating there are multiple or complex knowledge gaps requiring significant research work to progress these options.

If a suitable placement area is available the habitat restoration through direct placement option potentially offers environmental benefits, likely to be socially acceptable, and provides the prospect of a collaborative environmental research project. However, the availability of suitable areas for mangrove rehabilitation may limit the option as a long term solution. There may be an opportunity to implement this option as a pilot program in the Sandringham Bay area accompanied by stakeholder engagement (e.g. fisheries, reef catchment, research bodies) to assess suitability for future beneficial reuse.

There are a number of reuse options where the majority of performance criteria were scored moderate, with only one or two low performance criteria, namely concrete products (low strength), construction fill (low strength) and topsoil for agriculture. This finding may be interpreted as these options having few unknowns or constraints to their implementation. These options all involve the construction of onshore management ponds and potential long term treatment. If an onshore placement area were constructed this may create the potential for six of the beneficial options to be realised (construction fill (low strength), road base / pavement, lining material, concrete products (low strength), aquaculture and topsoil for agriculture). Subject to user demand for an end product, a single reuse option or combination of reuse options is possible once the material is placed onshore, enabling portions of the material to be directed to different reuse as demand arises.

A combination of beneficial reuse options may be considered over time as the long-term solution for dredged material management, including potential use for habitat restoration, which may be investigated, and potentially tested through a pilot program.

The report has met its primary objective of enabling a comprehensive comparative assessment of potential beneficial reuse options for sediment derived from maintenance dredging at the Port of Hay Point. Three recycle options ranked well on the number of 'high' performance evaluation criteria, namely habitat restoration through direct or indirect placement, and deep water habitat creation. The six options related to onshore dredge material management are considered worthy of further investigation to determine their feasibility, with particular consideration given to market demand for all the end products.

6 References

Aurecon, 2012. *Draft Final Port of Hay Point Ten Year Development Master Plan*. Developed for NQBP, September 2012

Australian Government, 2009. *National Assessment Guidelines for Dredging, 2009*. Commonwealth of Australia, Canberra

BMA, 2010. *Hay Point Coal Terminal Expansion (HPX) Marine Plants Restoration Project Plan, Hay Point, Queensland*. Developed by Eco Logical Australia for BMA

Bridgewater, P.B., and Cresswell, I.D., 1999. *Biogeography of mangrove and saltmarsh vegetation: implications for conservation and management in Australia*. Published in Mangroves and Salt Marshes 3: 117-125, 1999, Kluwer Academic Publishers

De Jong, M. F. 2016. *The ecological effects of deep sand extraction on the Dutch continental shelf: Implications for future extraction*. PhD thesis accessed from http://library.wur.nl/WebQuery/wda?q=De+Jong June 2016

Dear, SE, Moore, NG, Dobos, SK, Watling, KM and Ahern, CR, 2002. *Soil Management Guidelines in Queensland Acid Sulfate Soil Technical Manual*. Department of Natural Resources and Mines, Indooroopilly, Queensland, Australia

Dodds, K. 2004. *Estuarine and Marine Fisheries Resources and Habitats; an inventory of the central Queensland coast - Bowen - St Lawrence - 2004*. Mackay Whitsunday Natural resource Management Group. Natural Heritage Trust

Duke, N.C., Bell, A.M., Pederson, D.K., Roelfsema, C.M. Bengtson Nash, S. 2005. *Herbicides implicated as the cause of severe mangrove dieback in the Mackay region, NE Australia: consequences for marine plant habitats of the GBR World Heritage Area*. Published in Marine Pollution Bulletin 51 (2005) 308–324

Environmental Protection Agency (EPA), 2005. *Mackay Coast Study*. Produced by the Queensland Environmental Protection Agency, January 2005

Giroud, J. P., Badu-Tweneboah, K., and Soderman, K. L. ,1997. *Comparison of leachate flow through compacted clay liners and geosynthetic clay liners in landfill liner systems*. Geosynthetics International 4(3-4). 391-431

Koropchak, S.C., Daniels, W.L., Wick, A., Whittecar, G.R and Haus, N. (2015). *Beneficial use of dredge materials for soil reconstruction and development of dredge screening protocols*. Journal of Environmental Quality. Vol 45 No 1 pp62-73

Maritime Safety Queensland, 2016. *Port Procedures and Information for Shipping – Port of Hay Point, January 2016*. Accessed from http://www.msq.qld.gov.au/Shipping/Port-procedures/Port-procedures-hay-point June 2016

NQBP, 2009. *Port of Mackay Land Use Plan*. November, 2009

PIANC, 2009. *Dredged material as a resource: Options and constraints*. Environment Commission Report No. 104, 2009

PIANC, 1992. *Beneficial Uses of Dredged Material: A Practical Guide*. Report of PIANC Working Group 19, 1992

Pilarczyk, 2000, *Geosynthetics and Geosystems in Hydraulic and Coastal Engineering*, A.A. Balkema, Rotterdam

Pons, L.J. and Zonneveld, I.S. 1965. *Soil ripening and soil classification. Initial soil formation of alluvial deposits with a classification of the resulting soils*. H.Veenman&Zonen N.V. Wageningen, The Netherlands

Ports and Coastal Environmental Pty Ltd, 2014. *Port of Hay Point, DBCT Berths 1 and 2 - Sediment Characterisation Report*. Developed for North Queensland Bulk Ports Corporation, 2014

Rayment, GE and Lyons, DJ 2011, *Soil Chemical Methods – Australasia*, CSIRO Publication, Collingwood, Victoria, Australia

Rick Morton Consulting (RMC) Pty Ltd, 2012. Dudgeon Point Coal Terminals Project – Dredged Material Reuse Review. Prepared for WorleyParsons and North Queensland Bulk Ports Corporation, 2012

Royal HaskoningDHV, 2016a. *Hay Point Port: Bathymetric Analysis and Modelling*. Developed for North Queensland Bulk Ports Corporation, February 2016

Royal HaskoningDHV, 2016b. *Hay Point Port: Bathymetric Analysis*. Developed for North Queensland Bulk Ports Corporation, March 2016

Schroeder, P. R., Dozier, T. S., Zappi, P. A., McEnroe, B. M., Sjostrom, J. W., and Peyton, R. L., 1994. *The hydrologic evaluation of landfill performance (HELP) model: Engineering documentation for version 3*, EPA/600/R-94/168b, U.S. Environmental Protection Agency, Cincinnati, OH

TenCate, 2016. *Geotube, Geosynthetics, Containment*. Product sheet, accessed from http://www.tencate.com/amer/geosynthetics/solutions/marine-structures/default.aspx June, 2016

US ACE, 2004. *Dredging Operations and Environmental Research (DOER) Technical Note ERDC TN-DOER-R6*. Published in December 2004

Van Breeman, N. and Buurman, P. (2002) *Soil Formation*. Kluwer Academic Publishers. Netherlands

van Driel, W. and Nijssen, J (1988) *Development of dredged material disposal sites: Implications for soil, flora and food quality* pp101-126. Chemistry and Biology of Solid Waste. Springer-Verlag

Appendix A: Marine sediment properties assessment

Appendix B: Conceptual cost calculations

Appendix B, Table 1 - Estimated Cost of Beneficial Reuse Options

	Beneficial Reuse Option											
	Reuse Dredge material as an engineering material							Recycle Dredge material as an environmental enhancement			Reuse Dredge material in agricultural application	
Key Activity	1. Land Reclamation	2. Construction Fill	3. Roadbase/Pavement	4. Lining Material	5. Concrete Products	6. Shoreline Protection	7. Beach Nourishment	8. Environmental Bunds	9. Wetland Restoration	10. Habitat Creation	11. Aquaculture	12. Topsoil for Agriculture
Offshore												
TSHD Dredge mobilisation and demobilisation	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000
Pipeline mobilisation and demobilisation	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000		$7,000,000	$7,000,000	$5,000,000		$5,000,000	$5,000,000
Workboat	$500,000	$340,000	$340,000	$340,000	$340,000	$500,000	$500,000	$500,000	$340,000		$340,000	$340,000
TSHD Dredge and pump ashore	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$3,000,000	$3,000,000	$3,000,000	$3,000,000		$2,000,000	$2,000,000
TSHD Dredge and seabed placement										$2,000,000		
Tug and Barge mobilisation and demobilisation						$3,500,000						
Barge mooring						$1,000,000						
Place nearshore with tug, barge and geobags						$8,000,000						
Onshore												
Dredge management ponds construction		$4,000,000	$4,000,000	$4,000,000	$4,000,000						$4,000,000	$4,000,000
Processing dewatering/desalination/ripening	$1,000,000	$500,000	$1,000,000	$500,000	$500,000						$500,000	$1,000,000
Processing screening/blending/mixing		$1,000,000	$2,000,000	$2,000,000	$1,000,000						$2,000,000	$1,000,000
Processing pug mill					$450,000							
Processing additive portland cement (3.5%)					$3,250,000							
Rock Armouring for reclaimation area	$4,320,000											
Monitoring and management	$250,000	$250,000	$500,000	$500,000	$250,000	$250,000	$500,000	$500,000	$500,000	$500,000	$500,000	$250,000
Transport - road transport from site to end user		$2,700,000	$2,700,000	$4,200,000	$2,700,000						$2,700,000	$2,700,000
Totals	$18,070,000	$20,790,000	$22,540,000	$23,540,000	$24,490,000	$21,250,000	$16,000,000	$16,000,000	$13,840,000	$7,500,000	$22,040,000	$21,290,000
$/m^3	90	104	113	118	122	106	80	80	69	38	110	106

Basis of Estimate Assumptions:

Offshore Estimated Costs

1 Assume sediment material dredge volume 200,000m^3.

2 TSHD assume 'TSHD Brisbane' (or similar dredge vessel) including mobilisation ($2M -$3M) and demobilisation ($2M). Assume $5M total for TSHD mobilisation and demobilisation.

3 Pipeline mobilisation and installation/construction ($3 to $4M) and demobilisation ($2M to $3M). Assume $5M for up to 1.5km length, less complex pipeline transport to dredge pond storage (6 pond options, land reclaimation, wetland restoration). Assume $7M for longer length up to 5km including 1No. booster station and more complex operations restricted by tides and slower production rates, estimated 7.2 week duration, pump ashore process options (beach nourishment, environmental bunds).

4 Workboat assume aluminium cat 10m length, day rate at $10,000/day. Assume 34 days for straightforward pump ashore to dredge ponds storage (6 pond options) =$34,000. Assume 50 days for more complex pump ashore operations (land reclamation, shoreline protection, beach nourishment, environmental bunds)= $50,000.

5 Dredge and pump ashore ($10-$15/m^3), assume 'TSHD Brisbane' (or similar dredge vessel), hopper capacity 2900m3, dredge volume 200,000m3, estimate 68 trips, TSHD coupled to pump ashore pipeline 2 cycles per day. Assume $2M for straightforward pump ashore to dredge ponds storage (6 pond options and land reclaimation) with discharge within 7km of dredge area and with low tide access to nearshore, 24/7 operation, 4.8 weeks, 34 days, 816 hours dredging campaign. Assume $3M for more complex pump ashore option, discharge operations more restricted by tides, slower production rates, up to 10km sailing distance, 7.2 weeks, 50 days, 1209 hours (shoreline protection, beach nourishment, environmental bunds, wetland restoration). No allowance for downtime due to weather or sea state.

6 Dredge and seabed placement ($5-$10/m^3). Assume $10/m^3 for 200,000m^3 = $2M (habitat creation).

7 Tug (3No.)and Barge (3No.) mobilisation and demobilisation $3.5M. Tug and Barge transport (split hopper) for shoreline protection /geobags option.

8 Construction of barge mooring for receiving point for TSHD discharge (shoreline protection). Assume $1M for facility installation.

9 Place dredge sediment into geobags on barge and place filled geobags nearshore with tug and barge $40/m^3, 200,000m^3= $8M. Assume fill geobag at a location within 10km radius of dredge area, estimate 3 tugs, 3 barges 60 hour per week, 5 weeks dredging campaign 300 hour per tug. (shoreline protection with geobags). No allowance of downtime due to weather or sea state.

Onshore Estimated Costs

10 Onshore construction of dredge management ponds 50ha area, sediment material placed 0.5m deep for treatment. Estimate pond embankment dimensions 500m wide x 1000m long x 1.5m deep, bund walls volume 27,000m^3 at $150/$m^3$ supply and place a combination of site and imported material including pond liner = $4M. Estimate 12 weeks construction 60h/week, 2 x 36t excavator, 19t wheel loader, imported material assume 75km round trip, 20m^3 truck and dog (6 pond options).

11 Processing treatment for dewatering and desalination and soil ripening in dredge management pond assume 1000h per year for 3 years duration, excavator 36t and D6 Dozer at $150/h each =$900,000 and 2x 4WD passenger vehicles = $100,000. Assume $1M where soil ripening or a higher level of treatment processing and desalination required for end use (land reclaimation, road base/pavements, topsoil for agriculture). Assume $500,000 where less treatment processing and desalination is required for reuse option (construction fill, lining material, concrete products, aquaculture).

12 Processing screening/blending/mixing reuse material post-treatment for end user estimate $1M for screening plant and equipment at assumed production rate 40m^3/h, 5000h, with excavator 36t and 19t wheel loader 3000h each at $150/h $900,000. Assume $1M for end uses requiring less processing (construction fill, concrete products, topsoil for agriculture). Assume $2M for end uses requiring higher level of processing (roadbase/pavement, lining material, aquaculture).

13 Processing utilising a pug mill to create homogenous mix. daily rate $3,500/day including pug mill operator. Production rate 200m^3/h (1000h) for 125days assume = $450,000. Bulk Portland cement additive assume $200/t by weight betwenn 2% = $9.20/$m^3$ and 5% = $23.00/$m^3$. assume midway 3.5% =$16.10/m^3 for 200,000m^3 assume = $3,250,000.

14 Rock armouring for reclamation area, assume 20ha area 200m wide x 1000m long average depth 3m (min depth 0m to 6m depth) = 7,200m^2 face area of amour rock, supply and place estimate $600/$m^2$ = $4.32M.

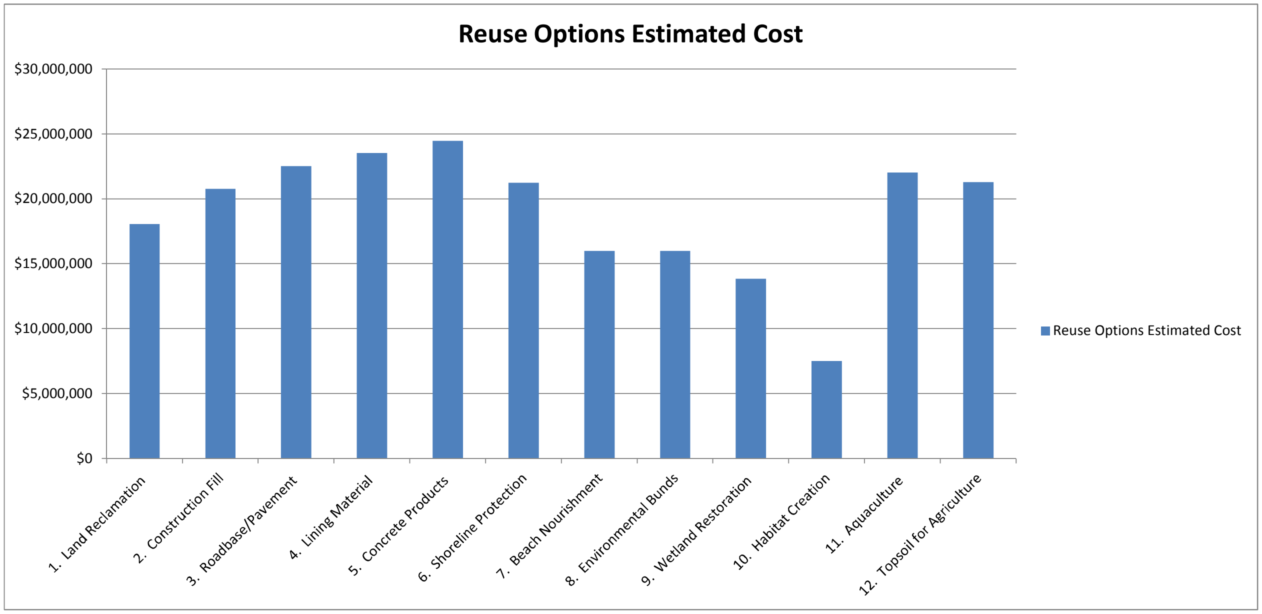
15 Monitoring and management, estimate $150,000 per year for site monitoring, investigation and reporting plus laboratory testing $25,000 for 3 years. Assume $500,000 for end uses requiring a higher level of materials quality control (roadbase/pavement, lining material, beach nourishment, environmental bunds, habitat creation, wetland restoration, aquaculture) and $250,000 for end uses requiring a lower level or material quality control (land reclamation, concrete products, topsoil for agriculture).

16 Transport processed sediment material off site to end user. Estimate 200m3/h loading for 36t excavator and 19t wheel loader 1000h at $150/h each =$300,000. Assumed 75km round trip, 20m^3 truck and dog 10,000x2hour trips 20,000h at $120/h = $2,400,000. Assume $2.7M for 75km round trip transport to off-site end users (construction fill, roadbase/pavement, concrete products, aquaculture, topsoil for agriculture) except Hogan's Pocket landfill 130km 3.5h round trip estimate 35,000h = $4.2M (lining material).

17 Mobilisation rate depends on location of vessels and pipeline at the time.

18 No allowance for on costs such as project management, administration, design, approvals, specialist engineering or scientific studies or access road to intermediate storage location.

19 No contingency.



Appendix C: Greenhouse gas emissions calculations

Appendix C, Table 1 - Greenhouse Gas Emissions Estimation

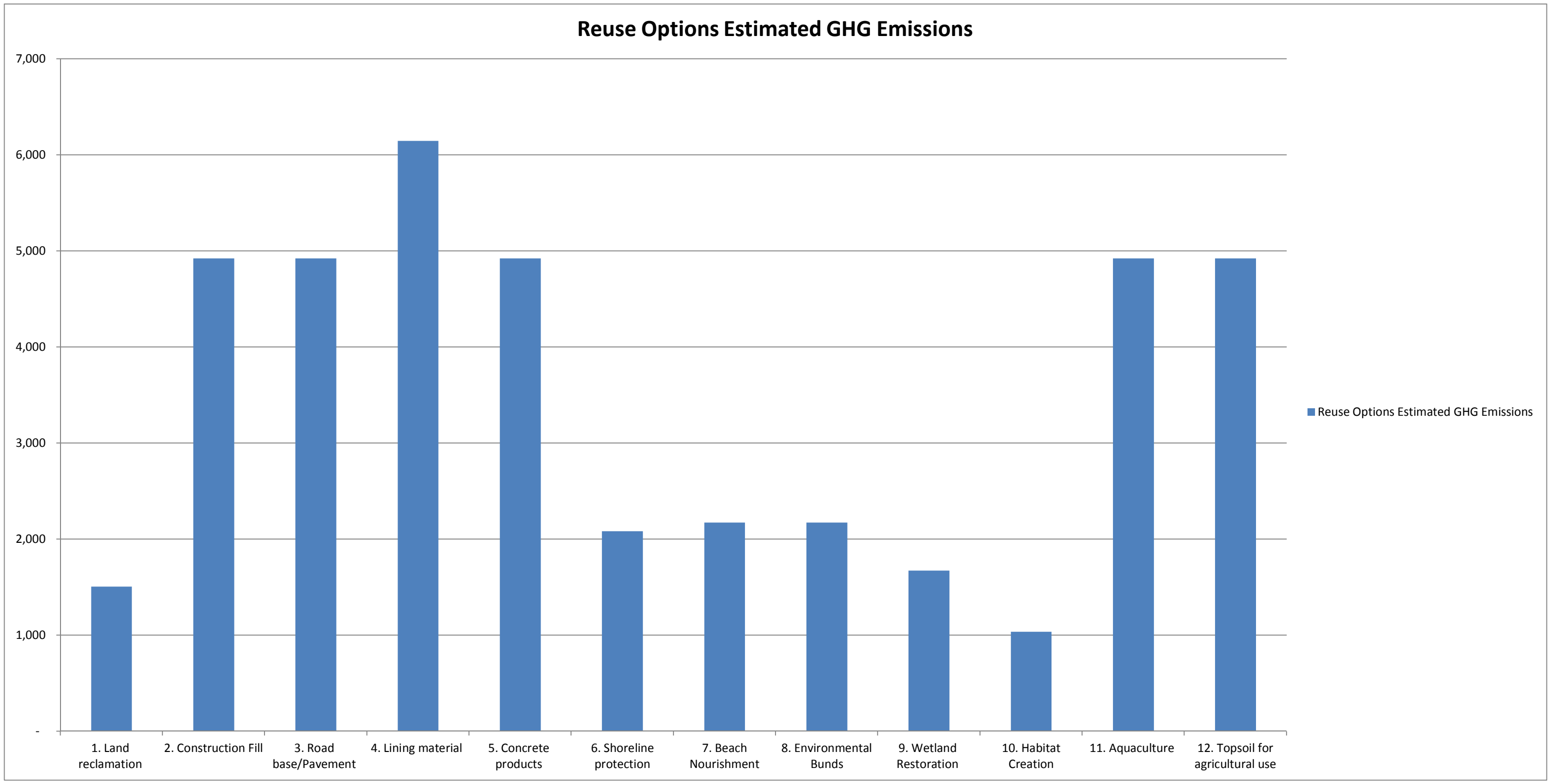
				GHG Emissions (t CO2-e)											
				Reuse Dredge material as an engineering material							Recycle Dredge material as an environmental enhancement			Reuse Dredge material in agricultural application	
Key Activity	Fuel Type	Volume (kL)	Emission Factor	1. Land reclamation	2. Construction Fill	3. Road base/Pavement	4. Lining material	5. Concrete products	6. Shoreline protection	7. Beach Nourishment	8. Environmental Bunds	9. Wetland Restoration	10. Habitat Creation	11. Aquaculture	12. Topsoil for agricultural use
Offshore															
Dredging (short duraation) - Trailing Suction Hopper Dredge (TSHD) [1]	Fuel Oil	351	As per NGA Factors 2015	1,035	1,035	1,035	1,035	1,035					1,035	1,035	1,035
Dredging (complex/long duration) - Trailing Suction Hopper Dredge (TSHD) [1]	Fuel Oil	520	As per NGA Factors 2016						1,533	1,533	1,533	1,533			
Floating Pipeline booster station [2]	Diesel	160	As per NGA Factors 2015							434	434				
Workboat - (short duration) [3]	Diesel	52	As per NGA Factors 2015		141	141	141	141				141		141	141
Workboat - (complex/long duration) [3]	Diesel	76	As per NGA Factors 2015	207					207	207	207				
Tug and Barge transport (e.g. split hopper barge) [4]	Diesel	126	As per NGA Factors 2015						343						
Onshore															
Onshore dredge management ponds construction [5]	Diesel	224	As per NGA Factors 2015		609	609	609	609						609	609
Processing, blending, mixing, soil ripening [6]	Diesel	348	As per NGA Factors 2015		947	947	947	947						947	947
Screening [7]	Diesel	100	As per NGA Factors 2015		271	271	271	271						271	271
Reclaimtion, rock amour wall construction [8]	Diesel	97	As per NGA Factors 2015	264											
Transport - road transport (excluding lining material) [9]	Diesel	705	As per NGA Factors 2015		1,919	1,919		1,919						1,919	1,919
Transport - road transport for lining material [9]	Diesel	1155	As per NGA Factors 2015				3,144								
Total				**1,505**	**4,921**	**4,921**	**6,146**	**4,921**	**2,083**	**2,173**	**2,173**	**1,674**	**1,035**	**4,921**	**4,921**

Notes:

1 Basis of assumption for GHG calculations outlined in assumptions sheet (refer 'assumptions' sheet)

2 Key activity column superscript numbers refer to the GHG calculation assumption notes relate to that activity

3 GHG calculation utilise NGER Scope 1 Emission Factors - Referenced from National Greenhouse Accounts Factors 2015 (refer 'NGA' sheet)


Reuse Options Estimated GHG Emissions
7,000
6,000
5,000
4,000
3,000
2,000
1,000
-
1. Land reclamation
2. Construction Fill
3. Road base/Pavement
4. Lining material
5. Concrete products
6. Shoreline protection
7. Beach Nourishment
8. Environmental Bunds
9. Wetland Restoration
10. Habitat Creation
11. Aquaculture
12. Topsoil for agricultural use
Reuse Options Estimated GHG Emissions