THE CONTINENTAL SHELF AS A SITE FOR DREDGED MATERIAL DISPOSAL, NORTHEAST NEW ZEALAND

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ABSTRACT

Disposal of dredged material has been an on-going problem in the Auckland Coastal Marine Area (CMA) since the early 1980s in New Zealand. Many disposal grounds have been established and used, but public concern over adverse effects resulted in their ultimate closure. Presently, dredged material is disposed off-shore at a site simultaneously accessed by the Royal New Zealand Navy for disposal of WWII munitions recovered from coastal areas. As early as the mid-1990s, parliamentary focus groups established the need for a more suitable disposal option for dredged material. Establishment of a disposal site north of Cuvier Island in waters deeper than 100 m was one of the key recommendations presented by these groups. The need for a new site was compounded after the establishment of the Hauraki Gulf Marine Park in 2000. Taking up the majority of the Auckland CMA this culturally significant Park makes the consent for open water disposal a complex process.

A site east of Great Barrier Island in 140 m of water has been identified as a potential suitable site for disposal of dredged material. The main goal of the present study is to determine the suitability of this site and provide the necessary information required by enforcing authorities for permit submission.

Investigations to determine the suitability of the site were undertaken in several ways. An extensive literature review of previous studies was carried out to gain insight into the physical and biological characteristics of the northeast coast and shelf. The main hydrodynamic features of the region and the observed behaviours were determined. Attentions were then directed at determining the more specific site characteristics. Analytical calculations were undertaken using known site parameters to estimate the potential for transport of sediment away from the site after disposal. Through analysis of known wave and current measurements it was estimated that only rarely would sediment be entrained off the seafloor. Samples were then collected from the site in November 2007, which were used for sediment textural analysis and benthic identification. It was determined that the main textural component of the site sediments is muddy/sand. Diversity of benthic species is relatively high, but abundance is low. Polychaetes were the most diverse and abundant taxon identified at sample locations across the site. Next, the 3DD model was used to numerically simulate 2-dimensional tidal currents. Depth-averaged spring tidal currents at the site were predicted to be less than 0.2 ms^{-1}. The derived bottom velocity for such a current is 0.08 ms^{-1}, which is much less than the velocity required for initiation of sediment movement in this case. The numerical simulation also showed that residual spring tidal flow is directed to the southeast. Finally, an assessment of potential impacts was done by reviewing previous studies of ecological impacts caused by disposal of dredged material. Based on the preliminary studies summarised above, the review of potential impacts indicates that there will only be minimal effects at and surrounding the proposed site. The result of this study is an encouraging step toward establishment of a new disposal option, but further research is required to confidently declare that the site is suitable for disposal operations.

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CHAPTER ONE: INTRODUCTION

1.1 A DREDGING DISPOSAL DILEMMA

Auckland area ports and marinas typically accumulate 10,000 to 50,000 m^3 per year of sediment that requires maintenance dredging (Parliamentary Commissioner for the Environment, 1995 and Pine Harbour Marina permit submission, 1999). Future capital works dredging projects could easily double the amount of material that must be disposed of annually.

Disposal of this dredged material is an ongoing problem in the Auckland coastal marine area, especially for those ports and marinas that contain predominantly muddy and/or contaminated sediments. The inability to dredge resulting from the scarcity of disposal options could impact the future sustainability and profitability of a port or marina, and eventually lead to its closure. As the ever-expanding shipping and recreational boating industry is a vital part of the New Zealand economy, such an outcome is highly undesirable.

Under the terms of the London Dumping Convention and the 1996 Protocol, to which New Zealand is a signatory, it is required that dredge spoil disposal sites be monitored. Accordingly, there is a need to identify a suitable site for disposal of the dredged sediment originating from the Auckland region as well as those coastal areas within the Hauraki Gulf Marine Park which include the Coromandel Peninsula (Figure 1.1).

A proposed disposal site has been identified on the continental shelf, outside the Hauraki Gulf Marine Park boundary, located some 20 km east of Great Barrier Island in the Exclusive Economic Zone. It is expected that this proposed disposal site will be more feasible to monitor than the existing deep water disposal site and will have less adverse environmental effects than historical disposal sites within the Hauraki Gulf. The assessment of this proposed site is the primary focus of this thesis.

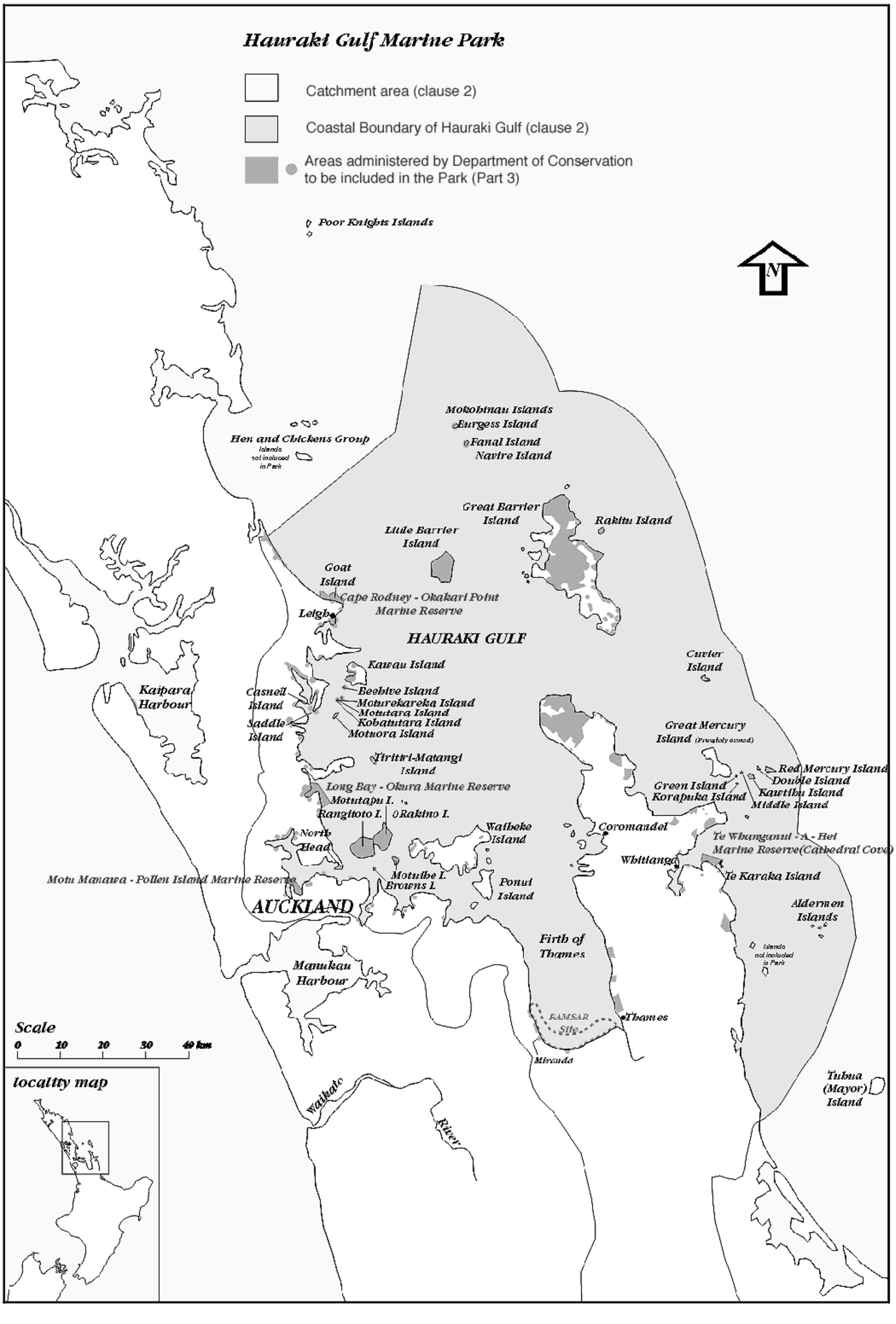

Figure 1.1 Boundary of the Hauraki Gulf Marine Park (indicated by the black line) established in 2000 (Source: Department of Conservation).

1.2 RESEARCH AIM & OBJECTIVES

The general aim of this study is to investigate the proposed disposal site in order to assess its suitability with regards to its function for disposal operations and the environmental impacts that may result. The ultimate goal of this study is to establish a disposal option for dredged material, originating from the Auckland and Coromandel area ports and marinas, which can be used in the long-term and will have minimal adverse environmental impacts.

The specific objectives of this thesis are to:

i. Review current and historical disposal sites in the Auckland coastal marine area (CMA) to determine the need for the establishment of a new disposal site.

ii. Review international, national, and regional guidelines and policies regarding disposal operations in the Auckland and Waikato coastal marine areas and the Exclusive Economic Zone to ascertain the necessary physical and biological parameters to be investigated at the proposed disposal site for long term disposal.

iii. Review current sediment texture and toxicity studies of Auckland area port and marina harbour sediments to determine the appropriateness for disposal at the proposed site.

iv. Undertake a detailed literature review of previous studies on the physical, biological, and hydrodynamic features of the north-east coast region of New Zealand for preliminary assessment of the suitability of the proposed site for disposal operations.

v. Characterise the seafloor sediments at the proposed site through sediment textural analysis.

vi. Estimate sediment transport potential via horizontal currents and waves at the proposed site through analytical calculations.

vii. Investigate the level of biological diversity and abundance at the proposed site through identification of benthic fauna retained from collected sediment samples.

viii. Through a numerical simulation, approximate regional hydrodynamic features to predict the potential for entrainment of disposed sediment off the seafloor.

ix. Carry out a literature review of studies that quantify environmental impacts resulting from disposal operations to determine what adverse effects may arise at the proposed site.

1.3 THESIS OUTLINE

Following this introductory chapter, thesis concepts and themes are presented in the following succession:

Chapter 2 reviews the history of dredgings disposal in the Auckland Coastal Marine Area. It evaluates the perceived success or failure of the sites by the public and various involved government agencies. In this chapter, alternative disposal methods that have been examined are also described and assessed with respect to ocean disposal methods. Finally, features and issues involved with using the existing disposal site are described in order to provide justification for the establishment of a new disposal site.

Described in **Chapter 3** are the various international, national, and regional guidelines and policies set forth to manage open water disposal of dredged material, which ports and marinas must comply with when undertaking disposal operations. Detailed in this chapter are the specific features of a proposed disposal site that must be appropriately investigated in order for disposal operations to be permitted at the site. These features are used as an indicator for determining the suitability of the site for disposal operations with the goal being to minimise adverse environmental effects that may occur. These required investigations are what will here forth govern the topics described in this thesis.

Detailed in **Chapter 4** are the various characteristics of the harbour sediments to be dredged and designated for an eventual disposal at the proposed site. The expected origins of these dredged materials are specified. Known chemical characteristics and textures of these areas are reviewed to determine if the sediment planned for disposal is appropriate for the proposed site.

Presented in **Chapter 5** are the significant features of the proposed site of which investigation is mandated by the policies presented in Chapter 3. The information detailed in this chapter is obtained from both previous studies of the north-east coast region and current studies undertaken as a part of this thesis research in particular. Specifically, geology and geomorphology, water properties, hydrodynamics, residual flows, sediment transport potential and biological composition and activity occurring at or in the region of the proposed site are described.

Results of a numerical simulation of the tidal hydrodynamic processes are reported in **Chapter 6**. These findings are significant for estimating the potential impacts that disposal operations at the proposed site may cause.

Potential impacts of disposal operations at the proposed site are outlined in **Chapter 7** by reviewing previous impact assessments and considering the results reported in Chapter 5 and Chapter 6.

Chapter 8 presents the major findings of the study. The implications of these findings to the interested stakeholders are also described, and recommendations for future research are given.

CHAPTER TWO: THE HISTORY OF DREDGE SPOIL DISPOSAL IN THE AUCKLAND COASTAL MARINE AREA

2.1 INTRODUCTION

In the early days of dredging and disposal of dredged material from the Port of Auckland, permits for disposal operations were granted by the Ministry of Transport, under the *Marine Pollution Act of 1974*. The main concern was primarily that operations did not hinder vessel mobility into and out of the harbours. Environmental issues involved with disposal operations were not thought to be a concern that needed to be regulated.

It was not until the late 1980s that concern over these issues, mainly expressed by the general public, made environmental matters a priority for the government organisations establishing and managing disposal grounds in the Hauraki Gulf coastal marine area.

2.1.1 BROWN'S ISLAND DISPOSAL GROUND

In 1987, marina developers began using a previously established disposal site north-east of Brown's Island in the Waitemata Harbour to dispose of muddy sediment dredged from Half Moon Bay and Beachlands as a part of marina developments (Ryan, 1989). The site was controlled by the, then, Auckland Harbour Board, and the permit for its usage was awarded by the Ministry of Transportation.

Public concern was raised after traces of the material began washing up on local beaches. Through court action it was decided that a Water Right, under the *Water and Soil Conservation Act of 1967* was needed, especially as it was determined that the Ministry of Transportation was acting negligently by not assessing potential environmental impacts of the disposal operations before awarding the permit (Ryan, 1989).

Accordingly, an assessment of the site was then commissioned by the Auckland Harbour Board to determine the ecological state of the site (Grace, 1988 as cited by Ryan, 1989). It was found that disposal operations at the site had significantly reduced the diversity and abundance of marine life at and surrounding the site. This habitat degradation was significant as the area surrounding the site was known to be a feeding ground for snapper (Ryan, 1989).

2.1.2 RANGITOTO DISPOSAL GROUNDS

Two dredging disposal grounds were used for many years in the 1980s near Rangitoto Island by Ports of Auckland. Assessment of the sites in 1988 and 1989 revealed several impacts on the surrounding ecosystems (Roberts *et al.*, 1991). Although recovery of the benthic fauna in the region was evident, it was apparent that there was a permanent change in the composition of the species (Roberts *et al.*, 1991). These two sites were located in shallow areas where species composition is typically diverse and populations are abundant. The impact assessment also concluded that effects could have been lessened if the dredged sediments had been dumped on sub-stratum texturally similar to that of the principle source (Roberts *et al.*, 1991).

2.1.3 NOISES DISPOSAL GROUND

A site for disposal of dredged sediment in 32 m water depth located centrally between Tiritiri Matangi Island and Waiheke Island in the Inner Hauraki Gulf was used by Ports of Auckland in 1992 (Parliamentary Commissioner for the Environment, 1995; Kingett Mitchell & Associates, 1990).

Consent was granted in 1991 for disposal of 270,000 m^3 of dredged sediment at the site, but conditions were put in place that mandated an extensive monitoring programme to assess the effects of the disposal operations (Parliamentary Commissioner for the Environment, 1995).

Post-disposal monitoring detected higher than expected levels of contaminants and it was also determined that not all of the originally dumped sediment could be accounted for, which implied a loss off-site (Dominic McCarthy (ARC), *pers.com.*, 2007). The investigations did not confirm that adverse effects were occurring offsite, but El Niňo conditions in that year made interpretation of results difficult.

The Parliamentary Commissioner for the Environment became involved when public concern over the disposal operations caused a significant amount controversy in the community. A technical review panel was formed by the Commissioner for the Environment to review the results of the monitoring programme, make recommendations for additions or changes to the monitoring programme, and to report the findings to the stakeholders (Parliamentary Commissioner for the Environment, 1995).

In the independent review of the findings, concern was raised over the loss of material offsite and the effectiveness of the site as a containment site was challenged (*pers. comm.*, Dominic McCarthy, 2007), but generally there were no particular red flags indicating that significant adverse effects were occurring.

However, in a show of good faith, the Ports of Auckland withdrew a pending disposal application for additional disposal of dredged sediment at the site. As a result, the Noises disposal ground was only used once for the disposal of 270,000 m^3 of sediment.

2.2 ASSESSMENT OF ALTERNATIVE DISPOSAL OPTIONS

As previously mentioned, modern environmental idealism was born in 1980s in New Zealand, especially with respect to issues surrounding dredge spoil disposal. Restrictions on consents for disposal operations in the Auckland Coastal Marine Area reflect this shift. By the 1990s, the concerns had become a global issue.

The *Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972*, otherwise known as the *London Dumping Convention*, had been in effect for a number of years and was used as a global convention on how to acceptably dispose of dredged material so as to avoid environmental impacts. By 1996, a Protocol to the *London Dumping Convention* had been produced, appropriately named the *1996 Protocol*, that amended and enhanced some of the guidelines of the *London Dumping Convention*.

The modern aims of the *1996 Protocol* were to assess dredgings disposal with a more precautionary approach than in previous times. That is, the Protocol aims to force applicants to consider alternative options for disposal that may have less environmental impacts and in fact, may be a benefit to the community than that of disposal at sea.

Known for its environmental activism, New Zealand was implementing precautionary measures related to dredge spoil disposal activities before the advent of the *1996 Protocol*. The public concern that was raised over the use of the Noises disposal site, mentioned above, initiated the formation of the Disposal Options Advisory Group that assessed numerous alternative options for disposal of dredged material beyond those which had already been used.

2.2.1 DISPOSAL OPTIONS ADVISORY GROUP

The Disposal Options Advisory Group (DOAG) was set up in 1993 to examine and report on the disposal options for dredged materials, especially regarding specific disposal operations at the Noises Disposal site by the Ports of Auckland, as noted above.

The series of reports detailed the potential disposal options for the dredged material being taken out of the Ports of Auckland with respect to cost, environmental effects, and feasibility. Besides reviewing marine disposal options, they also addressed harbour edge disposal options and land based disposal options.

2.2.1.1 Harbour edge disposal

The following are summary responses to the harbour edge disposal options for the Ports of Auckland disposal operations examined by the DOAG (DOAG, 1994):

i. **Reclamation:** thought to be unsuitable because mud is not commonly used in reclamation practices and for proper and safe consolidation of reclaimed material a period of 5-10 years must pass before the material can develop any load-bearing capacity.

ii. **Beach nourishment:** found to be unsuitable in the Auckland region because most dredged material is texturally muddy and cannot be used to re-nourish the local beaches.

iii. **Habitat enhancement or creation:** only two sites were identified as artificial wetland habitat that met the depth constraints for operation and were not in direct conflict with existing uses. It was stated that establishment of a viable wetland habitat would take 17 years as the duration of most dredging projects is approximately 15 years. Additionally, no locations for establishment of an artificial island were identified.

2.2.1.2 LAND BASED DISPOSAL

The following are summary responses to the land based disposal options examined by DOAG (DOAG, 1994):

i. **Solid landfill (or monofill):** found that "*solid landfills on existing reserves will have no overall benefits for existing residents. The necessary resource consents will be difficult to obtain"* (DOAG, 1994).

ii. **Disposal to sanitary landfill:** found to be an unsuitable option because most existing landfills are unable to assimilate large quantities for reasons relating to the potential for saltwater and heavy metal leaching.

iii. **Commercial and industrial applications:** found to be unsuitable because there is an oversupply of topsoil in Auckland and "*it would be difficult to balance the rate of dredging production with the ability to sell or off-load the material*" (DOAG, 1994).

iv. **Solid landfill or landscape reconstruction:** found to be a potential option but that possible negative effects such as aesthetics, dust/noise, odours, safety issues, and environmental effects would need to be assessed to ensure that they did not outweigh the positive effects.

v. **Disposal to Lake Pupuke:** rejected for various environmental factors.

vi. **Forestry applications:** thought to be not of beneficial use to forestry around Auckland.

2.2.1.3 DOAG CONCLUSIONS

After assessment of the various disposal options available to Ports of Auckland for dredged material the following preferences were stated (DOAG, 1994):

i. *For highly contaminated dredged material*

a) Port reclamation
b) Approved sanitary landfill

ii. *For maintenance dredgings that meet regulatory guidelines*

a) Port reclamation
b) Marine disposal in water deeper than 100m.

iii. *For capital works dredging*

a) Port reclamation
b) Marine disposal in water deeper than 100m.

These studies and others by the Parliamentary Commissioner for the Environment (1995) (Section 2.1.3) resulted in the discontinuation of disposal operations by the Ports of Auckland at the Noises Disposal site. Interestingly, that particular site is now located within the boundaries of what is now, the Hauraki Gulf Marine Park. The current policies governing this protected area are discussed in Section 3.7.

In the absence of any reclamation projects, according to the findings of the DOAG, future disposal of maintenance or capital works dredged sediment from the ports and marinas in the Auckland coastal marine area should be directed to a site in waters deeper than 100 m.

2.3 EXISTING DISPOSAL OPTIONS

2.3.1 EXPLOSIVES DUMPING GROUND

Currently, dredged sediment from various ports and marinas in the Auckland CMA, especially that which is contaminated or muddy, is being disposed of at the Explosives Dumping Ground (Figure 2.1). This site is located on the continental slope, at water depths ranging from 500 to 1300 m, east of Cuvier Island. It is used simultaneously by the Royal New Zealand Navy to dispose of unexploded munitions abandoned on the sea floor since WWII. When these munitions are discovered, they are transported to the site to be permanently disposed of in an area deemed safe because of its depth and distance from the coastline.

Despite the fact that the *London Dumping Convention* and the *1996 Protocol*, to which New Zealand is a signatory, call for extensive environmental monitoring of established dredge spoil disposal sites, the Explosives Dumping Ground has never been surveyed or monitored exclusively for dredge spoil disposal. The extreme water depth and danger in sampling around the munitions make the required monitoring of this site virtually impossible and the impacts of years of disposal operations at the site and on the surrounding areas is unknown.

The Explosives Dumping Ground is not suitable for future use for the following reasons:

i. Presence of explosives pose a threat during disposal operations and environmental monitoring;
ii. Disposal sites must be monitored under *London Dumping Convention* and *1996 Protocol*; and
iii. The Explosives Dumping Ground is too deep to easily monitor.

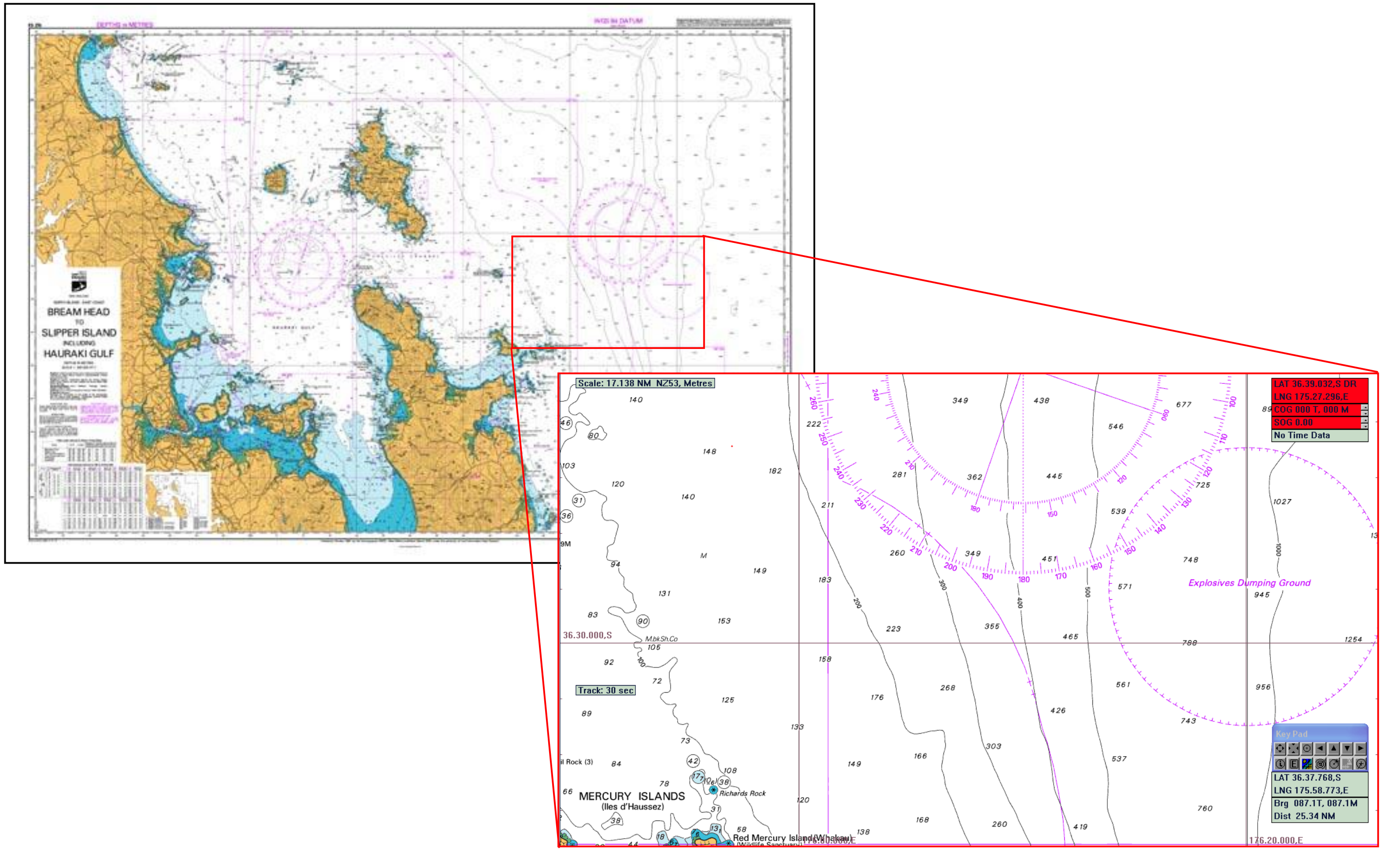

Figure 2.1 Hydrographic chart of the north-east coastal region of New Zealand (inset: location of the existing dredging disposal ground used simultaneously by the Royal New Zealand Navy as an explosives dumping ground) (Source: Frisken, 1992).

2.3.2 Pine Harbour Marina thin-layer disposal

Pine Harbour Marina has, since 1994, obtained several dredging and disposal consents for sediment that accumulates in the approach channel of the marina. The accumulated sediment is typically uncontaminated as it is not exposed to terrestrial runoff inside the marina, making the consent process for dredging and disposal relatively uncomplicated.

In 1994, Pine Harbour received its first consent for dredging and disposal of these sediments to the adjacent intertidal flats and, subsequently, in 1997 for disposal in the Beachlands-Howick embayment (Healy *et al*., 1999). These sediments were disposed as a thin-layer over the fluffy, silty sediments in the centre of the embayment. In this way, there is no formation of a distinct spoil mound. Surveys of the dredging and disposal process determined that there were no adverse affects from these operations occurring despite the proximity of the disposal site to the coastline (Healy, 1997). Subsequent reports on more recent dredging and disposal operations of the sediment from the approach channel determined similar results (Healy and Tian, 1998; Healy, 2002).

While the thin-layer disposal of the approach channel sediments has proven to be a successful undertaking (Healy *et al*., 1999), the case is different for the sediment that accumulates within the marina basin. Due to the slightly contaminated nature of the marina basin sediments, the consent process for dredging and disposal is significantly more complex. At the moment, the only site approved for disposal of these sediments, and other similar sediments from nearby ports and marinas, is the previously mentioned Explosives Dumping Ground, where Pine Harbour Marina currently disposes its slightly contaminated marina basin sediments (Dominic McCarthy (ARC), *pers. com*., 2007).

2.4 CONCLUSIONS

The history of dredging disposal in the Auckland coastal marine area is lengthy and intricate, lending evidence to the importance of the shipping industry in this area. Many disposal operations have been undertaken with varying degrees of success with respect to the resulting environmental effects. The majority of these, incidentally, have caused effects adverse enough to be discontinued completely.

Currently, only one disposal site has been deemed appropriate (mistakenly) for future disposal of slightly contaminated sediments originating from the Auckland coastal marine area, namely, the Explosives Dumping Ground. While this may be a convenient option for dredged material disposal, it does not satisfy the necessary requirements mandated by the *London Dumping Convention* and the *1996 Protocol,* to which New Zealand is a signatory. Therefore, it is likely that in the future, the Explosives Dumping Ground will no longer be an option and a new, environmentally conscious site will be identified.

CHAPTER THREE: NATIONAL AND INTERNATIONAL RESPONSIBILITIES

3.1 THE LONDON CONVENTION

The *Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972 (London Dumping Convention)* is the global convention from which all New Zealand laws on the dumping of dredged material, among other things, evolve from. This Convention, to which New Zealand is a signatory, has been in force since 1975. It aims to promote control over the sea disposal (dumping) of waste in order to protect the marine environment. Besides New Zealand, there are 81 other marine states who are parties to this convention.

Within the Convention "dumping" is referred to as, *"any deliberate disposal at sea of wastes or other matter from vessels, aircraft, platforms, or other man-made structures at sea"* or *"any deliberate disposal at sea of vessels, aircraft, platforms or other man-made structures at sea"*. Enforcement of the Convention is carried out through verification that no illegal dumping operations are occurring and that the conditions agreed upon in dumping permits are being met. The enforcing authority, as designated by New Zealand, is Maritime New Zealand. This organisation ensures that all dumping operations in New Zealand waters are in accordance with the *London Dumping Convention*.

3.2 THE 1996 PROTOCOL

A modernisation of the *London Dumping Convention*, the *1996 Protocol* was adopted in 2006 and will eventually replace the Convention. The main difference from the original Convention is that the *1996 Protocol* defines all dumping activities as a prohibited activity, unless otherwise stated. This means that all parties intending to dispose of waste at sea are required to obtain a permit from the appropriate enforcement authority to undertake the intended activities. There are currently 32 parties signed onto the *1996 Protocol*.

The main goal of the *1996 Protocol* is to take a precautionary approach when considering applications to undertake disposal at sea. This is accomplished in the Protocol by the inclusion of policies that encourage the avoidance, re-use, and minimisation of waste sources which eventually need to be disposed.

The *1996 Protocol* establishes specified categories of waste that may be considered for disposal at sea. Proposals for disposal of these materials must demonstrate that any adverse effects caused can be avoided and/or mitigated. The accepted categories as set for by the Protocol are as follows:

a) Dredged material;
b) Sewage sludge;
c) Fish waste, or material resulting from industrial fish processing operations;
d) Vessels and platforms or other man-made structures at sea;
e) Inert, inorganic geological material;
f) Organic material of natural origin; and
g) Bulky items primarily comprising iron, steel, concrete and similarly unharmful materials for which the concern is physical impact, and limited to those circumstances where such wastes are generated at locations, such as small islands with isolated communities, having no practicable access to disposal options other than dumping

In general, guidelines set forth by the *1996 Protocol* are more specific with regards to types of materials allowed for disposal and the specific requirements that the material must satisfy in order to be disposed than in the *London Convention*. It also designates the specific boundaries to where the laws set forth apply and allows for review with contracting parties to ensure that the procedures undertaken are effective.

3.3 New Zealand Coastal Policy Statement 1994

The *New Zealand Coastal Policy Statement* (NZCPS) was gazetted in 1994 under the *Resource Management Act 1991* (RMA). Under the RMA, it is the only compulsory national policy statement and is meant to give local authorities in New Zealand guidance in their management of the coastal environment. The NZCPS is significant because all regional policies and plans, district plans, and consenting authorities must comply with its statements.

3.3.1 NZCPS outline

The first section of the NZCPS describes the *General Principles for the sustainable management of New Zealand's coastal environment.* The purpose of the NZCP is stated in Section 56 of the RMA which states: *The purpose of the New Zealand Coastal Policy Statement is to state policies in order to achieve the purpose of this Act* (RMA) *in relation to the coastal environment of New Zealand.* It then goes on to state the purpose of the RMA as set out in Section 5 of the Act which is, essentially, to promote the sustainable management of the natural and physical resources of New Zealand and in doing so the principles of the Treaty of Waitangi must be given regard.

The general principles of the NZCPS are as follows:

1. *Some uses and developments which depend upon the use of natural and physical resources in the coastal environment are important to the 'social, economic and cultural well-being' of 'people and communities'. Functionally, certain activities can only be located on the coast or in the coastal marine area.*
2. *The protection of the values of the coastal environment need not preclude appropriate use and development in appropriate places.*
3. *The proportion of the coastal marine area under formal protection is very small and therefore management under the Act is an important means by which the natural resources of the coastal marine area can be protected.*
4. *Expectations differ over the appropriate allocation of resources and space in the coastal environment and the processes of the Act are to be used to make the appropriate allocations and to determine priorities.*
5. *People and communities expect that lands of the Crown in the coastal marine area shall generally be available for free public use and enjoyment.*
6. *The protection of habitats of living marine resources contributes to the social, economic, and cultural well-being of people and communities.*
7. *The coastal environment is particularly susceptible to the effects of natural hazards.*
8. *Cultural, historical, spiritual, amenity and intrinsic values are the heritage of future generations and damage to these values is often irreversible.*
9. *The Tangata Whenua are the kaitiaki of the coastal environment.*
10. *It is important to maintain biological and physical processes in the coastal environment in as natural a condition as possible, and to recognise their dynamic, complex and interdependent nature.*
11. *It is important to protect representative or significant natural ecosystems and sites of biological importance, and to maintain the diversity of New Zealand's indigenous coastal flora and fauna.*
12. *The ability to manage activities in the coastal environment sustainably is hindered by the lack of understanding about coastal processes and the*

effects of activities. Therefore, an approach which is precautionary but responsive to increased knowledge is required for coastal management.

13. *A function of sustainable management of the coastal environment is to identify the parameters within which persons and communities are free to exercise choices.*
14. *The potential for adverse effects of activities to spread beyond regional boundaries may be significant in the coastal marine area.*

3.3.1.1 Chapter 1 – National priorities for the preservation of the natural character of the coastal environment including protection from inappropriate subdivision, use and development

This chapter of the NZCPS generally refers to the preservation of the coastal environment with respect to the intent for subdivision. This chapter states that it is a national priority to have regard for natural character, potential effects, areas of significant vegetation and habitats of indigenous fauna, landscapes and seascapes, areas of cultural significance particularly to Maori, and the need for restoration and rehabilitation. Although the policies in this chapter refer specifically to the coastline and development there within, the priorities apply to all parts of the coastal environment including off-shore areas where dredging disposal may take place.

3.3.1.2 Chapter 2 – The protection of the characteristics of the coastal environment of special value to the Tangata Whenua including Waahi Tapu, Tauranga Waka, Mahinga Maataitai, and Taonga Raranga

Policies in Chapter 2 provide for the identification of characteristics of special value to the tangata whenua in accordance with tikanga Maori and the protection of these characteristics. It is recommended that the power to protect these characteristics be transferred to iwi authorities or that it be transferred to a local committee comprised of representatives of the tangata whenua.

3.3.1.3 Chapter 3 – Activities involving the subdivision, use or development of areas of the coastal environment

Similar to Chapter 1, policies in Chapter 3 are related to protection of the coastal environment from development activities. The policies are in related to the following topics:

1. *Maintenance and enhancement of amenity values*
2. *Providing for the appropriate subdivision, use and development of the coastal environment*
3. *Adoption of a precautionary approach to activities with unknown but potentially significant adverse effects*
4. *Recognition of natural hazards and provision for avoiding or mitigation their effects*
5. *Maintenance and enhancement of public access to and along the coastal marine area*

3.3.1.4 Chapter 4 – The crown's interests in land of the crown in the coastal marine area

Chapter 4 provides for the protection of lands administered by the Department of Conservation. In the case of consent applications for activities in these areas, plans should first require consideration of alternatives to the activities that the applicant intends to undertake and when there are none, plans should provide for the avoidance of adverse effects resulting from these activities. Also covered in this chapter, is the provision for use of coastal marine areas for defence purposes. Any regional plans involving these topics should recognise and facilitate the relationship established by the Treaty of Waitangi.

3.3.1.5 Chapter 5 – The matters to be included in any or all regional coastal plans in regard to the preservation of the natural character of the coastal environment, including the specific circumstances in which the Minister of Conservation will decide resource consents

Policies in Chapter 5 are related to the following topics:

1. *Maintenance and enhancement of water quality*
2. *Limiting of adverse environmental effects from vessel waste disposal or maintenance*
3. *Defining the specific circumstances in which the Minister of Conservation will decide on resource consent applications*

The specific circumstances described in topic 3, are those listed in Schedule 1 of the NZCPS and are significant to activities involved in dredge spoil disposal. Schedule 1 of the NZCPS will be reviewed presently.

3.3.1.6 Chapter 6 – The implementation of New Zealand's international obligations affecting the coastal environment

Chapter 6 makes the statement, "*Where the government has accepted international obligations which affect the coastal environment, the intention is that guidelines shall be issued from time to time by the government outlining the manner in which these obligations can best be carried out and implemented.*"

Such government guidelines have been produced by Maritime New Zealand with specific regard to the national policies on the sea disposal of waste, of which dredge spoil disposal activities fall under. These policies will be reviewed in Section 3.4.3. The investigations undertaken as part of this thesis were designed to comply with these policies.

3.3.1.7 Chapter 7 – The procedure and methods to be used to review the policies and to monitor their effectiveness

Policies included in this chapter provide for the review of the NZCPS by an independent reviewer no later than 9 years after its gazettal and also by the Minister of Conservation in cooperation with regional councils. As the NZCPS was gazetted in 1994, an independent review was produced by Rosier (2004) which has resulted in the preparation of the *Proposed New Zealand Coastal Policy Statement 2008* for which review and feedback from local authorities is currently being gathered.

3.3.1.8 Schedule 1 – The circumstances in which activities that have a significant or irreversible adverse effect on the coastal marine area will be made restricted coastal activities

The circumstances significant to dredge spoil disposal activities are included in Schedule 1.7 of the NZCPS. The circumstances are as follows:

a) Any activity involving the depositing of any material on the foreshore and seabed which involves quantities less than or equal to 50,000 cubic metres at a site in the coastal marine area in any 12 month period is ***not*** *a restricted coastal activity.*

b) Any activity involving the depositing of any material on the foreshore and seabed:

- i. *Which is specified in an operative or proposed regional coastal plan as a discretionary activity;*
- ii. *For which the plan defines or provides the criteria for determining:*
  - – *the location where the activity can be carried out;*
  - – *the time during which the activity can be carried out; and*
- *iii.* *for which the plan:*
  - – *requires consideration of the likely adverse effects of the depositing of the material; and*

– *defines, or provides the criteria for determining, the limits on the likely adverse effects of the depositing of the material;*

*is **not** a restricted coastal activity.*

c) *Except as provided for in S1.7(a) and (b) above, any activity involving the depositing of any material on the foreshore or seabed in quantities greater than 50,000 cubic metres in any 12 month period in the coastal marine area is a restricted coastal activity.*

3.3.1.9 Summary

Plans and policies developed by regional and district councils must have regard for the policies of the NZCPS, described above. The aim of this is to uphold the principles for sustainable management of the natural and physical resources of New Zealand put forth in Section 56 of the *Resource Management Act 1991* with respect to the coastal environment.

3.3.2 Proposed New Zealand Coastal Policy Statement 2008

In 2002, the Minister of Conservation commissioned an independent review (Rosier, 2004) of the NZCPS 1994 as required by Policy 7.1.1 of the NZCPS for the purpose of determining its effectiveness. The intent is to determine the need to review, change, or revoke the statement.

As a result of the independent review, the *Proposed New Zealand Coastal Policy Statement 2008* was released 10 March 2008 and is now in the public submission process. Submissions will be accepted until 7 May 2008, which will then be followed by public hearings on the matter. Upon finalisation of the new NZCPS, policies must be amended by local councils and be in effect no later than 5 years after its gazettal.

Besides altering the general structure of the NZCPS, the proposed document also includes detailed explanations of the policies for clarification purposes. Costs and benefits to each interested party (central government, local authorities, and resource users) are described for each policy.

With specific respect to the circumstances described in Schedule 1, changes to the *Depositing of substances in the coastal marine area* (S1.7) restrictions include the removal of the policy giving discretion to regulate deposition as a discretionary activity and all such activities must first have consent from the Minister of Conservation.

It is also noted in the proposed NZCPS that the dumping of 'dredged material' from a vessel is controlled by the *Marine Pollution Regulations 1998* which deems this activity to be a discretionary activity of the regional coastal plan or the proposed regional coastal plan. Incidentally, the *Marine Pollution Regulations 1998* came into effect in New Zealand in August 1998 in accordance with the *1996 Protocol to the London Dumping Convention 1972*, described above.

3.4 National Policy on the Sea Disposal of Waste – Marine Pollution Prevention

This document describes the matters that must be considered in reviewing a proposal to dispose of waste and other materials within the limits of the Exclusive Economic Zone (EEZ), bearing in mind that coastal marine areas shoreward of the EEZ are the territorial seas in which similar disposal operations are controlled by the regional councils (Figure 3.1). The standards set forth in this document are derived from the *1996 Protocol to the London Dumping Convention 1972*, the aims of which are described in Sections 3.1 and 3.2 of this thesis.

The authority to uphold the policies and, therefore, assess and issue permits, set forth in this document is given to the Director of Maritime New Zealand established by the *Maritime Transport Act (1994)*. The aims of which are to comply with the standards and processes described in the *1996 Protocol* for applications to dispose of materials in the EEZ of New Zealand.

To assist in the processes involved in assessing disposal applications, the *New Zealand Guidelines for Sea Disposal of Waste* (NZSDW) and has been compiled by Maritime New Zealand in cooperation with the Ministry of the Environment. This document includes the necessary technical information needed for the appropriate assessment of applications and will be discussed in Section 3.4.2.

A major aim of the *National Policy on the Sea Disposal of Waste – Marine Pollution Prevention* document is to encourage the establishment of *'designated'* sites especially in areas where the submission of multiple applications for disposal is likely. The primary advantage of having one designated site for disposal of dredged material is that the potential effects caused by disposal operations will be confined to specific areas. It is envisaged by Maritime New Zealand that a consortium of interested parties can share the responsibilities and costs involved in establishing and maintaining such a site. An additional advantage to using a designated site is that once the management plan (monitoring plan) is established, the focus can be directed to the assessment of the material to be disposed, which upholds the objectives of the *1996 Protocol* to use a precautionary approach when assessing disposal applications.

3.4.1 Policies

The national policies set forth in this document are as follows:

- **Policy 4.1** states that barring any other relevant policies, the marine disposal of dredged material shall generally be deemed appropriate, but that the following must be demonstrated regarding the disposal application:

  a) *There is no reasonable and practicable alternative disposal method or site;*

b) *Disposing of the dredged material in the EEZ is the best practicable option, having had regard to alternative disposal methods or sites;*
c) *The material can be satisfactorily contained within the disposal site, or if it is a dispersive site, adverse effects associated with the dispersal of the material will be avoided, remedied or mitigated;*
d) *There will be less environmental effect from disposing of the waste or other matter in the marine environment than on land; and*
e) *The proposed disposal site will not interfere with or adversely affect in more than a minor way other legitimate users of the marine environment.*

- **Policy 4.2** is subject to Policy 4.1 of this document and states that the disposal of waste or other matter in the EEZ should be avoided unless the following can be demonstrated:

a) *There is no reasonable and practicable alternative disposal method onto land;*
b) *In the case of inert inorganic material, the material being disposed of has similar physical characteristics to the sediments at the site;*
c) *There will be less environmental effect from disposing of the waste or other matter in the marine environment than on land;*
d) *The proposed disposal site will not interfere with or adversely affect in more than a minor way other legitimate users of the marine environment; and*
e) *The disposal, having considered (a) to (d) above, is for a purpose which has environmental, scientific, cultural, amenity, or social benefits for the community, or will enhance the natural marine environment.*

- If the material to be disposed is contaminate to an extent that it will cause greater than minor adverse effects on the environment, then **Policy 4.3** states that disposal shall be avoided unless, after assessing the waste management options set forth in NZGSDW (Section 3.4.2), if it can be demonstrated that:

a) *There is no reasonable and practicable alternative disposal method or site;*
b) *Disposing of the contaminated dredged material, waster or other matter in the marine environment is the best practicable option, having had regard to alternative disposal methods or sites; and*
c) *The contaminants can be satisfactorily contained within the disposal site, or if it is a dispersive site, adverse effects associated with the release of contaminants will be avoided, remedied, or mitigated.*

- In the absence of the necessary scientific data to determine potential adverse effects, **Policy 4.4** states that a precautionary approach should be taken by imposing conditions to ensure that the effects of the activity are avoided, remedied, or mitigated. These conditions may include, but are not limited to the following:

a) *That permit holders may be required to keep and maintain records of waste disposal activities undertaken at sites in the EEZ, which shall be made available to the Director on request;*
b) *That permit conditions and site management plans may be reviewed in order to avoid, remedy, or mitigate any adverse effects which may be generated by the activity;*
c) *That permit holders be required to regularly monitor the effects of the disposal; and*
d) *That the term of any permit be limited.*

- Regarding selection of a disposal site, **Policy 4.5** states that the disposal of dredged material where:

a) *The volume exceeds 50,000 m^3 per annum; or*
b) *Subject to Policy 4.3, the material is contaminated to an extent where those contaminants will result in a greater than minor adverse effect on the marine environment;*

shall be undertaken at sites surveyed and managed specifically for that purpose.

This policy also states that proposal for the establishment of such sites must demonstrate the following:

a) *The proposed site is located so as to avoid, as far as practicable, the spread or loss of sediment and other contaminants to the surrounding seabed and coastal waters through the action of coastal processes such as waves, tides and other currents, unless the use of a dispersive marine disposal site is the best practicable option given the type of material to be disposed of;*
b) *Use of the proposed site will avoid as far as practicable, remedy or mitigate adverse effects on:*
    i. *The growth and reproduction of marine and coastal vegetation and the feeding, spawning, and migratory patterns of marine and coastal fauna;*
    ii. *Recreational use of the EEZ;*
    iii. *Other established activities located in the EEZ which are likely to be affected by the disposal;*
    iv. *Water quality, including any contributing factors which may lead to or promote algal blooms*
c) *The disposal will not result in the sustained loss of any habitat of a rare or endangered species.*

- **Policy 4.6** states that the sites, as provided in Policy 4.5, will be the subject of a management plan set forth by the Director and prepared in cooperation with the interested parties to that site. The management plan should include, but is not limited to the following:

a) *A description of the nature of the site and the receiving environment;*
b) *The nature of the material permitted to be disposed of within the site;*
c) *The annual assimilative capacity of the site with respect to both quantity and quality of material to be disposed of;*

d) *An impact hypothesis describing the expected consequences of waste disposal;*
e) *The frequency and extent of impact monitoring required to be undertaken to verify the adequacy of the impact hypothesis;*
f) *The actions to be undertaken in the event that impact monitoring specified in (e) above demonstrates a greater than minor impact on the site resulting from waste disposal activities.*

- **Policy 4.7** states that proposals for the disposal of dredged material to a site that is surveyed and managed specifically for that purpose, provided for by Policies 4.5 and 4.6, must demonstrate the following:

a) *After undertaking and assessment of waste management options in terms of the NZGSDW* (Section 3.4.2) *and the site management plan, there are no reasonable and practicable alternatives either within or outside of the EEZ which would have less adverse effects on the environment;*
b) *The disposal will be undertaken in accordance with the requirements on the site management plan; and*
c) *The material is acceptable for disposal in the designated site using acceptable guidelines based on current published material for such disposal, as well as material that has been provided as part of the site management plan approval.*

- As stated in **Policy 4.8**, disposal of the following types of material may be undertaken provided that the applicant demonstrates that the proposed site is suitable for disposal of that type of material:

a) *Dredge material where the volume of material does not exceed 50,000* m^3 *per annum; or*
b) *All other categories of waste that may be considered appropriate for disposal within the EEZ.*

- **Policy 4.9** states that proposals for disposal of any waste in the EEZ, as provided for in Policy 4.8, must demonstrate the following:

  a) *That after undertaking an assessment of waste management options in terms of the New Zealand Guidelines for the Sea Disposal of Waste, there are no reasonable and practicable alternatives either within or outside of the EEZ which would have less adverse effects on the environment;*
  b) *That the disposal will be undertaken in a location and at times of the day or year that will avoid as far as practicable, remedy, or mitigate adverse effects on:*
     i. *The growth and reproduction of marine and coastal vegetation and the feeding, spawning, and migratory patterns of marine and coastal fauna;*
     ii. *Recreational use of the EEZ;*
     iii. *Other established activities located in the EEZ which are likely to be affected by the disposal;*
     iv. *Water quality, including any contributing factors which may lead to or promote algal blooms.*

  c) *That in the case of vessels, platforms or other man-made structures, the disposal site is located in water depth greater than 2,000 metres, unless it can be demonstrated that a disposal site in shallower water is the best practicable option for the disposal of that material;*
  d) *How adverse environmental effects will be avoided, remedied, or mitigated; and*
  e) *How assumptions made during the site selection and assessment process may be monitored to ensure that they are correct and sufficient/adequate/appropriate to protect the environment and human health.*

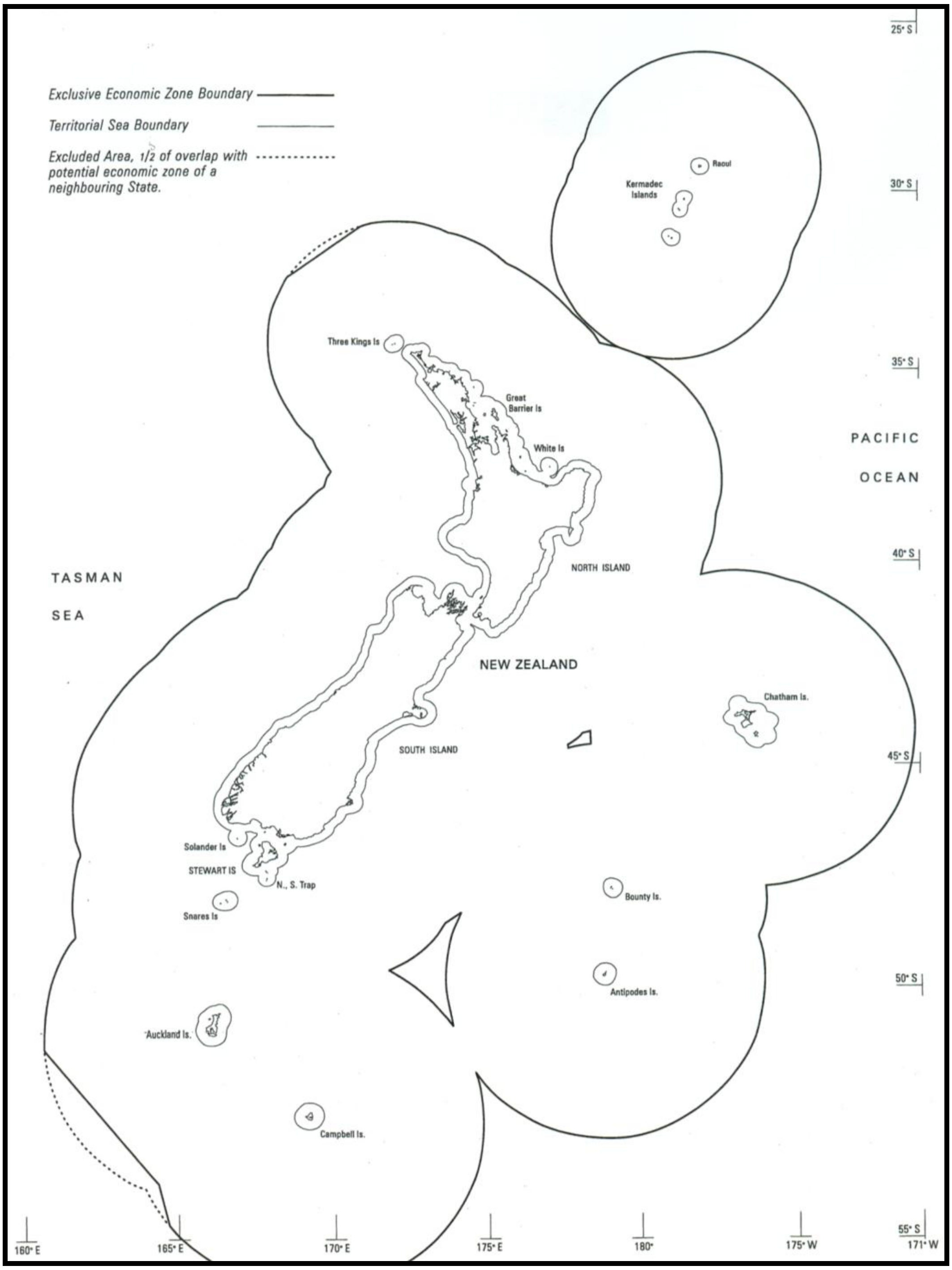

Figure 3.1 New Zealand Territorial Sea and Exclusive Economic Zone (EEZ) (Source: Kelly and Marshall, 1996).

3.4.2 New Zealand Guidelines for the Sea Disposal of Waste

Compiled jointly by Maritime New Zealand and The Ministry for the Environment, this document is referred to by the Director for guidance in assessing permit applications submitted disposal activities in the EEZ under the

Maritime Transport Act 1994 (MTA). These guidelines are intended to uphold the standards set forth, first, in the *1996 Protocol* and, second, in the *National Policy on the Sea Disposal of Waste – Marine Pollution Prevention*. The general aims of this document are as follows:

i. *Assist applicants for resource consents and permits to dump wastes at sea from ships, aircraft or offshore installations, or to dump ships and offshore installations;*
ii. *Assist the issuing authorities tasked with making decisions on such applications;*
iii. *Promote a consistent, practical consenting / permitting regime for dumping in accordance with the 1996 Protocol in all areas of the sea that New Zealand has jurisdiction and responsibilities for dumping.*

No equivalent requirements exist for the assessment of applications for disposal activities in the territorial seas under the *Resource Management Act 1991* (RMA). However, the guidelines are available to the regional councils for assessment of such applications.

3.4.2.1 Section 2 of NZGSDW

Section 2 of this document describes the legislative schemes that give effect to the New Zealand requirements for the sea disposal of waste. As mentioned above, dumping applications for areas within the 12 nautical mile limit (the territorial seas) must be submitted to the relevant regional council and similar applications for disposal outside the 12 nautical mile limit (EEZ) must be submitted to the Director of Maritime New Zealand. Consultation with interested stakeholders such as the local iwi and Crown entities is required for applications for disposal in the CMA. It is not, likewise, required for disposal applications in the EEZ, but is highly recommended as a measure of good faith.

3.4.2.2 SECTION 3 OF NZGSDW

Section 3 addresses the issue of waste reduction, management, and alternatives to dumping at sea. The main aim of these guidelines is to minimise the impact that the disposal activities will have on the environment. In this section of the NZGSDW, a waste prevention audit framework is presented as a method to reduce waste creation, give consideration to land disposal, and to minimise the potential impacts of disposal activities. The guidelines recommend that an evaluation of the following be considered in the assessment of alternative options:

i. *Types, amounts and relative hazard of wastes generated;*
ii. *Details of the production process and the sources of wastes within that process;*
iii. *Feasibility of the following waste reduction / prevention techniques;*
iv. *Product reformulation;*
v. *Clean production technologies;*
vi. *Process modification;*
vii. *Input substitution;*
viii. *On site, closed loop recycling.*

If it is found, through implementation of the waste prevention audit, that there is potential for the reduction of wastes, applicants will be required design and undertake the strategy to do so.

This section of the document also describes the potential alternative uses of wastes available so that it may be considered before choosing the option of disposal at sea. The alternatives available for the following types of waste material are listed:

1. *Dredged material*
2. *Sewage sludge*
3. *Fish waste*

4. *Vessels and platforms*
5. *Inert, inorganic geological material*
6. *Organic material of natural origin*
7. *Bulky items*

3.4.2.3 Section 4 of NZGSDW

This section of the NZDSDW describes the required framework for the characterisation of the waste material. The framework is set up in four levels of investigation, whereby, if it is determined in the early stages of the investigation that the material is acceptable for disposal at sea, the more detailed investigations may not be necessary.

- The **Level 1** investigation involves the collection and review of the available information on the waste material in question. The review should reveal the following:

  i. *The nature of the waste*
  ii. *Previous history of the site from where the waste originates*
  iii. *Site condition*
  iv. *Previous studies*
  v. *Contaminants of concern*

- Undertaking a **Level 2** investigation involves a full physical and chemical characterisation of the material. The basic physical characteristics that must be determined are: volume, basic sediment grain size, specific gravity of solids, and moisture content of the material. The physical characterisation must also consider the amount of non-biodegradable material, such as plastics, in the material. Large amounts of this type of material will make it unacceptable for disposal at sea.

  Also included in the Level 2 investigation is the chemical characterisation of the waste material. Testing for the presence of basic heavy metals and other more site specific contaminants is required. The guidelines include the specific contaminants that must be tested for and the acceptable and unacceptable levels of those contaminants that the assessment will be based on.

- If is concluded that there is still insufficient data to characterise the waste material fully, then a **Level 3** investigation will be required. A Level 3 investigation will be required if it is found that the level of one or more of the contaminants tested falls in between the acceptable and unacceptable levels and can include elutriate and possibly acute toxicity testing.

  Elutriate testing simulates the release of contaminants from waste material during and after disposal operations either by the effect of pore water pressure that can occur in a spoil mound or by various chemical reactions such as oxidation. The mobility of the contaminants or the ease with which the contaminants become desorbed from the solid waste can be determined. If the levels exceed the accepted standards after an initial dilution, an acute toxicity test may be required as part of the Level 3 investigation.

  The acute toxicity test involves exposing suitably relevant and sensitive marine organisms to the contaminant. If the contaminant is found to be non-toxic to the organisms, then the material may be deemed acceptable for unconfined ocean disposal. However, if the contaminant does have a toxic effect on the organisms, the applicant can choose to treat the waste material to make it less contaminated, undertake a Level 4 investigation, consider applying for disposal at contained site, or forego any planned disposal operations.

- A **Level 4** investigation carries out further tests on chronic and bioaccumulative effects of the contaminant. These tests must be carried out to acceptable international standards and the applicant must also be required to carry out a more comprehensive evaluation of the environmental conditions at and surrounding the disposal site.

3.4.2.4 Section 5 of the NZGSDW

This section describes the implementation of a national action list mandated by the *1996 Protocol* in Annex 2 of the document. This action list contains the acceptable and unacceptable levels of various contaminants and is used to assess the suitability of a waste material. Most of the standards in this list are based on North American guidelines as levels specific to New Zealand are still being researched. The list is frequently used by issuing authorities, but is not yet a national statute.

The purpose of the action list is to categorise all waste materials intended for disposal at sea in one of the following ways:

i. *Wastes which contain specified substances exceeding the relevant upper level should not be dumped, unless made acceptable for dumping through the use of management techniques or processes, or, following further detailed biological testing, are shown to be acceptable (i.e. a level 4 investigation).*
ii. *Wastes that contain specified substances below the relevant lower levels should be considered to be of little environmental concern in relation to dumping.*
iii. *Wastes that contain specified substances below the upper level, but above the lower level shall be assessed for their suitability for dumping. Further testing will be required (i.e. a level 3 investigation).*

3.4.2.5 Section 6 of the NZGSDW

Section 6 of this document describes the criteria involved in assessment of the proposed dump site. The information required for an accurate assessment of the site includes:

i. *Physical, chemical, and biological characteristics of the water column and the seabed*
ii. *Location of amenities, values, and other uses of the sea in the area under consideration*
iii. *Assessment of the constituent fluxes associated with dumping in relation to existing fluxes of substances in the marine environment*
iv. *Economic and operational feasibility.*

The information described above may be taken from the relevant literature, but in the case of a lack of data, field work must be undertaken to fill in any gaps.

Factors influencing the selection of the site include:

i. Size
   - it must be large enough that most of the material stays within the limits of the site;
   - large enough to contain the waste material once it is diluted to near background levels at the seafloor;
   - with regards to the anticipated volumes, the site should be able to serve its purpose for many years; and
   - monitoring the site should not make using the site a cost prohibitive operation because it is too large.

ii. Capacity
   - the anticipated loading rates per day, week, month, and year must be known;
   - whether or not the site is dispersive or non-dispersive
   - the maximum height above the sea floor the spoil mound can reach without affecting other users of the area
   - historical use of the site and whether or not future use will compound any current effects there.

iii. Position
   - are there any nearby areas of beauty or cultural significance?
   - are there any areas of scientific or biological importance (marine reserves)?
   - are there any other uses of the area (sport or commercial fishing)?

3.4.2.6 Section 7 of the NZGSDW

This section describes the decision making process that Maritime New Zealand uses when considering approval for an application for disposal. The following criteria are used in this process:

i. *Characterisation of waste shows that substance is acceptable for dumping;*
ii. *Characterisation of the waste shows that dumping will not result in toxic effects at the site. Testing to a level required to prove this, in line with the precautionary approach, should have been carried out on the waste;*
iii. *Where appropriate, suitable alternatives to dumping wastes have been investigated. In such cases, waste reuse, recycling and reduction have been considered by the applicant and found to be unavailable or not cost-effective and so dumping at sea is determined as the most suitable disposal mechanism;*
iv. *The site assessment states whether the site is a dispersive site or contained site, defines the animal and plant life at the site, and shows that alternative uses of the site are considered such as recreational, fishing, cultural significance, etc. Consideration of the site characteristics shows that there will not be significant adverse effects as a result of dumping there;*
v. *The comments received by interested parties following the notification period either support the proposal, or are considered and the proposal adjusted to take account of reasonable concerns raised;*
vi. *Any adverse effects can be adequately avoided, remedied or mitigated, for example by imposition of conditions.*

3.4.2.7 SECTION 8 OF THE NZGSDW

This section describes the monitoring process of approved applicants should take once disposal operations have begun at the site. Operational monitoring should be undertaken during disposal operations to ensure compliance with the conditions of the permit. Environmental monitoring should also be undertaken verify the nature of the effects that may or may not be occurring.

The monitoring plan should be designed to assess whether changes that occur at the dump site are consistent with the changes that were predicted according to the assessment of potential effects. The guidelines require consideration of the following issues:

i. *What testable hypotheses can be derived from the effects hypothesis?*
ii. *What measurements (type, location, frequency, performance requirements) are required to test these hypotheses?*
iii. *How should the data be managed and interpreted?*

The monitoring program should consider the physical parameters involved in the disposal operations such as the character of the dredged material, the size and location of the site, biological, chemical, and physical conditions of the site. Consideration of these parameters can determine the need to alter disposal conditions of the permit to avoid adverse effects.

3.4.3 SUMMARY

The *New Zealand Guidelines for the Sea Disposal of Waste* (NZGSDW) is the document that puts into action the international and national standards and policies recognised by New Zealand. The guidelines are intended for the specific use of the Director of Maritime New Zealand in assessing applications for dredging disposal the waters of the Exclusive Economic Zone, but are commonly used by local authorities in the assessment of disposal applications for the coastal marine areas. This document is significant because it standardises the requirements for assessing the material and the site intended for disposal. This lends credibility to the enforcing authorities and compels applicants to fully appreciate the level of environmental concern they must have in undertaking disposal operations.

3.5 The Regional Policy Statement

Dredging disposal operations that take place in the territorial seas or the coastal marine areas are regulated by the local regional councils. Each council has generated a regional policy statement that describes the policies of the region with respect to the coastal marine areas and a regional coastal plan that is used to put the policies into action.

Environment Waikato and Auckland Regional Council are the relevant councils to this thesis research. Each of these councils controls coastal marine areas in the immediate vicinity of the proposed disposal site discussed in Chapter 1 of this thesis. Ports and marinas in both regions have expressed an interest in accessing the proposed site for disposal operations should the application be approved.

Activities in the EEZ are generally governed on a national level and not by the regional councils. However, considering the proximity of the proposed site to these regional coastal marine areas, it is ethical to also consider the policies of these two councils and determine the expectations of each with respect to the ocean disposal of dredged sediment.

3.5.1 The Auckland Regional Council

The *Auckland Regional Policy Statement* was approved and became operative in August of 1999. The policies included in this document are designed to fulfil the requirements of the *Resource Management Act 1991* along with those of the *New*

Zealand Coastal Policy Statement. A schematic of the hierarchy of the policy documents that govern the Auckland region are presented in Figure 3.2.

The Auckland Coastal Marine Area (CMA) (Figure 3.3) extends to the 12 nautical mile limit of the territorial seas of New Zealand. The proposed disposal site investigated in this thesis lies just beyond this limit in the Exclusive Economic Zone (EEZ) (Figure 3.1).

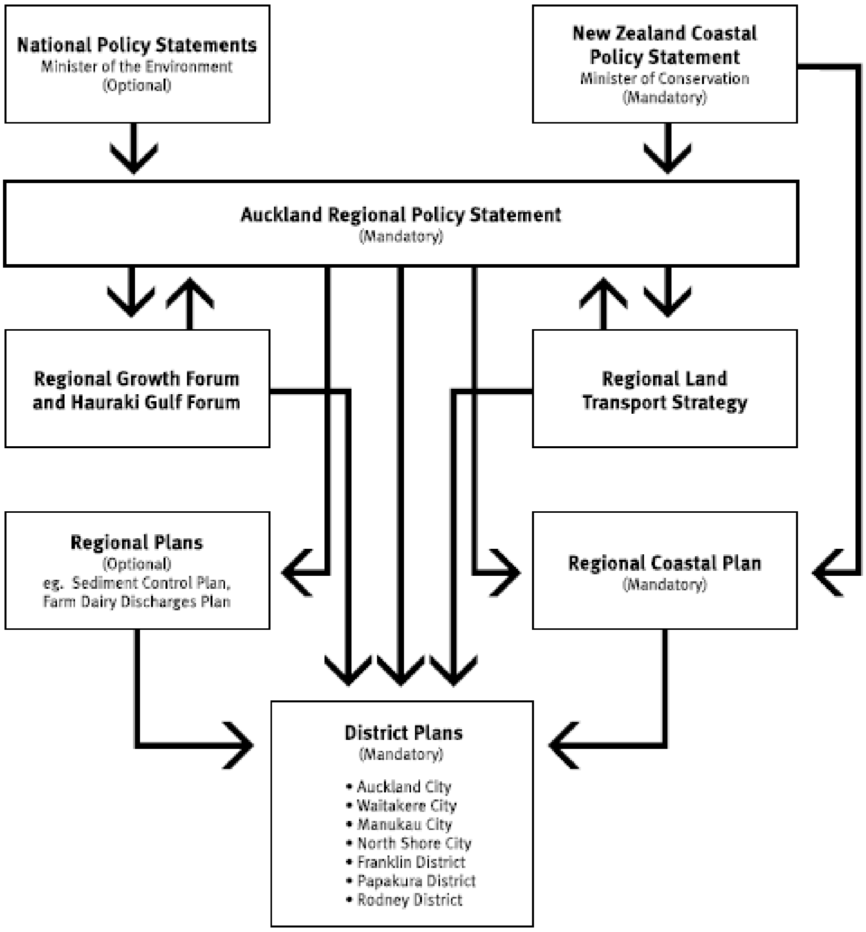

Figure 3.2. Policy statements and plans in the Auckland Region (Source: Auckland Regional Policy Statement).

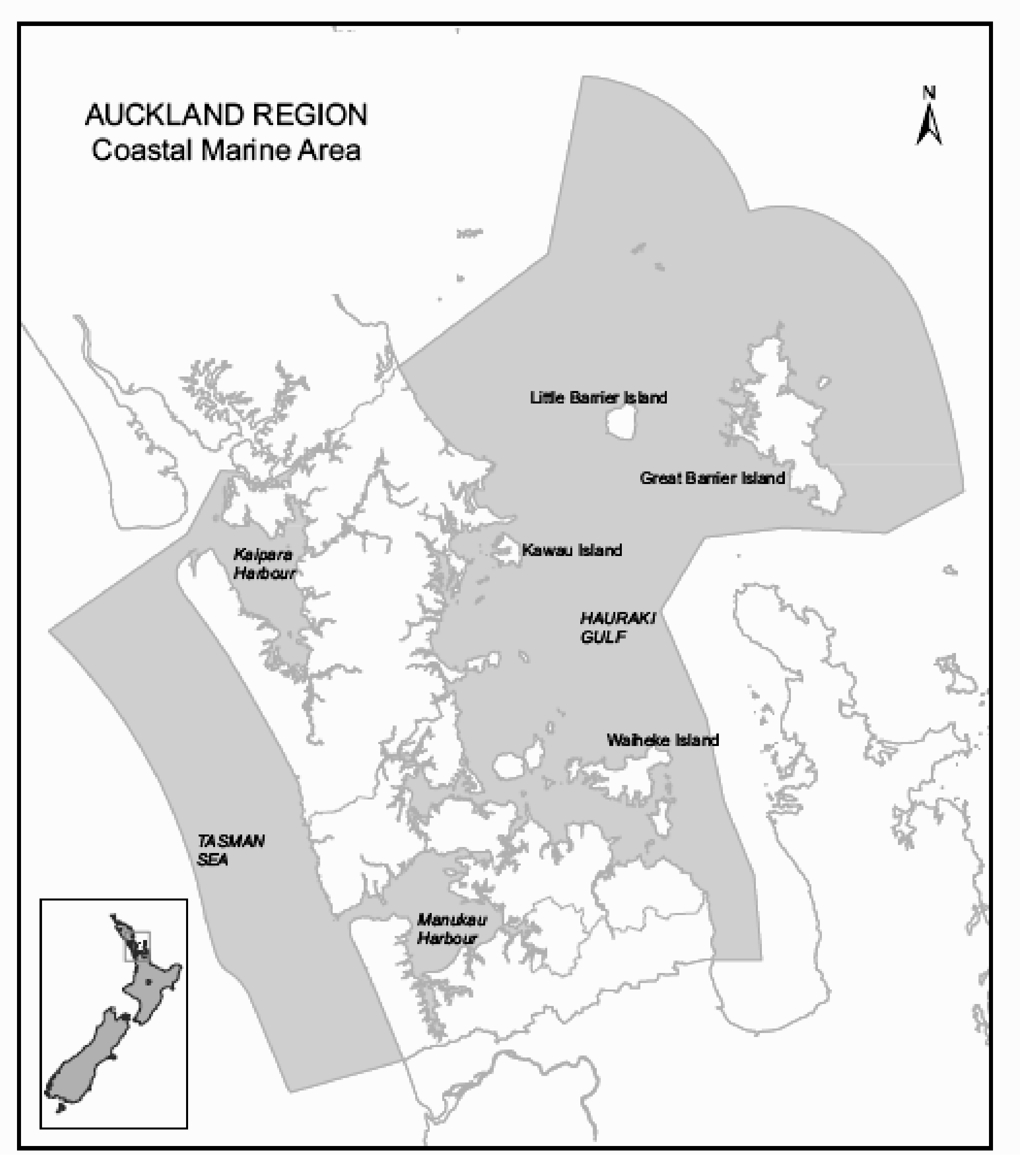

Figure 3.3. Auckland Coastal Marine Area (Source: Auckland Coastal Policy Statement).

Chapters 3 (*Matters of Significance to Iwi*), 6 (*Heritage*), 7 (*Coastal Environment*), and 8 (*Water Quality*) of the *Auckland Regional Policy Statement* give effect to the *Resource Management Act 1991* and the *New Zealand Coastal Policy Statement* with respect to the coastal environment of the Auckland region.

Chapter 7 of this document covers the issues and policies regarding dredge spoil disposal activities. Policy 7.4.22, in particular, deals directly with dredge spoil disposal activities in the Auckland CMA. The policy is stated as follows:

1. *The need to maintain or enhance adequate water depths for the safe navigation and berthing of vessels or to provide access to facilities shall be recognised and provision shall be made for the dredging of appropriate areas of the coastal marine area.*
2. *The natural character of the coastal environment shall be preserved and protected from significant adverse effects arising from the marine disposal of dredged materials or other solid matter.*
3. *A precautionary approach shall be taken where potentially significant adverse effects, which cannot be fully assessed due to inadequate information or understanding, (particularly where there is a lack of scientific or technical knowledge), may arise from a proposal for the marine disposal of dredged materials or other solid matter.*
4. *The disposal of dredged materials or other solid matter to the coastal environment shall be avoided, as far as practicable where, due to its volume, degree of contamination, physical composition or disposal method and location, such disposal is likely to result in the following:*

    i. *Significant adverse effects on habitats, coastal ecosystems and fisheries;*
    ii. *Significant alteration to natural processes;*
    iii. *Significant adverse effects on amenity values and the natural character of the coastal environment;*
    iv. *Significant adverse effects on the relationship of Maori and their culture and traditions with their taonga;*
    v. *Significant adverse effects on the social, cultural and economic wellbeing of the community.*

5. *In assessing proposals for the marine disposal of dredged material in the Hauraki Gulf and other parts of the Auckland coastal marine area where relevant, regard shall be had to the conclusions and recommendations of the Disposal Options Advisory Group (DOAG) in terms of:*

    a) *the disposal of significant quantities of dredged material;*

b) the disposal of highly contaminated dredged material.

The controversial Noises disposal site, which resulted in the formation of the DOAG, as described in Section 2.2.1 of this thesis, was located in the Auckland CMA. With respect to Part 5 of Policy 7.4.22 of the *Auckland Regional Policy Statement*, it is, therefore, appropriate that the ARC have specific regard for the findings of the DOAG in assessing future disposal applications in the CMA.

3.5.2 ENVIRONMENT WAIKATO

Similar to the *Auckland Regional Policy Statement*, the *Waikato Regional Policy Statement* gives effect to the *Resource Management Act 1991* and the *New Zealand Costal Policy Statement*. A schematic of the hierarchy of the policy documents that govern the Waikato region are presented in Figure 3.4.

The Waikato Coastal Marine Area (CMA) extends to the 12 nautical mile limit of the territorial seas of the east and west coast of the Waikato region of New Zealand. The eastern portion of the Waikato CMA (Figure 3.5) is relevant to this thesis research as the investigated proposed disposal site lies just north of Cuvier Island in the Exclusive Economic Zone (EEZ) (Figure 3.1).

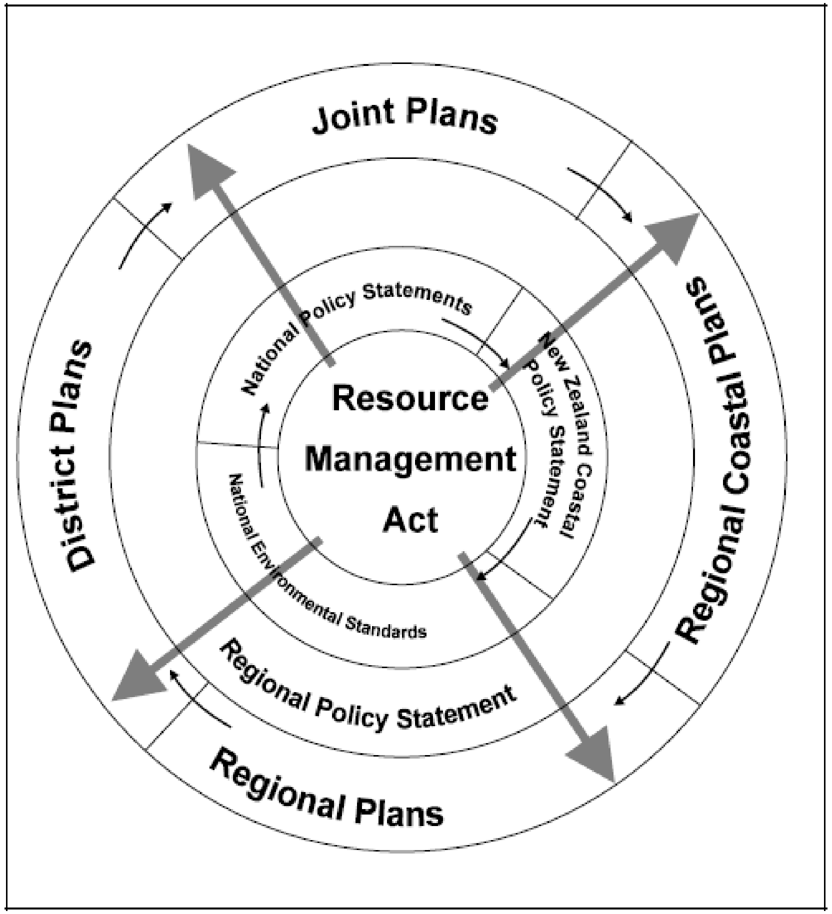

Figure 3.4 The planning framework of the Waikato Region (Source: Waikato Regional Policy Statement).

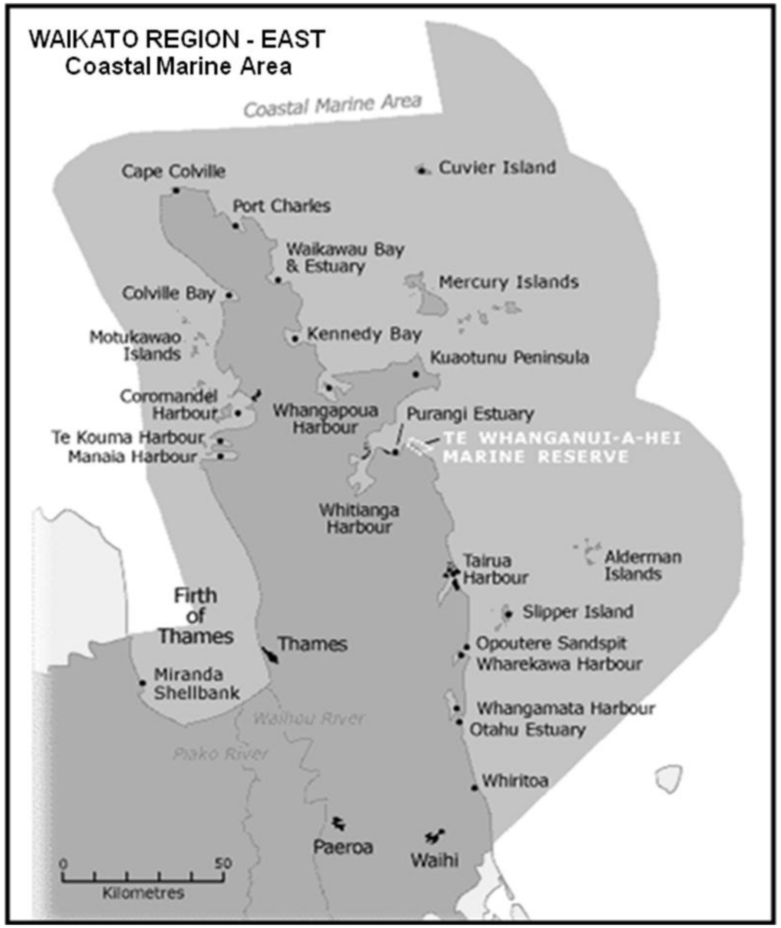

Figure 3.5. Eastern portion of the Waikato Coastal Marine Area (Source: Waikato Regional Policy Statement).

There are currently no policies included in the *Waikato Regional Policy Statement* that specifically discuss dredge spoil disposal activities. However, there are several policies in this document that generally refer to coastal marine activities under which dredge spoil disposal operations would fall.

The policies of the *Waikato Regional Policy Statement* that are relevant to dredge spoil disposal activities are as follows:

- **Policy 3.5.4.1** identifies and gives protection to the following significant areas, features, processes, and the range and diversity of species and their habitats in the coastal environment:

    a) Natural character of the coastal environment
    b) Outstanding landforms and landscapes
    c) Significant indigenous vegetation and significant habitats of indigenous fauna
    d) Areas of importance to tangata whenua

- **Policy 3.5.4.2** ensures that any development and/or use of the coastal environment has regard for the unique processes that operate in the coastal environment.

- **Policy 3.5.4.3** requires that a precautionary approach be taken when managing the coastal environment. This approach should recognise the likely occurrence of events that may occur in the coastal environment that hold a high potential for impact, but a low probability for occurrence.

- **Policy 3.5.5.1** protects the characteristics for which coastal waters are valued by avoiding, remedying, and mitigating any adverse effects on water quality.

3.5.3 SUMMARY

The policies of *Regional Coastal Policy Statements* for Auckland and the Waikato, discussed above, are intended to give effect to the *Resource Management Act 1991* and the *New Zealand Coastal Policy Statement*. These policies are intended to ensure the sustainable management of the coastal environment of the Auckland and Waikato regions of New Zealand.

3.6 REGIONAL COASTAL PLAN

Each regional council of New Zealand has developed a *Regional Coastal Plan*, which is designed to give effect to the policies of their respective *Regional Policy Statemens*. Consideration of the specific policies regarding dredge spoil disposal activities in the CMAs of the Auckland and Waikato regions should be had for the investigation and assessment of the proposed disposal site and activities examined in this thesis.

3.6.1 AUCKLAND REGIONAL COUNCIL

Part IV of the *Auckland Regional Coastal Plan* sets out the provisions relating to the use and development of the Auckland CMA. The included chapters state the rules pertaining to such activities as recreational pursuits, building a wharf, reclaiming the seabed, and the discharge of contaminants. Chapter 17 of Part IV of the *Auckland Regional Coastal Plan* refers directly to the regulations on dredge spoil disposal activities.

The policies set out in Chapter 17 of the *Auckland Regional Coastal Plan* are designed to fulfil the following objectives:

1. *To provide for the appropriate disposal of dredged material within the coastal marine area, while avoiding, remedying or mitigating adverse environmental effects.*

2. *To avoid the deposition of organic or contaminated waste and other matter in the coastal marine area, unless it is the best practicable option to promote the sustainable management of natural and physical resources.*

3. *To avoid the deposition of inorganic solid waste and other matter in the coastal marine area, except where it is for the purpose of maintaining or enhancing particular values or for appropriate uses, and adverse environmental effects are avoided, remedied, or mitigated*

The relevant policies are as follows:

- **Policy 17.4.1** *The deposition of any waste or other matter in Coastal Protection Areas, Tangata Whenua Management Areas, or any site, building, place or area listed for preservation in Cultural Heritage Schedule 1 shall be avoided where it will result in more than minor modification of, or damage to, or the destruction of the values contained in these places or areas.*

- **Policy 17.4.2** *The relevant provisions of Part III: Values, Chapters 3 to 9 shall be considered in the assessment of any proposal to deposit any waste or other matter into the coastal marine area.*

- **Policy 17.4.3** *In assessing proposals for the disposal of dredged material in the Hauraki Gulf and other parts of the Auckland coastal marine area where relevant, regard shall be had to the recommendations of the Disposal Options Advisory Group (DOAG) in terms of:*

  a) the disposal of significant quantities of dredged material; and

b) *the disposal of highly contaminated dredged material.*

- **Policy 17.4.4** *The marine disposal of waste or other matter with significant levels of contaminants shall be generally be considered inappropriate, unless after undertaking an assessment of waste management options in terms of Part 1 of Schedule 3 of the Marine Pollution Regulations it can be demonstrated that:*

a) *there is no reasonable and practicable alternative disposal method or site; and*

b) *disposing of the contaminated waste or other matter in the coastal marine area is the best practicable option having regard to alternative disposal methods or sites; and*

c) *the contaminants can be satisfactorily contained within the disposal site, or if it is a dispersive site, adverse effects associated with the release of contaminants will be avoided, remedied or mitigated.*

- **Policy 17.4.5** *The coastal margin disposal of dredged material in any part of the coastal marine area shall be considered inappropriate unless:*

a) *it is associated with any permitted dredging*
b) *activity; or*

c) *it is for the purpose of beach nourishment; or*

d) *the material to be deposited is appropriate fi ll for a lawful reclamation, and is in accordance with the provisions of Chapter 13: Reclamation and Drainage; or*

e) *it is for any other purpose which has environmental, scientific, cultural, amenity or social benefits, and the adverse environment effects of the disposal can be avoided as far as practicable, remedied or mitigated.*

- **Policy 17.4.6** *The deposition of solid inorganic waste or other matter into the coastal marine area, shall generally be considered inappropriate unless it can be demonstrated that:*

a) *it is for the purpose of beach nourishment, and the material to be deposited has similar physical characteristics to the sediments at the site; or*

b) *the material to be deposited is appropriate fill for a lawful reclamation, and is in accordance with the provisions of Chapter 13: Reclamation and Drainage; or*

c) *it is for any other purpose which has environmental, scientific, cultural, amenity or social benefits and the adverse effects associated with the deposition can be avoided as far as practicable, remedied or mitigated.*

- **Policy 17.4.7** *The disposal of vessels or platforms or other man-made structures in the coastal marine area shall generally be avoided, unless it can be demonstrated that:*

a) *there is no reasonable alternative method for the removal of the vessel, platform or structure from the coastal marine area and its subsequent disposal onto land;*

b) *there will be less environmental effect from disposing of the vessel, platform or structure in the coastal marine area than on land;*

c) *the proposed disposal site will not interfere with or adversely affect other legitimate users of the coastal marine area;*

d) *the disposal may be for a purpose which has environmental, scientific, cultural, amenity or social benefits for the community.*

- **Policy 17.4.8** *The disposal of any waste or other matter in the coastal marine area shall avoid, remedy, or mitigate adverse effects on:*

  a) *characteristics of the coastal marine area of special value to Tangata Whenua, including access to, use and enjoyment of mahinga mataitai, taonga raranga, tauranga ika, tauranga waka, and waahi tapu;*

  b) *relevant initiatives of Tangata Whenua, including rahui, whakatupu and taiapure.*

- **Policy 17.4.9** *Proposals for the disposal of any waste or other matter into the coastal marine area shall generally demonstrate that:*

  a) *after undertaking an assessment of waste management options in terms of Part 1 of Schedule 3 of the Marine Pollution Regulations there are no reasonable and practicable alternatives to disposal available; and*

  b) *the disposal will be undertaken in a location and at times of the day, or year that will avoid as far as practicable, remedy or mitigate adverse effects on:*

     i. *the growth and reproduction of marine and coastal vegetation and the feeding, spawning and migratory patterns of marine and coastal fauna; and*

     ii. *recreational use of the coastal marine area; and*

     iii. *other established activities located in the coastal marine area which are likely to be affected by the disposal; and*

iv. *water quality, including any contributing factors which may lead to or promote algal blooms; and*

c) *in the case of dredged material, the site is located so as to avoid, as far as practicable, the spread or loss of sediment and other contaminants to the surrounding seabed and coastal waters through the action of coastal processes such as waves, tides and other currents, unless the use of a dispersive marine disposal site is the best practicable option given the type of material to be disposed of; and*

d) *in the case of dredged material, the material is acceptable for disposal in a dispersive environment using acceptable guidelines based on current published material for such disposal, as well as material that has been provided as part of an application being considered; and e the disposal will not result in the sustained loss of any habitat of a rare or endangered species.*

- **Policy 17.4.10** *In assessing any application for the disposal of any waste or other matter in the coastal marine area, particular regard shall be had to:*

a) *the volume of material to be disposed of; and*

b) *the degree of contamination of the material; and*

c) *the physical characteristics (texture, colour, composition) of the material; and*

d) *the sensitivity of the receiving environment, with particular reference to natural character and ecological values; and*

e) *the characteristics of the disposal site, with particular reference to the potential for contaminants to be released from the site, and the potential for resuspension of the material; and*

f) *the disposal technique, including in the case of dredged material, the water content or solidity of the material at the time of disposal; and*

g) *available alternative disposal techniques, including land-based disposal; and*

h) *those other matters contained in Schedule 3 of the Marine Pollution Regulations; and*

i) *how adverse environmental effects will be avoided, remedied, or mitigated.*

- **Policy 17.4.11** *In assessing the effects of the marine disposal of dredged material under Policies 17.4.9 and 17.4.10 and significant contaminant levels in terms of Policy 17.4.4, regard shall be had to:*

a) *acceptable guidelines for the disposal of material in the coastal marine area, including the New Zealand Guidelines for Sea Disposal of Waste;*

b) *information obtained from resource consents granted for the disposal of dredged material in the coastal marine area, including the results of monitoring programmes.*

3.6.2 Environment Waikato

Chapter 7 of the *Waikato Regional Coastal Plan* sets out the provisions relating to the disturbance of the foreshore and/or seabed in the Waikato CMA. This chapter states the rules pertaining to such disturbances as general disturbances, dredging and/or removal of material, deposition or disposal of material, and reclamation. Section 7.3 of the *Waikato Regional Coastal Plan* refers directly to the regulations on dredge spoil disposal activities.

The policies set out in Section 7.3 of the *Waikato Regional Coastal Plan* are designed to fulfil the following objective:

Any disposal or deposition of material in the CMA carried out in a manner which avoids as far as practicable adverse effects on natural coastal processes, water quality and ecology.

The following policies and explanations of the policies are designed to fulfil the above objective:

- **Policy 7.3.1** *Require all uncontaminated sand, shingle and shell removed from any part of the CMA to be returned to the coastal environment, while allowing muddy sediments and other contaminated materials to be removed from the CMA.*

  Explanation and Principal Reasons for Adopting:

  It is necessary to conserve existing reserves of sand, shell and coarser sediments in coastal sediment systems as the CMA is a dynamic system with limited sediment supplies. Therefore if an activity removes such sediment from one part of the system it is preferable to have the sediment disposed of elsewhere in the same system, or if appropriate in another coastal sediment system. However, muddy sediments can be removed from the CMA with little effect on sediment systems and it is difficult to return such sediments to the CMA without significant adverse effects.

- **Policy 7.3.2** *Adverse effects from the disposal of material into the marine environment avoided.*

  Explanation and Principal Reasons for Adopting:

Where sand, shingle, shell or other natural material is deposited in the CMA, the composition of the material must be suitable for the site, in terms of particle size and composition, and all contaminants which are likely to, or have the potential to adversely affect the CMA, must be removed. Disposal must be at a rate that allows the receiving environment to process the new material without adverse effects. Introduction of contaminants, or reduction in water quality, can cause significant adverse effects and such effects should be avoided. (Refer Policy 4.1.4 of the NZCPS).

3.6.3 SUMMARY

The regulations observed by the Auckland and Waikato regional councils in assessing applications to undertake dredge spoil disposal in their respective coastal marine areas do not typically apply to similar activities in the EEZ. However, they are included as a statutory responsibility and should also be considered, in addition to international and national regulations, in the establishment, operation of, and management of the proposed disposal site investigated in this thesis.

With respect to the present study, the relevant regional policies have been considered in an effort comply with Section 2.1.3 of the *New Zealand Guidelines for the Sea Disposal of Waste*. This section encourages consultation with the relevant parties before undertaking disposal operations in the EEZ.

3.7 HAURAKI GULF MARINE PARK ACT 2000

The *Auckland Regional Policy Statement*, discussed above, states, *inter alia*, "*The Hauraki Gulf plays an important role in the image and identity of Auckland. As well as being used for port and shipping purposes, it is of major recreational, fisheries, economic and amenity value to the community. The Gulf also has* *special value for Tangata Whenua of the region*." These values and public concern over the disposal of significant quantities of dredged material in the Hauraki Gulf led the central government to establish the Hauraki Gulf Marine Park.

The Hauraki Gulf Marine Park was established in 2000 and covers the Hauraki Gulf, Waitemata Harbour, the Firth of Thames, and the east coast of the Cormandel Peninsula out to the Exclusive Economic Zone boundary (Figure 1.1). It includes well-known areas such as Little Barrier Island, the Mokohinau Islands, a large portion of Great Barrier Island, Cuvier Island, Mansion House on Kawau Island, North Head Historic Reserve, Rangitoto Island, Motutapu Island, Mount Moehau, and the four marine reserves in the area.

The preamble to the *Hauraki Gulf Marine Park Act 2000* states that "*The Hauraki Gulf has a quality and diversity of biology and landscape that makes it outstanding within New Zealand….A diverse marine environment extends from the deep ocean to bays, inlets, and harbours off the coastline…*"

The purpose of the *Hauraki Gulf Marine Park Act 2000* is to:

a) *integrate the management of the natural, historic, and physical resources of the Hauraki Gulf, its islands, and catchments;*
b) *establish the Hauraki Gulf Marine Park;*
c) *establish objectives for the management of the Hauraki Gulf, its islands, and catchments;*
d) *recognise the historic, traditional, cultural, and spiritual relationship of the tangata whenua with the Hauraki Gulf and its islands;*
e) *establish the Hauraki Gulf Forum.*

- **Part 1** of the *Hauraki Gulf Marine Park Act 2000* describes the provisions for management of the Hauraki Gulf. Management of the park must be in accordance with the following:

1. *Recognition of national significance of Hauraki Gulf*
2. *Management of Hauraki Gulf*
3. *Relationship of Act with Resource Management Act 1991*
4. *Creation of New Zealand coastal policy statement by this Act*
5. *Statements of general policy under Conservation Act 1987 and Acts in Schedule 1 of that Act*
6. *Amendment to Fisheries Act 1996*
7. *Obligation to have particular regard to sections 7 and 8*
8. *Preservation of existing rights*

- **Part 2** of the *Hauraki Gulf Marine Park Act 2000* introduces the Hauraki Gulf Forum. The purposes of the forum are as follows:

  a) *to integrate the management and, where appropriate, to promote the conservation and management in a sustainable manner, of the natural, historic, and physical resources of the Hauraki Gulf, its islands, and catchments, for the benefit and enjoyment of the people and communities of the Gulf and New Zealand;*
  b) *to facilitate communication, co-operation, and co-ordination on matters relating to the statutory functions of the constituent parties in relation to the Hauraki Gulf, its islands, and catchments, and the Forum;*
  c) *to recognise the historic, traditional, cultural, and spiritual relationship of tangata whenua with the Hauraki Gulf, its islands, and, where appropriate, its catchments.*

  The specific functions of the Forum in relation to the Hauraki Gulf, its islands, and catchment are as follows:

  a) *to prepare a list of strategic issues, determine a priority for action on each issue, and regularly review that list;*

b) *to facilitate and encourage co-ordinated financial planning, where possible, by the constituent parties;*
c) *to obtain, share, and monitor information on the state of the natural and physical resources;*
d) *to receive reports on the completion and implementation of deeds of recognition;*
e) *to require and receive reports from constituent parties on the development and implementation of policies and strategies to address the issues identified under paragraph (a);*
f) *to receive reports from the tangata whenua of the Hauraki Gulf on the development and implementation of iwi management or development plans;*
g) *to prepare and publish, once every 3 years, a report on the state of the environment in the Hauraki Gulf, including information on progress towards integrated management and responses to the issues identified in accordance with paragraph (a);*
h) *to promote and advocate the integrated management and, where appropriate, the sustainable management of the Hauraki Gulf, its islands, and catchments;*
i) *to encourage, share, co-ordinate where appropriate, and disseminate educational and promotional material;*
j) *to liaise with, and receive reports from, persons and groups having an interest in the Hauraki Gulf and business and community interests to promote an interest in the purposes of the Forum;*
k) *to commission research into matters relating to the functions of the Forum.*

Additionally, Part 2 of the Act states that when carrying out the aforementioned functions, the Forum must have regard for the historic, traditional, cultural, and spiritual relationship of the tangata whenua with the natural, historic, and physical resources of the Hauraki Gulf, its islands, and catchments.

Part 2 of the Act also describes and details the powers of the Forum, the costs of the functions of the Forum, and other various mandated requirements of the Forum.

- **Part 3** of the *Hauraki Gulf Marine Park Act 2000* details the provisions of the Act in relation the Park. The purposes of the Park are as follows:

  a) *to recognise and protect in perpetuity the international and national significance of the land and the natural and historic resources within the Park;*
  b) *to protect in perpetuity and for the benefit, use, and enjoyment of the people and communities of the Gulf and New Zealand, the natural and historic resources of the Park including scenery, ecological systems, or natural features that are so beautiful, unique, or scientifically important to be of national significance, for their intrinsic worth;*
  c) *to recognise and have particular regard to the historic, traditional, cultural, and spiritual relationship of tangata whenua with the Hauraki Gulf, its islands and coastal areas, and the natural and historic resources of the Park;*
  d) *to sustain the life-supporting capacity of the soil, air, water, and ecosystems of the Gulf in the Park.*

Part 3 of the Act describes the establishment of the Park and the various requirements on persons or organisations using, controlling, and administering any public or private areas within the Park.

The Hauraki Gulf Marine Park is said to consist of the following:

a) *all conservation areas, wildlife refuges, wildlife sanctuaries, reserves, marine mammal sanctuaries, and marine reserves held, managed, or administered by the Crown from time to time in accordance with the*

Conservation Act 1987 or any Act in Schedule 1 of that Act within the Hauraki Gulf, its islands, and coastal area;

b) *any reserve controlled and managed from time to time by an administering body (whether or not that administering body is a local authority) under an appointment to control and manage made in accordance with the Reserves Act 1977 or any corresponding former Act, within the Hauraki Gulf, its islands, and coastal area;*
c) *all foreshore and seabed that is land owned by the Crown within the Hauraki Gulf other than foreshore or seabed held for defence purposes;*
d) *all seawater within the Hauraki Gulf;*
e) *all land of the Crown in the Hauraki Gulf, within a wetland approved by the Minister of Foreign Affairs and notified to the Bureau of the Convention on Wetlands of International Importance done at Ramsar on 2 February 1971;*
f) *all land included in the Park in accordance with section 34 or section 35;*
g) *all mataitai reserves and taiapure-local fisheries included in the Park in accordance with section 36.*

The boundaries of the Hauraki Gulf Marine Park include portions of the territorial seas of the Auckland and the Waikato. Therefore, the enforcement of the objectives set forth in the *Hauraki Gulf Marine Park Act 2000* is the responsibility of the Auckland Regional Council and the Waikato Regional Council. The act requires that the regional council must ensure that any and all parts of the regional policy statements or regional plans related to the Hauraki Gulf, its islands, and catchments, must not conflict with Part 1 of the act discussed above with specific regard to *Section 7: Recognition of the national significance of the Hauraki Gulf* and *Section 8: Management of the Hauraki Gulf*.

3.8 CONCLUSIONS

The international, national, and regional policies and regulations described in the previous sections, although sometimes redundant and usually tedious to decipher, are vital to the investigations described in this thesis. They are the comprehensive statutes that determine:

i. The required information needed by the relevant government agencies for assessment of applications to undertake disposal of dredged material at sea;
ii. The parameter levels of the physical and biological nature of the dredged material required to be deemed suitable for disposal at sea;
iii. The suitability of the proposed disposal site with specific regard for the suitability of the material intended for disposal.
iv. The necessary issues to be considered in evaluating the potential impacts of disposal at sea; and
v. The requirements involved in designing, implementing, and reviewing the monitoring and management plan of the disposal operation.

As previously stated, the ultimate goal of this study is to establish a disposal option for dredged material, originating from the Auckland and Coromandel area ports and marinas, which can be used in the long-term and will have minimal adverse environmental impacts. In order to achieve this goal in accordance with the relevant policies described in the previous sections, each of the above matters will be addressed throughout the remainder of this thesis.

CHAPTER FOUR: DREDGED MATERIAL CHARACTERISATION

4.1 ORIGINS

As described in the previous chapter, characterisation of the material intended for disposal is required by the international, national, and regional policies set forth for disposal of dredged material at sea. Analyses typically undertaken to characterise dredged sediment include determination of sediment texture and its chemical content. Depending on the level of detail required for the characterisation, biological characteristics may also be examined.

There are several ports and marinas in the Auckland CMA that routinely undertake dredging operations and may request access to the proposed site for disposal of dredged sediment. The dredged material will potentially originate from the following locations: Pine Harbour Marina, Westpark Marina, Ports of Auckland, Half Moon Bay, and Clevedon Marina (Figure 4.1). Additionally, from the Coromandel region, access to the proposed site may be necessary for dredging operations at Whitianga and Whangamata.

Figure 4.1 Potential Auckland CMA sources for dredged sediment destined for disposal at the proposed site (Source: Google Earth).

4.2 PROPERTIES OF THE SEDIMENT TO BE DREDGED

The majority of the dredged material originating from the Auckland CMA is of muddy/sand quality and has some level heavy metal contamination as a result of storm water outfalls in the marina basins. By reviewing past sediment texture and toxicity reports, the material that will be dredged from these areas can be characterised. Special attention will be given to determining extent of the heavy metal contamination in the sediment of these locations.

4.2.1 PINE HARBOUR MARINA

Pine Harbour Marina, located in the south-east of Auckland, is situated on the western side of the Beachlands – Maraetai Pennisula (Figure 4.1). The marina was built on low-lying land and extends approximately 200 m over the intertidal flats on the western side of the peninsula (Figure 4.2). Steady infilling by littoral sediment since the opening of the marina in 1988, has resulted in routine maintenance dredging of the approach channel and the marina basin (Hull, 1996).

Figure 4.2 Aerial photo of Pine Harbour Marina berthing area and approach channel in the Beachlands-Howick embayment of the Auckland Coastal Marine Area (Source: Prof Terry Healy).

4.2.1.1 Texture

A sediment assessment undertaken by Golder Kingett Mitchell (2007) for Pine Harbour Marina determined that the sediments found in the entrance area of the marina are finer than those from the approach channel. The dominant sediment class from the entrance of the marina was determined to be silt (0.004-0.063 mm) with a minimal fine sand component (Golder Kingett Mitchell, 2007). The dominant sediment classes from the approach channel were fine sand and very fine sand (0.06-0.3mm) (Golder Kingett Mitchell, 2007). These areas were included in the assessment because they are the areas undergoing the fastest infilling at Pine Harbour Marina and are, therefore, most likely to be targeted for maintenance dredging.

4.2.1.2 Chemical characteristics

A sediment assessment report at Pine Harbour Marina showed that heavy metal concentrations (copper, chromium, lead, mercury, nickel, and zinc) were higher in the entrance to the marina than in the approach channel (Golder Kingett Mitchell, 2007). These differences are mainly a result of the difference in sediment texture between the marina basin and the approach channel, discussed above (Golder Kingett Mitchell, 2007). It is commonly understood that heavy metal molecules typically adhere more readily to finer sediments, a result of the Van der Waals forces of cohesive sediments. Therefore, the higher heavy metal concentrations in the marina entrance are most likely a result of the finer sediments that occur there.

Golder Kingett Mitchell (2007) found that all the heavy metal concentrations examined in the sediment assessment study of the Pine Harbour Marina entrance and approach channel were below the ISQG-low (interim sediment quality guideline-low) recommended by ANZECC (2000). Contaminant concentrations of sediments from the entrance of Pine Harbour are compared to ANZEEC (2000) guidelines in Table 4.1 (Golder Kingett Mitchell, 2007). Based on these guidelines, it was concluded that there was a very low likelihood of adverse environmental effects resulting from the heavy metal concentrations found in Pine Harbour Marina (Golder Kingett Mitchell, 2007).

Table 4.1 Comparison of sediment quality of Pine Harbour Marina entrance to ANZECC (2000) guidelines for trace elements (Source: Golder Kingett Mitchell, 2007).

	2007 Survey data		ANZECC (2000)	
	Mean ± SD	**Maximum**	**ISQG-low**	**ISQG-high**
Cadmium	0.06 ± 0	0.06	1.5	10
Chromium	30.87 ± 0.32	31.5	80	370
Copper	36.3 ± 3.65	43.4	65	270
Lead	17.37 ± 0.74	18.2	50	220
Mercury	0.11 ± 0.003	0.11	0.15	1.0
Nickel	12.77 ± 0.74	13.5	21	52
Zinc	99.6 ± 2.25	104	200	410

Notes: * All data mg/kg as dry weight.

Additionally, in a study by Bioresearches (1993) undertaken for Pine Harbour Marina Ltd., heavy metal concentrations were examined at three sites (M3 and M6 were along the approach channel and M8 was in the marina basin). Results from this study are presented in Table 4.2.

Table 4.2 Heavy metal concentrations in the approach channel (M3 and M6) and the marina basin (M8) sediments of Pine Harbour Marina in 1993. (Source: Bioresearches, 1993).

	Cd	**Cr**	**Cu**	**Pb**	**Hg**	**Ni**	**Sn**	**Zn**
	Mean ± SD	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**
M3	0.03 ±0.008	14.0 ±1.7	4.6 ±0.7	5.6 ±1.1	0.039 ±0.007	5.8 ±1.5	0.56 ±0.17	26.8 ±3.2
M6	0.02 ±0.004	9.9 ±1.9	3.2 ±0.5	4.1 ±0.6	0.03 ±0.002	3.3 ±0.4	0.53 ±0.4	20.8 ±1.3
M8	0.05 ±0.008	34.8 ±2.9	38.7 ±2.4	18.3 ±1.0	0.13 ±0.006	8.9± 1.6	1.9 ±0.3	89.3 ±5.1

Sample sites outside the marina basin (M3 and M6) show significantly lower heavy metal concentrations than the site inside the marina. The approach channel is the area of Pine Harbour Marina subject to the fastest infilling and subsequently is the area that requires the most frequent maintenance dredging. Therefore, the majority of the dredged material removed from Pine Harbour to be disposed at a proposed disposal site will contain very low concentrations of contaminants.

4.2.2 WESTPARK MARINA

Westpark Marina is located in the upper Waitemata Harbour in the Auckland CMA (Figure 4.3). Significant accumulation of sediment in the marina basin has been observed since its opening in 1985. Loomb (2001) determined that the freshwater outflows in the marina induced flocculation of the muddy suspended sediment which accelerated its deposition. These deposition processes require ongoing dredging to maintain the basin and channel depths for vessel passage.

Figure 4.3 Aerial photo of Westpark Marina, looking to the north (Source: http://www.westpark.co.nz/support.htm#).

4.2.2.1 Texture

Sediment analysis at Westpark Marina showed that the dominant components of sediments from within the marina were mainly fine silt and clay (Loomb, 2001). The mean grain size for sample locations within the marina ranged from 0.065mm to 0.111mm (Loomb, 2001). It was also determined that grain size of sediment taken from the fairway within the marina tended to be slightly larger than that of the sediments in the berthing areas of the marina, which is most likely a result re-suspension and winnowing by vessels in the fairway (Loomb, 2001).

4.2.2.2 Chemical characteristics

Loomb (2001) examined the heavy metal concentrations (cadmium, chromium, copper, nickel, lead, tin, zinc, and mercury) present in the Westpark Marina sediments and compared them to various guidelines presented by Smith *et al*., (1996), Long *et al*., (1995), and Williamson and Wilcock (1994). All three guidelines have a threshold level, or a biological effects level low (ER-L), where effects on the marine environment are minimal. The guidelines also include a biological effects range median (ER-M), where adverse effects will occur more frequently on the marine environment (Loomb, 2001). These comparisons are presented in Table 4.3.

Table 4.3 Sediment quality criteria as proposed by Williamson and Wilcocks (1994), Long *et al*. (1995), and Smith *et al*. (1996) compared to the mean concentration (mg/kg) of heavy metals in Westpark Marina (Source: Loomb, 2001).

	Williamson and Wilcocks (1994)		**Long *et al*. (1995)**		**Smith *et al*. (1996)**		**Westpark Marina Sediment**
	ER-L	**ER-M**	**ER-L**	**ER-M**	**ER-L**	**ER-M**	**Mean Concentration (mg/kg)**
Cd	5	9	1.2	9.6	0.676	4.21	0.065
Cr	80	145	81	370	52.3	160	25.3
Cu	70	390	34	270	18.7	108	51.8
Ni	30	50	20.9	51.6	15.9	42.8	9.6
Pb	35	110	46.7	218	30.2	112	36
Zn	120	270	150	410	124	271	147.2
Hg	*	*	0.15	0.71	0.13	0.70	0.18

* = no value
ER-L= Effects range low
ER-M= Effects range medium

Based on the presented guidelines, the sediment that may eventually dredged from Westpark Marina is relatively uncontaminated. However, copper, lead, zinc, and mercury did exceed one or more of the ER-L (effects range-low) levels.

4.2.3 OTHER POTENTIAL SOURCES OF DREDGED SEDIMENT

Besides Pine Harbour Marina and West Park Marina, there are several other locations at which maintenance dredging is currently being undertaken or locations where future capital dredging works are being planned. If the proposed disposal site is approved for disposal operations, consent may be requested for these additional locations to dispose of dredged material provided the material is suitable for the conditions at the site.

4.2.4 BIOLOGICAL CHARACTERISTICS OF THE SOURCE MATERIAL

Most nearshore coastal regions are highly productive as a result of nutrient inputs from freshwater sources and sewage outfalls. As a result, it can be expected that there will be a significant amount of benthic fauna inhabiting the sediments to be dredged from the interested ports and marinas. Bivalves and worms are quite common in nearshore soft-sediment habitats of New Zealand (Hayward *et al.*, 1982; Hayward *et al.*, 1986; McKnight, 1969). It is likely that survival rates of the organisms present in the material will be low during dredging, transport, and deposition processes.

Various forms of colloidal proteins, a physiological bi-product of benthic invertebrates, typically occur as a superficial coating on the seafloor or as a matrix throughout the sediments in which the organisms live. These colloidal proteins give the sediment a cohesive nature which will, in turn, alter the mechanical behaviour of the sediment when it is released into the water column during disposal operations. Typically, cohesive sediments are made of flocs, which move as a “lump” rather than separately, as non-cohesive sandy sediments do. This feature will accelerate the deposition process and which means that less sediment will be lost via dispersion and advection during the descent of the sediment load.

4.2.5 ESTIMATED VOLUMES

Dredged sediment to be disposed at the proposed disposal site is expected to average up to 50,000 m^3 per year. Initially, Westpark Marina is likely to dredge approximately 40,000 m^3 per year and Pine Harbour Marina will dredge approximately 10,000 m^3 per year. Should consent for disposal operations at the proposed site be granted, it is likely that the maximum quantity allowed for disposal at the site will be 50,000 m^3anually. This is an acceptable quantity, as declared in the *New Zealand Coastal Policy Statement 1994* and the *Proposed New Zealand Coastal Policy Statement 2008,* to avoid adverse effects from disposal at sea. Consent for quantities over this limit may only be granted provided that further investigations of the site show that an increased volume of disposed sediment at the site will not cause additional environmental impacts.

4.3 CONCLUSIONS

Previous studies show that sediment dredged from ports and marinas in the Auckland CMA is typically of fine sandy mud texture, containing low levels of heavy metal concentrations. The heavy metals detected in the marina sediments may be considered to have little or no adverse effects on the environment should they eventually be disposed at the proposed site (ANZECC, 2000; Smith *et al*., 1996; Long *et al*., 1995; Williamson and Wilcock, 1994).

CHAPTER FIVE: A POTENTIAL SITE SUITABLE FOR DISPOSAL OF DREDGED MATERIAL ON THE SHELF

5.1 LOCATION

The proposed disposal site is located approximately 20 km east of Great Barrier Island, directly north of Cuvier Island (Figure 5.1). The site is beyond the limit of the territorial seas and located in the Exclusive Economic Zone (EEZ) at 175º 47’.00E and 36º 13’.00S.

The territorial waters adjacent to the site in the east are part of the Auckland Coastal Marine Area (Figure 3.3), which includes, in this area, the Hauraki Gulf Marine Park (Figure 1.1). Additionally, the proposed boundaries of the Aotea (Great Barrier) Marine Reserve extend from the north-east coast of Great Barrier Island to the limit of the territorial seas (Figure 5.2). Located to the south of the proposed site is the northern boundary of the Waikato Coastal Marine Area (Figure 3.4).

5.2 SIZE AND CAPACITY

The proposed disposal site is 1500 m by 1500 m with an additional 1000 m of monitoring area included around the perimeter of the site making the total area included in the survey 3500 m by 3500 m.

At a disposal rate of 50,000 m^3 per year, dredged material spread over the proposed site will result in the accumulation of a layer of sediment approximately 20 cm thick over the site. However, it is unlikely that a layer with such an even thickness could be achieved assuming different synoptic current conditions occur at the site. In practice, most of the material disposed would deposit toward the central part of the disposal site, which might conceivably create a low mound 1-2 m high.

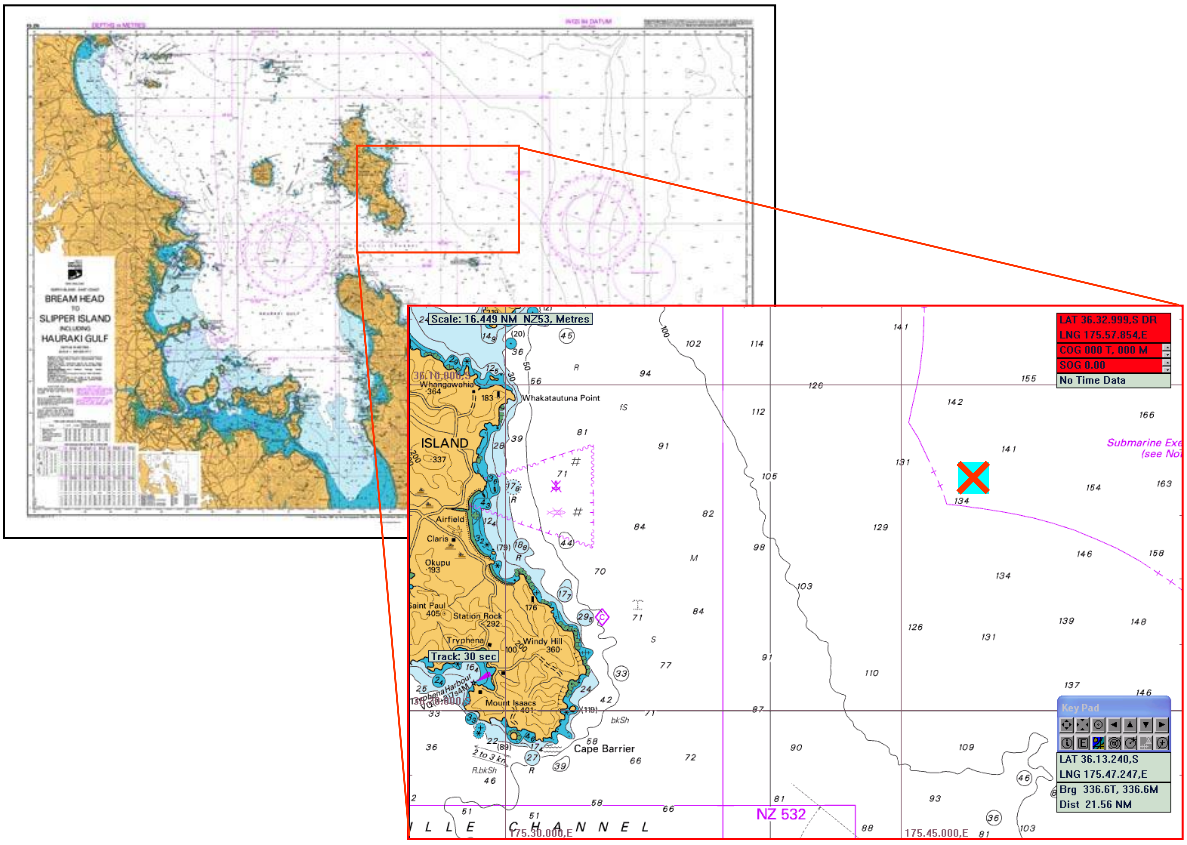

Figure 5.1 Hydrographic chart of the north-east coastal region of New Zealand (inset: location of the proposed disposal site ~2 km within the EEZ boundary) (Source: Frisken, 1992).

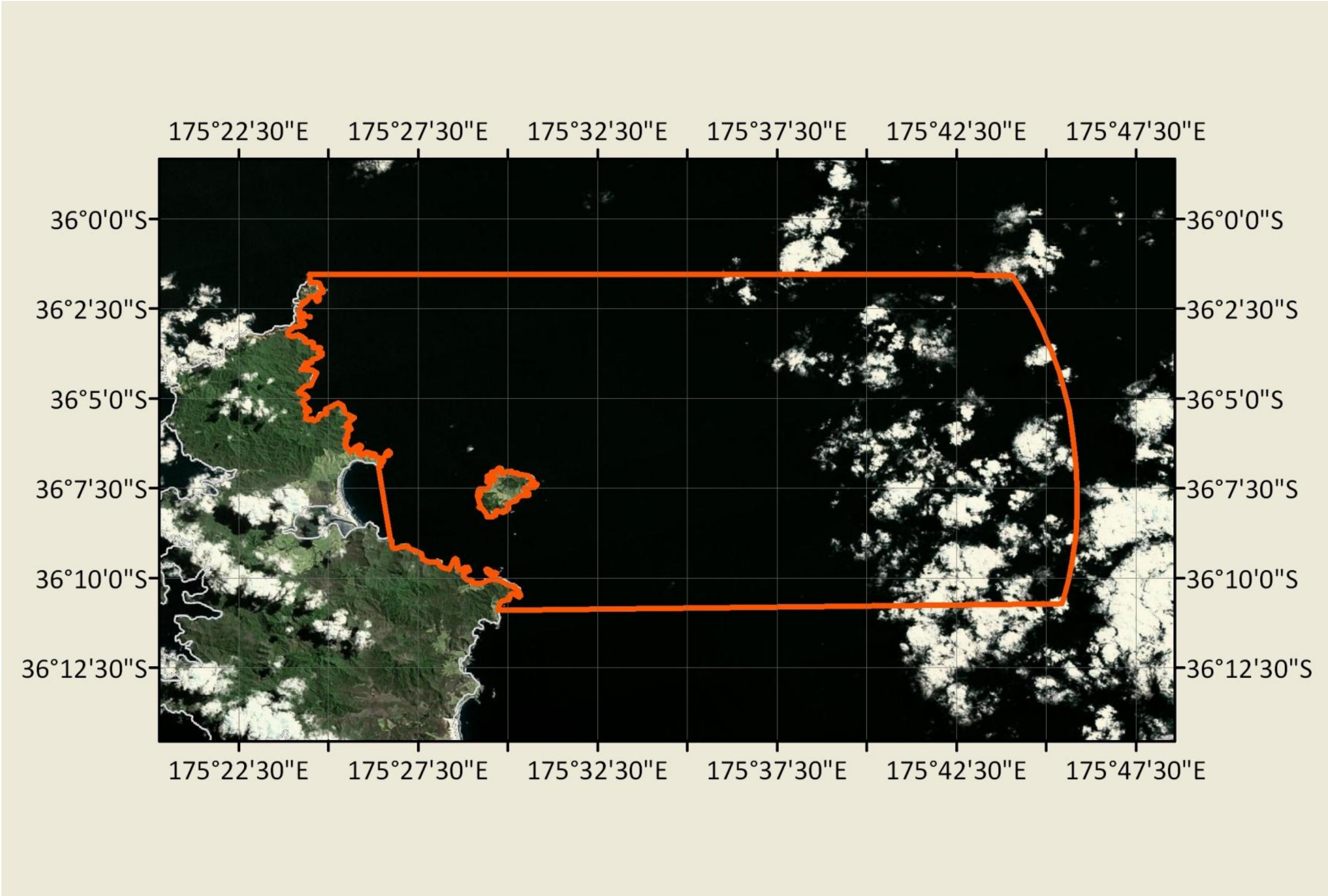

Figure 5.2 Boundaries of the proposed Great Barrier Marine Reserve (Source: Department of Conservation).

5.3 Geology and geomorphology

5.3.1 Surrounding bottom topography

Surrounding the North Island of New Zealand, there are numerous topographic bottom features that influence the hydrodynamic processes occurring on the north-east continental shelf where the proposed site is situated.

The North Island is flanked to the west by the Tasman Sea which separates it from Australia to the north-west. To the north-east of the North Island is the South Fiji Basin which is flanked by the Colville Ridge and the Havre Trough reaching toward the Bay of Plenty, and the Kermandec Ridge, respectively (Figure 5.3). The Kermandec Ridge is adjacent to the Kermandec Trench. At 9000 m, this bottom feature is thought to be one of the deepest parts of the world's oceans (Harris, 1985).

The dominant features to the north of the North Island flank the western boundary of the South Fiji Basin and include the Three Kings Ridge, the Norfolk Ridge, and the Lord Howe Rise, from east to the west of the South Fiji Basin (Heath, 1985) (Figure 5.3). The Three Kings Ridge, in parts, is as shallow as 500 m and is situated between the South Fiji Basin and the Norfolk Basin, both of which are relatively deep at 4000 m (Mercer, 1979). The Norfolk Ridge has an average depth of 1000 m and is considered to be relatively shallow compared to other oceanic submerged ridges. Dividing the latter ridge from the Lord Howe Rise is the New Caledonia Trough, averaging 3000 m deep. The westernmost of the bottom topographic features is the Lord Howe Rise which ranges from 1000-2000 m deep (Harris, 1985).

It is the combination of these bottom features that dictate the path of the regional oceanic geostrophic current flows and the tidal behaviour observed on the north-east continental shelf where the proposed disposal site is located.

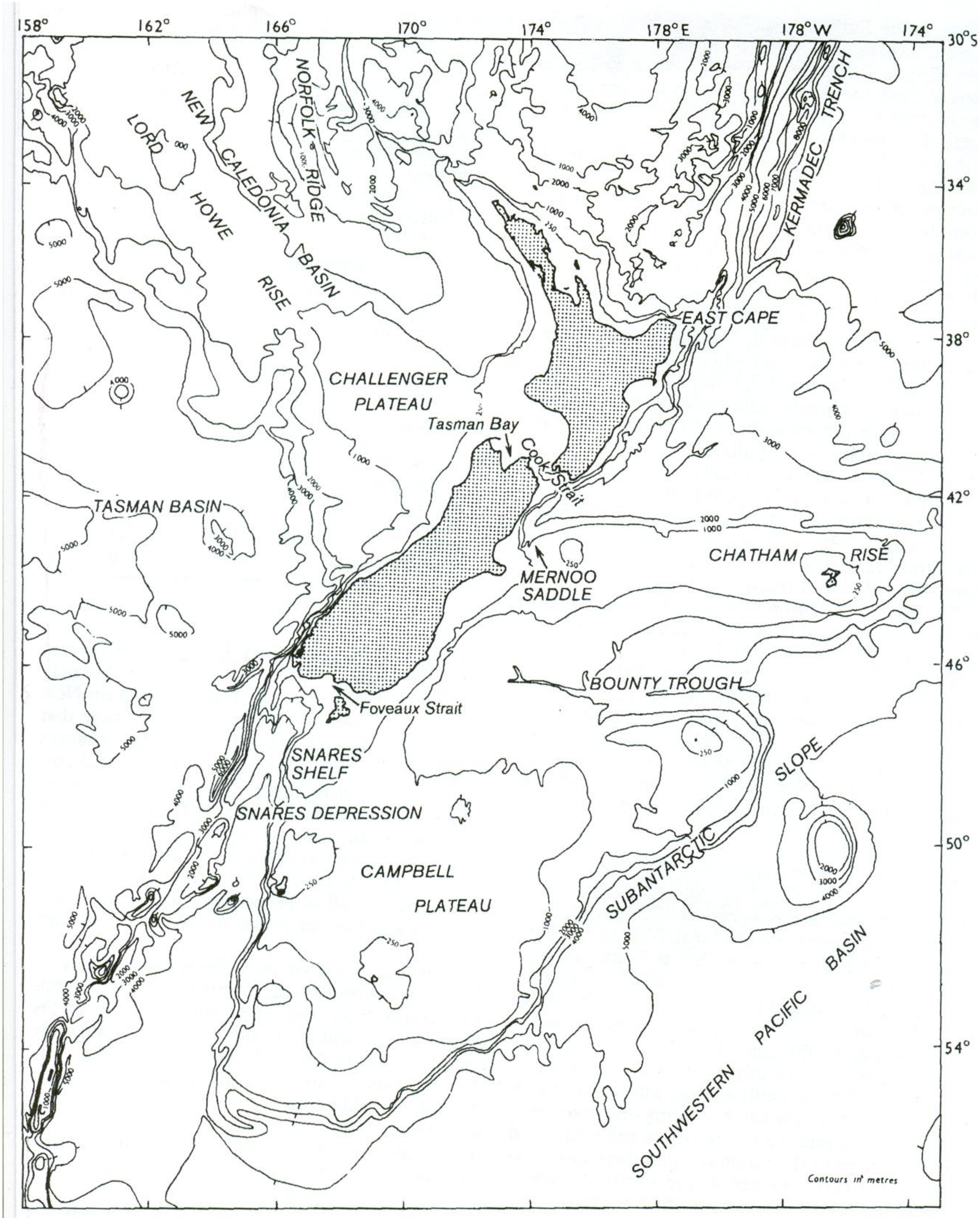

Figure 5.3 Bottom topographic features surrounding New Zealand (Source: Heath, 1985).

5.3.2 BOTTOM TOPOGRAPHY AT THE PROPOSED SITE

The site is located on the mid-continental shelf off the north-east coast of Great Barrier Island in water depths from 130 m to 140 m. The continental shelf width in this region ranges from just 11 km to ~100 km (Harris, 1985). At the latitude where the site has been designated, the shelf-break occurs at the 200 m contour

(Harris, 1985) proceeding onto the continental slope. Bathymetry of the site from the eastern side of Great Barrier Island to approximately 100 km off shore can be seen in Figure 5.4. The white line included in this image represents a transect across the continental shelf through the proposed site. The location of the proposed site and the Explosives Dumping Ground site can be seen in the continental shelf profile plot of the transect line included in Figure 5.4 (Figure 5.5).

Initial site inspection in November, 2007 using a single depth sounder and drop camera video images indicated a flat plain seafloor only varying 1-3 m in depth over the proposed site area.

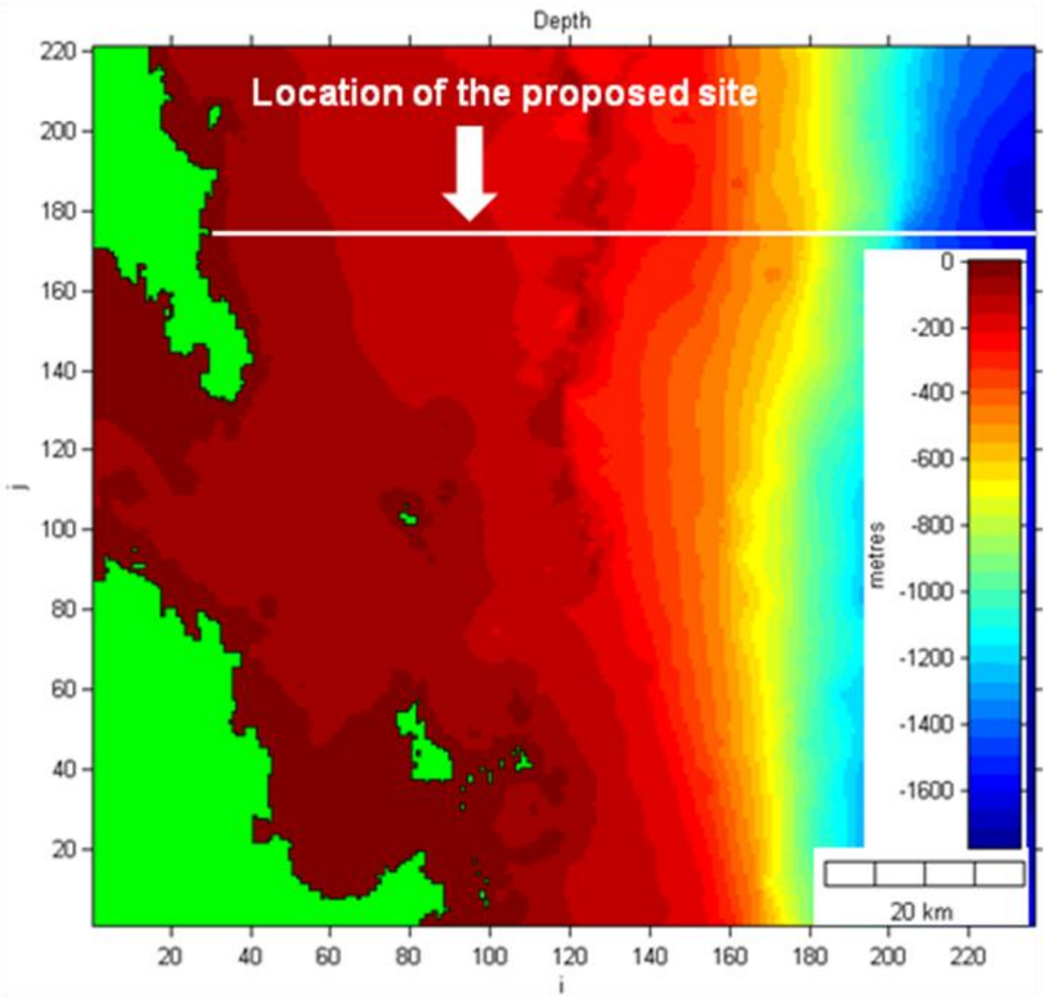

Figure 5.4. Bathymetry of the regions surrounding the proposed disposal site from the eastern side of Great Barrier Island to ~100 km off-shore. The white line represents a transect of the continental shelf profile which is plotted in Figure 5.5.

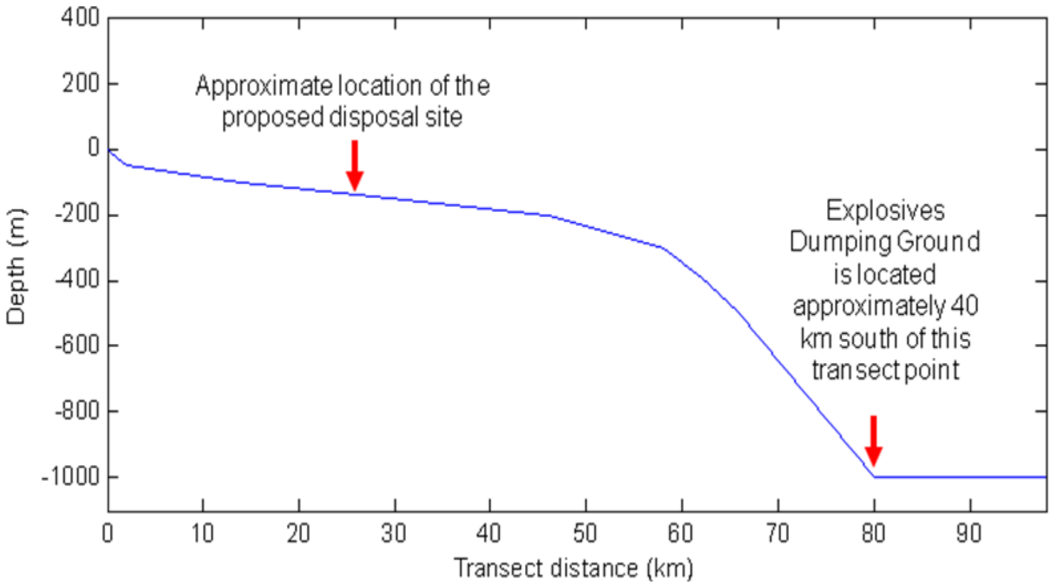

Figure 5.5 Profile of the continental shelf extending from the east coast of Great Barrier Island past the shelf break (vertical exaggeration= 50).

5.3.3 SEDIMENT TYPE

As recorded by The New Zealand Oceanographic Institute, the sediments at the mid-shelf depths in the area of the proposed site are typically muddy/sand to sandy/mud (Carter, 1980) (Figure 5.6). Samples retrieved in November 2007, at the proposed site, confirmed the reported sediment types. Visual observations of samples indicated that the sediment at the site is, in fact, muddy/sand to sandy/mud with little variation across the area of the site (Figure 5.7).

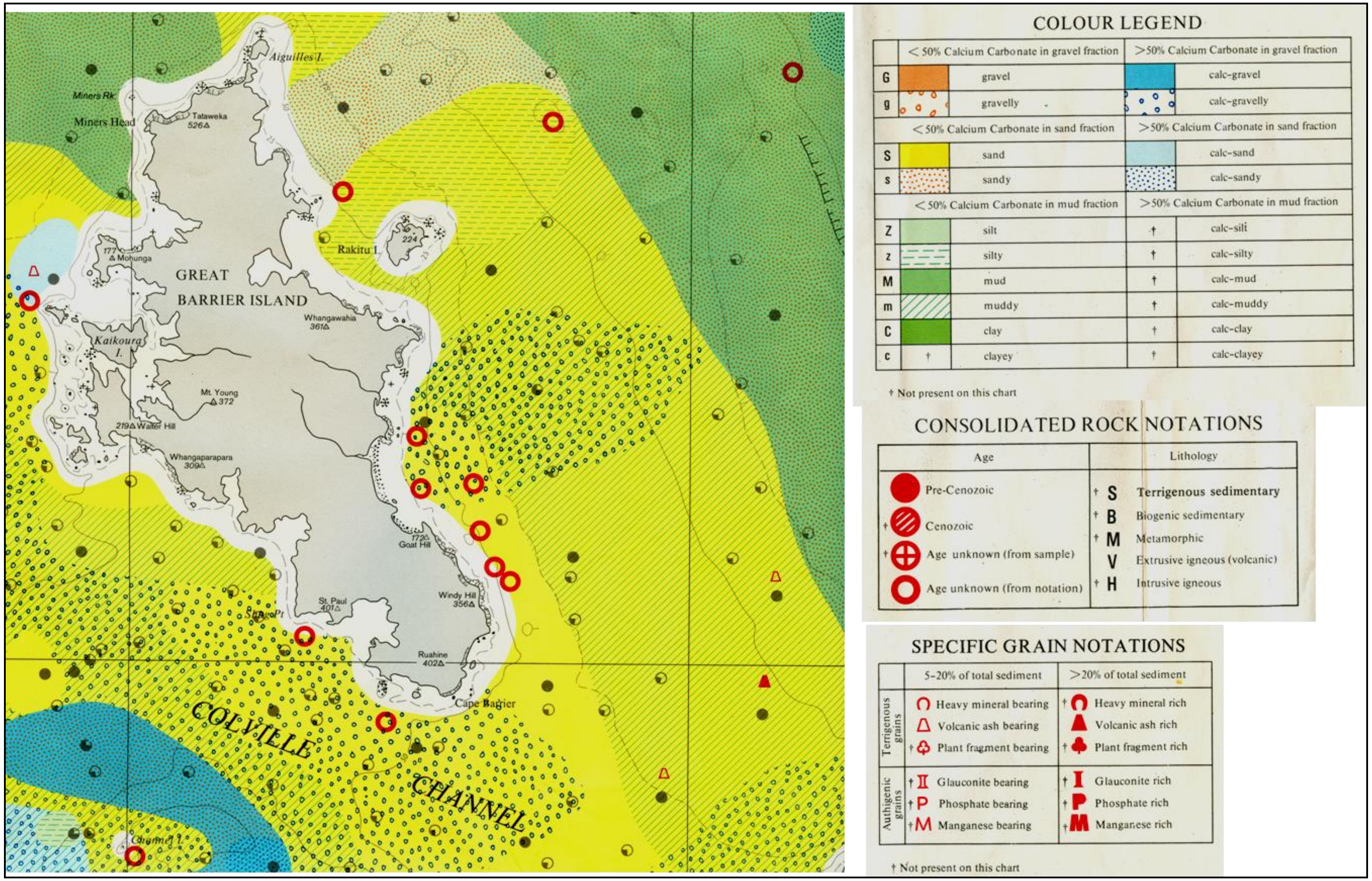

Figure 5.6 Sediment map of regions east of Great Barrier Island (Source: Carter and Eade, 1980).

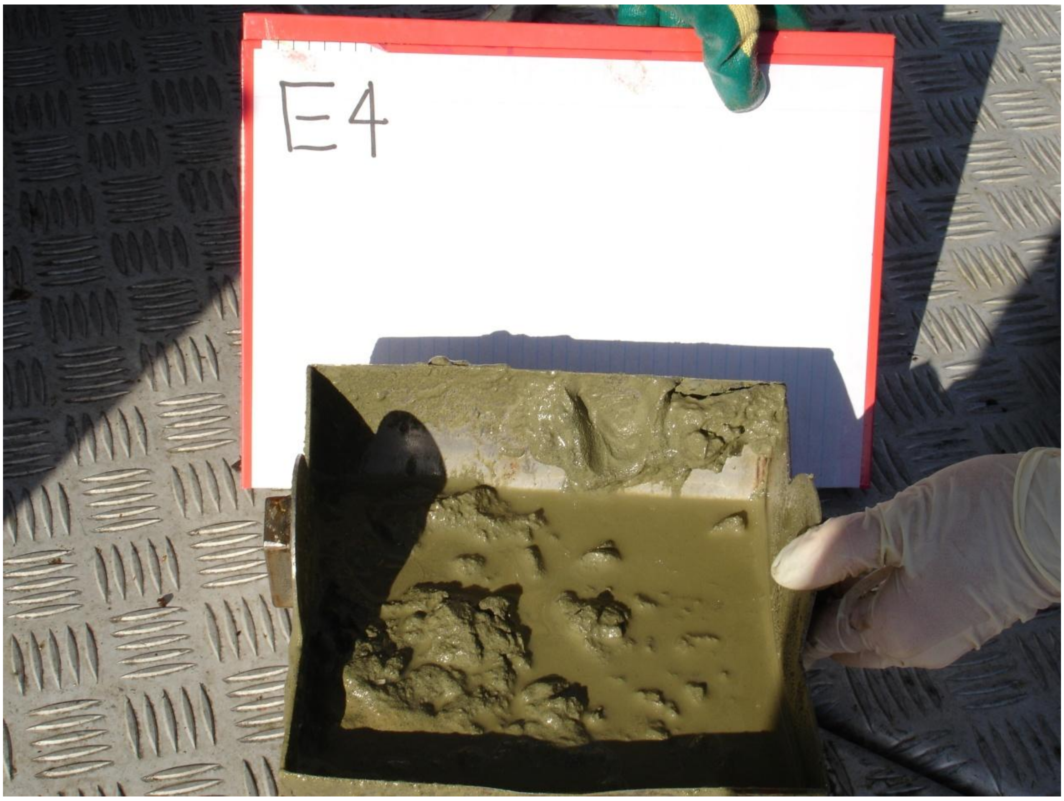

Figure 5.7 Photograph of the sediment retrieved during the November, 2007 survey, from the centre sample location of the proposed disposal site (subsequent sample locations yielded sediment visually consistent with that of the centre location).

5.3.3.1 Sediment texture analysis methods

During the survey cruise of November 2007, 20 sediment samples were retrieved using a 'SHIPEK' grab sampler (Figure 5.8). The samples were obtained at even intervals across the site to ensure a reliable representation of the possible variations in sediment texture over the area. Sample locations across the site area are indicated in Figure 5.9.

The 'SHIPEK' grab sampler was designed to obtain a 3000 mL volume of sediment over a 0.04 m^2 area to a depth of 102 mm. However, the majority of the samples retrieved filled less than a third of the collection bucket indicating that the layer of loose sediment on the continental shelf at the depths of the site is substantially less than that of the inshore depths that the 'SHIPEK' grab sampler was designed for. Nonetheless, the samples retrieved are considered to be representative of the sediment sizes at the site.

Prior to texture analysis, samples were treated with hydrogen peroxide (H_2O_2, 10%) to remove organic material from the sediment particles, the presence of which would skew results. Through visual observations of the samples, it was determined that laser-sizer analysis (Malvern Mastersizer-S 300RF) was suitable for determining the sediment size classes of the samples.

Figure 5.8 Photograph of the 'SHIPEK' grab sampler used to retrieve sediment samples on the November 2007 survey cruise.

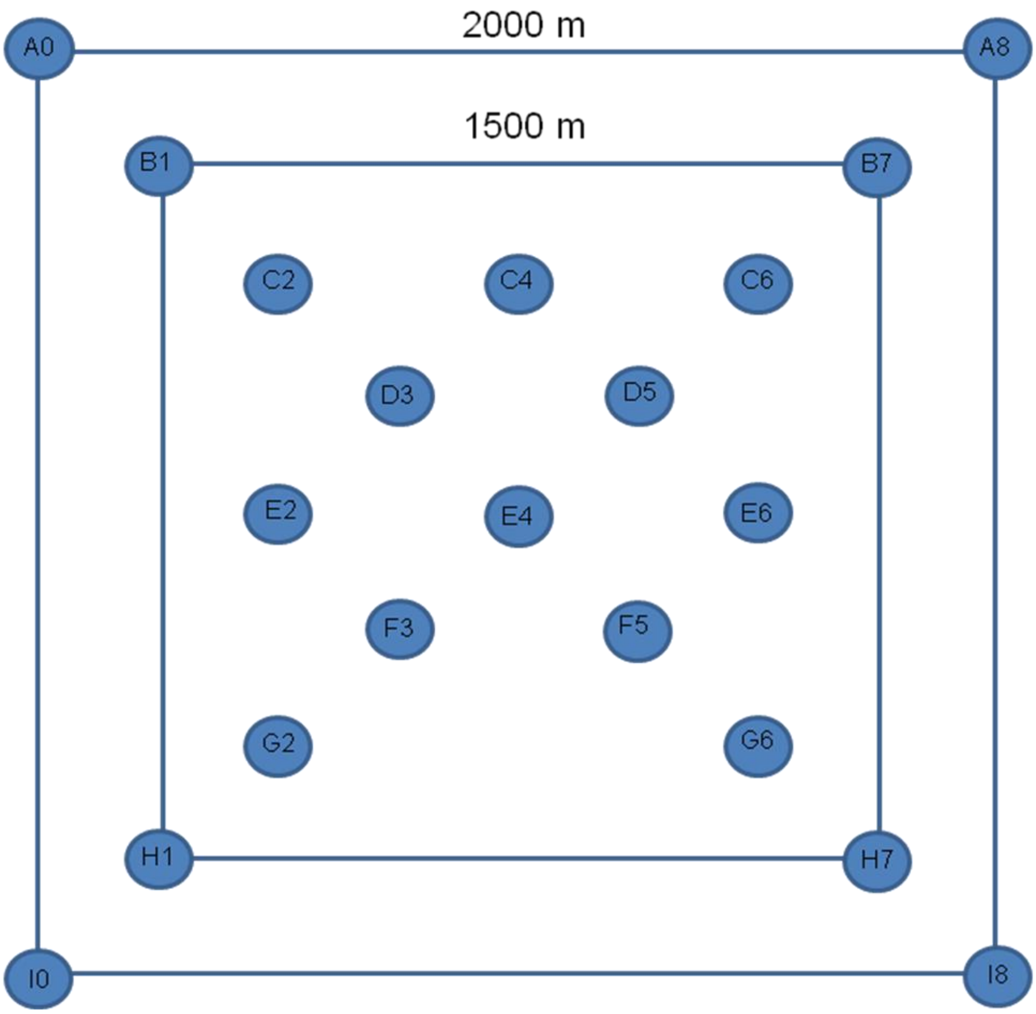

Figure 5.9 Schematic of the locations sampled at the study site on the November 2007 survey cruise.

5.3.3.2 SEDIMENT TEXTURE ANALYSIS RESULTS

Sediment size classes were designated in the following way: clay (0.05-3.9 µm), very fine silt (7.8 µm), fine silt (15.6 µm), medium silt (31 µm), coarse silt (32-62.5 µm), very fine sand (62.6-12.5 µm), fine sand (126-250 µm), and medium sand (251-500 µm).

For the majority of samples, the dominant sediment size class ranged from approximately 0.8 µm to 35 µm or clay through to coarse silt sized particles (Figure 5.10). However, another substantial textural component to the samples was particles ranging from approximately 50 µm to 350 µm. These size classes are classified as very fine sand through to medium sand.

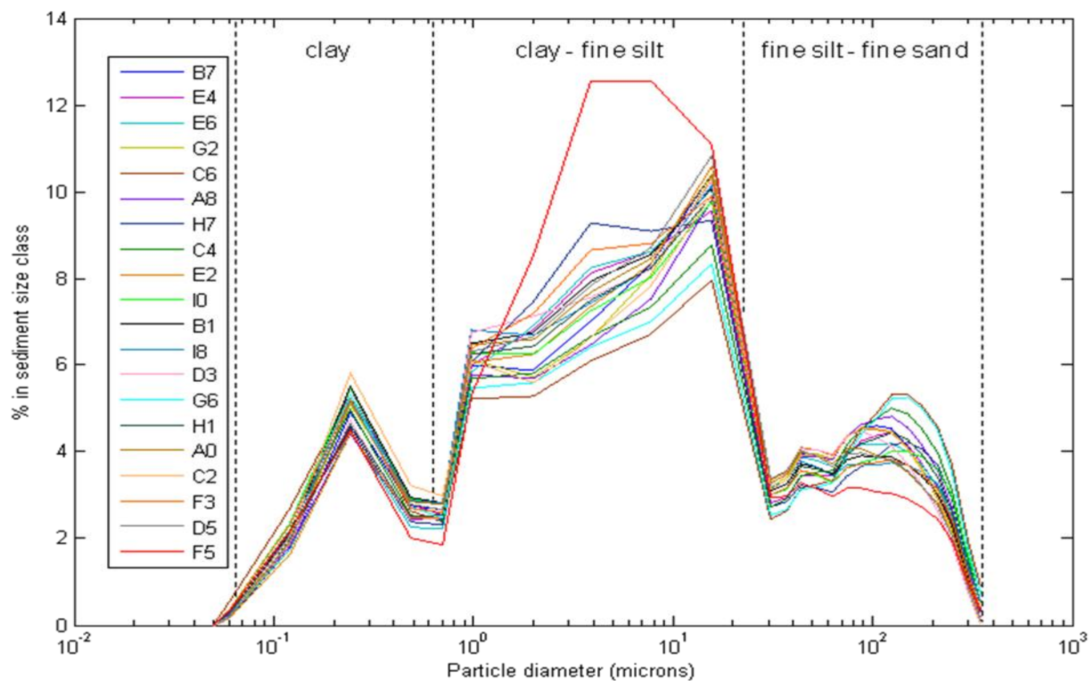

Figure 5.10 Particle diameter (μm) percentages from each sample taken at locations B7-F5 during the November 2007 survey cruise.

Textural analysis comparisons between sample locations showed very little variation across the site area. Figure 5.11 shows proportions of general sediment size classes at each site depicted on the sample location schematic (Figure 5.9). The major textural class for all sample locations is that of clay sized particles (0.05-3.9 μm). Particles classed as very fine sand (7.8 μm) make up the second largest size class for all sampling locations. Medium sized sand particles (251-500 μm) make up the smallest size class of the locations sampled.

5.3.3.3 Discussion

Sediment samples retrieved across the study site during the November 2007 survey cruise exhibit similar textural characteristics to those reported on by the New Zealand Oceanographic Institute (Carter, 1980). The seafloor sediment of the continental shelf on the north east coast of New Zealand, at the depths of the study site, ranges from sandy/mud to muddy/sand. Particularly, the seafloor sediment within the boundary of the study site contains a larger component of smaller size particles which designates it muddy/sand. The sediment at the study site is homogenous and displays very little variation across the 2 km^2 area.

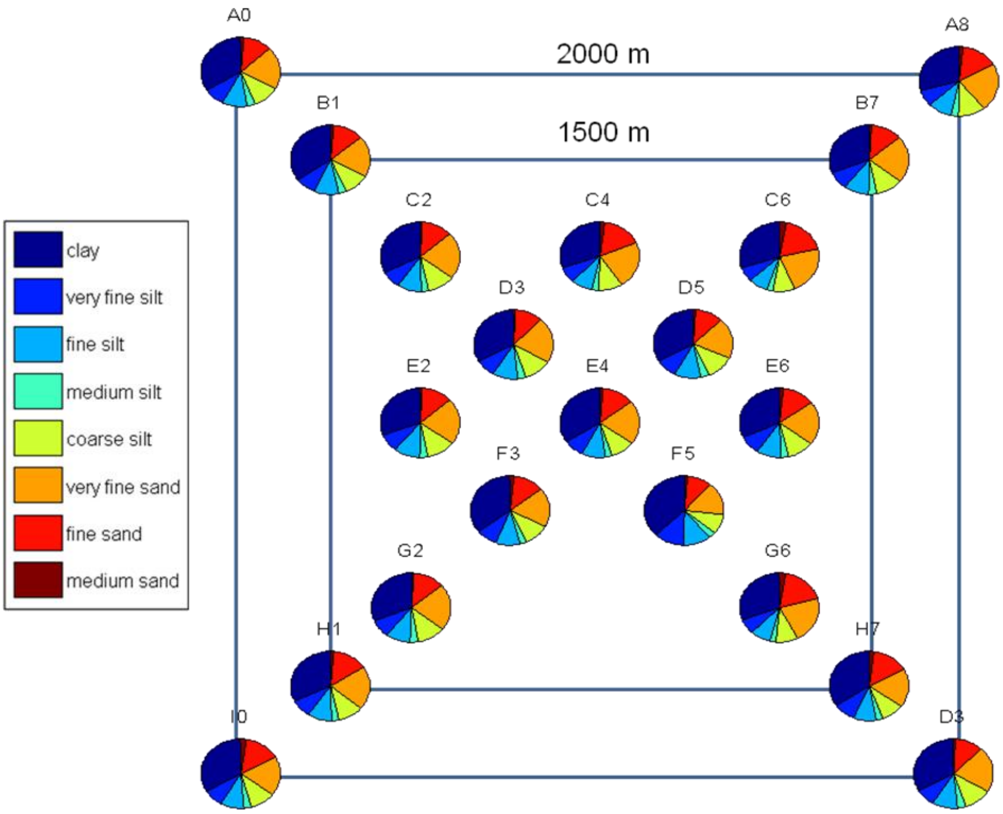

Figure 5.11 Sediment size class proportions for each location sampled at the study site.

5.3.4 Summary

Although a diverse range of bottom topographic features influence the processes of the continental shelf on the north east coast of New Zealand (Figure 5.3), the continental shelf in this region is relatively unremarkable. In the area of the study site, the bottom topography is flat, varying only 1-3 m. Likewise, seafloor sediments are muddy/sand varying only minimally over the 2 km^2 area of the site.

5.4 WATER PROPERTIES

5.4.1 TEMPERATURE

Mercer (1979) found that the surface temperatures in the north-east coast region of the North Island, were at maximum values in the end of summer and beginning of autumn. These coincided with maximum air temperatures. The maximum sea-surface temperature observed off the north-east coast was 23.54ºC, but ranged through to 12.62ºC.

Bottom water temperatures were influenced by seasonal weather variations only to a depth of 100 m; below that, temperature values were relatively constant. Similar to sea surface temperatures, the maximum bottom temperatures (~22.54ºC) for the north-east coast region occurred in February (summer) (Mercer, 1979). Likewise, the minimum temperatures occurred in July (winter) and reached 12.53ºC in the north-east coast region.

It is expected that at the proposed site, surface temperatures will, likewise, be at a maximum during summer and a minimum during the winter, as is true with near shore sites on the north-east coast. However, because of the water depth in the area of the study site (~140 m), seafloor temperatures will most likely vary only slightly from season to season. With summer easterly winds, the intrusion of the southerly flowing East Auckland Current may cause surface temperatures at the site to reach a maximum before near shore sites (Sharples, 1997).

5.4.2 SALINITY

The ocean surrounding New Zealand is a mixing zone for several distinct water masses, which greatly influence the regional oceanography. In the northern oceans around New Zealand the surface waters originate as Subtropical Water (Heath, 1985). This southerly flowing water mass tends to possess relatively high salinity and temperature, and originates from the tropical and subtropical central

Pacific Ocean. In New Zealand, this water mass is derived from the southward flow along the east Australian coast, which is in turn, fed by the westward flowing south Equatorial Current (Heath, 1985).

Surface salinities have been observed to gradually decrease in early autumn from north to south off the north-east coast of New Zealand and were found to be at a minimum in the winter (Mercer, 1979). Bottom salinity in this region ranges from 35.67‰ - 33.4‰ with the highest values being recorded in the outer Hauraki Gulf (Mercer, 1979). As the proposed dredging disposal site is not far from the outer reaches of the Hauraki Gulf, it can be expected that surface and bottom salinity will be similar, that is, salinity is expected to be relatively high considering that there are no freshwater inputs to this region so distant from land.

5.4.3 NUTRIENTS AND PRIMARY PRODUCTIVITY

The presence of chlorophyll a and, therefore, phytoplankton, in coastal waters can be used as a reliable indicator of the nutrient levels and primary productivity occurring in a region. Phytoplankton distributions around New Zealand, reported by Murphy *et al*. (2001), were derived from SeaWiFS remotely-sensed ocean colour data from 1997 to 2000. Images of chlorophyll a concentrations during this time period can be seen in Figures 5.12a and 5.12b.

During the study, chlorophyll a concentrations off the north-east coast and on the continental shelf were elevated in the winter and reached a maximum in spring (September-October) (Figure 5.12a) (Murphy *et al*., 2001). The minimum concentrations in these regions occurred at the end of summer (February-March) (Figure 5.12b) (Murphy *et al*., 2001).

It was also found by Murphy *et al.* (2001) that there was very little inter-annual variability in magnitude and timing of these maximums and minimums occurring in the north-east coast and shelf region, where patterns show generally low chlorophyll a concentrations throughout the year compared to other regions around New Zealand. This may be due to weak winter mixing in this region where bloom conditions are only optimal approximately 3 months out of the year (Murphy *et al*., 2001).

These findings indicate that primary production is relatively low in the region of the north-east coast due to nutrient limitations and/or light limitations in the mixed layer.

5.4.4 SUMMARY

The water column overlying the continental shelf tends to have significantly different properties to that of nearshore areas as a result of water depth. Typically, properties such as salinity and temperature are only seasonally variable to a water depth of 100 m, below which, these properties tend to be relatively constant. In the shelf surface waters of the north east coast of New Zealand, temperature and salinity are driven by seasonal variations associated with wind patterns and intrusion of subtropical waters. However, bottom waters in this region tend to remain relatively constant. As optimal mixing conditions are limited in this area, nutrient rich bottom waters are not consistently upwelled to the photic zone. As a result, primary productivity is low in the region of the study site compared to nearby coastal areas in New Zealand.

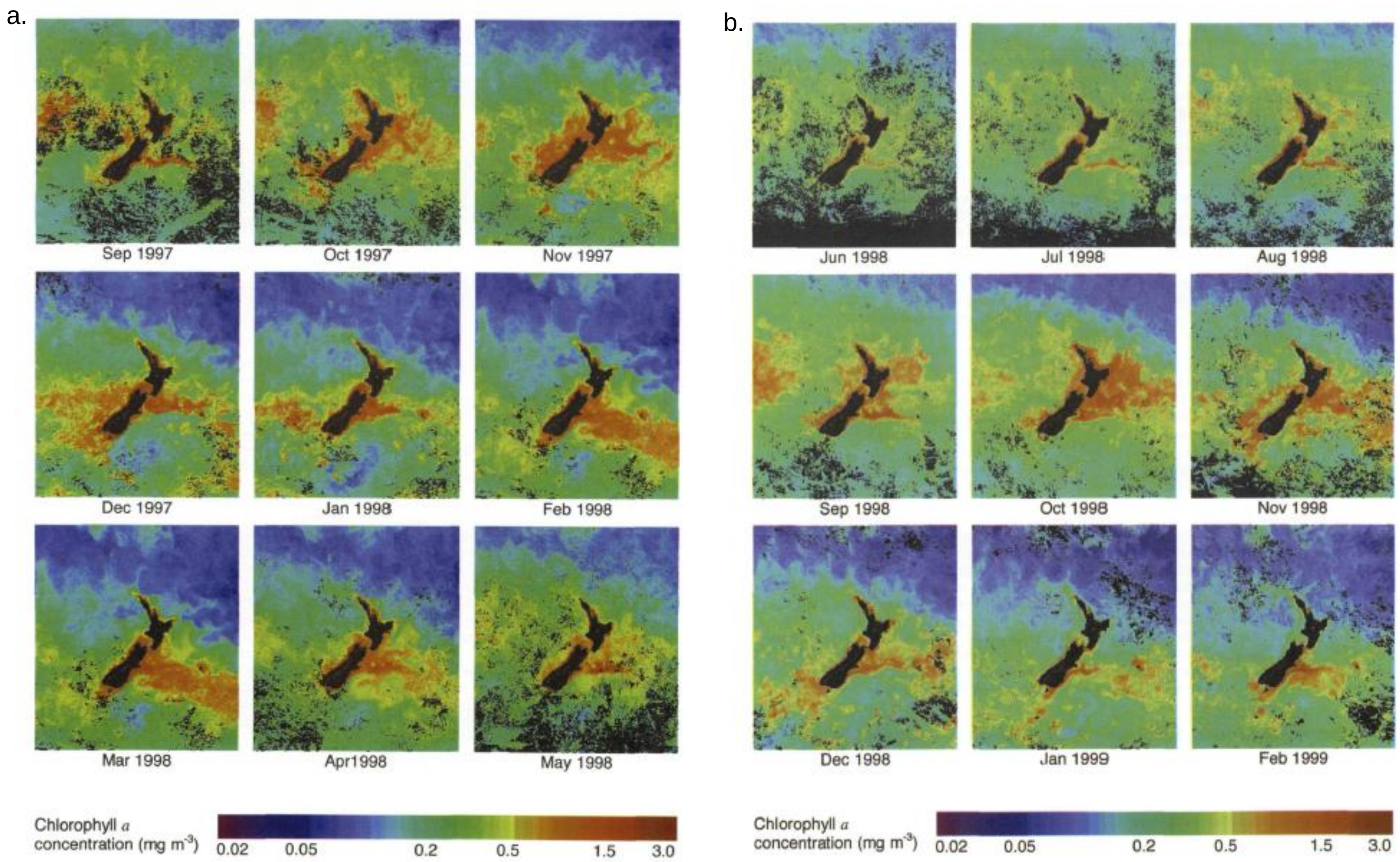

Figure 5.12. Monthly chlorophyll a concentrations in the coastal waters of New Zealand from (a) September 1997- May 1998 and (b) June 1998- February 1999. (Source: Murphy *et al*., 2001).

5.5 Hydrodynamics

5.5.1 Tidal features of the region

The waters of the north-east continental shelf of New Zealand are influenced by several tidal waves of varying amplitude and significance. The majority of these tidal waves propagate anti-clockwise around the New Zealand land mass (Heath, 1977). It has been found that the tidal wave takes on the features of a trapped Kelvin wave resulting in a direction of propagation so that the coastline lies on the left of the wave (Walters *et al*., 2001) causing the anti-clockwise type propagation.

The dominant tidal constituent in this region is the M2 semi-diurnal tide, which has a tidal period of 12.42 hours (Heath, 1977, 1985). As previously stated, the M2 tide propagates anti-clockwise around New Zealand in the form of a trapped Kelvin wave. The unique features of New Zealand's continental shelf and slope induce this progressive barotropic wave to pass around the land mass with little energy loss (Heath, 1985). As the wave completes its full 360º rotation around New Zealand (Heath, 1977), it is maintained by incoming tidal wave additions from its easterly and westerly situated amphidromic points (Walters *et al*., 2001). The tidal amplitudes tend to increase as the tidal wave gets closer to shore (Walters *et al.*2001). Despite the dominance of the M2 tide over other tidal constituents, its influence compared to other geostrophic flows is minor with respect to the shelf dynamics (Sharples and Greig, 1998). In the region of the proposed site, M2 tidal current velocities are found to be only 5-10 cms^{-1} where mean current flows in this region can be 20-30 cms^{-1} (Sharples and Greig, 1998).

During certain conditions off the north-east coast of New Zealand, the M2 tide may be induced to separate into its M4 and M6 tidal harmonics (Sharples and Grieg, 1998). The formation of these harmonics may be a result of an internal tide propagating over the Kermandec Ridge (Figure 5.3) where the M2 barotropic energy gets converted to baroclinic modes (Forman *et al*., 2004). This would cause the water column to develop density stratified layers resulting in very little mixing.

Internal tides are baroclinic and have the same frequency as the associated barotropic component, the M2 tide in this case (Heath, 1985). The wavelength of the internal tide will be smaller than that of the barotropic tide. The presence of these harmonic constituents may result in tidal currents reaching 20 cms^{-1} in this region (Sharples and Grieg, 1998). In these cases, the influence of the tide on the circulation in this region can be considered important.

As these internal tides propagate shorewards, they can disintegrate as they reach the continental shelf break (Boczar-Karakiewicz *et al.*, 1991). This subsequent disintegration can result in internal waves breaking on the continental shelf causing near-bed motions sufficient enough to lift and transport sediment on the outer shelf (Boczar-Karakiewicz *et al.*, 1991).

In the case of the proposed disposal site, it is possible that an internal wave breaking on the shelf may influence the re-entrainment of disposed dredge spoil, but the site may be far enough from the edge of the shelf that the effects may only be minimal.

5.5.2 CURRENTS

Geostrophic flow is described as current flow in the ocean that is a result of a horizontal pressure gradient in the water column (Tomczak and Godfrey, 1994). This force is balanced by the horizontal component of the Coriolis force that arises from the rotation of the earth.

The geostrophic flow will follow the contours generated by the geopotential height changes in the sea surface and the speed of this flow is proportional to the slope of the sea surface (Garner, 1969). Geostrophic flow may also be determined by following the isothermal contours resulting from temperature variation with depth (Tomczak and Godfrey, 1994).

A significant geostrophic flow known as the East Australian Current (EAC), crosses eastward over the Tasman Sea towards New Zealand, creating the Tasman Front (Sharples, 1997; Stanton, 1981). This front is not associated with the convergence of two water masses, rather, it is a product of the flow dynamics in the area (Heath, 1985). Flow velocities in this region can be relatively fast and are evidently a result of spatial restriction from bottom features such as the Lord Howe Rise and the Norfolk Ridge (Heath, 1980) (Figure 5.3).

Once in contact with the New Zealand land mass, the flow decreases in velocity somewhat to form the East Auckland Current (EAUC) (Figure 5.13). This geostrophic current flows south-eastward along the eastern shelf of the North Island from North Cape to East Cape where the current forms the mainly barotropic East Cape Current (ECE) (Bye, 1979).

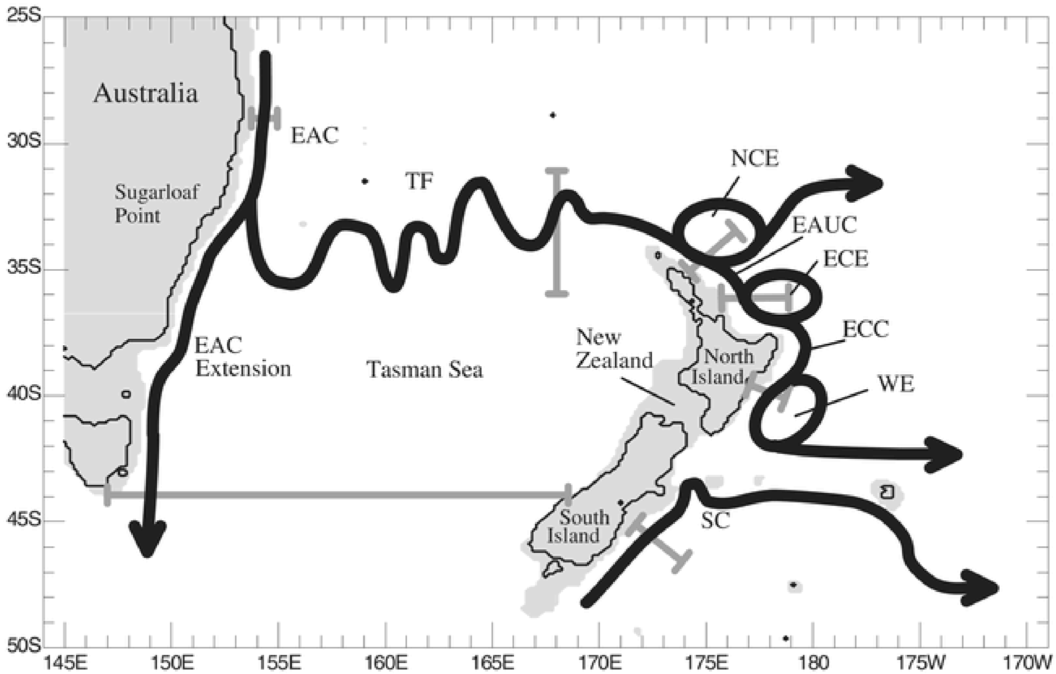

Figure 5.13 East Australian Current (EAC) system forming the East Auckland Current (EAUC) on the north-east coast of New Zealand showing the approximate locations of the Tasman Front (TF), North Cape Eddy (NCE), East Cape Eddy (ECE), East Cape Current (ECC), Wairapa Eddy (WE) and the Southland Current (SC) (Source: Tilburg *et al.*, 2001).

The flow eastward around the North Cape feeds a clockwise flow north of the Hauraki Gulf (Heath, 1980). This clockwise flow near North Cape manifests itself as the quasi-permanent North Cape Eddy (NCE) (Figure 5.13). Flow north of 37ºS extends toward the north-east and south of that latitude, the flow turns east around the East Cape as the East Cape Eddy (ECE) (Figure 5.13).

The path of this flow has been confirmed by a drogue trajectory study undertaken by Heath (1980). Near surface flows were estimated to be between 20 and 30 cms^{-1} in typical conditions, arising primarily as the result of wind-driven currents (Heath, 1980). However, as reported by Stanton and Sutton (2003), near surface flows measured by moorings located on the inshore side of the North Cape Eddy reached 45 cms^{-1}, but generally the position of the North Cape Eddy is some distance north of the proposed disposal site. Therefore, it is not likely that currents of that magnitude would occur in the area of the proposed disposal site.

The path of the EAUC is traditionally situated off-shore from the continental shelf. Sharples (1997) observed a cross-shelf intrusion onto the continental shelf of subtropical water. It was suggested that a local weakening of off-shore winds commonly associated with summer conditions allowed the EAUC to approach closer to the shelf.

This coastal intrusion was earlier noted by Denham *et al.* (1984), but the distinct summertime movement onshore of the current was not evident. In fact, the current was measured to be closest to shore in the spring (Denham *et al.*, 1984). The full development of the intrusion is thought to require the addition of summertime easterly winds so that the water column may become distinctly stratified (Sharples, 1997).

This theory was questioned by Zeldis et *al*. (2004) based on their finding that the observed intrusion was apparently not correlated with a prolonged easterly wind. They found that the intrusion formed independently and was a result of stratification of the water column. It is likely that the intrusion observed by Denham *et al.* (1984) was not derived from the same physical elements. This variable flow path can have widespread consequences related to community structure of coastal marine ecosystems (Sharples, 1997).

These contradictory findings as to the variable nature of the EAUC demonstrate that much is still unknown and further study is required. It can be said, however, that it is possible that the influence of the EAUC on the proposed dredging disposal site may be less during certain seasons and more during others.

Overall, the EAUC is likely the most influential of all hydrodynamic features in the region impacting upon the proposed disposal site according to previously measured velocities.

5.5.3 Wind-driven transport

Wind stress in the region of the north-east coast of New Zealand is thought to be an important factor driving currents in the coastal ocean. The local wind climate in this region is relatively variable, but it can be generalised that westerly winds prevail in the winter and easterly winds prevail in the summer (Sharples and Greig, 1998). Harris (1985) illustrated the inter-annual variability of the winds by noting extreme westerly winds in December 1982, which tends to be the season that easterly winds occur most often. Regardless of direction, at the mean wind speeds found in the north-east coast region, 5-10 hours of steady wind is required to establish a wind driven current.

The wind affected surface layer, otherwise known as the Ekman layer, is always associated with turbulent mixing and therefore, uniform density. Ekman layer transport is characterised by a perpendicular shift of the net water transport relative to the direction of the wind (Tomczak, 2002). In the southern hemisphere, the water will shift to the left of the wind direction.

The East Auckland Current was found to have a mass transport of 20 Sv off the north-eastern coast of New Zealand (Harris, 1985). This means that approximately 20 million cubic meters of water per second are moved in this geostrophic flow. The origin of this transport is primarily wind-driven.

A study on the wind-driven circulation of the South Pacific Ocean (Szoeke, 1987), employed a numerical model to estimate net Sverdrup transport. The study used annual mean wind stress data to force the model (Hellerman and Rothstein, 1983 as cited by Szoeke, 1987). This study found the equivalent transport to be 30 Sv in a large scale circulation cell to the north-east of New Zealand. Admittance to the lack of wind stress data from the South Pacific was identified as the possible cause of inconsistencies.

Deep coastal upwelling occurs when applied wind stress is parallel to the coastline and when the coastline is on the right in the southern hemisphere. The net movement of the upper water level will be 90º to the left in the southern hemisphere. In this case, the surface waters water will move off shore. The piling up of water off-shore will create a pressure gradient normal to shore and will induce a geostophic flow in the same direction as the wind. The net water movement will then be at an angle offshore in mid-depth water (below the Ekman layer, but above the bottom boundary layer). To compensate for this offshore movement of water, the bottom boundary layer will then be directed in the onshore direction.

It has been observed that the strongest upwelling events occur in waters exceeding 60m depth with wind stress parallel to shore and the shore on the right (in the southern hemisphere) (Tomczak, 2002). Ekman transport reacts differently in shallower water. As depth decreases, net-transport direction becomes more aligned with wind stress direction causing upwelling to be less intense (Tomczak, 2002).

For the case of the north-east coast of New Zealand the relationship between currents and wind stress was examined by Sharples and Grieg (1998). Tidal currents on the north-east shelf of New Zealand were found to have typical amplitudes of 5-10 cms^{-1}. Comparing this value to that of the mean flow velocites in the region, 20-30 cms^{-1}, it's apparent that wind stress is a significant force driving currents along the shelf.

Current direction and velocity were correlated to the component of wind stress in the coastal waters. It was found that an increase in surface current velocity at the shelf edge was often associated with wind stress toward the north-west (Sharples and Grieg, 1998). Current speed and direction variability during the sampling period tended to be 3-7 days and was associated with pulses in the along-shelf wind stress (Sharples and Grieg, 1998). When wind stress was toward the south-east, surface currents would exhibit a small rotation to the left, or off-shore, demonstrating an Ekman transport response to along-shelf wind stress.

When the near-bed current velocities were examined in the Sharples and Grieg (1998) study, no obvious mean direction along the shelf edge was found, but the marked variability correlated well with that of the wind stress. During several pulses with a south-easterly wind stress component, a rotation towards the coast of the near-bed current vectors was observed. This rotation occurred at the same time as a decrease in near-bed water temperature. The decreased water temperatures indicate the rise of the cooler bottom boundary layer. This variation associated with the noted change in the near-bed current direction can be attributed to wind-driven upwelling.

Zeldis *et al*. (2004) found that in addition to the prevailing wind variability, winter westerlies and summer easterlies, small scale changes in wind behaviour were embedded in these broad scale tendencies. These short term wind events lasted an average of 2.5 days and induced small upwelling and downwelling flows. These events were distributed throughout the north-east coast and shelf region (Zeldis *et al.*, 2004). Similar observations were made by Longdill *et al* (2008) for upwelling responses to wind stress in the Bay of Plenty region south of the Hauraki Gulf waters on the North Island of New Zealand. Zeldis (2004) hypothesized that there would be a substantial time lag between these favourable wind conditions and the associated up and downwelling. Model results and calculations using *in situ* wind stress values established this lag to be on the order of two weeks (Zeldis *et al.*, 2004). However, Longdill *et al* (2008) found this time lag to be significantly shorter, likely a result of the shorter distance to offshore areas from the Bay of Plenty compared to that of the Hauraki Gulf.

According to these studies, upwelling conditions may occasionally be experienced at the proposed site, but the currents are so small at the seafloor that is unlikely that sediment on a disposal mound could be re-entrained via upwelling flows.

5.5.4 Wave climate

Typically, waves in this region are generated by weather systems of mid-latitude or Tasman depressions moving west to east (Heath, 1985). The east coast of New Zealand receives swell from the south and from locally generated southerly and northerly storm waves, but the north-east has a wave climate distinct from the rest of the coastline and shelf due to the north-east aspect of the land in this region (Harris, 1985).

The prevailing waves are from the north-east and are generated from short-period weather cycles associated with larger scale weak seasonal cycles. Waves typically possess a height and period of 0.5-1.5 m and 5-7 sec, respectively (Heath, 1985), but wave heights depend on how quickly the weather systems move. Due to the relatively local generation of the weather systems, wave heights tend to rise quickly in this area (Heath, 1985).

Gorman *et al*. (2003) produced a synthetic wave climate for the waters around New Zealand using numerical modelling techniques. These results were validated with satellite altimeter data and *in situ* wave-recorder buoy data. It was found that net wave energy occurs off the west coast of New Zealand and that lower mean wave heights occur in the north-east coastal regions as a result of the sheltering effects of the New Zealand land mass (Gorman *et al.*, 2003). Mean wave heights in these waters were 2 m with an annual mean range in wave heights of only 1 m. Annual minimum wave heights occurred in the summer, but the maximum wave heights occurred on a more variable time scale.

In a compilation of wave records from deep water and shore-based stations the wave climate of the north-east coast of New Zealand was summarised by Pickrill and Mitchell (1979). Generally, they concluded that based on the sheltering effects of the land mass, this region tends to have a low energy wave climate (Pickrill and Mitchell, 1979). Records showed that mean wave heights of deep water waves were 1.4 m with storm waves rarely exceeding 3 m (Pickrill and Mitchell, 1979). Shallow water wave observations of mean wave height were between 0.5 and 0.8 m with storm waves at the shore only exceeding 2.5 m occasionally (Pickrill and Mitchell, 1979). Wave periods from the north-east coast region had a mean of 6.5 s in deeper water with a range of 6-9 s most of the time (Pickrill and Mitchell, 1979).

El Niño Southern Oscillation (ENSO) is a large contributor to inter-annual variations in the atmospheric circulation. Wave train response to ENSO is larger in the winter than in the summer for the same forcing (Karoly, 1989). The La Niña phase of ENSO is characterised by an increased occurrence of north-easterly winds which are on-shore in the north-east coast region of New Zealand (Gorman *et al.*, 2003). This results in increased wave-heights in this region. During the El Niño phase of ENSO there are increased occurrences of south-westerly winds which are off-shore and these result in decreased wave heights in this region (Gorman *et al.*, 2003).

It is not likely, however, that waves will have a large effect on the dredge spoil operations at the site. Simplified calculations of wave attenuation to the depths found at the site, show that typical wave height and periods recorded off the north-east coast are not likely to reach the bottom. Locally generated storm waves may occasionally be energetic enough to affect a dredge spoil mound at the proposed site, but the low frequency of these occurrences will make the effects minimal.

5.5.5 RESIDUAL FLOWS

Generally, mean flows in the north-east coast region of New Zealand are driven by non-tidal forcing, such as wind-driven and geostrophic currents. Typical near-surface flows were almost always parallel to bathymetry, toward the south-east and are attributed to the East Auckland Current (Sharples and Grieg, 1998). Conversely, near-bed flows tended to be in the cross-shelf direction as a result of along-shelf wind events. The correlation with wind stress decreases as the water becomes stratified in the spring and summer (Sharples and Grieg, 1998).

Model output from the Ocean Circulation and Climate Advanced Modelling (OCCAM) project was used to illustrate averaged bottom and mid-depth currents off the east coast of Great Barrier Island from October 2003 through October 2004 (Figure 5.14). This is a three-dimensional, ocean-atmosphere heat exchange, free surface global circulation model based on 'primitive' equations and solved over a 0.25° grid (Webb *et al.*, 1998; Saunders *et al.*, 1999). Wind data from the European Centre for Medium-Range Weather Forecasts (ECMWF) is used to force the model along with fresh-water runoff. Details of the initialisation, forcing, domain, boundaries, parameterisation and numerical methodologies can be obtained from Webb *et al.* (1998).

Annual averaged currents from the OCCAM model show that mid-depth currents (25-75 m water depth) east of Great Barrier Island, do not exceed 4.0 cms^{-1} and are generally directed toward the south-east (Figure 5.14). Output demonstrates that bottom currents (75-150 m water depth) in this region are slightly faster than mid-depth currents (up to 6.0 cms^{-1}) and all data points indicate that residual currents are directed toward the southeast (Figure 5.14). The critical velocity of entrainment of sediments from the seafloor (discussed in more detail in section 5.5.6.3) for near-bed currents was calculated to be approximately 18 cms^{-1}. Therefore, near-bed currents predicted by the OCCAM model will not be fast enough to entrain sediments from the sea floor in the region of the study site.

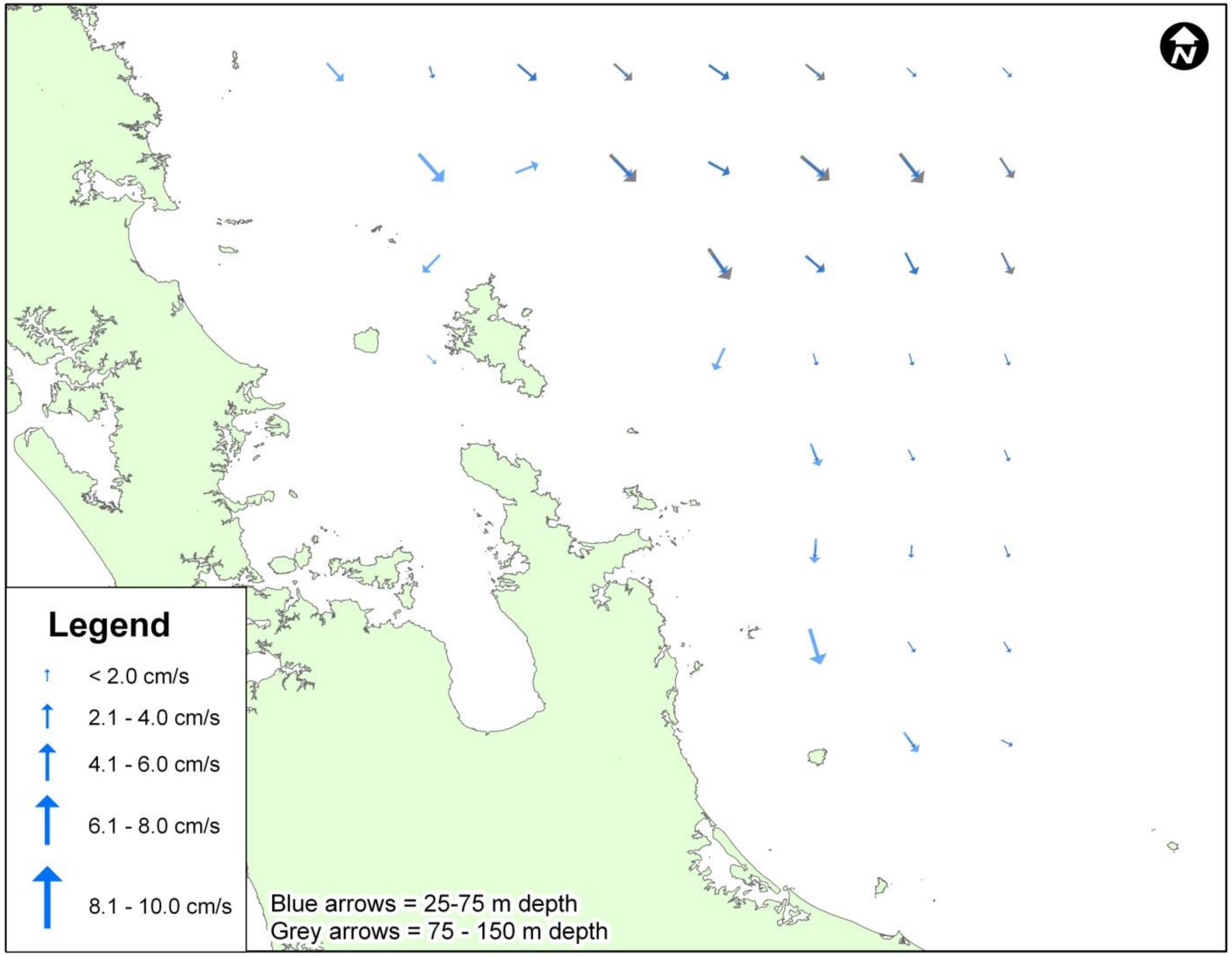

Figure 5.14 Model output from the Ocean Circulation and Climate Advanced Modelling (OCCAM). Annual averaged currents from October, 2003 to October, 2004 where blue arrows indicate the mid-depth (25-75 m) directional current flow and the gray arrows indicate the bottom (75-150 m) directional current flow (Source: Peter Longdill, 2007).

5.5.6 Sediment transport potential

5.5.6.1 Descent

When dredged material is released from a hopper, it descends through the water column as a fluid-like jet (Figure 5.15) (Truitt, 1988). Depending on the cohesive properties of this sediment, there may be large clumps of cohesive material within this jet. Clay, expected to be a dominant size fraction of the dredged material, typically possesses a high cation exchange capacity (CEC), which is a measure of the cohesive nature of the sediment (Hales, 1996). The low settling velocities of the cohesive flocs make them more susceptible to entrainment processes by turbulent forces into the water column (Truitt, 1988) (Figure 5.15). Therefore, the rapid descent of high density material in the jet is usually accompanied by a small plume of dispersed low-density material.

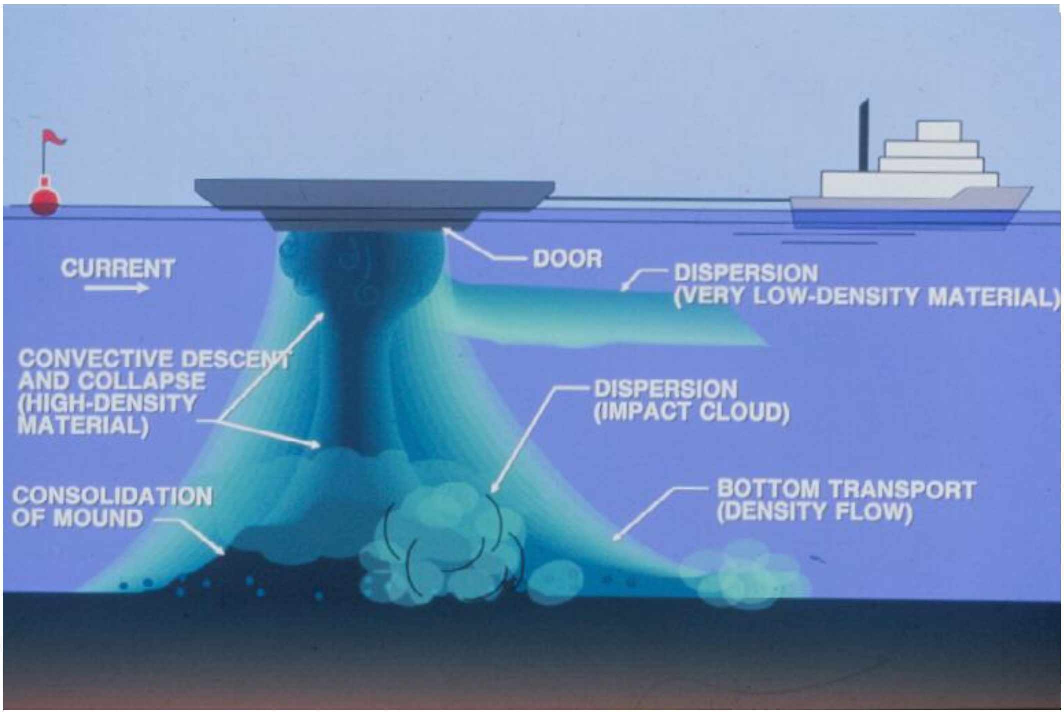

Figure 5.15 Dredge spoil descent (Source: Gailiani and Smith for the US Army Corps of Engineers dredge spoil disposal program).

5.5.6.2 Horizontal displacement

Entrainment of water in the descending jet of dredged sediment will cause some of the material to be separated from the sediment mass (Truitt, 1988). This material will be advected in the direction of the prevailing current (Figure 5.15). It is expected that the East Auckland Current (EAUC) will cause some horizontal displacement of material during the descent process of disposal operations proposed for the study site. As the EAUC flows in a south-easterly direction down the north-east coast of New Zealand (Denham *et al*., 1984), it is expected that this lost sediment will disperse in southerly direction. However, residual flows are influenced by not only the EAUC, but also the tide, wind, and waves.

Simple calculations were undertaken to determine the horizontal displacement of individual sediment particles of varying densities. Particle sizes and respective settling velocities were taken from the literature (Dyer, 1986 and Krumbein and Pettijohn, 1938; as cited by Davis, 1985). Figure 5.16 illustrates the respective displacement of these particles by horizontal currents with velocities similar to those measured in the East Auckland Current. A representative dredge spoil load of 900 m^3 was included in the calculations to illustrate the significant difference in horizontal displacement between a large quantity of sediment descending at once and that of an individual particle.

Calculations show that a small floc of floating sediment (a clump of cohesive sediment, usually clay) can be dispersed the farthest by the horizontal currents. However, it was found that typically, only 1-5% of the sediment load is lost by dispersion from horizontal currents (Truitt, 1988).

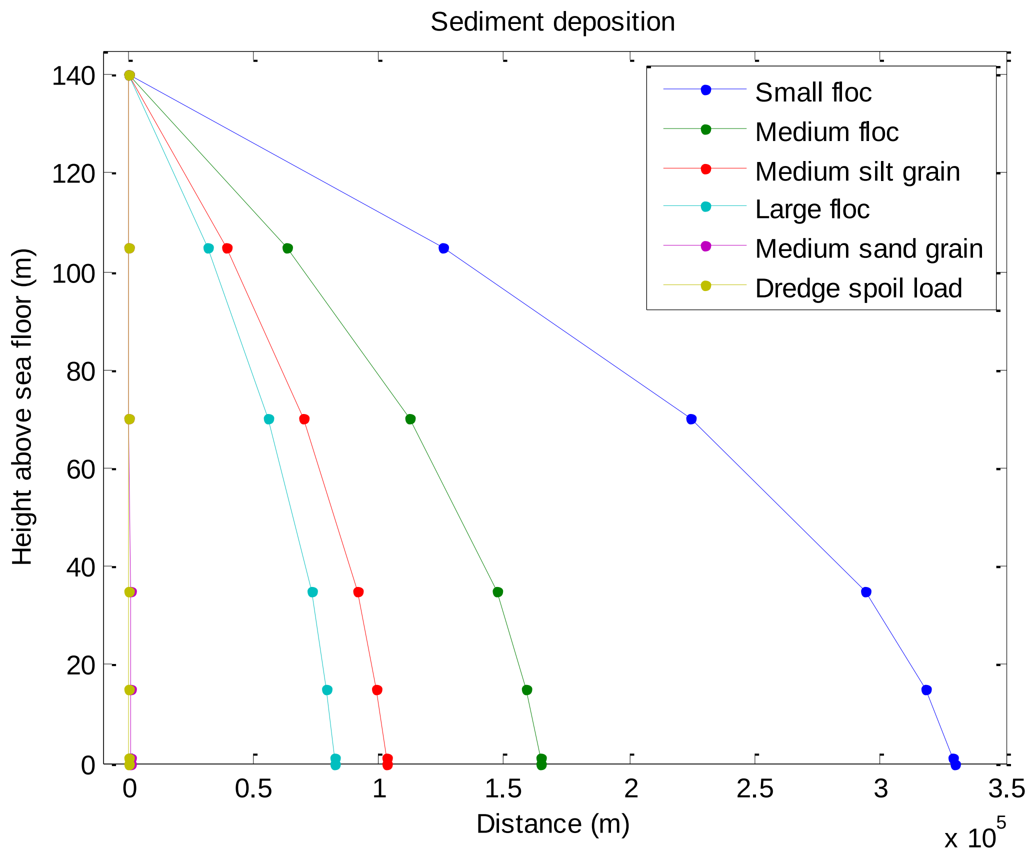

Figure 5.16 Displacement of a small sized floc of sediment particles, medium sized floc of sediment particles, medium sized grain of silt, large sized floc of sediment particles, medium sized grain of sand, and representative dredge spoil load of 900 m^3 by horizontal currents during descent to the seafloor.

5.5.6.3 ENTRAINMENT

5.5.6.3.1 Horizontal currents

The potential for entrainment of sediment off the seafloor by near-bed horizontal currents was determined using the following equation based on the "law of the wall" that calculates the critical near-bed velocity for entrainment:

$$u = \left(\frac{u_*}{k}\right) \times \log\left(\frac{z}{z_o}\right)$$

where u_* is the shear velocity, k is von Karman's constant, and z is the depth of the water column. The well-known empirical relationship between Shields number and Reynolds number described by the Shields curve (Shields, 1936) was used to estimate u_*. A u_* value 0.02 (dimensionless) based on a medium sized silt particle of 0.03 mm was used for the following velocity profile.

The above equation can be used to derive a velocity profile based on known u_*, particle size, and water depth. This velocity profile is plotted in Figure 5.17. The velocity corresponding to the near-bed water depth is taken to be the critical velocity for sediment entrainment. The calculation yielded a critical velocity for entrainment of 18 cms^{-1} for a medium-sized grain of silt.

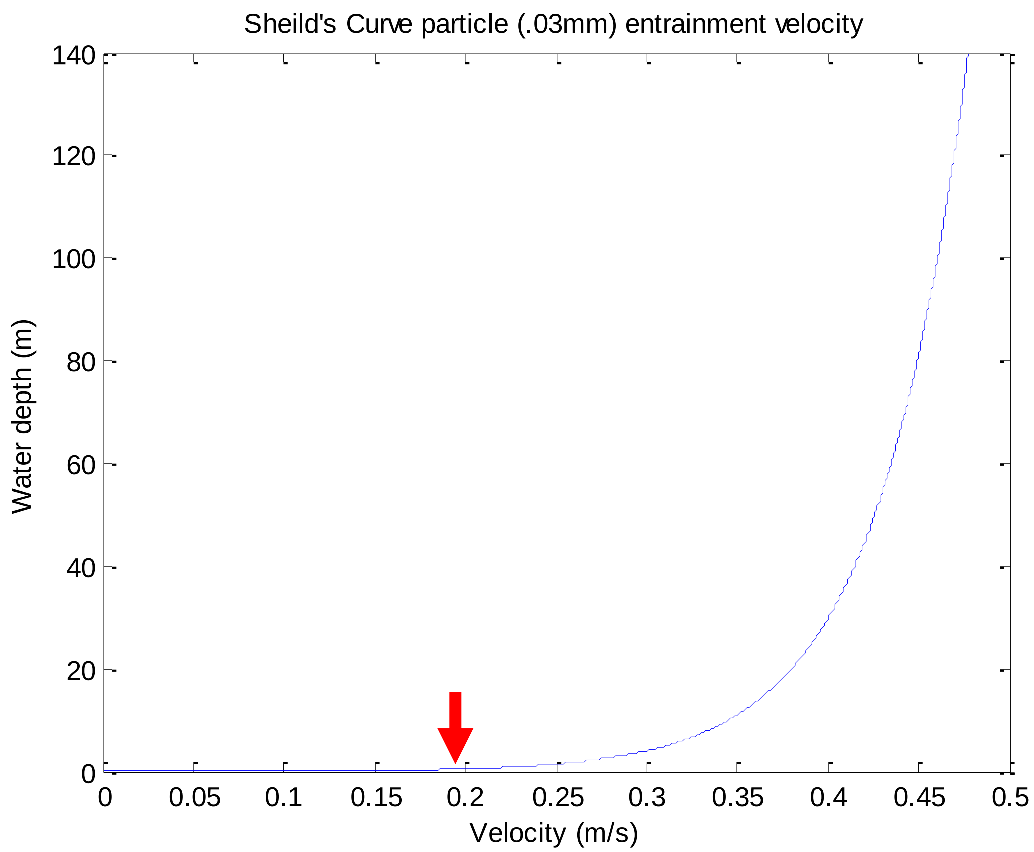

Figure 5.17 Velocity profile based on a sediment threshold u_* predicted using Shield's curve. The arrow indicates the nearbed velocity which is taken to be the critical velocity for entrainment of a medium sized silt particle in 140 m of water.

Stanton and Sutton (2003) determined the maximum velocities of the East Auckland Current to be 45 cms^{-1}, but these measurements were determined to be part of the North Cape Eddy (north of the proposed disposal site). More realistic for the region of the proposed disposal site were the velocities reported by Heath

(1980) determined to be 20-30 cms^{-1}. The critical entrainment velocity calculated for a medium-sized silt particle is 18 cms^{-1} (Figure 5.17).

Hjulström (1935) determined this critical velocity of entrainment for the same sized particle to be greater than 20 cms^{-1} (Figure 5.18). Regardless, these values are in the range of velocities measured in the region, which means that when the East Auckland Current occasionally reaches high velocities, sediment may be entrained off the seafloor.

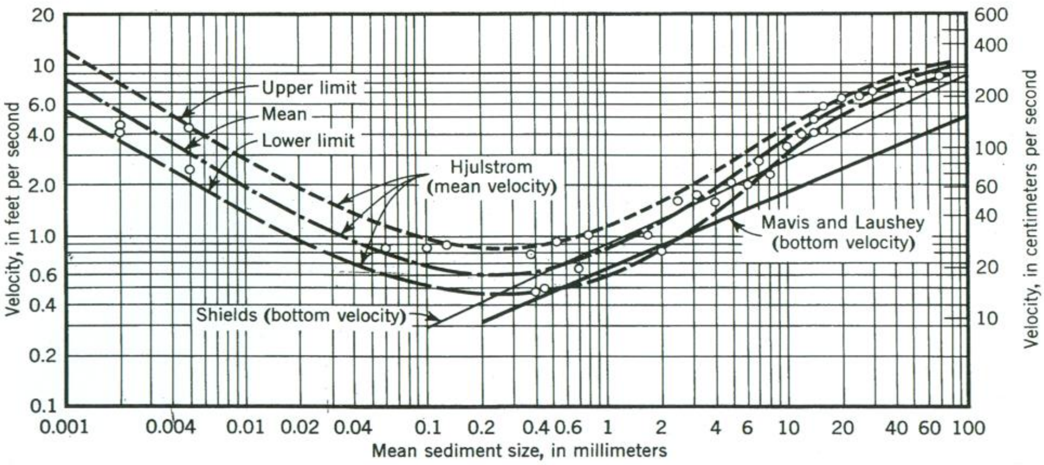

Figure 5.18 Critical water velocities for quartz sediment as a function of mean grain size (Source: Hjulström, 1935).

5.5.6.3.2 Waves

Nearbed currents are also commonly created by the local wave conditions. By looking more closely at the north-east coast wave climate and more specifically, conditions at the proposed disposal site, it can be estimated whether local waves will increase nearbed currents to a velocity fast enough to induce sediment motion on the seafloor, also known as the threshold of sediment motion.

A report prepared for Tauranga Bridge Marina Ltd., Cardno Lawson Treloar (2007) examined design wave conditions in the local sea. Using approximately 10 years of offshore data from the NOAA Wavewatch III global database for the north-east coast of New Zealand, the 100 year ARI (average recurrent interval) for offshore peak storm conditions were determined for the region (Cardno Lawson

Treloar, 2007). The significant wave height (H_s), described as an average of the highest $\frac{1}{3}$ of the waves measured in a single burst or moment of measurement (Stephens and Gorman, 2006), for this particular set of extracted data was determined to be 7.8 m. This value, the average of the largest waves that occurred in the region over a ten year period, along with the respective wave period (15 s) was applied in the following equation (Komar and Miller, 1973) to determine a nearbed velocity:

$$u_t = \frac{\pi H}{T \sinh(2\pi h/L)}$$

where H is the wave height (m) or H_s, T is the wave period (s), h is the water depth (m), and L is the wave length (m). These calculations determined that a nearbed current with a velocity of 27 cms^{-1} can be induced under these specific wave conditions at a water depth of 140 m such as that at the proposed disposal site. Once again applying this velocity to the Hjulsrtöm curve (Figure 5.18), this velocity will induce motion in a medium-sized grain of silt.

Based on these calculations and assumptions, the horizontal currents and local waves at the proposed site may occasionally entrain sediment deposited on the seafloor. However, the critical entrainment velocity will be higher for larger and heavier sediment particles such as sand and for sediment with highly cohesive properties such as those expected from the interested ports and marinas. Additionally, potential for entrainment is highest immediately after disposal prior to consolidation of the sediment, which increases the threshold velocity for entrainment required to induce sediment motion.

5.5.6.4 Consolidation

Typically, consolidation of the dredge spoil mound occurs at dredging disposal sites (Halka *et al*., 1991). Consolidation acts to compact the sediments making entrainment by near-bed currents less likely. If the disposal site is used on a regular basis, the sediments composing the spoil mound will have gone through varying degrees of consolidation. Figure 5.19 illustrates the consolidation process expected to occur over time. One study examined the volume change of a disposal mound over time and found that after the first six months the mound had reduced in volume by 23-48% and by 18 months, the mound had reduced in volume by 39-63% (Halka *et al*., 1991). However, Healy *et al* (1998) observed no such consolidation processes in a study of the morphologic changes of a dump ground used by Port of Tauranga Ltd., New Zealand. In that case, the morphology of the dump ground remained relatively stable during the study period of 1989 through 1994.

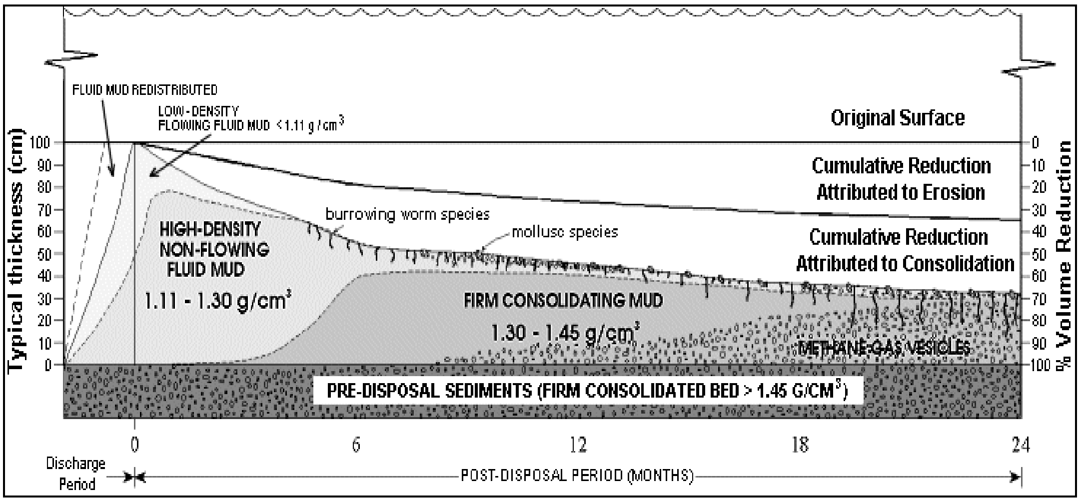

Figure 5.19 Volumetric and biological change of a dredge spoil mound over time (Source: Maryland Geological Survey, 2008).

5.5.7 SUMMARY

The features of M2 tide, the East Auckland Current, various wind driven currents, and the local wave climate are the major hydrodynamic features of the north east coast region of New Zealand where the study site is located. A literature review of previous studies and basic calculations show that there is some potential for sediment transport in the water column and off the sea floor. These findings are significant for determining the suitability of the study site for use as a disposal ground. However, the findings generally show that the potential for sediment transport is low based on the known conditions at the study site.

5.6 Biological composition and activity

5.6.1 Benthic fauna

A limited number of benthic surveys have been undertaken at the depths of the proposed site on the north-east continental shelf of New Zealand. Most of the surveys performed, have been in waters less than 80 m deep. The data collected from these surveys can only be used as an indicator of the biological composition and abundance at the study site because water depth can be a limiting factor for species inhabiting the seafloor. Many species found in shallow waters cannot persist successfully in deep water and the opposite may be true for species inhabiting deep seafloor sediments.

One survey in particular, commissioned by the Department of Conservation (DOC), was undertaken at depths greater than 80 m off the north-east coast of Great Barrier Island. This study, undertaken in 2002, examined the benthic biological composition and activity of the area for the purposes of establishing a marine reserve. The study site extended from Korotiti Bay in the south to Needles Point in the north and from mean high water spring to 12 nautical miles off shore where water depths are typically greater than 100 m (Sivaguru and Grace, 2002). The eastern boundary of the study area reached to the limit of New Zealand's territorial seas. Beyond that is the Exclusive Economic Zone (EEZ). The proposed dredging disposal site is situated ~2 km east of this boundary (Figure 3.1). Therefore, biological features of the seafloor at study sites sampled near the outer limit of the DOC survey are likely similar to those at the study site.

Survey methods for benthic classification used in the Sivaguru and Grace (2002) survey included digital video of the seafloor mounted on a remote operated vehicle (ROV) to identify epifauna, and sediment collection using a small rectangular dredge to identify infauna. From the ROV/video portion of the study, only one sampled site can be considered relevant based on depth and vicinity to the study site.

The sampled site was at 120 m water depth and from the video it was observed that there were scattered silt covered boulders on a muddy sediment bottom (Sivaguru and Grace, 2002). In total, there were 10 different species identified: 6 Porifera (sponges), 3 Anthozoa (coral and anemone), and 1 Bryzoan. Details of the specific species identified at the deep water ROV/video site as presented by Sivaguru and Grace (2002) are included in Table 5.1.

Sponges were the dominant community observed in the video clips, but in general they report that the deep water site was home to the fewest number and types of benthic species.

Table 5.1 Benthic fauna identified from the easternmost site of the DOC commissioned survey with ROV/video (Source: Sivaguru and Grace, 2002).

Depth	120 m	
Site Characteristics	Scattered silt-covered boulders on muddy sediment bottom	
Taxa	**Species name (if available)**	**Common name (if available)**
Porifera (sponges)	*Aciculites pulchra*	
	Trachycladus stylifer	Finger sponge
	Euplacella sp	Trumpets
	Siphonochalina latituba	Tube sponge
	Axinella australiensis	
	Biemna rufescens	Large frilly mass
Phylum Coelenterates		
Anthozoa		Black coral species 1
	Monomyces rubrum	Coral
	Keratoisis sp	Gorgonian
Phylum Bryzoa		
	family Phidoloporidae	

Sediment was collected by small rectangular dredge from 4 sites with depths corresponding to that of the present study site ranging from 125 m to 146 m. The association found to be present at these deep water sites were less diverse than the association identified at the shallower sites included in this survey (Sivaguru and Grace, 2002).

The most commonly identified species at the four deep water sites were Phylum Polychaeta (worms). Subgroup Ophiuroidea *Amphiura* sp. (brittle stars) were also relatively common at these sites. Details of the species identified at the four deep water sites of the DOC commissioned survey are included in Table 5.2.

Table 5.2 Benthic fauna identified from the four deep water sites of the DOC commissioned survey from sediment collected with a small rectangular grab (X indicates the presence of a species) (Source: Sivaguru and Grace, 2002).

Depth (m)			131	146	125	144
Phylum	**Subgroup**	**Species**				
Porifera		Unidentified sponges	3			1
Cnidaria	Scleractinia	*Caryophyllia quadragenaria*	1			
		Kionotrochus suteri				1
	Actiniaria	*Edwardsia* sp.	1			
Polychaeta	Orbiniidae	*Scoloplos* sp.			1	
	Maldanidae	*Asychis* sp.	1			
		Axiothella sp.	1			
	Chaetopteridae	*Spiochaetopterus* sp.	9	1		1
	Nephtyidae	*Aglaophamus macroura*		1		
	Lumbrinereidae	*Lumbrineris coccinae*			1	
		Ninoe sp.		1		
	Flabelligeridae	*Bradabyssa* sp.	1	1		
	Terebellibae	*Lysilla* sp.	1			
		Terebellides sp.	1			
	Trichobranchid	unidentified	1			
	Sabellidae	unidentified		1		
Crustacea	Cumacea	*Eudorella* sp.	1			
	Ostracoda	Ostracoda				1
	Amphipoda	Ampeliscidae	1			
		“Phreatogrammaridae”	3			
		Paradexamine sp.	2			
		Parawaldekia sp.				2
	Decapoda	Auxidae	1			
		Ebalia tuberculata	1			
Mollusca	Scaphopoda	*Anatalis nana*	X			
	Gastropoda	*Chlamys gemmulata*		X		
Echinodermata	Ophiuroidea	*Amphiura* sp.	1	3		1

Several conclusions were made by Sivaguru and Grace (2002) regarding biological composition and activity at the deeper sample sites. The ROV/video surveys at 120 m revealed a low energy environment as evidenced by the silt covered boulders observed in the video clips (Sivaguru and Grace, 2002). Video clips from this deep water site also showed that species diversity was lower than the other shallower ROV/video sample sites. Sediment sample collection at the four deepest sites supported the observations made from the video survey.

The association identified by Sivaguru and Grace (2002) of the species found at the four deepest sites was less diverse than the association of the shallower sites surveyed. They suggested that species richness in this region east of Great Barrier Island may vary with a range of depth (Sivaguru and Grace, 2002). It was also noted that the polychaetes identified are typical of a soft sediment, low energy regime (Sivaguru and Grace, 2002), which supports the conclusion that the silt covered boulders observed in the 120 m deep sample site indicate a low energy sedimentation environment at the eastern most limits of the DOC commissioned survey.

This information can be used to suggest the potential biological composition and activity at the proposed disposal site, which is relatively close (~20 km) to the deepest sample sites of the DOC commissioned survey. However, the trend observed by Sivaguru and Grace (2002), that species diversity is related to depth suggests that the study site will have an even lower diversity as the depth there ranges from 10 – 20 m deeper than the sites sampled in the DOC survey.

5.6.1.1 Benthic fauna identification methods

A preliminary survey of the benthic fauna at the study site does show some inconsistency with the above hypothesis. Visual observations of benthic fauna recovered from grab samples taken at the site in November, 2007 indicated a low diversity and abundance at the study site based on the individuals recovered. However, a closer look at the samples revealed a more robust composition of individuals.

Sediment samples for benthic identification were retrieved in a similar manner to the samples collected for textural analysis (described in Section 5.3.3.1). Once the 'SHIPEK' was recovered, sediment was immediately sieved (1 mm) for collection of benthic fauna. The specimens were then preserved in 95% ethanol and dyed with Rose Bengal for later identification.

For the purposes of this thesis the preliminary identification of benthic fauna undertaken was only to class and in one case order, allowing for coarse taxonomic grouping of the individuals present. The number species per class were also counted to ascertain the diversity of species present at the locations sampled.

5.6.1.2 Benthic fauna abundance and diversity results

Species diversity and abundance results for the sum of all the sample locations are presented in Figures 5.20 and 5.21. There were a total of 273 individuals divided into 78 different species at the 20 locations sampled from the study site.

There were 45 different species from the class Polychaeta made up of 148 individuals. Other marine worms (non-polychaetes) collected, only totalled 6 different species with 20 individuals.

The class Malacostraca totalled 75 individuals in 14 different species. This class of crustaceans was further identified to order. Amphipods made up half of the 14 different malacostracan species with 27 individuals. The tanaids, however, totalled 30 individuals in only 2 different species. Other malacostracan orders present at the study site included: Decopoda, Isopoda, Cumacea, and Ostracoda.

Individuals comprising the class Gastropoda totalled 10 in a total of 9 different species. Another molluscan class, Bivalvia, had a total of 3 species made up of 11 individuals. There was only one species of Ophiuroidea (Brittle Stars) identified, but it included 9 individuals.

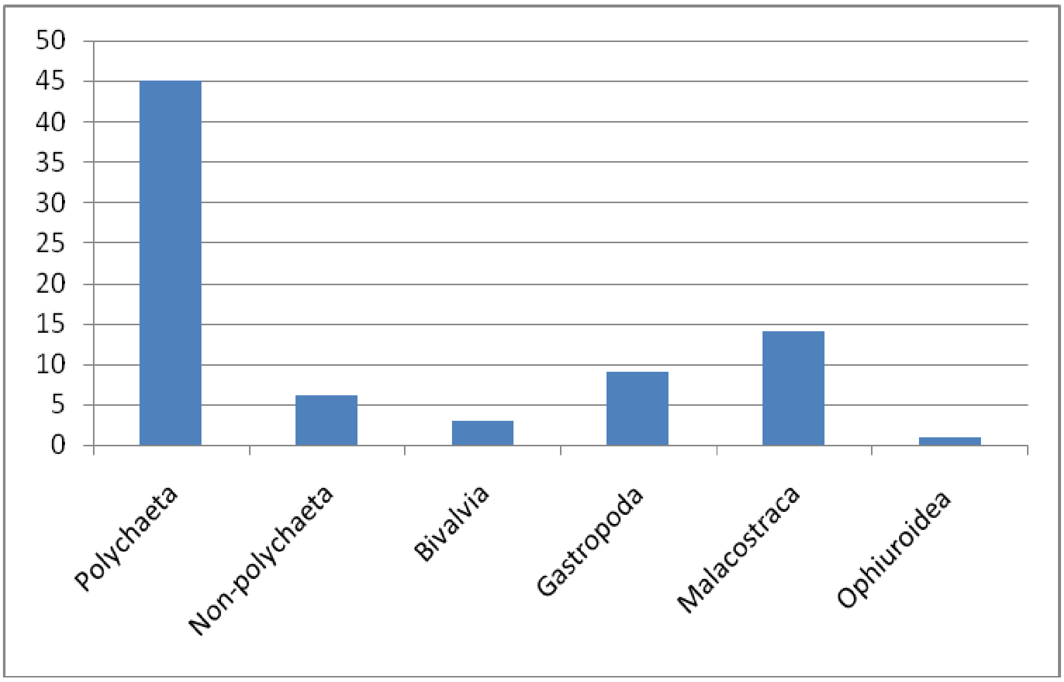

Figure 5.20 Total number of species identified in each taxonomic class from the sum of the locations sampled at the study site during the November 2007 survey cruise.

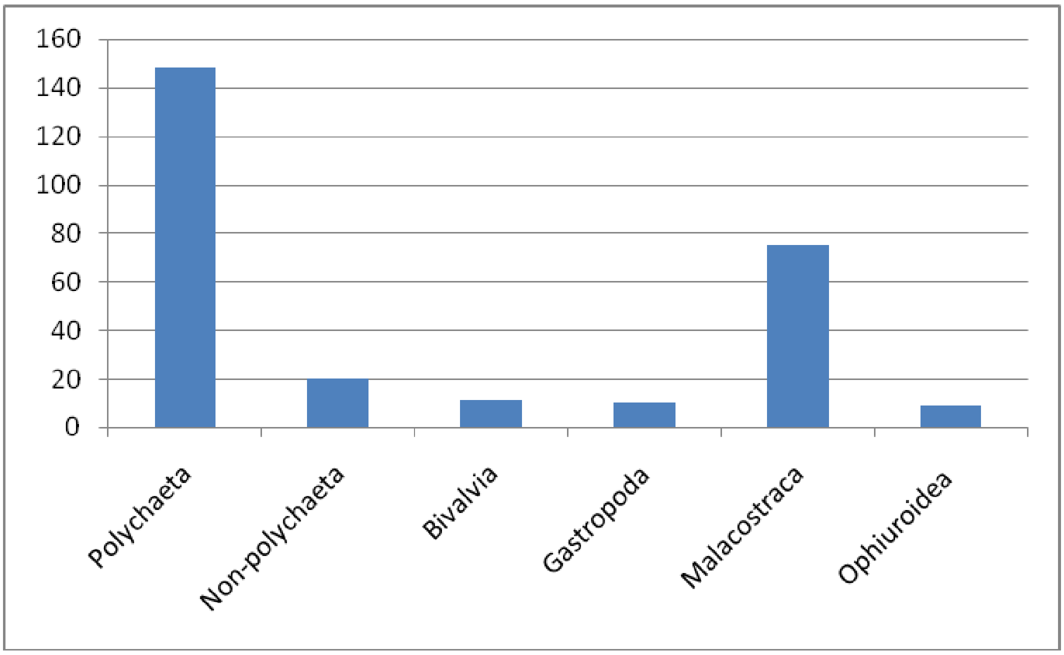

Figure 5.21 Total number of individuals identified in each taxonomic class for the sum of the locations sampled at the study site during the November 2007 survey cruise.

5.6.1.3 Discussion

Polychaeta was the most abundant and diverse group of organisms recovered from the study site. Other marine worms (non-polychaetes) were significantly lower in abundance and diversity compared to polychaetes. Compared to the polychaetes identified by Sivaguru and Grace (2002), totalling 23 individuals in 12 different species, polychaetes at the study site are significantly more diverse and abundant.

Malacostraca was the second most abundant and diverse class of organisms identified at the study site. Of this class, Amphipoda was the most diverse order and Tanaidacea the most abundant. Similarly, Sivaguru and Grace (2002) determined that Amphipoda was the most diverse, but also the most abundant order of crustaceans. However, they found only 4 amphipod species made of only 8 individuals.

Gastropods were unique in this survey in that they show a high diversity, but very low abundance. Bivalves, in contrast are relatively low diversity and high abundance. Interestingly, Sivaguru and Grace (2002) only noted the presence of a gastropod or multiple gastropods (it was not clear) at one sample site. They did not report the presence of any bivalves. Similar to the present survey, Sivaguru and Grace (2002) identified high relatively high abundance of Ophiuroidea (5 individuals), but a low diversity (1 species).

It is clear that the abundance and diversity of individuals collected from the present study site are significantly higher than at the deep water sites surveyed in the DOC commissioned survey that took place just to the north of the study site.

5.6.2 Fin fish

Similar to benthic surveys, very few pelagic surveys have been undertaken in the region of the proposed site. The study done by Sivaguru and Grace (2002) included identification of fin fish recorded by the ROV/video survey. At the easternmost and deepest video site, only two fish were observed, a sea perch and one unidentified species (Table 5.3). This is not to say that there are not fish inhabiting this area, but lack of sea floor habitat conducive to pelagic fish, such as algae, in the deeper areas suggests that bottom feeding fin fish are unlikely to inhabit the muddy bottom at the proposed disposal site.

Video recorded at the site on the November 2007 survey cruise showed no fish present in the drop camera video clips. The camera used was mounted in a downward facing fashion on a large metal frame. It is possible that if any fish were present, the presence of the frame would have caused them to swim away. In fact, a school of fish were detected by echo sounder approximately 100 m below the sea surface (Figure 5.22).

Table 5.3 Fin fish identified from the easternmost site of the DOC commissioned survey using ROV/video (Source: Sivaguru and Grace, 2002).

Depth	120 m	
Site characteristics	Scattered silt-covered boulders on muddy sediment bottom	
Taxa	**Species name (if available)**	**Common name (if available)**
Osteichthyes (Fishes)	*Heliocolenus percoides*	Jock Stewart or Sea Perch
		undentified fish species

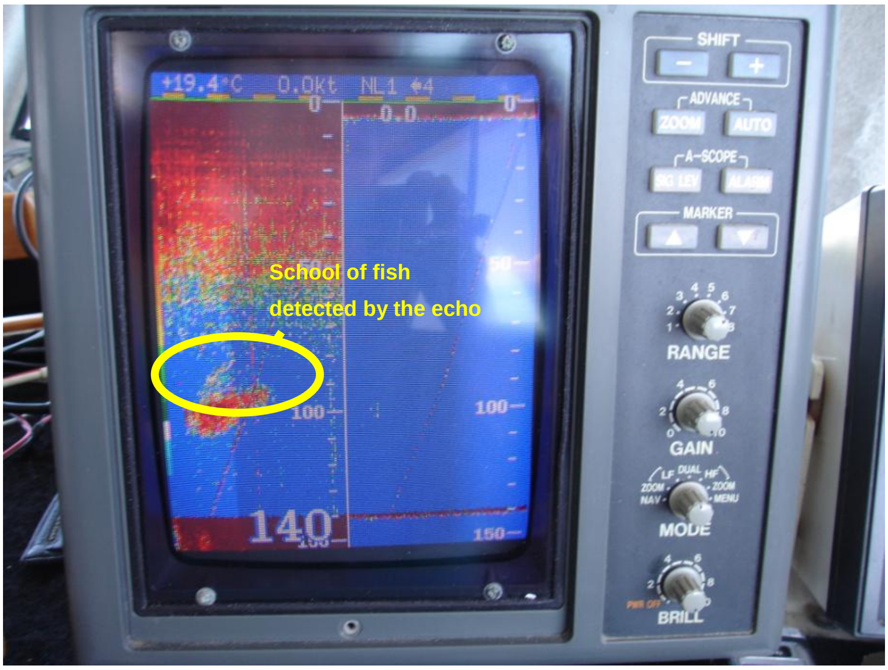

Figure 5.22 Image of a school of fish detected by the echo sounder in approximately 100 m of water during the November, 2007 survey.

Despite the lack of specific data on the exact species composition and abundance of fin fish at the proposed site, it is well known that diversity is quite high in the north-east shelf region. This is due to the presence of many tropical, sub-tropical, and warm temperate fishes in combination with widespread New Zealand species.

As previously discussed, the East Auckland Current (EAUC) intermittently flows southwards on the north-east coast bringing warm sub-tropical waters from the areas such as the Norfolk Island (Denham *et al*., 1984). The EAUC will transport with it planktonic fish larvae which supplies the north-east coast with its unique fish population composition (Francis, 1996). During summer and autumn especially, many species ranging from large, pelagic species such as tunas and marlins to small, rare reef fishes are present in the waters of the north-east coast (Francis *et al*., 1999). The pelagic species migrate southward with the warmer water, but typically retreat as cooler water fills in with winter conditions (Francis *et al*., 1999).

In general, there are not expected to be a significant number of fin fish as bottom feeders at the proposed site. Reef fish will undoubtedly stay closer to shore where reef habitats are more prevalent. Large pelagic species may migrate in during warmer seasons, but these occurrences are likely to be rare and mostly seasonal. However, as detected by the echo sounder, schools of fish do pass by in the water column over the study site.

5.6.3 MAMMALS

Marine mammals, such as whales and dolphins, using the north-east region as part of a migratory path and/or nursery grounds should be identified and quantified before establishing a dredge spoil disposal ground in the region. Disposal operations such as the presence of a vessel and the periodic addition of a large quantity of sediment to the water column may disrupt their natural behaviours by forcing the animals off their normal migratory path. However, studies have shown that the presence of these animals in the vicinity of the site is not common.

Using a pair of hydrophones, McDonald (2006) attempted to identify and quantify baleen whale songs east of Great Barrier Island. The hydrophones were deployed 600 m apart and 5 km east of Great Barrier Island in 70 m of water. A year of acoustical data recorded by these hydrophones was analysed to examine seasonal variation in migration patterns for baleen whales. Table 5.4 includes the findings of this year long study.

Table 5.4 Findings of a baleen whale song study off the north-east caost of New Zealand (Source: McDonald, 2006).

Baleen whale	Number of songs recorded	Season	Location	Misc
Bryde's whale	> 140 (2 types)	Year round and seasonally	Inshore and offshore (outside the continental shelf)	Possibly, some individuals are travelling inshore seasonally and some individuals are staying off shore
Humpback whale	65	February through September	Not specified	Possible north bound migration of males
Fin whale	26	June through September	Off shore (outside continental shelf)	
Blue whale	10	Most May through July	Offshore (outside continental shelf)	

Studies of dolphins in New Zealand have determined that *Delphinus delphis* (common dolphin) is commonly found north of the Subtropical Convergence (approximately 42°S) (Gaskin, 1968 and Neumann *et al*., 2002). One study in particular determined that the common dolphin regularly moves from the Hauraki Gulf to areas of the Coromandel coastline and back (Neumann *et al*, 2002). It is possible that during these movements, the animals may visit areas very close to the proposed site.

Visser (2000) determined that out of a population of approximately 115 orcas in New Zealand waters, the highest number of sightings were in the north-east coast region. The majority of the sightings were in nearshore areas (Visser, 2000). Therefore, it is not likely that New Zealand orcas will be present at the study site except perhaps for transient passage through the site or in surrounding waters.

On the survey cruise of November 2007, one whale was observed travelling south near the site. Its path was east of Great Barrier Island and approximately 500 m west of the proposed site. To the untrained eye, it was guessed to be a humpback whale. Additionally, several groups of common dolphins were observed, but they were travelling in waters west of Great Barrier Island and within the Hauraki Gulf.

Based on previous studies and field observations from the November 2007 survey, it is possible that Bryde's whales, Humpback whales and common dolphins may transit the region of the proposed disposal site, but there are no indications that the area is being used as a nursery ground by any of these species.

5.6.4 Summary

Benthic fauna diversity and abundance are the main biological features of concern at the study site. Being situated directly on or in the sea floor sediments, the benthos will be directly affected by the deposition of dredged material at the site. Through a preliminary survey of coarse taxonomic groupings, a general indication of the diversity and abundance of benthic fauna was determined. The sea floor sediments at the study site appear to be home to a relatively diverse and somewhat abundant population of benthic fauna, comprised mainly of polychaete marine worms, compared to those examined at a nearby study site. However, underwater video clips show no evidence of large macrofaunal invertebrates inhabiting the area. Similarly, there does not appear to be any large or long term population of pelagic species inhabiting the overlying water column at the study site.

5.7 Conclusions

The extensive body of literature on the study of the north east coast of New Zealand made possible the preliminary examinations of the proposed disposal site discussed in this thesis. Well known hydrodynamic features such as the M2 tidal wave and the East Auckland Current were assessed in relation to the position of the study site and for the effect they would have on processes occurring there. The main concern in examining these hydrodynamic features was to determine the extent to which they would induce sediment movement during and after disposal activities. It was estimated that current velocities induced by the tide, geostrophic currents, wind, and waves could entrain and advect sediment particles at the site, but the frequency of these occurrences is expected to be low.

Existing data on the specific sediment and biological features at the study site was limited. To fill in this lack of data, sample collection at 20 locations across the study site was undertaken for sediment textural analysis and for benthic fauna identification. Textural analysis revealed that the seafloor sediments at the study site are of a muddy/sand quality. Proportions of different texture classes varied only slightly from location to location. Quantitative analysis of the benthic invertebrates recovered from samples determined that the majority of benthic fauna inhabiting the sea floor sediments at the site are polychaetes, which are represented by a diverse number of species. Other populations were relatively low in abundance and diversity compared to the polychaetes. Overall, the site does not appear to be harbouring any large or significant populations of benthic fauna.

Assessment of the above features of the proposed site indicates that dredged material deposited at the site will not be greatly or frequently disturbed during or after the descent process. The magnitude of the environmental impact the deposited material will have on the existing conditions at and surrounding the site is expected to be small as the benthic population at the site is neither significant nor particularly sensitive. However, appropriately calibrated numerical simulations of hydrodynamic and sediment transport processes at the site will add another level of reliability to these predictions and will be discussed in the following chapter of this thesis.

CHAPTER SIX: NUMERICAL SIMULATION OF HYDRODYNAMIC PROCESSES AT THE PROPOSED DISPOSAL SITE

6.1 INTRODUCTION

Determining the suitability of a site for open-sea disposal of dredged sediment and minimising the potential adverse effects of such activities are significant concerns in the management of coastal areas. Policies regarding open-sea disposal activities require an in-depth understanding of the hydrodynamic processes occurring at and in the vicinity of the proposed site. Once characterised, these processes can be used to infer the main forcing mechanisms occurring at the site and ultimately what the potential effects of disposal operations may be.

On a small scale, such as at the proposed site, hydrodynamic processes, among others, can be measured directly for short periods of time via deployment of the relevant instruments. However, an understanding of the processes on a much larger spatial and temporal scale is necessary to determine what effects may occur beyond the boundaries of the site and in the long term future. Numerical simulations can provide reliable predictions to fill in the inevitable gaps encountered with *in situ* field survey results.

Accordingly, in this chapter, a numerical simulation of hydrodynamic (currents) processes is undertaken in order to obtain and improved understanding of the effects these features may have on the seafloor at 140 m water depth.

6.2 HYDRODYNAMIC PROCESSES

Hydrodynamic processes occurring on the open coastline and the continental shelf are influenced by a variety of factors, both local and remote such as, tides, winds, and geostrophic flows. Numerically simulating these features is a complex process (Csanady, 1997). The impact of each forcing mechanism can only be determined through strategic placement and well-timed deployment of field instruments along with thorough calibration and validation of numerical model output data.

6.2.1 NUMERICAL MODEL DESCRIPTION

The 3DD model (Black, 1995) was designed to simulate 2-dimensional currents and 3-dimensional wind driven and buoyancy forced flows. The model has successfully been applied in New Zealand and international waters since the 1980s (Black, 1987, 1989; Black and Gay, 1987; Black *et al*, 1993, 2000; Middleton and Black, 1994; Young *et al*, 1994; Hume *et al*, 2000).

3DD model uses an explicit, finite difference (Eulerian) scheme to solve momentum and continuity equations for velocity and sea level (Black, 1995). The model accounts for spatial variation through bed roughness length (z_o), and horizontal eddy viscosity (A_H). The model can also account for various non-linear terms and Coriolis forcing.

The horizontal equations of motion for an incompressible fluid are:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} - fv = -g\frac{\partial \varsigma}{\partial x} - \frac{1}{\rho}\frac{\partial P}{\partial x} + A_H\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) + \frac{\partial}{\partial z}\left(N_z\frac{\partial u}{\partial z}\right)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}+fu=-g\frac{\partial \varsigma}{\partial y}-\frac{1}{\rho}\frac{\partial P}{\partial y}+A_H\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+\frac{\partial}{\partial z}\left(N_z\frac{\partial v}{\partial z}\right)$$

$$w=-\frac{\partial}{\partial x}\int_{-h}^{z}udz-\frac{\partial}{\partial y}\int_{-h}^{z}vdz$$

assuming a rotating earth with Cartesian coordinates with z axes positive in the upward direction and where t is the time, u and v are the horizontal velocities in the x and y directions, w is the vertical velocity (positive upward), h is the depth, g is the gravitational acceleration, ς is the sea level above a horizontal datum, f is the Coriolis parameter, P is the pressure, A_H is the horizontal eddy viscosity coefficient, N_z is the vertical eddy viscosity coefficient, ρ is the density.

Neglecting vertical acceleration, the hydrostatic equation for pressure at a depth z is:

$$P=P_{atm}+g\int_{z}^{\varsigma}\rho dz$$

where P_{atm} is the atmospheric pressure.

The physical forces represented in the equations of motion are local acceleration, inertia, Coriolis, pressure gradient due to variations in sea level, pressure gradient due to variations in atmospheric pressure, horizontal eddy viscosity, wind stress, and bed friction.

6.3 A TWO-DIMENSIONAL NUMERICAL SIMULATION OF TIDAL DYNAMICS

As a preliminary numerical study of the region encompassing the proposed disposal site, a simulation of the tidal dynamics was undertaken. Only the two-dimensional capabilities of the 3DD model were utilised in this case as a means of gaining a basic understanding of the depth-averaged flows that occur in the region.

6.3.1 THE MODEL DOMAIN AND BOUNDARY CONDITIONS

The tidal dynamics were simulated over a computational domain that included North Island coastal areas east of Great Barrier Island, north of the Coromandel Peninsula, and extending out to beyond continental shelf break in the Exclusive Economic Zone (EEZ) (Figure 6.1). The model domain is based on a 500 m x 500 m grid resolution oriented north to south (j) and east to west (i). The domain includes all off-shore islands such as Rakitu Island east of Great Barrier Island and the Mercury Islands north-east of the Coromandel Peninsula. The grid origin is located at 351216.45 E, 5931565.39 N (UTM 60).

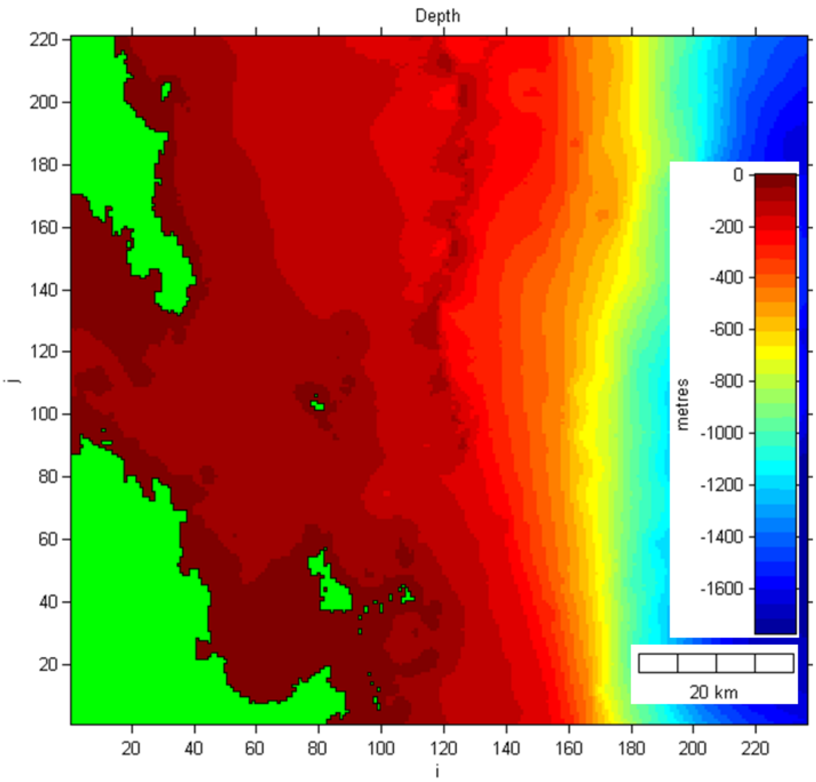

Figure 6.1 The model domain and bathymetry for the 500 m x 500 m grid used in the numerical simulation of tidal dynamics. The model grid is oriented north to south (j) and east to west (i). The areas included in the grid are waters east of Great Barrier Island, north of the Coromandel Peninsula, and out past the continental shelf break in the EEZ. The origin of the grid is 351216.45 E, 5931565.39 N (UTM 60).

The shelf bathymetry was interpolated into the model grid based on the hydrographic chart (NZ53) produced by the Royal New Zealand Navy (Frisken, W. D., 1992).

Water level fluctuations were extracted from the National Institute of Water and Atmospheric Research (NIWA) tidal model (forced using data from the U.S.-French oceanographic satellite TOPEX/Poseidon) along the open boundaries of the grid. Water level data from 31 March – 6 June 2008 was interpolated along the length of the open boundary based on 3 time series in the north, 3 time series in the east, 2 time series in the south, and 1 time series in the west (Figure 6.2).

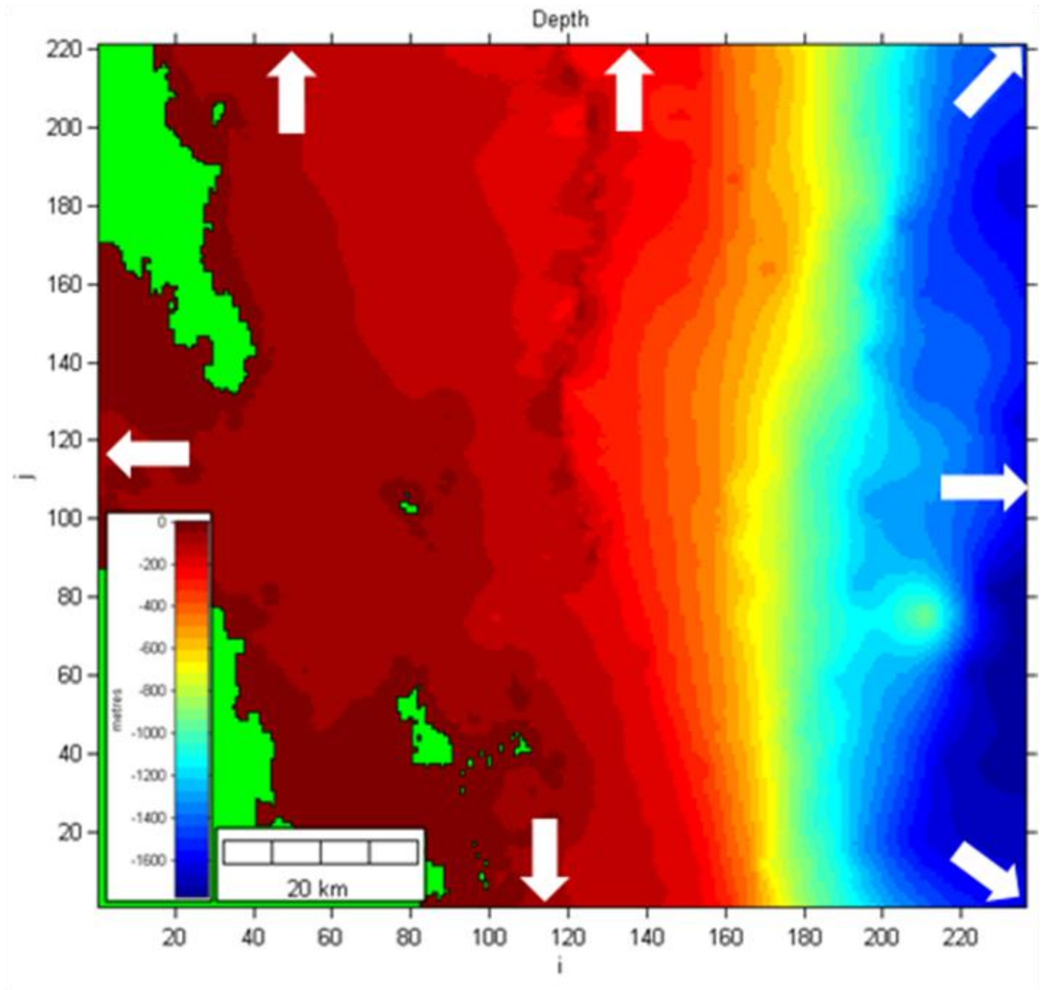

Figure 6.2 Model grid domain. White arrows indicate the locations of the water level time series extracted from the NIWA tidal model along the 4 open boundaries of the model grid.

6.3.2 MODEL PARAMETERS

Due to a lack of necessary field measured water elevation data, full calibration of the model was not undertaken. This task will be included in future numerical simulation studies.

The parameters utilised for the model are included in Table 6.1 and include the two adjustable coefficients of the 3DD model, bed roughness length and horizontal eddy viscosity. A value of 0.01 m was applied as bed roughness length as the model domain did not include estuarine features. A median value of 1 m^2s^{-1} was applied for horizontal eddy viscosity. These values were applied consistently across the model grid, which is reasonable given the relatively even topography of the continental shelf in the vicinity of the model domain.

Table 6.1 Numerical parameters for the two-dimensional tidal model of the regional area encompassing the proposed disposal site.

Parameter	Value
Time step	1.8 seconds
Roughness length	0.01 m
Horizontal eddy viscosity coef.	1 m^2s^{-1}
Model time start (t_0)	31/03/2008 0:00 NZST
Grid resolution	500 m x 500 m
Grid dimensions	236 x 221
Grid orientation	0° true
Grid origin	351216.45 E, 5931565.39 N, UTM 60
Grid latitude (approx.)	-36°
Coastal slip	100%
Effective depth	0.3 m
Drying height	0.05 m
North boundary	Water level flux values- NIWA tide model
East boundary	Water level flux values- NIWA tide model
South boundary	Water level flux values- NIWA tide model
West boundary	Water level flux values- NIWA tide model

6.3.3 MODEL VALIDATION

Model output was extracted from the grid cell corresponding to the centre of the proposed site (176° 47’ 00 E, 36° 13’ 00 S). Water level predictions are plotted in

Figure 6.3. Tidal amplitudes range from ~1 m for the spring tide to ~0.8 m for the neap tide. Similar amplitudes were described by Heath (1977), Stanton *et al*. (2001), Walters *et al*. (2001), and Foreman *et al*. (2004), suggesting that the modelled values are reasonable for the region of interest.

Predicted spring and neap water levels were then plotted against those predicted by the NIWA tidal model for the same location and time period (Figure 6.4). The 3DD model replicates the NIWA water level data effectively and relatively accurately, considering the lack of calibration (Figures 6.5 and 6.6). The spring tidal results show slightly more variance than those of the neap tide.

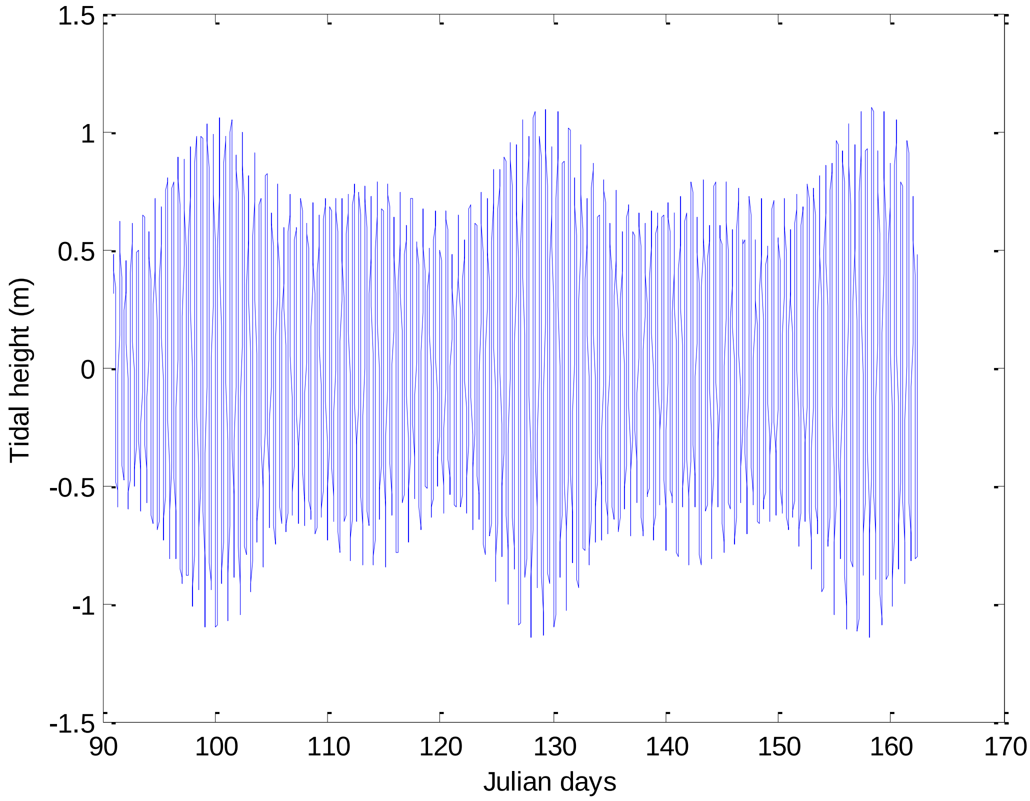

Figure 6.3 Time series of tidal height predicted by the model at the centre of the proposed disposal site (176° 47’ 00 E, 36° 13’ 00 S).

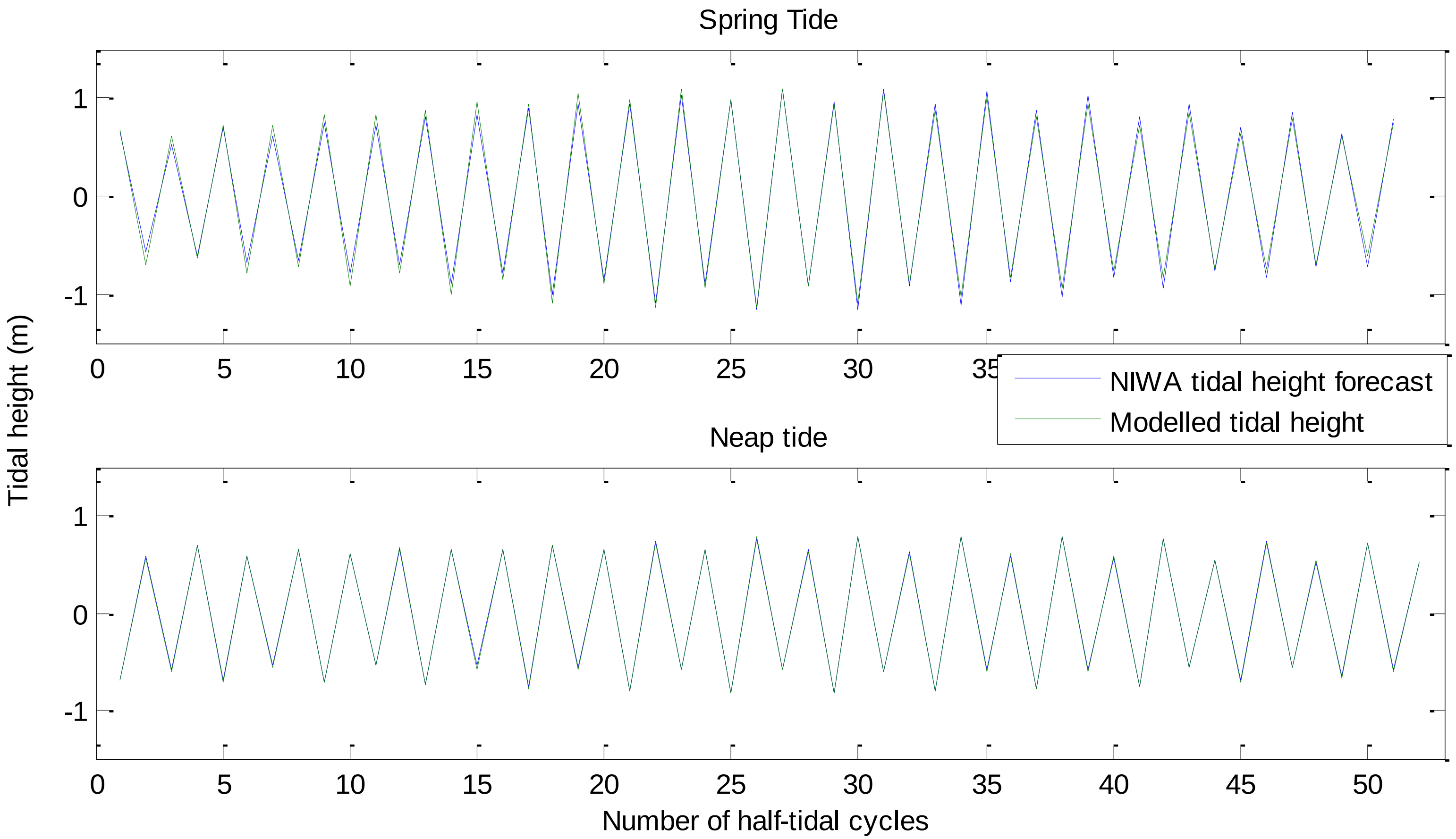

Figure 6.4 Tidal component of water levels predicted by the 3DD model at the centre of the proposed disposal site (green line) and that predicted by the NIWA tidal model (blue line) for a spring and subsequent neap tidal phase.

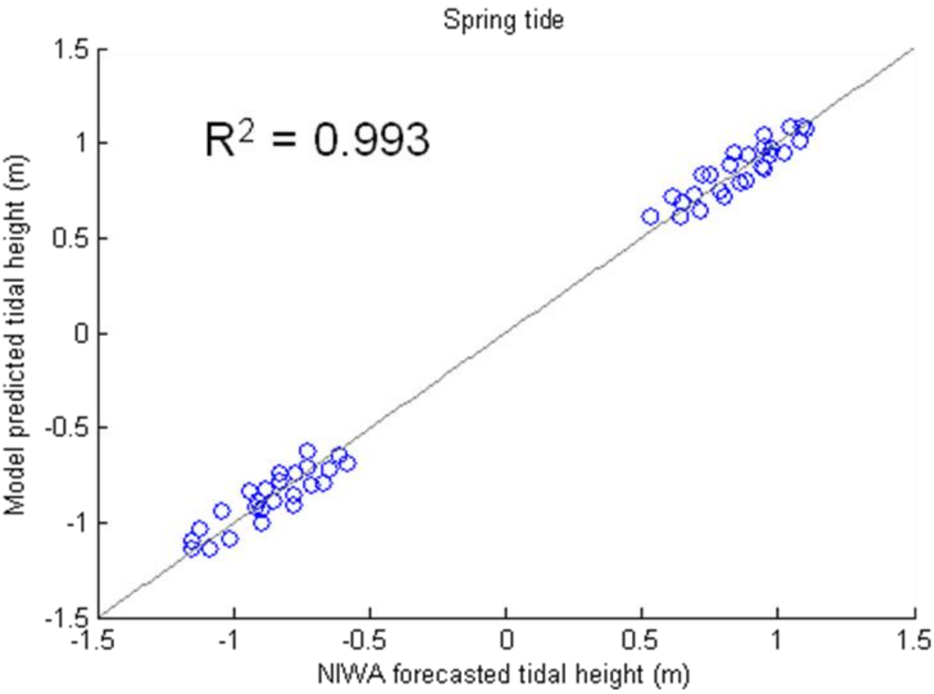

Figure 6.5 Scatter plot of NIWA forecasted and modelled water levels at the grid cell corresponding to the centre of the proposed disposal site. Data points represent 6-hourly measurements over a spring tide.

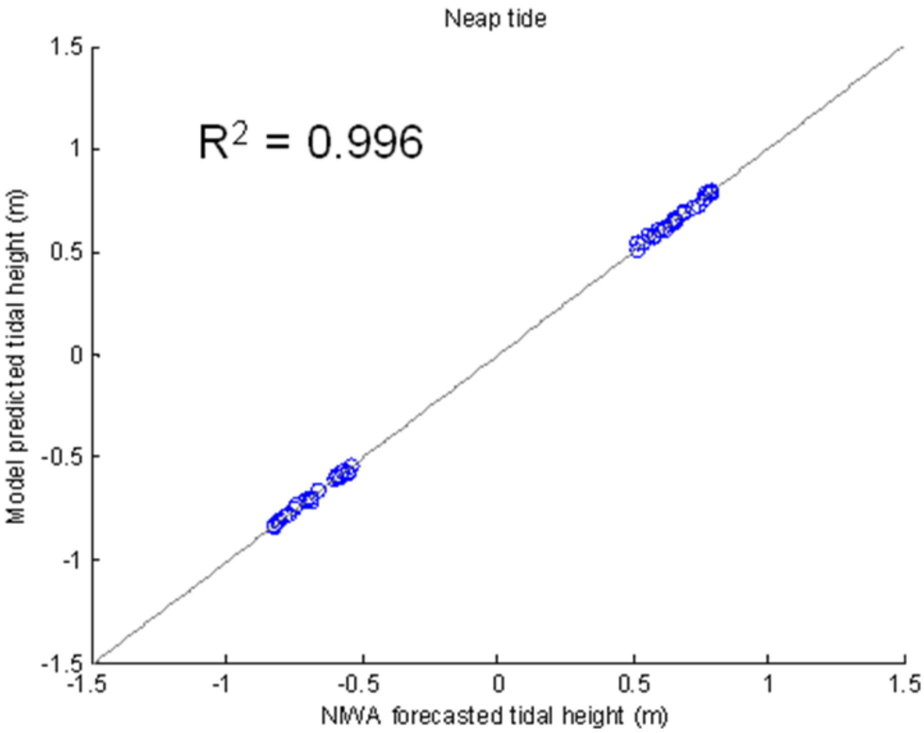

Figure 6.6 Scatter plot of NIWA forecasted and modelled water levels at the grid cell corresponding to the centre of the proposed disposal site. Data points represent 6-hourly measurements over a neap tide.

Additional, model validation was undertaken by performing a harmonic analysis on the modelled tidal height and the NIWA tidal forecast used for boundary forcing at the approximate centre of the proposed disposal site using the program T_TIDE (Pawlowicz *et al*, 2002). This program resolved the tidal amplitude and phase (95% CI estimate) of different tidal constituents which explained 99.8% of the total variance. The M2 tidal wave, discussed in Section 5.5.1, is the main constituent in the north-east region of New Zealand. Table 6.2 details the amplitude and phase of the M2 tidal constituent derived from the modelled output and the NIWA tidal forecast at the centre of the proposed disposal site. The model results show little variance from the data used to force the model with respect to amplitude and phase of the tidal wave. The model results also show strong agreement with the results reported in numerous other studies on the tidal components of New Zealand waters (Heath, 1985; Stanton *et al*, 2001; Walters *et al*, 2001; Foreman *et al*, 2004) (Table 6.2).

Table 6.2 Amplitude and phase of the M2 tidal constituent derived through harmonic analysis of results, extracted from the centre of the proposed disposal site, from the present numerical simulation study. This is followed by the results of a harmonic analysis on a NIWA tidal forecast time series used for boundary forcing of the model. Reported results from previous studies on the tidal components of New Zealand waters are also included.

Tidal Results	Consituent	Amplitude	Phase
Modelled tidal wave	M2	0.7567	204.32
NIWA tidal forecast (boundary forcing)	M2	0.7018	207.98
Heath, 1985	M2	0.88	213
Stanton *et al*, 2001	M2	Not available	206.3
Walters *et al*, 2001	M2	0.8	210
Foreman *et al*, 2004	M2	0.69	199

6.3.4 TIDALLY FORCED MODELLED CURRENTS IN THE REGION ENCOMPASSING THE PROPOSED DISPOSAL SITE

In the region east of Great Barrier Island, modelled tidally forced peak ebb and flood velocities during a spring tidal phase of the simulation (29 April-16 May, 2008) over the immediate region of the proposed disposal site were less than 0.2

ms^{-1} (Figures 6.7 and 6.8). Based on the principle of the "law of the wall", discussed in Section 5.5.6.3, bottom velocities would only reach approximately 0.08 ms^{-1}. Moreover, extraction of residual currents for the same spring tidal phase showed that tidal current velocities were less than 0.003 ms^{-1} (Figure 6.9). Also notable are the strong current velocities produced in the Colville Channel just south of the region of interest. Here water velocities increase to approximately 1 ms^{-1}. Similarly fast currents were modelled in the vicinity of the small off shore islands, the Mercury Islands and Rakitu Island, most likely a result of the shallow bathymetry surrounding them.

Tidal currents appear to maintain a northwest to southeast flow pattern throughout the majority of the model domain (Figure 6.7 and 6.8). The residual flow direction over the region of the proposed disposal site for the spring tidal phase examined was toward the southeast (Figure 6.9). Although, modelled tidal currents through the Colville Channel are rotated slightly to take on a cross-shelf flow direction (Figures 6.7 and 6.8). This observed change in current direction is most likely a result of the shallower waters in this region and constriction of water passage by the southern end of Great Barrier Island and the north tip of the Coromandel Peninsula.

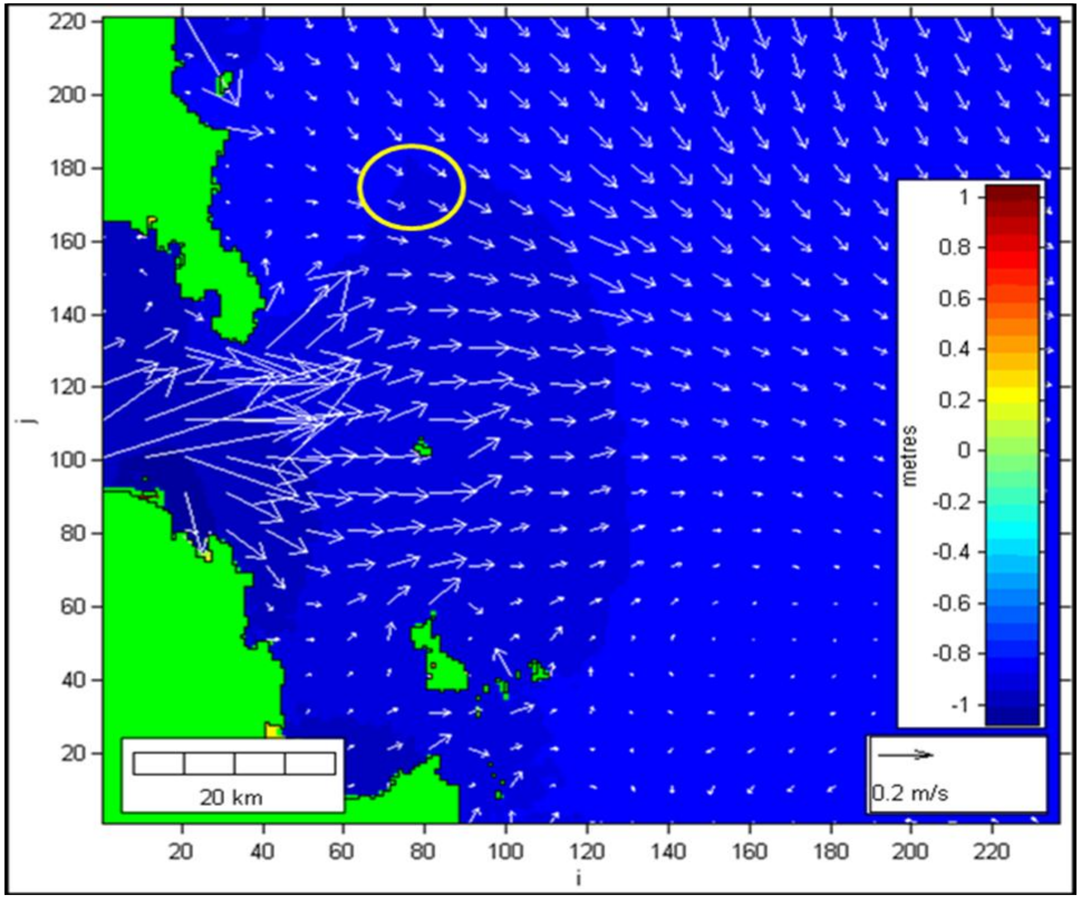

Figure 6.7 Tidally forced peak ebb currents during a spring tidal phase over the coastal and shelf regions encompassing the proposed disposal site. Encircled area indicates the approximate location of the proposed disposal site.—

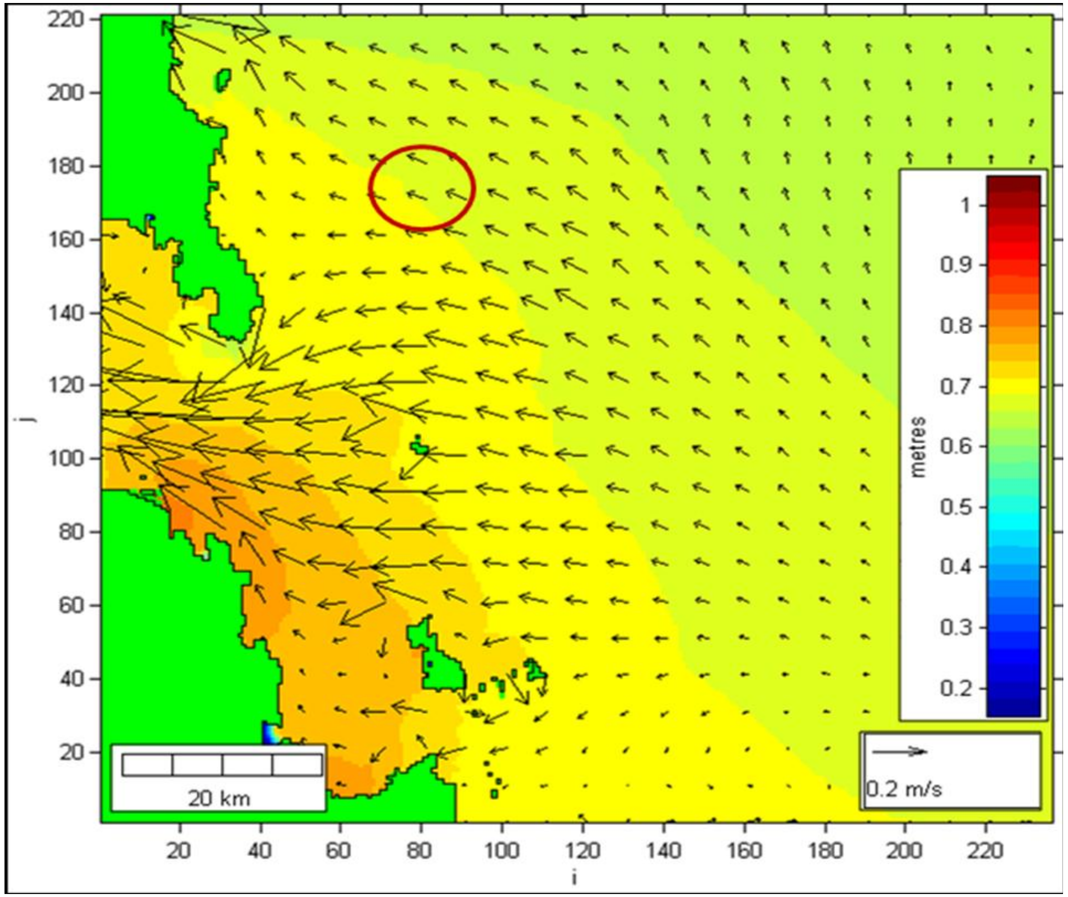

Figure 6.8 Tidally forced peak flood currents during a spring tidal phase over the coastal and shelf regions encompassing the proposed disposal site. Encircled area indicates the approximate location of the proposed disposal site.--

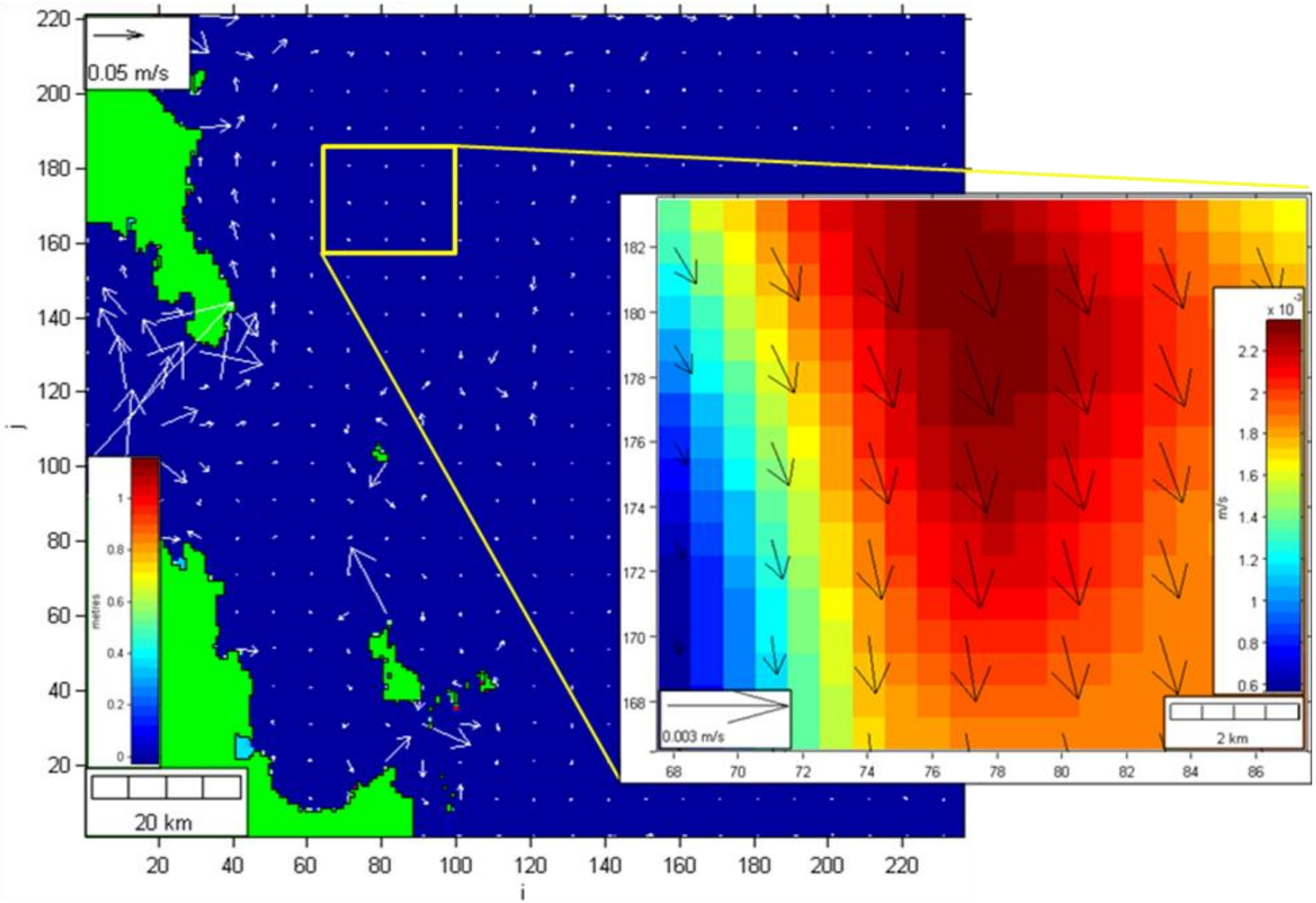

Figure 6.9 Modelled tidally forced residual currents for a spring tidal phase (29 April-16 May 2008) over the coastal and shelf areas encompassing the proposed disposal site. Inset is a close up of current vectors over the region of the proposed disposal site (arrows indicate that depth-averaged residual current velocities are less than 0.003 ms^{-1} and are directed toward the southeast.

6.4 DISCUSSION

Tidal circulation in the northeast of New Zealand has been extensively discussed in previous studies (Bowman and Chiswell, 1982; Greig and Proctor, 1988; Proctor and Grieg, 1989; Sharples and Grieg, 1998; Black *et al*, 2000; Longdill, 2008), but mainly with reference to the Hauraki Gulf. There have been relatively few studies of the tidal circulation on the continental shelf of the northeast coast, but available data shows good agreement with the modelled results.

Modelled tidal current velocities are consistent with those measured by Sharples and Grieg (1998) and also those modelled by Longdill (2008) in the Bay of Plenty. Reported tidal velocities from these previous studies ranged from 0.5-0.2 ms^{-1} on the northeast shelf of New Zealand and were considered to be relatively slow compared to non-tidal current velocities. As discussed in Section 5.5.6.3, velocities on the order of 0.2 ms^{-1} are needed to initiate sediment movement at the seafloor. As such, tidal currents alone will not likely to be able to entrain sediment after it has following during disposal operations. However, Sharples and Greig (1998) propose that under certain conditions, tidal influences can be significant as the M2 tidal wave breaks down to form an internal tide. Modelling of such instances, must be 3-dimensional and be validated using various temperature and salinity measurements.

The northwest to southeast directional flow of the modelled tidal currents and the southeasterly residual currents are significant to the present study because it implies that if sediment is advected, either through the water column during descent to the seafloor or by entrainment off the seafloor, suspended sediment will maintain a path parallel to the shore. A flow path perpendicular to shore would potentially result in the transport of suspended sediment to nearshore areas. Consideration must be taken with these predictions as it is unlikely that tidal currents will be the sole mode of sediment transport. All that considered, model results suggest that suspended sediment will not be transported by tidal currents toward protected areas shoreward of the proposed disposal site, such as the Hauraki Park Marine Park and the proposed Great Barrier Marine Reserve.

Two major criteria for considering a site to be suitable for disposal operations are that currents over the site area are slower than the critical velocity for entrainment of sediment and that residual flows are not directed toward ecologically significant areas. These requirements are in place to minimise the impacts that disposal operations can potentially have on the environment. The results suggest that deposited sediments will not easily be entrained by tidal currents and in the event that they are, dispersion clouds will be directed offshore and away from significant areas. The findings of this numerical simulation are a positive step, albeit a small one, toward the establishment of the proposed site as a designated disposal ground.

CHAPTER SEVEN: POTENTIAL IMPACTS

7.1 INTRODUCTION

Although, it is not possible to determine the precise impacts from disposal operations at a study site, general predictions can be made based upon a review of previous studies. The following chapter assesses the results reported for previous environmental impact studies and, where appropriate, applies them to this present study.

7.2 WATER QUALITY

Disposal operations can compromise water quality in the vicinity of the disposal site by the addition of suspended sediment to the water column in the form of a low-density dispersion cloud (Figure 5.15). Approximately 1-5% of the sediment load can be expected to be lost by dispersion in the water column upon descent (Truitt, 1988). These transient pulses of fine sediment will cause waters in the plume to become temporarily turbid. Any contaminants bound in the sediments will be exposed to float freely in the water column.

However, some heavy metal contaminants such as iron and manganese, upon release into the oxygenated surface waters, coagulate and precipitate immediately (Burks and Engler, 1978). These heavy metal oxides have an affinity to other heavy metals and as a result, most of the released heavy metal contaminants will quickly be removed from the water column (Burks and Engler, 1978). While their presence in the water column is not ideal for the surrounding areas, the small amount of time heavy metal contaminants stay in the water column means that the impact on the water quality will be minimal.

Typically, species associated with muddy environments, such as those surrounding the proposed disposal site, are highly tolerant of sediment suspensions (Hirsch *et al*, 1978), especially if they are only occurring as transient pulses of turbidity as they would during disposal operations. The compromised quality of the water column proceeding disposal will be short-lived and is unlikely to affect surrounding areas.

7.3 MOVEMENT OF THE SPOIL MOUND

Entrainment of the disposed sediments off or over the seafloor may result in movement of the spoil mound. However, in such water depths (135 – 140 m) the wave generated currents are very small and infrequent (as determined in section 5.5.6.3), as are the tidal and shelf currents. Moreover, the dredged material is cohesive, and thus little migration of the dredge spoil mound is expected. Monitoring using side scan sonar and ground-truthing techniques will determine whether any migration occurs.

In a survey of the morphological changes of the disposal ground (22-30 m water depth) used by Port of Tauranga for the capital dredging undertaken from 1991-92, profiles from bathymetric transects at the site were examined pre-, during, and post-disposal operations (Matthews, 1997). Data showed that during these periods, aside from the expected profile change due to dredged material addition, there was no significant morphological change related to movement of the spoil mound (Matthews, 1997).

During the post-dumping period, there was some indication of redistribution of materials from the disposal mound (Matthews, 1997). However, volumetric calculations indicated no significant change in the amount of sediment present during the post-dumping period (Matthews, 1997). It was reported that near bottom currents measured at or near the disposal ground were not capable of transporting sediments the majority of the time. However, the current speeds associated with a cyclone during December 1996 did, in fact, erode approximately 1m of sediment from the tops of the spoil mounds (Matthews, 1997).

Therefore, it was concluded that at that disposal site, in 22-30 m of water, on the inner shelf at Port of Tauranga, the primary means of sediment transport and morphological change in the disposal mounds was via large waves and fast currents associated with storm conditions. Matthews (1997) estimated that a storm with mean currents speeds of 0.4 ms^{-1} can transport 0.1 m^3/ $m^{-1}s^{-1}$ of and a storm with mean current speeds of 0.3 ms^{-1} can only transport 0.01 / $m^{-1}s^{-1}$.

These findings are marginally significant to the processes that may occur at the proposed disposal site, which it must be emphasised, is in substantially deeper water. The effects of a cyclone, such as the one described above, on a spoil mound in 140 m of water depth would be vastly reduced and only transport a fraction of the sediment reported at 22-30 m water depth. As storms of these magnitudes only occur rarely, movement of the spoil mound at the proposed disposal site is expected to be minimal.

7.4 CONTAMINANT LEACHING

With dredged materials that are contaminated or even slightly contaminated with various heavy metals, pesticides, polychlorinated biphenyls, and petroleum hydrocarbons, the leaching of the spoil mound may add to the adverse effects on the environment that some disposal operations can cause.

Normally, significant leaching requires a pore water pressure (a pressure gradient from the spoil mound to the overlying surface water). Typically, a distinctive pressure gradient is only established when the mound is very large and solid. In this case, it is envisaged that only a low mound of sediment will result from the deposition of the dredged material, so that pore water pressure and, therefore, leaching of heavy metals into the overlying water column will be minimal.

Accordingly, we do not expect a high pore water pressure to induce leaching on the sea floor.

Even so, the establishment of a pore water pressure gradient does not necessarily mean that contaminants will be released into the water column. Studies have shown that contaminated sediment is no longer thought to always be toxic because contaminants are not as easily desorbed from sediments as previously thought (Hirsch *et al*, 1978). Indeed, a laboratory study on the long term leaching of contaminants determined that arsenic, cadmium, lead, and mercury showed virtually no long-term (8 month) net release (Brannon, 1978). Contaminants are less toxic to the environment bound into the sediments than in a free state (Hirsch *et al*, 1978).

Additionally, studies by Hirsch *et al* (1978), as part of the US Army Corps of Engineers Dredged Material Research Program, dispute the traditional belief that exposure of heavy metal contaminants to organisms always result in adverse effects. The studies examined the response of the clam *Rangia cuneata*, the grass shrimps *Palaemonetes pugio* and *P. kadiakensis*, and the worms *Neanthes arenaceodentata* and *Tubifex* sp. to concentrations of heavy metal contaminants. The contaminants that were routinely measured in these investigations were iron, manganese, copper, cadmium, nickel, lead, zinc, chromium, and mercury. They determined that the uptake of heavy metals by organisms was minimal and variable and the impacts resulting from heavy metal bioaccumulation were not evident. However, they did find that bioaccumulation potential appeared to be related to the physical and chemical form that the heavy metal occurred in (Hirsch *et al*, 1978).

7.5 Biological impacts

7.5.1 Benthic fauna

Benthic fauna at the dredge locations and at the disposal site will be affected by the disposal operations. Most individuals inhabiting the sediments to be dredged will be destroyed in the dredging and/or disposal operations. Likewise, the individuals inhabiting the sediments at the disposal site will be buried once the sediment load is deposited on the seafloor.

Response after burial will differ between species. There may be a decrease in abundance of less opportunistic species and an increase in abundance of species with a more opportunistic life-style (Harvey *et al*., 1998). Smith and Rule (2001) actually found that effects of dredge-spoil dumping on a shallow water (~6 m) soft-sediment community had no detectable effect on the structure of the invertebrate community at the receiving site. This is most likely due to the specific methods used for disposal operations which were implemented to minimise impacts (Smith and Rule, 2001).

Many benthic species are capable of vertical migration through sediment substrate, which allows them to re-emerge at the sediment-water interface after a burial event (Hirsch *et al*, 1978). Several major taxa such as, polychaetes, molluscs, and crustaceans can be expected to recolonise a disposal ground through vertical migration (Harvey *et al*, 1998). The three largest benthic taxa identified in this study were, in fact, polychaetes, molluscs, and crustaceans. This suggests that recolonisation at the study site may occur quickly as a large portion of the individuals may survive burial through their vertical migration capabilities. Furthermore, recolonisation through vertical migration typically occurs more quickly than that of larval settlement (Bolam and Rees, 2003).

Survival potential may increase if the material disposed is a similar quality to that of the sediment the benthic species previously inhabited (Hirsch *et al*, 1978).

Indeed, Maurer et al (1980; 1981; 1982) found that mortalities increase with an increase in sediment depth and exotic sediment.

The specific recovery rate of invertebrate benthic communities in an unstressed habitat has been estimated to take between 1 and 4 years (Bolam and Rees, 2003). Interestingly, Bolam and Rees (2003) found that communities in more stressed environments only took approximately 9 months to recover. Classic community disturbance literature demonstrates that macrofaunal communities in environmentally stressed environments are more naturally resilient (Bolam and Rees, 2003).

This is significant to the present disposal discussions in that after the first disposal operations have taken place at the proposed site, benthic communities may take a year or more to recover. However, if disposal operations are ongoing, it can be expected that the benthic communities will be able to recover in less than a year after the initial recovery from the first disposal event.

7.5.2 Fin fish and mammals

It seems that the only impacts that disposal operations would realistically have on fin fish and marine mammals would be that vessels travelling to and from the site will pass through typical migratory paths of certain species (Section 5.6.3). If a vessel en route or involved in disposal operations were encountered by one of these migratory species, it is likely that the individual will divert its path to maintain distance from the vessel and in that, protect it from being covered by dredged material descending to the seafloor. Aside from altering their typical migratory path, other disruptions to these individuals are not presently evident.

7.6 CONCLUSIONS

Factors such as the character of dredged sediment, disposal methods, and site physical and biological features must all be considered to best predict the potential impacts that may occur at and around a disposal site. Predictions can be made more accurate by considering the findings of previous studies, but all must be considered with caution. Influencing factors may be vastly different from study to study and these differences can cause the extent of the impact to vary from minimum to maximum levels between studies. Therefore, the intent is that the potential impacts discussed here will be verified through a post-disposal impact study.

For the purposes of determining the suitability of the site for disposal operations potential impacts on water quality, movement of the spoil mound, contaminant leaching, and biological activity have been estimated. Water quality will most likely be compromised through the addition of suspended sediment and therefore contaminants, but for only short transient pulses immediately after the disposal, making impacts minimal and short-lived. Once the sediment is deposited on the seafloor, the water depth is likely to prevent the re-agitation and entrainment of the sediment, which means the mound will remain relatively stable. Any effects incurred from the presence of the mound will be confined to the site area. However, as the mound is not likely to be large and highly compact, it is unlikely that there will be significant leaching of contaminants into the water column. The most significant impacts will be on the benthic fauna buried under the deposited sediment, but the three major taxa collected from the site all have capabilities for vertical migration. These capabilities act to increase the rate of recolonisation. The site may never return to its natural state after disposal operations begin, but a simulated natural state may be achieved within one year of disposal.

CHAPTER EIGHT: RESEARCH CONCLUSIONS

8.1 MAJOR FINDINGS OF THE STUDY

The main goal of this study was to further the effort of establishing a disposal site on the shelf for dredged material originating from the Auckland and Waikato Coastal Marine Areas that would leave behind a minimal amount of adverse effects. The dilemma of dredged spoil disposal goes back a long way in the Auckland CMA and yet, there are still no viable disposal options. Sediments will always accumulate in coastal areas and therefore, it is with great certainty that a call for a new long term disposal option is made.

As part of the preliminary research process, an extensive review of the policies regarding disposal of dredged material at sea revealed the key concerns of the international, national, and regional enforcing authorities with respect to open water disposal operations. For the purposes of establishment of a site, the majority of the policy documents called for the investigation of the proposed site with respect to seven key topics: characterisation of the material to be dredged, size and capacity of the site, geology and geomorphology, water properties, hydrodynamics of the region, biological composition and activity, and identification of potential impacts. The remainder of the research was designed to address these key concerns with the intention of submitting the findings as part of a permit application to undertake disposal at the site.

A review of the available data on the sediments at Pine Harbour Marina and Westpark Marina in the Auckland CMA gave a good understanding of the types of materials that may eventually be disposed at the proposed site. Both locations possess channel and basin sediments that are mainly texturally fine. Contaminant testing at the above locations, revealed that heavy metal concentrations were at low levels at the time of the tests, compared to standardised toxicity testing guidelines. In general, the sediments at both marinas showed a higher level of contamination in the basin sediments as opposed to those of the approach channel. This is significant because typically, an approach channel will infill more quickly than a marina basin and therefore, will be the source of more maintenance dredged sediment. It was determined that the expected dredged material will be mainly composed of fine muddy sediments with a low level of heavy metal contamination making it reasonably well-suited for disposal at the texturally similar proposed site.

The research was then devoted to assessing the site characteristics in accordance with the policies on disposal operations at sea. A literature review first gave an overall understanding of the geology and geomorphology, water properties, hydrodynamics, and biological composition and activity in the northeast coast region of New Zealand. This was followed by various analyses, calculations, and simulations which were used to gain a more detailed understanding of the specific features of the site itself.

Textural analysis was undertaken on sediment samples collected at the site in November 2007. Results confirmed that the seafloor sediments at the proposed site are composed of mainly fine textural classes. Clay and very fine sand made up the main components of the samples collected. Also significant to note is that there was very little variation in sediment texture across the sampled areas of the site.

The potential for sediment transport was predicted through analytical calculations as a means of determining whether disposed sediment will be dispersed away from the site. Results confirming the latter would indicate that the site is potentially unsuitable for disposal operations. The calculations showed that the potential for sediment transport under normal conditions at the site are low, but that rare occurrences of extreme storm conditions could induce agitation of seafloor sediments and disperse them away from the site.

Samples collected during the same survey cruise, mentioned above, were examined to account for the level of diversity and abundance of benthic fauna.

Individuals were grouped into coarse taxonomic classes including polychaetes, non-polychaetes, bivalves, gastropods, malacostracans (crustaceans), and ophiuroidea. Analysis revealed that there was a surprising level of diversity with a total of 78 different species, whereas overall abundance was generally less impressive. Only a total of 273 individuals were collected from 20 sample locations across the proposed site.

A numerical simulation was also included in this study to further the understanding of the hydrodynamic processes influencing the region of the proposed site. These processes are essential to examine as they are the driving forces behind sediment and, therefore, dredged material transport pathways. Output of the two-dimensional, tidal, numerical simulation predicted that peak spring tidal depth-averaged currents at the site will be less than 0.2 ms^{-1}. Bottom currents derived from this depth-averaged velocity will be approximately 0.08 ms^{-1}, re-calling that the velocity required to initiate sediment motion at the seafloor was calculated to be approximately 0.2 ms^{-1}. Residual flows extracted for a spring tidal phase were directed toward the southeast of the model domain. These findings imply that entrainment of sediment from the seafloor will rarely be achieved and when those rare occasions occur, advected sediment will be directed toward the southeast, away from adjacent areas of ecological importance.

The last key requirement of the relevant policies was to undertake an assessment of the potential impacts that disposal operations might have should the permit application be approved. A literature review of relevant studies on the ecological impact of disposal operations identified two main features that may incur some ecological damage. Short-term impacts may occur in the water column where water quality will be temporarily compromised. Short transient pulses of suspended sediment and some contaminants will be present following the release of dredged material into the water column. These suspensions will be short-lived and are unlikely to cause long-term effects. However, long-term impacts, on the order of 1-5 years will occur resulting from the burial of the benthic fauna inhabiting the site. Depending on the survivorship of these organisms, re-establishment of the community can take several years. The mortality rate will decrease after subsequent disposal events, however, as environmentally stressed communities tend to be more resilient. Therefore, it will be the initial disposal of material at the site which will have the most impact.

8.2 Implications

The findings of this research are encouraging mainly for Kaipara Ltd., the chief supporter of this project, but also to a lesser degree, all other ports and marinas in the Auckland and Waikato CMAs. Based on the preliminary results of this study, the site proposed to be a designated disposal ground for dredged material is suitable. Disposal operations are not expected to result in adverse effects to the surrounding environment.

The implications are that a potential long-term disposal option has been identified and may eventually be available for use by many ports and marinas that have struggled with a disposal dilemma for many years. Wider implications are that the overall productivity, profitability, and environmental sustainability of these ports and marinas will increase. Without giving this research more credit than it is worth, the end result may contribute to the economic and ethical (in the sense of environmental responsibility) worth of New Zealand's shipping and recreational boating industry.

8.3 Recommendations for future research

As this study was mainly a preliminary undertaking, the opportunities for future research in this area are almost limitless. However, there are several arenas that certainly deserve special attention, as they will deliver the important information that is still needed for the purposes of establishing the disposal site. There are several features such as the East Auckland Current, internal tides, and localised upwelling which may shed new light on this project. Numerical simulations of three-dimensional tidal and geostrophic flow in the region must be undertaken to complete the hydrodynamic picture. Additionally, determining sediment transport processes through modelling can show in great detail where the deposited material will end up.

Another important avenue for future research is the monitoring of the site once it has been established. Before and after comparisons can validate whether disposal operations are impacting the site. This type of research must include a detailed baseline survey of the site and an adjacent control site. Periodic monitoring of post-disposal conditions can determine the rate of recovery of the benthic fauna, the stability of the spoil mound, and whether there is an accumulation of contaminants.

Disposal site establishment in shelf waters deeper than 100 m has been suggested in the past by parliamentary focus groups concerned about the environmental impacts of nearshore disposal of dredged material. Thus far, this study is the first in New Zealand to address this suggestion. As such, successful establishment of this present site as an environmentally viable and functionally feasible disposal option can potentially set the bar for future disposal site establishment in New Zealand.

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APPENDIX I: GRAIN SIZE ANALYSIS

MASTERSIZER

Result: Histogram Report

User Name: Conny | Security Level: 2

Sample Details

Sample ID: A0
Sample File: NOV07
Sample Path: C:\SIZERS\DATA\BRYNA\
Sample Notes:

Run Number: 17
Record Number: 16

Measured: Tue 1 Apr 2008 11:17a.m.
Analysed: Tue 1 Apr 2008 11:17a.m.
Result Source: Analysed

System Details

Range Lens: 300RF mm
Presentation: 3OHD
Analysis Model: Polydisperse
Modifications: None

Beam Length: 2.40 mm
[Particle R.I. = (1.5295, 0.1000); Dispersant R.I. = 1.3300]
Sampler: MS17

Obscuration: 27.4 %
Residual: 0.709 %

Result Statistics

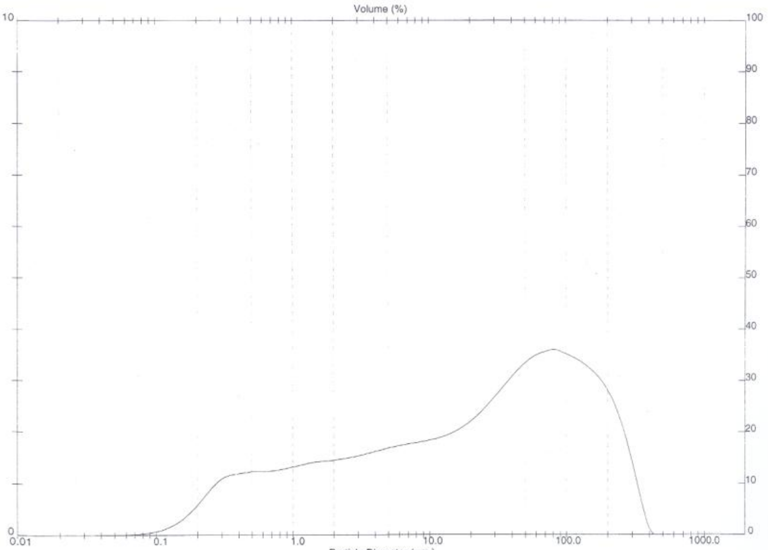
Distribution Type: Volume
Mean Diameters:
D [4, 3] = 59.23 um

Concentration = 0.0191 %Vol
D (v, 0.1) = 0.69 um
D [3, 2] = 2.15 um

Density = 2.560 g / cub. cm
D (v, 0.5) = 26.66 um
Span = 6.477E+00

Specific S.A. = 1.0880 sq. m / g
D (v, 0.9) = 173.34 um
Uniformity = 1.970E+00

Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %
0.050	0.00	3.90	7.69	74.00	4.07	300.0	1.06
0.060	0.21	7.80	8.46	88.00	4.08	350.0	0.32
0.120	1.91	15.60	10.40	105.0	3.92	420.0	0.00
0.240	5.17	31.00	3.29	125.0	3.80	500.0	0.00
0.490	2.86	37.00	3.49	149.0	3.53	590.0	0.00
0.700	2.79	44.00	4.01	177.0	3.21	710.0	0.00
0.980	6.48	53.00	3.91	210.0	2.81	840.0	0.00
2.00	6.61	63.00	3.73	250.0	2.18	1000.0	0.00
3.90		74.00		300.0		2000.0	



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MASTERSIZER

Result: Histogram Report

User Name: Conny

Security Level: 2

Sample Details

Sample ID: A8
Sample File: NOV07
Sample Path: C:\SIZERS\DATA\BRYNA\
Sample Notes:

Run Number: 6
Record Number: 6

Measured: Tue 1 Apr 2008 10:43a.m.
Analysed: Tue 1 Apr 2008 10:43a.m.
Result Source: Analysed

System Details

Range Lens: 300RF mm
Presentation: 3OHD
Analysis Model: Polydisperse
Modifications: None

Beam Length: 2.40 mm
[Particle R.I. = (1.5295, 0.1000); Dispersant R.I. = 1.3300]

Sampler: MS17

Obscuration: 23.2 %
Residual: 0.755 %

Result Statistics

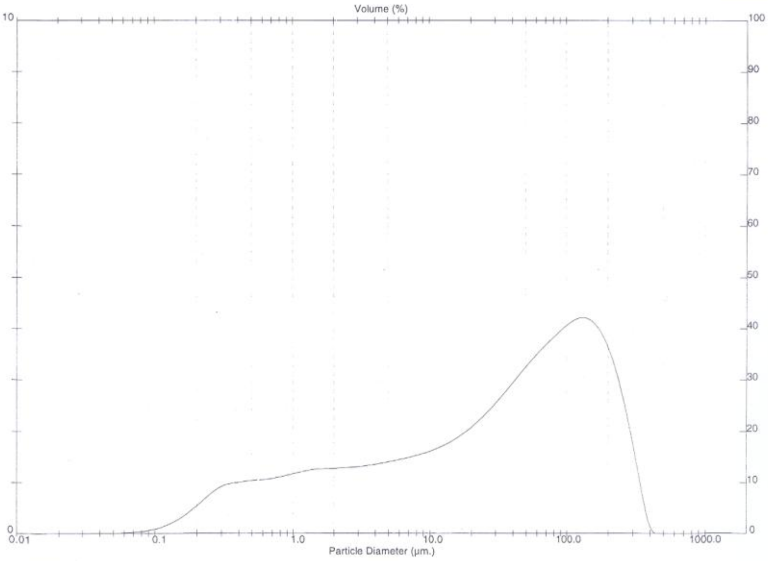
Distribution Type: Volume
Mean Diameters:
D [4, 3] = 69.53 um

Concentration = 0.0178 %Vol
D (v, 0.1) = 0.81 um
D [3, 2] = 2.36 um

Density = 2.560 g / cub. cm
D (v, 0.5) = 37.36 um
Span = 5.132E+00

Specific S.A. = 0.9917 sq. m / g
D (v, 0.9) = 192.54 um
Uniformity = 1.599E+00

Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %
0.050		3.90		74.00		300.0	
0.060	0.01	7.80	6.47	88.00	4.34	350.0	1.29
0.120	0.26	15.60	7.53	105.0	4.64	420.0	0.36
0.240	1.83	31.00	9.81	125.0	4.74	500.0	0.00
0.490	4.40	37.00	3.12	149.0	4.82	590.0	0.00
0.700	2.46	44.00	3.34	177.0	4.58	710.0	0.00
0.980	2.46	53.00	3.89	210.0	4.17	840.0	0.00
2.00	5.78	63.00	3.88	250.0	3.58	1000.0	0.00
3.90	5.69	74.00	3.83	300.0	2.71	2000.0	0.00



MASTERSIZER

Result: Histogram Report

User Name: Conny | Security Level: 2

Sample Details

Sample ID: B1 | Run Number: 12 | Measured: Tue 1 Apr 2008 11:01a.m.
Sample File: NOV07 | Record Number: 11 | Analysed: Tue 1 Apr 2008 11:01a.m.
Sample Path: C:\SIZERS\DATA\BRYNA\ | Result Source: Analysed
Sample Notes:

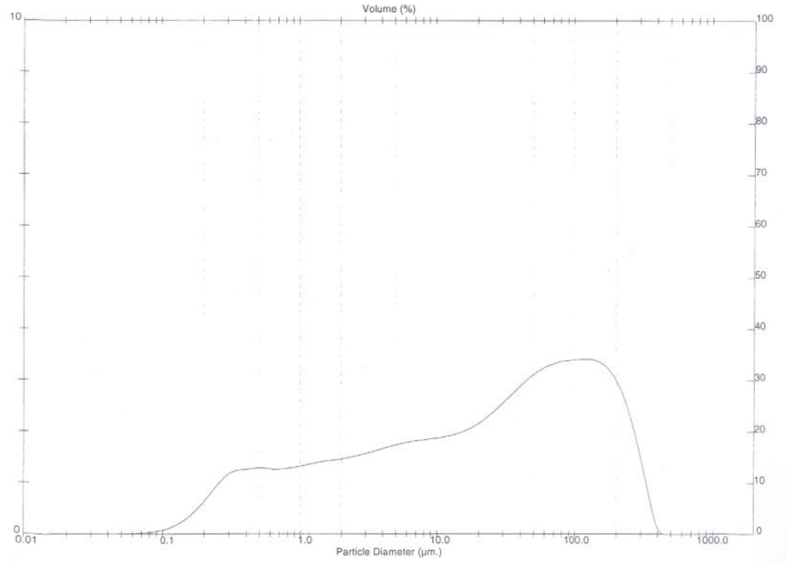
System Details

Range Lens: 300RF mm | Beam Length: 2.40 mm | Sampler: MS17 | Obscuration: 32.9 %
Presentation: 3OHD | [Particle R.I. = (1.5295, 0.1000); Dispersant R.I. = 1.3300]
Analysis Model: Polydisperse | Residual: 0.739 %
Modifications: None

Result Statistics

Distribution Type: Volume | Concentration = 0.0231 %Vol | Density = 2.560 g / cub. cm | Specific S.A. = 1.1515 sq. m / g
Mean Diameters: | D (v, 0.1) = 0.63 um | D (v, 0.5) = 25.02 um | D (v, 0.9) = 178.23 um
D [4, 3] = 59.85 um | D [3, 2] = 2.04 um | Span = 7.100E+00 | Uniformity = 2.144E+00

Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %
0.050	0.01	3.90	7.94	74.00	3.81	300.0	1.10
0.060	0.24	7.80	8.57	88.00	3.91	350.0	0.31
0.120	2.10	15.60	10.09	105.0	3.88	420.0	0.00
0.240	5.51	31.00	3.10	125.0	3.89	500.0	0.00
0.490	2.95	37.00	3.27	149.0	3.71	590.0	0.00
0.700	2.81	44.00	3.73	177.0	3.43	710.0	0.00
0.980	6.49	53.00	3.63	210.0	3.00	840.0	0.00
2.00	6.74	63.00	3.47	250.0	2.31	1000.0	0.00
3.90		74.00		300.0		2000.0	



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Result: Histogram Report

User Name: Conny — Security Level: 2

Sample Details

Sample ID: C2 — Run Number: 18 — Measured: Tue 1 Apr 2008 11:19a.m.
Sample File: NOV07 — Record Number: 17 — Analysed: Tue 1 Apr 2008 11:19a.m.
Sample Path: C:\SIZERS\DATA\BRYNA\ — Result Source: Analysed
Sample Notes:

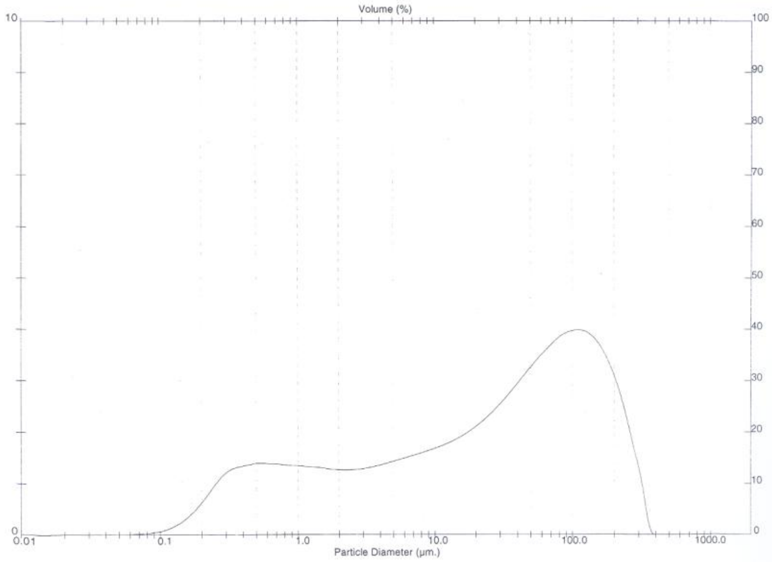
System Details

Range Lens: 300RF mm — Beam Length: 2.40 mm — Sampler: MS17 — Obscuration: 25.8 %
Presentation: 3OHD — [Particle R.I. = (1.5295, 0.1000); Dispersant R.I. = 1.3300]
Analysis Model: Polydisperse — Residual: 0.810 %
Modifications: None

Result Statistics

Distribution Type: Volume — Concentration = 0.0176 %Vol — Density = 2.560 g / cub. cm — Specific S.A. = 1.1458 sq. m / g
Mean Diameters: — D (v, 0.1) = 0.61 um — D (v, 0.5) = 30.37 um — D (v, 0.9) = 173.33 um
D [4, 3] = 61.15 um — D [3, 2] = 2.05 um — Span = 5.687E+00 — Uniformity = 1.768E+00

Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %
0.050		3.90		74.00		300.0	
0.060	0.00	7.80	6.62	88.00	4.36	350.0	0.88
0.120	0.20	15.60	7.83	105.0	4.57	420.0	0.02
0.240	2.04	31.00	9.92	125.0	4.54	500.0	0.00
0.490	5.81	37.00	3.12	149.0	4.46	590.0	0.00
0.700	3.24	44.00	3.34	177.0	4.08	710.0	0.00
0.980	2.99	53.00	3.90	210.0	3.58	840.0	0.00
2.00	6.09	63.00	3.91	250.0	2.95	1000.0	0.00
3.90	5.60	74.00	3.85	300.0	2.09	2000.0	0.00



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Result: Histogram Report

User Name: Conny | Security Level: 2

Sample Details

Sample ID: C4
Sample File: NOV07
Sample Path: C:\SIZERS\DATA\BRYNA\
Sample Notes:

Run Number: 9
Record Number: 8

Measured: Tue 1 Apr 2008 10:52a.m.
Analysed: Tue 1 Apr 2008 10:52a.m.
Result Source: Analysed

System Details

Range Lens: 300RF mm
Presentation: 3OHD
Analysis Model: Polydisperse
Modifications: None

Beam Length: 2.40 mm
[Particle R.I. = (1.5295, 0.1000); Dispersant R.I. = 1.3300]

Sampler: MS17

Obscuration: 32.2 %
Residual: 0.812 %

Result Statistics

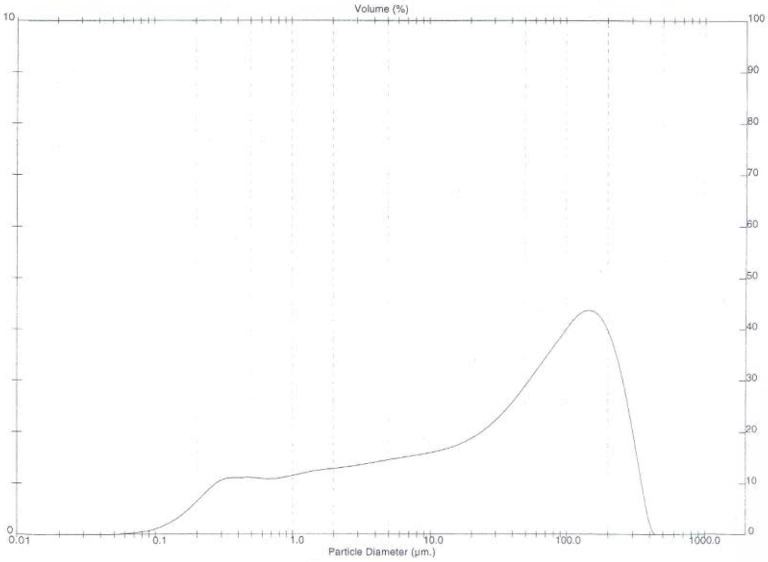
Distribution Type: Volume
Mean Diameters:
D [4, 3] = 72.93 um

Concentration = 0.0253 %Vol
D (v, 0.1) = 0.69 um
D [3, 2] = 2.13 um

Density = 2.560 g / cub. cm
D (v, 0.5) = 38.14 um
Span = 5.302E+00

Specific S.A. = 1.1018 sq. m / g
D (v, 0.9) = 202.90 um
Uniformity = 1.670E+00

Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %
0.050		3.90		74.00		300.0	
0.060	0.01	7.80	6.67	88.00	4.15	350.0	1.53
0.120	0.34	15.60	7.35	105.0	4.54	420.0	0.51
0.240	2.21	31.00	8.77	125.0	4.79	500.0	0.00
0.490	4.96	37.00	2.72	149.0	5.00	590.0	0.00
0.700	2.54	44.00	2.92	177.0	4.87	710.0	0.00
0.980	2.43	53.00	3.46	210.0	4.54	840.0	0.00
2.00	5.69	63.00	3.53	250.0	3.99	1000.0	0.00
3.90	5.83	74.00	3.57	300.0	3.10	2000.0	0.00



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Result: Histogram Report

User Name: Conny | Security Level: 2

Sample Details

Sample ID: C6
Sample File: NOV07
Sample Path: C:\SIZERS\DATA\BRYNA\
Sample Notes:

Run Number: 5
Record Number: 5

Measured: Tue 1 Apr 2008 10:40a.m.
Analysed: Tue 1 Apr 2008 10:40a.m.
Result Source: Analysed

System Details

Range Lens: 300RF mm
Presentation: 3OHD
Analysis Model: Polydisperse
Modifications: None

Beam Length: 2.40 mm
[Particle R.I. = (1.5295, 0.1000); Dispersant R.I. = 1.3300]

Sampler: MS17

Obscuration: 33.0 %
Residual: 0.784 %

Result Statistics

Distribution Type: Volume
Mean Diameters:
D [4, 3] = 79.94 um

Concentration = 0.0259 %Vol
D (v, 0.1) = 0.59 um
D [3, 2] = 1.89 um

Density = 2.560 g / cub. cm
D (v, 0.5) = 44.02 um
Span = 4.950E+00

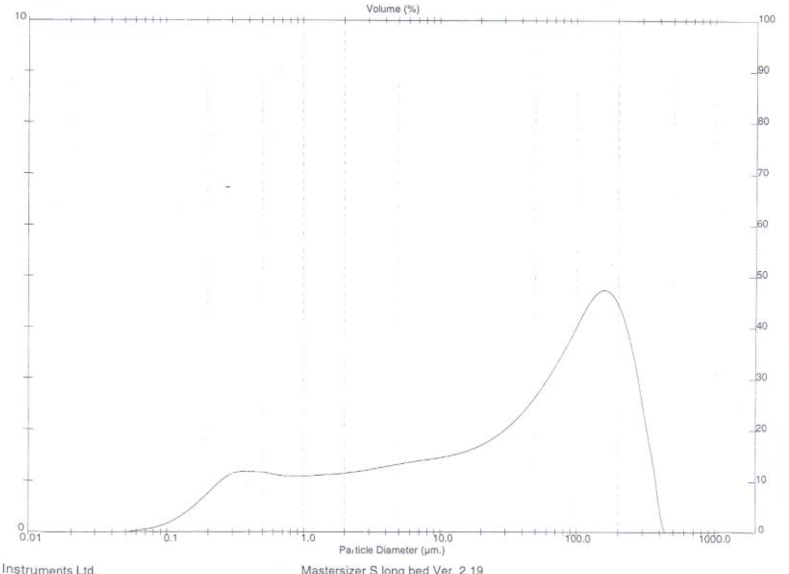
Specific S.A. = 1.2392 sq. m / g
D (v, 0.9) = 218.47 um
Uniformity = 1.584E+00

Size (um)	Volume In %
0.050	0.02
0.060	0.54
0.120	2.71
0.240	5.33
0.490	2.64
0.700	2.40
0.980	5.21
2.00	5.27
3.90	

Size (um)	Volume In %
3.90	6.11
7.80	6.71
15.60	7.96
31.00	2.46
37.00	2.65
44.00	3.15
53.00	3.26
63.00	3.36
74.00	

Size (um)	Volume In %
74.00	4.00
88.00	4.52
105.0	4.92
125.0	5.31
149.0	5.32
177.0	5.07
210.0	4.56
250.0	3.68
300.0	

Size (um)	Volume In %
300.0	1.96
350.0	0.90
420.0	0.00
500.0	0.00
590.0	0.00
710.0	0.00
840.0	0.00
1000.0	0.00
2000.0	



MASTERSIZER

Result: Histogram Report

User Name: Conny Security Level: 2

Sample Details

Sample ID: D3
Sample File: NOV07
Sample Path: C:\SIZERS\DATA\BRYNA\
Sample Notes:

Run Number: 14
Record Number: 13

Measured: Tue 1 Apr 2008 11:07a.m.
Analysed: Tue 1 Apr 2008 11:08a.m.
Result Source: Analysed

System Details

Range Lens: 300RF mm
Presentation: 3OHD
Analysis Model: Polydisperse
Modifications: None

Beam Length: 2.40 mm
[Particle R.I. = (1.5295, 0.1000); Dispersant R.I. = 1.3300]

Sampler: MS17

Obscuration: 27.3 %
Residual: 0.754 %

Result Statistics

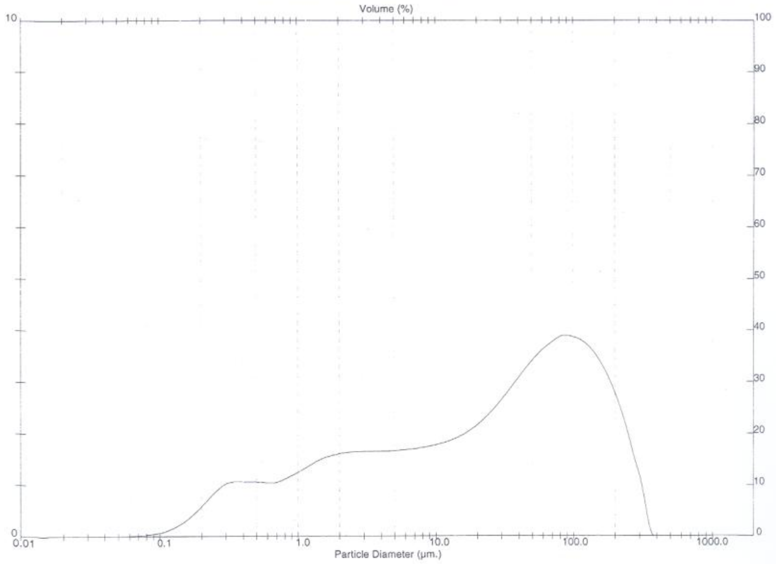
Distribution Type: Volume
Mean Diameters:
D [4, 3] = 57.88 um

Concentration = 0.0197 %Vol
D (v, 0.1) = 0.78 um
D [3, 2] = 2.25 um

Density = 2.560 g / cub. cm
D (v, 0.5) = 28.19 um
Span = 5.813E+00

Specific S.A. = 1.0402 sq. m / g
D (v, 0.9) = 164.67 um
Uniformity = 1.799E+00

Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %
0.050		3.90		74.00		300.0	
0.060	0.01	7.80	7.57	88.00	4.38	350.0	0.76
0.120	0.21	15.60	8.22	105.0	4.47	420.0	0.01
0.240	1.89	31.00	10.23	125.0	4.32	500.0	0.00
0.490	4.72	37.00	3.27	149.0	4.14	590.0	0.00
0.700	2.43	44.00	3.50	177.0	3.73	710.0	0.00
0.980	2.47	53.00	4.08	210.0	3.22	840.0	0.00
2.00	6.74	63.00	4.05	250.0	2.64	1000.0	0.00
3.90	7.14	74.00	3.94	300.0	1.85	2000.0	0.00



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Result: Histogram Report

User Name: Conny　　　　Security Level: 2

Sample Details

Sample ID: D5　　Run Number: 20　　Measured: Tue 1 Apr 2008 11:26a.m.
Sample File: NOV07　　Record Number: 19　　Analysed: Tue 1 Apr 2008 11:26a.m.
Sample Path: C:\SIZERS\DATA\BRYNA\　　Result Source: Analysed
Sample Notes:

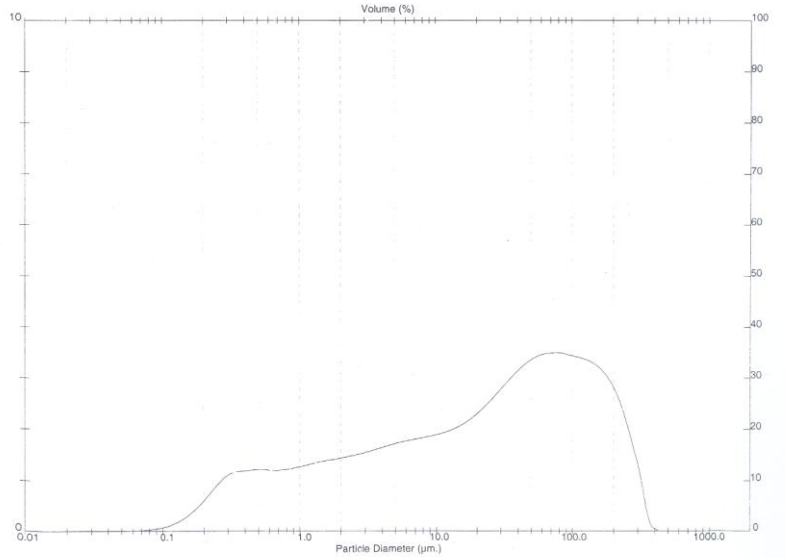
System Details

Range Lens: 300RF mm　　Beam Length: 2.40 mm　　Sampler: MS17　　Obscuration: 27.8 %
Presentation: 3OHD　　[Particle R.I. = (1.5295, 0.1000);　　Dispersant R.I. = 1.3300]
Analysis Model: Polydisperse　　Residual: 0.781 %
Modifications: None

Result Statistics

Distribution Type: Volume　　Concentration = 0.0195 %Vol　　Density = 2.560 g / cub. cm　　Specific S.A. = 1.0909 sq. m / g
Mean Diameters:　　D (v, 0.1) = 0.69 um　　D (v, 0.5) = 25.84 um　　D (v, 0.9) = 169.03 um
D [4, 3] = 57.49 um　　D [3, 2] = 2.15 um　　Span = 6.514E+00　　Uniformity = 1.967E+00

Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %
0.050	0.00	3.90	7.85	74.00	3.95	300.0	0.90
0.060	0.21	7.80	8.72	88.00	3.98	350.0	0.11
0.120	1.95	15.60	10.83	105.0	3.87	420.0	0.00
0.240	5.20	31.00	3.39	125.0	3.81	500.0	0.00
0.490	2.79	37.00	3.56	149.0	3.57	590.0	0.00
0.700	2.68	44.00	4.04	177.0	3.23	710.0	0.00
0.980	6.31	53.00	3.88	210.0	2.77	840.0	0.00
2.00	6.65	63.00	3.66	250.0	2.05	1000.0	0.00
3.90		74.00		300.0		2000.0	



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Mastersizer S long bed Ver. 2.19
Serial Number: 32913-57
p. 19
01 Apr 08 11:26

MALVERN INSTRUMENTS MASTERSIZER

Result: Histogram Report

User Name: Conny | Security Level: 2

Sample Details

Sample ID: E2
Sample File: NOV07
Sample Path: C:\SIZERS\DATA\BRYNA\
Sample Notes:

Run Number: 10
Record Number: 9

Measured: Tue 1 Apr 2008 10:55a.m.
Analysed: Tue 1 Apr 2008 10:55a.m.
Result Source: Analysed

System Details

Range Lens: 300RF mm
Presentation: 3OHD
Analysis Model: Polydisperse
Modifications: None

Beam Length: 2.40 mm
[Particle R.I. = (1.5295, 0.1000); Dispersant R.I. = 1.3300]

Sampler: MS17

Obscuration: 23.3 %
Residual: 0.760 %

Result Statistics

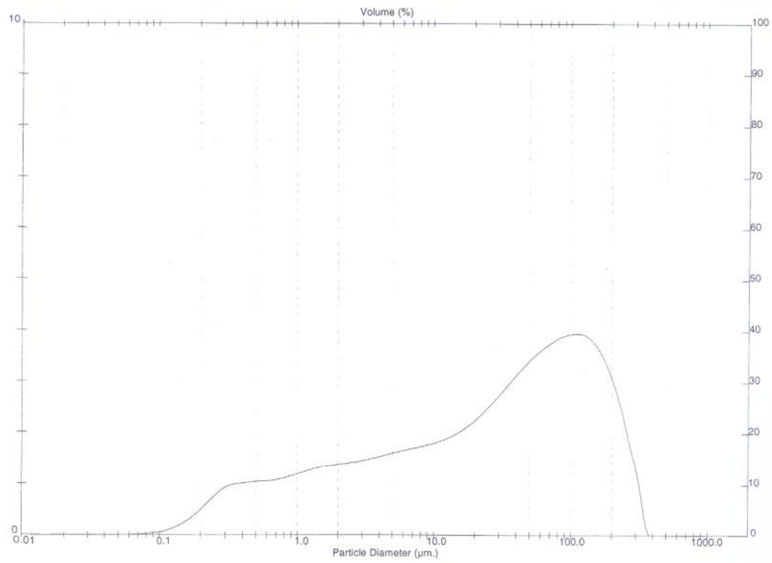
Distribution Type: Volume
Mean Diameters:
D [4, 3] = 61.17 um

Concentration = 0.0174 %Vol
D (v, 0.1) = 0.83 um
D [3, 2] = 2.44 um

Density = 2.560 g / cub. cm
D (v, 0.5) = 31.28 um
Span = 5.477E+00

Specific S.A. = 0.9608 sq. m / g
D (v, 0.9) = 172.12 um
Uniformity = 1.691E+00

Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %
0.050	0.00	3.90	7.35	74.00	4.35	300.0	0.84
0.060	0.18	7.80	8.35	88.00	4.53	350.0	0.01
0.120	1.64	15.60	10.59	105.0	4.49	420.0	0.00
0.240	4.44	31.00	3.35	125.0	4.43	500.0	0.00
0.490	2.47	37.00	3.55	149.0	4.07	590.0	0.00
0.700	2.49	44.00	4.09	177.0	3.56	710.0	0.00
0.980	6.07	53.00	4.03	210.0	2.92	840.0	0.00
2.00	6.26	63.00	3.91	250.0	2.04	1000.0	0.00
3.90		74.00		300.0		2000.0	



MALVERN INSTRUMENTS MASTERSIZER

Result: Histogram Report

User Name: Conny | Security Level: 2

Sample Details

Sample ID: E4
Sample File: NOV07
Sample Path: C:\SIZERS\DATA\BRYNA\
Sample Notes:

Run Number: 2
Record Number: 2

Measured: Tue 1 Apr 2008 10:30a.m.
Analysed: Tue 1 Apr 2008 10:30a.m.
Result Source: Analysed

System Details

Range Lens: 300RF mm
Presentation: 3OHD
Analysis Model: Polydisperse
Modifications: None

Beam Length: 2.40 mm
[Particle R.I. = (1.5295, 0.1000); Dispersant R.I. = 1.3300]

Sampler: MS17

Obscuration: 35.8 %
Residual: 0.762 %

Result Statistics

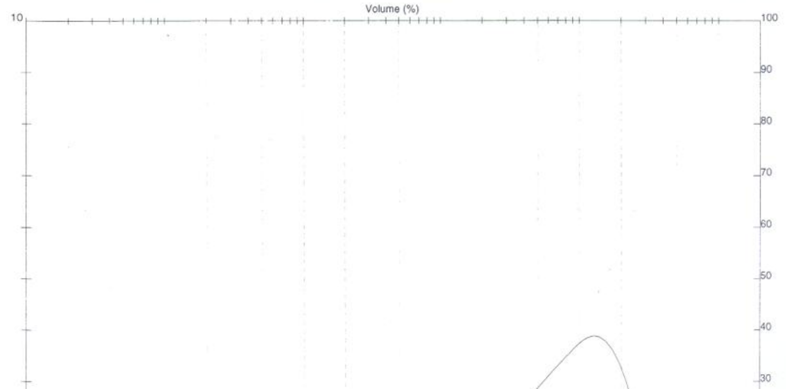
Distribution Type: Volume
Mean Diameters:
D [4, 3] = 62.01 um

Concentration = 0.0266 %Vol
D (v, 0.1) = 0.64 um
D [3, 2] = 2.07 um

Density = 2.560 g / cub. cm
D (v, 0.5) = 26.64 um
Span = 6.739E+00

Specific S.A. = 1.1323 sq. m / g
D (v, 0.9) = 180.20 um
Uniformity = 2.081E+00

Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %
0.050	0.01	3.90	8.12	74.00	3.95	300.0	1.05
0.060	0.24	7.80	8.62	88.00	4.27	350.0	0.18
0.120	2.13	15.60	9.56	105.0	4.38	420.0	0.00
0.240	5.47	31.00	2.81	125.0	4.43	500.0	0.00
0.490	2.78	37.00	2.96	149.0	4.16	590.0	0.00
0.700	2.55	44.00	3.45	177.0	3.73	710.0	0.00
0.980	5.99	53.00	3.46	210.0	3.15	840.0	0.00
2.00	6.80	63.00	3.45	250.0	2.31	1000.0	0.00
3.90		74.00		300.0		2000.0	



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MASTERSIZER

Result: Histogram Report

User Name: Conny Security Level: 2

Sample Details

Sample ID: E6
Sample File: NOV07
Sample Path: C:\SIZERS\DATA\BRYNA\
Sample Notes:

Run Number: 3
Record Number: 3

Measured: Tue 1 Apr 2008 10:34a.m.
Analysed: Tue 1 Apr 2008 10:34a.m.
Result Source: Analysed

System Details

Range Lens: 300RF mm
Presentation: 3OHD
Analysis Model: Polydisperse
Modifications: None

Beam Length: 2.40 mm
[Particle R.I. = (1.5295, 0.1000); Dispersant R.I. = 1.3300]

Sampler: MS17

Obscuration: 28.3 %
Residual: 0.721 %

Result Statistics

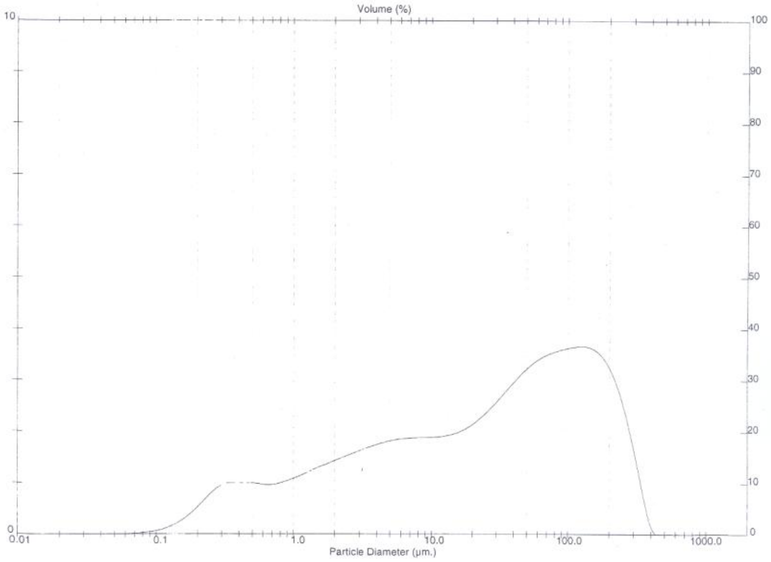
Distribution Type: Volume
Mean Diameters:
D [4, 3] = 63.92 um

Concentration = 0.0219 %Vol
D (v, 0.1) = 0.86 um
D [3, 2] = 2.40 um

Density = 2.560 g / cub. cm
D (v, 0.5) = 29.87 um
Span = 6.165E+00

Specific S.A. = 0.9757 sq. m / g
D (v, 0.9) = 185.01 um
Uniformity = 1.881E+00

Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %
0.050	0.00	3.90	8.26	74.00	4.02	300.0	1.20
0.060	0.20	7.80	8.61	88.00	4.17	350.0	0.36
0.120	1.77	15 60	10.06	105.0	4.16	420.0	0.00
0.240	4.46	31.00	3.16	125.0	4.19	500.0	0.00
0.490	2.27	37.00	3.35	149.0	4.00	590.0	0.00
0.700	2.22	44.00	3.87	177.0	3.70	710.0	0.00
0.980	5.85	53.00	3.79	210.0	3.24	840.0	0.00
2.00	6.92	63.00	3.66	250.0	2.50	1000.0	0.00
3.90		74.00		300.0		2000.0	



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Serial Number: 32913-57

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MASTERSIZER

Result: Histogram Report

User Name: Conny | Security Level: 2

Sample Details

Sample ID: F3
Sample File: NOV07
Sample Path: C:\SIZERS\DATA\BRYNA\
Sample Notes:

Run Number: 19
Record Number: 18

Measured: Tue 1 Apr 2008 11:23a.m.
Analysed: Tue 1 Apr 2008 11:23a.m.
Result Source: Analysed

System Details

Range Lens: 300RF mm
Presentation: 3OHD
Analysis Model: Polydisperse
Modifications: None

Beam Length: 2.40 mm
[Particle R.I. = (1.5295, 0.1000); Dispersant R.I. = 1.3300]

Sampler: MS17

Obscuration: 29.4 %
Residual: 0.777 %

Result Statistics

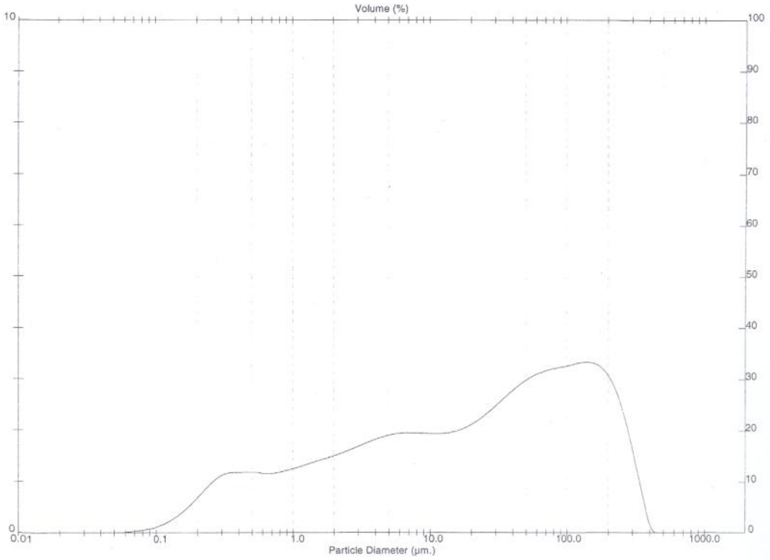
Distribution Type: Volume
Mean Diameters:
D [4, 3] = 60.49 um

Concentration = 0.0204 %Vol
D (v, 0.1) = 0.65 um
D [3, 2] = 1.98 um

Density = 2.560 g / cub. cm
D (v, 0.5) = 23.78 um
Span = 7.662E+00

Specific S.A. = 1.1829 sq. m / g
D (v, 0.9) = 182.85 um
Uniformity = 2.294E+00

Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %
0.050	0.01	3.90	8.64	74.00	3.63	300.0	1.21
0.060	0.35	7.80	8.81	88.00	3.74	350.0	0.39
0.120	2.31	15.60	9.89	105.0	3.75	420.0	0.00
0.240	5.23	31.00	3.01	125.0	3.82	500.0	0.00
0.490	2.71	37.00	3.15	149.0	3.71	590.0	0.00
0.700	2.61	44.00	3.58	177.0	3.49	710.0	0.00
0.980	6.37	53.00	3.47	210.0	3.12	840.0	0.00
2.00	7.18	63.00	3.31	250.0	2.46	1000.0	0.00
3.90		74.00		300.0		2000.0	



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Result: Histogram Report

User Name: Conny | Security Level: 2

Sample Details

Sample ID: G2
Sample File: NOV07
Sample Path: C:\SIZERS\DATA\BRYNA\
Sample Notes:

Run Number: 4
Record Number: 4

Measured: Tue 1 Apr 2008 10:37a.m.
Analysed: Tue 1 Apr 2008 10:37a.m.
Result Source: Analysed

System Details

Range Lens: 300RF mm
Presentation: 3OHD
Analysis Model: Polydisperse
Modifications: None

Beam Length: 2.40 mm
[Particle R.I. = (1.5295, 0.1000); Dispersant R.I. = 1.3300]

Sampler: MS17

Obscuration: 27.3 %
Residual: 0.768 %

Result Statistics

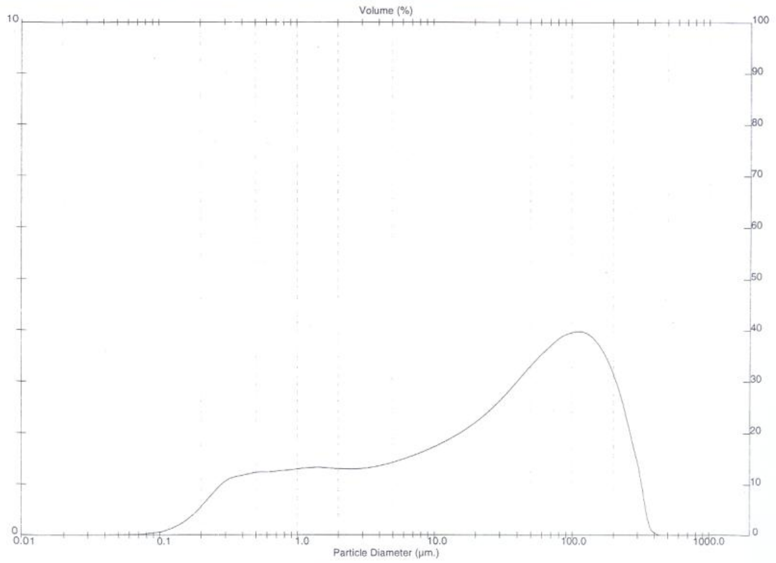
Distribution Type: Volume
Mean Diameters:
D [4, 3] = 62.62 um

Concentration = 0.0198 %Vol
D (v, 0.1) = 0.70 um
D [3, 2] = 2.23 um

Density = 2.560 g / cub. cm
D (v, 0.5) = 31.55 um
Span = 5.575E+00

Specific S.A. = 1.0506 sq. m / g
D (v, 0.9) = 176.62 um
Uniformity = 1.727E+00

Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %
0.050	0.00	3.90	6.63	74.00	4.35	300.0	0.97
0.060	0.19	7.80	8.10	88.00	4.55	350.0	0.12
0.120	1.83	15.60	10.34	105.0	4.52	420.0	0.00
0.240	5.09	31.00	3.21	125.0	4.46	500.0	0.00
0.490	2.89	37.00	3.41	149.0	4.11	590.0	0.00
0.700	2.79	44.00	3.96	177.0	3.63	710.0	0.00
0.980	6.13	53.00	3.93	210.0	3.03	840.0	0.00
2.00	5.71	63.00	3.86	250.0	2.20	1000.0	0.00
3.90		74.00		300.0		2000.0	



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Mastersizer S long bed Ver. 2.19
Serial Number: 32913-57

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MASTERSIZER

Result: Histogram Report

User Name: Conny | Security Level: 2

Sample Details

Sample ID: G6
Sample File: NOV07
Sample Path: C:\SIZERS\DATA\BRYNA\
Sample Notes:

Run Number: 15
Record Number: 14

Measured: Tue 1 Apr 2008 11:11a.m.
Analysed: Tue 1 Apr 2008 11:11a.m.
Result Source: Analysed

System Details

Range Lens: 300RF mm
Presentation: 3OHD
Analysis Model: Polydisperse
Modifications: None

Beam Length: 2.40 mm
[Particle R.I. = (1.5295, 0.1000); Dispersant R.I. = 1.3300]

Sampler: MS17

Obscuration: 34.6 %
Residual: 0.835 %

Result Statistics

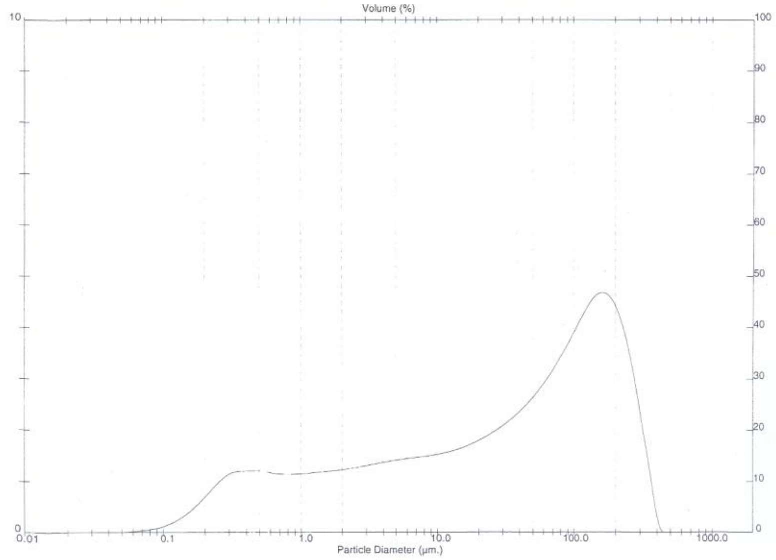
Distribution Type: Volume
Mean Diameters:
D [4, 3] = 77.50 um

Concentration = 0.0272 %Vol
D (v, 0.1) = 0.63 um
D [3, 2] = 2.04 um

Density = 2.560 g / cub. cm
D (v, 0.5) = 40.58 um
Span = 5.257E+00

Specific S.A. = 1.1467 sq. m / g
D (v, 0.9) = 213.93 um
Uniformity = 1.676E+00

Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %
0.050	0.01	3.90	6.42	74.00	3.90	300.0	1.80
0.060	0.35	7.80	7.01	88.00	4.40	350.0	0.69
0.120	2.33	15.60	8.34	105.0	4.79	420.0	0.00
0.240	5.33	31.00	2.53	125.0	5.22	500.0	0.00
0.490	2.72	37.00	2.67	149.0	5.26	590.0	0.00
0.700	2.49	44.00	3.14	177.0	5.02	710.0	0.00
0.980	5.48	53.00	3.21	210.0	4.49	840.0	0.00
2.00	5.59	63.00	3.28	250.0	3.54	1000.0	0.00
3.90		74.00		300.0		2000.0	



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MASTERSIZER

Result: Histogram Report

User Name: Conny | Security Level: 2

Sample Details

Sample ID: H1
Sample File: NOV07
Sample Path: C:\SIZERS\DATA\BRYNA\
Sample Notes:

Run Number: 16
Record Number: 15

Measured: Tue 1 Apr 2008 11:13a.m.
Analysed: Tue 1 Apr 2008 11:14a.m.
Result Source: Analysed

System Details

Range Lens: 300RF mm
Presentation: 3OHD
Analysis Model: Polydisperse
Modifications: None

Beam Length: 2.40 mm
[Particle R.I. = (1.5295, 0.1000); Dispersant R.I. = 1.3300]

Sampler: MS17

Obscuration: 26.5 %
Residual: 0.791 %

Result Statistics

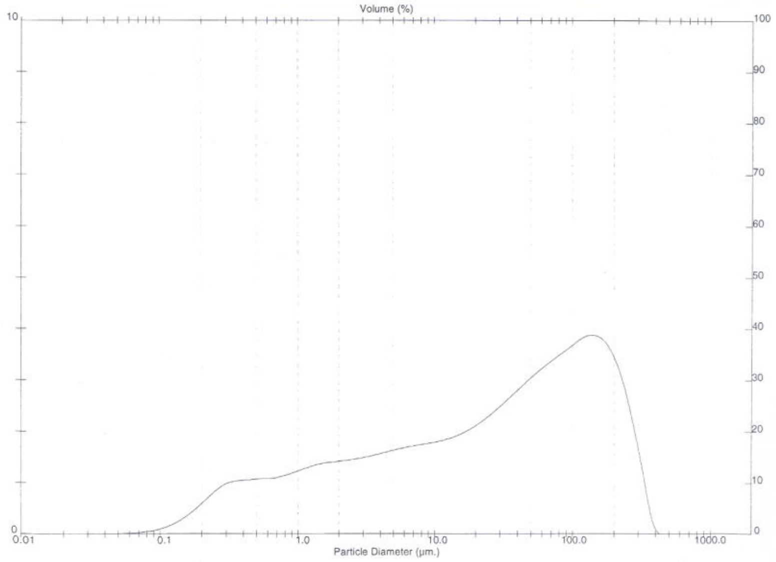
Distribution Type: Volume
Mean Diameters:
D [4, 3] = 65.28 um

Concentration = 0.0195 %Vol
D (v, 0.1) = 0.75 um
D [3, 2] = 2.20 um

Density = 2.560 g / cub. cm
D (v, 0.5) = 30.35 um
Span = 6.177E+00

Specific S.A. = 1.0663 sq. m / g
D (v, 0.9) = 188.23 um
Uniformity = 1.899E+00

Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %
0.050	0.01	3.90	7.50	74.00	3.95	300.0	1.21
0.060	0.30	7.80	8.26	88.00	4.20	350.0	0.29
0.120	2.01	15.60	9.89	105.0	4.32	420.0	0.00
0.240	4.64	31.00	3.02	125.0	4.45	500.0	0.00
0.490	2.51	37.00	3.18	149.0	4.29	590.0	0.00
0.700	2.54	44.00	3.65	177.0	3.95	710.0	0.00
0.980	6.25	53.00	3.60	210.0	3.42	840.0	0.00
2.00	6.44	63.00	3.52	250.0	2.59	1000.0	0.00
3.90		74.00		300.0		2000.0	



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Mastersizer S long bed Ver. 2.19
Serial Number: 32913-57

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MASTERSIZER

Result: Histogram Report

User Name: Conny | Security Level: 2

Sample Details

Sample ID: H7
Sample File: NOV07
Sample Path: C:\SIZERS\DATA\BRYNA\
Sample Notes:

Run Number: 8
Record Number: 7

Measured: Tue 1 Apr 2008 10:49a.m.
Analysed: Tue 1 Apr 2008 10:49a.m.
Result Source: Analysed

System Details

Range Lens: 300RF mm
Presentation: 3OHD
Analysis Model: Polydisperse
Modifications: None

Beam Length: 2.40 mm
[Particle R.I. = (1.5295, 0.1000); Dispersant R.I. = 1.3300]

Sampler: MS17

Obscuration: 26.7 %
Residual: 0.746 %

Result Statistics

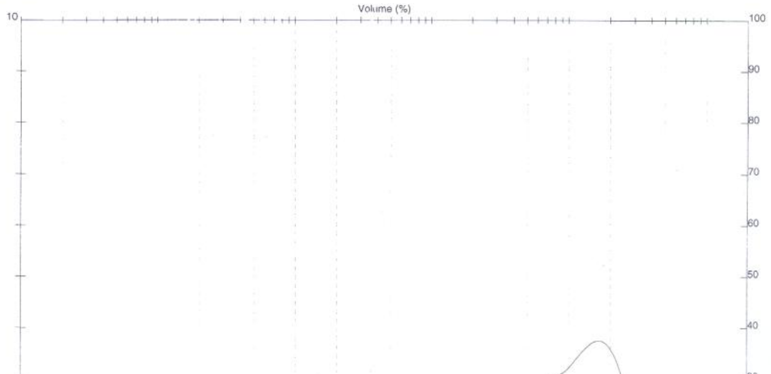
Distribution Type: Volume
Mean Diameters:
D [4, 3] = 66.00 um

Concentration = 0.0194 %Vol
D (v, 0.1) = 0.78 um
D [3, 2] = 2.19 um

Density = 2.560 g / cub. cm
D (v, 0.5) = 25.38 um
Span = 7.769E+00

Specific S.A. = 1.0688 sq. m / g
D (v, 0.9) = 198.00 um
Uniformity = 2.348E+00

Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %
0.050	0.01	3.90	9.28	74.00	3.44	300.0	1.48
0.060	0.31	7.80	9.08	88.00	3.67	350.0	0.55
0.120	2.04	15.60	9.35	105.0	3.89	420.0	0.00
0.240	4.58	31.00	2.74	125.0	4.17	500.0	0.00
0.490	2.37	37.00	2.84	149.0	4.21	590.0	0.00
0.700	2.33	44.00	3.23	177.0	4.06	710.0	0.00
0.980	6.08	53.00	3.15	210.0	3.68	840.0	0.00
2.00	7.48	63.00	3.06	250.0	2.93	1000.0	0.00
3.90		74.00		300.0		2000.0	



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MALVERN INSTRUMENTS MASTERSIZER

Result: Histogram Report

User Name: Conny

Security Level: 2

Sample Details

Sample ID: I0
Sample File: NOV07
Sample Path: C:\SIZERS\DATA\BRYNA\
Sample Notes:

Run Number: 11
Record Number: 10

Measured: Tue 1 Apr 2008 10:58a.m.
Analysed: Tue 1 Apr 2008 10:58a.m.
Result Source: Analysed

System Details

Range Lens: 300RF mm
Presentation: 3OHD
Analysis Model: Polydisperse
Modifications: None

Beam Length: 2.40 mm
[Particle R.I. = (1.5295, 0.1000); Dispersant R.I. = 1.3300]

Sampler: MS17

Obscuration: 32.1 %
Residual: 0.745 %

Result Statistics

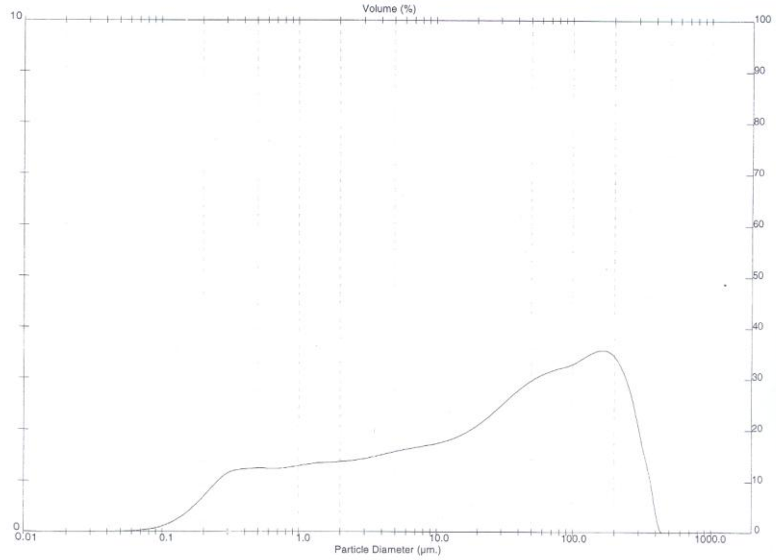
Distribution Type: Volume
Mean Diameters:
D [4, 3] = 67.11 um

Concentration = 0.0228 %Vol
D (v, 0.1) = 0.61 um
D [3, 2] = 1.95 um

Density = 2.560 g / cub. cm
D (v, 0.5) = 28.35 um
Span = 7.053E+00

Specific S.A. = 1.2030 sq. m / g
D (v, 0.9) = 200.55 um
Uniformity = 2.123E+00

Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %
0.050	0.01	3.90	7.24	74.00	3.63	300.0	1.61
0.060	0.35	7.80	8.02	88.00	3.76	350.0	0.76
0.120	2.36	15.60	9.78	105.0	3.84	420.0	0.00
0.240	5.46	31.00	3.00	125.0	4.01	500.0	0.00
0.490	2.91	37.00	3.14	149.0	4.00	590.0	0.00
0.700	2.78	44.00	3.56	177.0	3.89	710.0	0.00
0.980	6.28	53.00	3.45	210.0	3.61	840.0	0.00
2.00	6.25	63.00	3.30	250.0	2.99	1000.0	0.00
3.90		74.00		300.0		2000.0	



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Mastersizer S long bed Ver. 2.19
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MALVERN INSTRUMENTS MASTERSIZER

Result: Histogram Report

User Name: Conny | Security Level: 2

Sample Details

Sample ID: I8
Sample File: NOV07
Sample Path: C:\SIZERS\DATA\BRYNA\
Sample Notes:

Run Number: 13
Record Number: 12

Measured: Tue 1 Apr 2008 11:04a.m.
Analysed: Tue 1 Apr 2008 11:04a.m.
Result Source: Analysed

System Details

Range Lens: 300RF mm
Presentation: 3OHD
Analysis Model: Polydisperse
Modifications: None

Beam Length: 2.40 mm
[Particle R.I. = (1.5295, 0.1000); Dispersant R.I. = 1.3300]

Sampler: MS17

Obscuration: 31.4 %
Residual: 0.743 %

Result Statistics

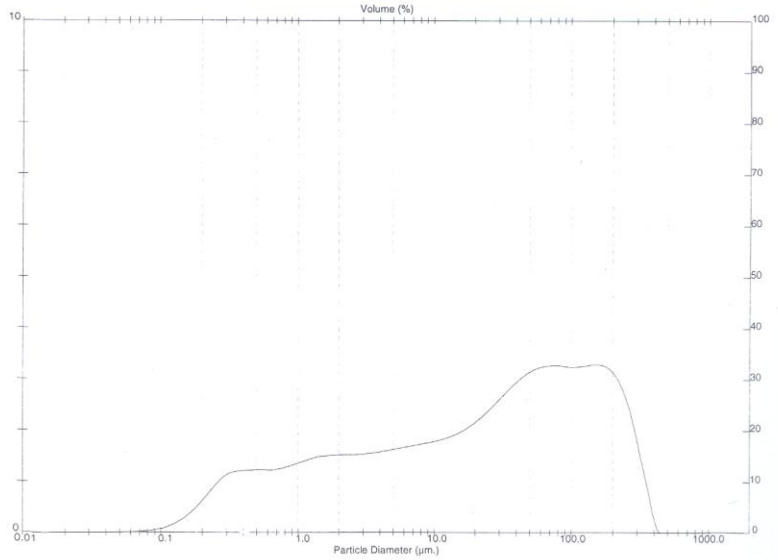
Distribution Type: Volume
Mean Diameters:
D [4, 3] = 62.77 um

Concentration = 0.0220 %Vol
D (v, 0.1) = 0.66 um
D [3, 2] = 2.07 um

Density = 2.560 g / cub. cm
D (v, 0.5) = 26.40 um
Span = 7.136E+00

Specific S.A. = 1.1321 sq. m / g
D (v, 0.9) = 189.07 um
Uniformity = 2.131E+00

Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %	Size (um)	Volume In %
0.050	0.01	3.90	7.45	74.00	3.70	300.0	1.37
0.060	0.23	7.80	8.24	88.00	3.74	350.0	0.56
0.120	2.06	15.60	10.16	105.0	3.69	420.0	0.00
0.240	5.33	31.00	3.18	125.0	3.76	500.0	0.00
0.490	2.87	37.00	3.34	149.0	3.69	590.0	0.00
0.700	2.83	44.00	3.79	177.0	3.55	710.0	0.00
0.980	6.81	53.00	3.64	210.0	3.26	840.0	0.00
2.00	6.69	63.00	3.43	250.0	2.65	1000.0	0.00
3.90		74.00		300.0		2000.0	



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Mastersizer S long bed Ver. 2.19
Serial Number: 32913-57

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