Proposal for

DREDGED SEDIMENT DISPOSAL ON THE CONTINENTAL SHELF in THE EEZ:

ENVIRONMENTAL IMPACT ASSESSMENT

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Te Whare Wānanga o Waikato

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1 EXECUTIVE SUMMARY

1.1

Auckland area ports and marinas typically dredge 10,000 to 50,000 m^3 of sediment annually in order to maintain access for vessels to channels and berths. Currently, there is no clear option for disposal of these dredged sediments in the Auckland area.

1.2

Several disposal grounds were previously used in the Hauraki Gulf in the 1980s (near Rangitoto Island) and in 1992 (Noises disposal site). These disposal sites are no longer operational.

1.3

The Hauraki Gulf Marine Park was established in 2000 in order to protect and manage the recreational, economic, cultural, and environmental amenities of the Gulf. As the governing bodies of the Park, regional council policies and plans uphold the Hauraki Gulf Marine Park Act. In particular, the Auckland Regional policy statement generally discourages the disposal of dredged material in the Hauraki Gulf, a result of the failure of the previous disposal sites within the Gulf. The policy statement suggests that the recommendations of the Disposal Options Advisory Group (DOAG) be considered with all future proposals for disposal within the Gulf. DOAG recommended, based on prior disposal operations within the Gulf that future disposal sites should be established north of Cuvier Island in more than 100 m of water. Future disposal in the Hauraki Gulf is no longer an appropriate option for Auckland ports and marinas.

1.4

Current use of the Explosives Dumping Ground (in 500-1300 m of water) does not follow the policies put forth by the London Dumping Convention and the 1996 Protocol. Use of this site for disposal operations should, therefore, be re-evaluated.

1.5

The need to establish a new disposal site has been recognised that will be a long term disposal option for the ports and marinas of the Auckland and Coromandel area. A proposed site on the continental shelf in the Exclusive Economic Zone at 175°47'.00E and 36°13'.00S has been identified as such a potential option. Initial assessments of the site features indicate that it will be suitable for disposal operations. An in depth survey of the site including numerical simulations of hydrodynamics and sediment transport is currently being undertaken in order confirm suitability.

1.6

Background information taken from previous studies done in the north-east shelf and coast region provides rationale behind the selection of the proposed site for further investigation regarding its suitability for disposal operations. Previous studies show that the sediment that will eventually be dredged from ports and marinas in the Auckland region have low heavy metal concentrations and are texturally similar to the sediment occurring naturally at the proposed site. Properties of the proposed site including bottom topography, water properties, and hydrodynamics indicate that adverse environmental effects resulting from disposal operations will be minimal.

1.7

Mobility of the dredged sediment is discussed by detailing expected features of the sediment descent, potential advection, possible re-entrainment, and consolidation mechanics. There is potential for a small amount of dredged material to be lost during descent to the seafloor. Very occasionally horizontal currents and wave action may entrain sediment from the seafloor, but previous studies show that the seafloor environment is characterised as having a relatively low hydrodynamic energy based on the presence of a fine layer of silt over boulders observed in the region, and the extensive flat homogeneous muddy bottom topography.

1.8

Potential environmental impacts of disposal operations at the site are overviewed and include impacts affecting water quality, spoil mound movement, benthic fauna, fin fish and mammals. Previous studies indicate that turbid waters resulting from disposal operations will only be transient and will not cause any long term adverse effects. Water depths (135 -140 m) at the proposed site indicate that there will be little, if any, movement of the spoil mound material away from its deposited position. Additionally, previous studies show that when disposed material is texturally similar to that found at the disposal site, re-establishment of benthic faunal communities start to occur within a few months of the disposal event. However, it is important to note that the benthic communities occurring naturally at the proposed site are neither, abundant or diverse.

1.9

A monitoring plan for before, during, and after disposal operations take place is presented as a recommendation to the proposed site managers. An initial monitoring plan is recommended to be used for the first 3 years after disposal operations commence. This plan includes a side scan survey to identify the location of the deposited material, a multibeam survey to ascertain bottom topography and topography of the deposited material, benthic fauna characterisation to assess impacts, sediment textural and chemical analysis, and drop camera video to obtain images of the seafloor. After the initial time frame of three years, provided no adverse effects are observed, the monitoring plan should be revised in light of the monitoring results obtained from the first three years.

2 BACKGROUND

2.1 Historical disposal options

2.1.1 Auckland area ports and marinas

Disposal of contaminated and/or muddy dredged sediments is a problem in the Auckland coastal marine area which has significant economic impacts. Auckland area ports and marinas typically accumulate 10,000 to 50,000 m^3 of in-filling deposited sediment per year that must be dredged in order to maintain navigation access for vessels (Parliamentary Commissioner for the Environment, 1995 and Pine Harbour Marina permit submission). If future capital works dredging projects are included, these volumes could be easily doubled.

2.1.2 Previous dredging 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 conclusions on the impact they were having 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 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 Site

A site within the boundaries of the Hauraki Gulf was used for disposal of dredged sediment by the Ports of Auckland until 1992. This site was in 32 m water depth and was located centrally between Tiritiri Matangi Island and Waiheke Island in the Inner Hauraki Gulf. Consent was granted for disposal of 270,000 m^3 of dredged sediment at the site. Post-disposal monitoring identified a higher than expected level 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. Controversy over these findings resulted in Ports of Auckland withdrawing permit applications for further disposal operations. Consequently, the Noises disposal site was used only once.

2.1.4 Hauraki Gulf Marine Park

The Auckland Regional Policy Statement 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). 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 of 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…*"

Part 1 of the Hauraki Gulf Marine Park Act recognises the national significance of the Hauraki Gulf by stating, "*The interrelationship between the Hauraki Gulf, its islands, and catchments and the ability of that interrelationship to sustain the life-supporting capacity of the environment of the Hauraki Gulf and its islands are matters of national significance*."

Part 1 of the act also cites the objectives of management of this park to be "*the protection and, where appropriate, the enhancement of the life-supporting capacity of the environment of the Hauraki Gulf, its islands and catchments*" and also, "*the protection and, where appropriate, the enhancement of natural, historic, and physical resources of the Hauraki Gulf, its islands, and catchments*". The act also cites a management objective to be "*the maintenance and, where appropriate, the enhancement of the natural, historic, and physical resources of the Hauraki Gulf, its islands, and catchments, which contribute to the recreation and enjoyment of the Hauraki Gulf for the people and communities of the Hauraki Gulf and New Zealand.*"

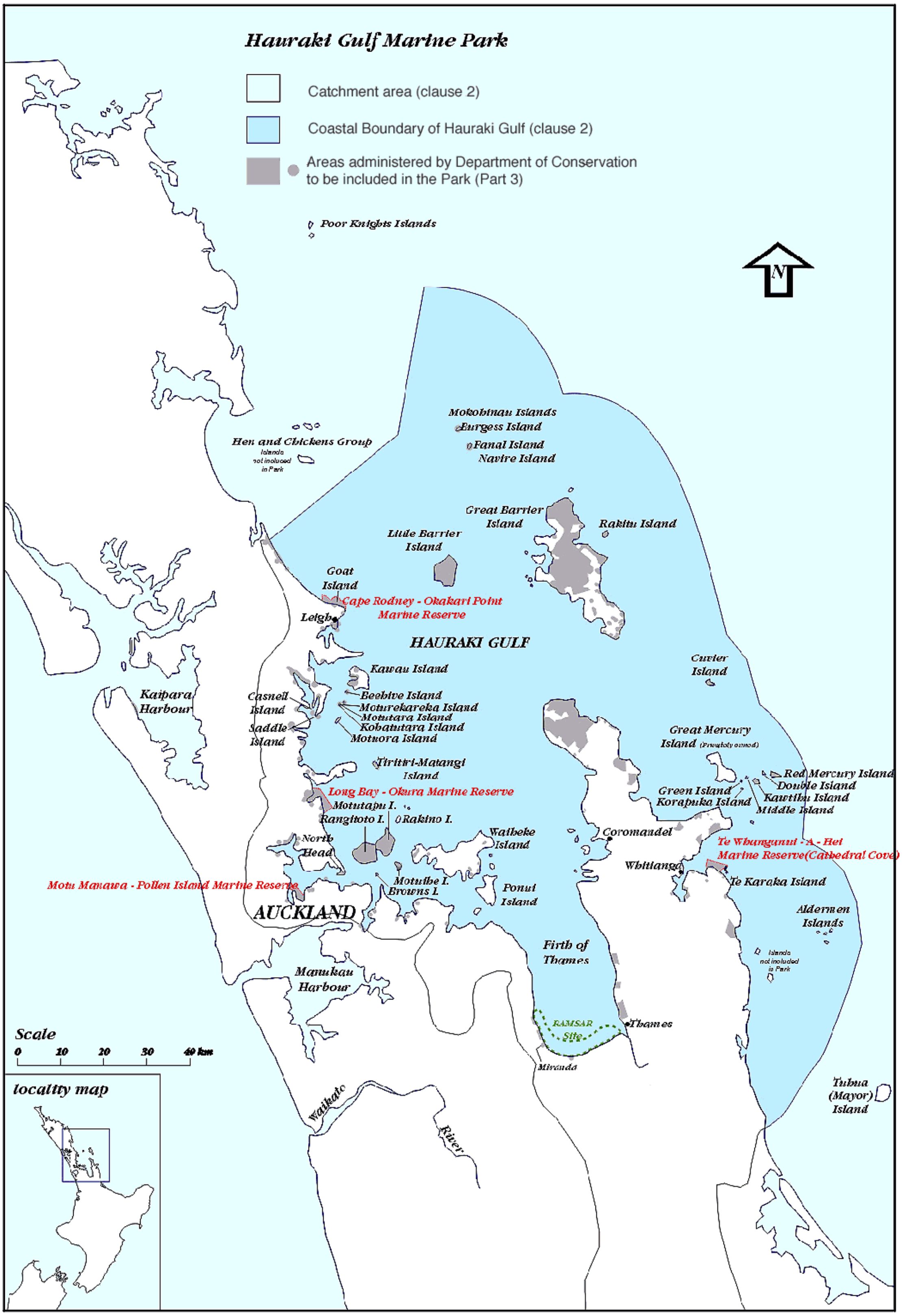


Figure 1. Boundary of the Hauraki Gulf Marine Park (indicated by the dashed black line) established in 2000. (Source: Department of Conservation).

The act requires that the regional council must ensure that any and all parts of the regional policy statement or regional plan related to the Hauraki Gulf, its islands, and catchments, must not conflict with the sections of the act discussed above (Section 7: Recognition of the national significance of the Hauraki Gulf and Section 8: Management of the Hauraki Gulf).

Part 3 of the Hauraki Gulf Marine Park Act details the purposes of the Hauraki Gulf Marine Park. In it, it is stated that its purpose is "*to protect in perpetuity….the natural and historic resources of the park including scenery, ecological systems, or natural features…"* and *"to sustain the life-supporting capacity of the soil, air, water, and ecosystems of the Gulf in the park.*"

Aside from the general statements made in the act, specific policies and management strategies are controlled by the regional councils, particularly the Auckland Regional Council. In section 7.4.22 of the Auckland Regional Policy Statement regarding dredging and the disposal of dredged material in the Auckland Region and the Hauraki Gulf Marine Park, it is stated that "*The disposal of dredged materials or other solid matter to the coastal environment shall be avoided….such disposal is likely to result in the following:*

- *Significant adverse effects on habitats, coastal ecosystems and fisheries;*
- *Significant alteration to natural processes;*
- *Significant adverse effects on amenity values and the natural character of the coastal environment;*
- *Significant adverse effects on the relationship of the Maori and their culture and traditions with their taonga;*

- *Significant adverse effects on the social, cultural and economic wellbeing of the community*."

Section 7.4.22.5 of the Auckland Regional Policy Statement states that "*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 Disposal Options Advisory Group (DOAG) was set up in 1993 to examine and report on the disposal options of dredged materials especially regarding specific disposal operations at the Noises Disposal site by the Ports of Auckland, discussed above. Based on assessment of the options, DOAG concluded that continuing marine disposal should be moved to a site north of Cuvier Island which would be located in waters deeper than 100 m. These studies and others by the Parliamentary Commissioner for the Environment resulted in the discontinuation of disposal operations by the Ports of Auckland at the Noises Disposal site which would now be located in the boundaries of the Hauraki Gulf Marine Park.

Section 7.4.24 of the Auckland Regional Policy Statement further states that even though the recommendations made by DOAG were for the specific disposal operations of Ports of Auckland, "*they should be taken into account in assessing* *proposals to dispose of similar types and amounts of dredged material in the Hauraki Gulf regardless of their source*."

Considering these policies set up by the Auckland Regional Council and the Hauraki Gulf Marine Park Act, an open-water disposal site within the boundaries of the Hauraki Gulf Marine Park is no longer an appropriate disposal option for the ports and marinas of the Auckland area.

2.2 Existing site

2.2.1 Explosives Dumping Ground

Currently, some dredged sediment, especially, that which is muddy, removed from various ports and marinas in the Auckland area is being disposed of at the Explosives Dumping Ground (Figure 2). This site is located on the continental slope, at water depths ranging from 500 to 1300 m, east of Cuvier Island. It is simultaneously used 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.

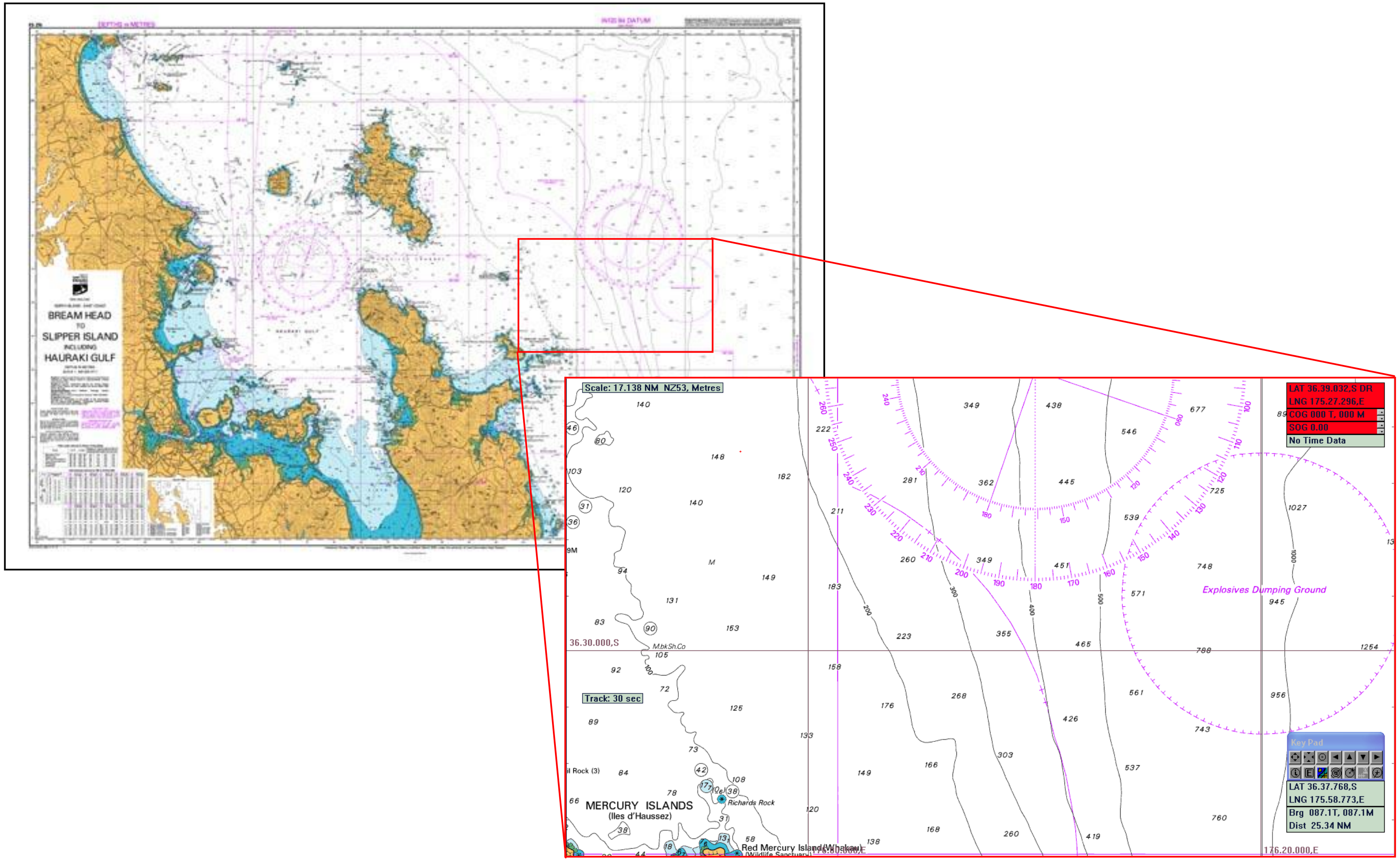


Figure 2. Hydrographic chart of the north-east coastal region of New Zealand (inset: location of the existing dredging disposal ground used simultaneously by the Royal New Zealand Navy as an explosives dumping ground). (Source: Frisken, 1992).

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

- Presence of explosives poses a threat to vessel operators and environmental monitors;
- Disposal sites must be monitored under London dumping convention and 1996 Protocol; and
- The Explosives Dumping Ground is too deep to monitor.

2.3 Alternative disposal options

The Disposal Options Advisory Group (DOAG) produced a series of reports for Ports of Auckland in 1993 and 1994 to summarise, review, and evaluate potential disposal options for the dredged material being taken out of the Ports of Auckland. Besides reviewing marine disposal options, they also addressed harbour edge disposal options and land disposal options.

2.3.1 Harbour edge disposal options

- **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. However, at present Ports of Auckland Ltd. are undertaking reclamation for the Ferguson Terminal using the concept of "mudcrete". This is an example of use of an alternative to disposal at sea.

- **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.

- **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. Additionally, no locations for establishment of an artificial island were identified.

2.3.2 Land based disposal options

- **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).

- **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.

- **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).

- **Solid landfill:** 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.

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

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

2.3.3 Disposal Options Advisory Groups (DOAG) conclusions

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

"For highly contaminated dredged material

- *Port reclamation*
- *Approved sanitary landfill*

For maintenance dredgings that meet regulatory guidelines

- *Port reclamation*
- *Marine disposal in water deeper than 100m.*

For capital works dredgings

- *Port reclamation*
- *Marine disposal in water deeper than 100m"*

As the sediment to be dredged is unlikely to be highly contaminated, most of the dredging works will fall under the categories of maintenance or capital works dredging.

2.4 Need for a new site

Accordingly, there is a need to identify a suitable site for disposal of dredged sediment originating from the Auckland region and those coastal areas within the Hauraki Gulf Marine Park which includes the Coromandel Peninsula (Figure 1).

A proposed site is on the continental shelf, outside the Hauraki Gulf Marine Park boundary some 20 km east of Great Barrier Island in the EEZ (Figure 3; Figure 4). It is considered that this proposed site will be more feasible to monitor than the Explosives Dumping Ground site which is several kilometres further off-shore.

At approximately 135-140 m water depth, the proposed site is shallow enough that monitoring activities can still be undertaken, but deep enough that wind and wave affects on the sea floor will most likely be minimal. This will result in a decreased potential for dispersal and re-entrainment of dredge spoil.

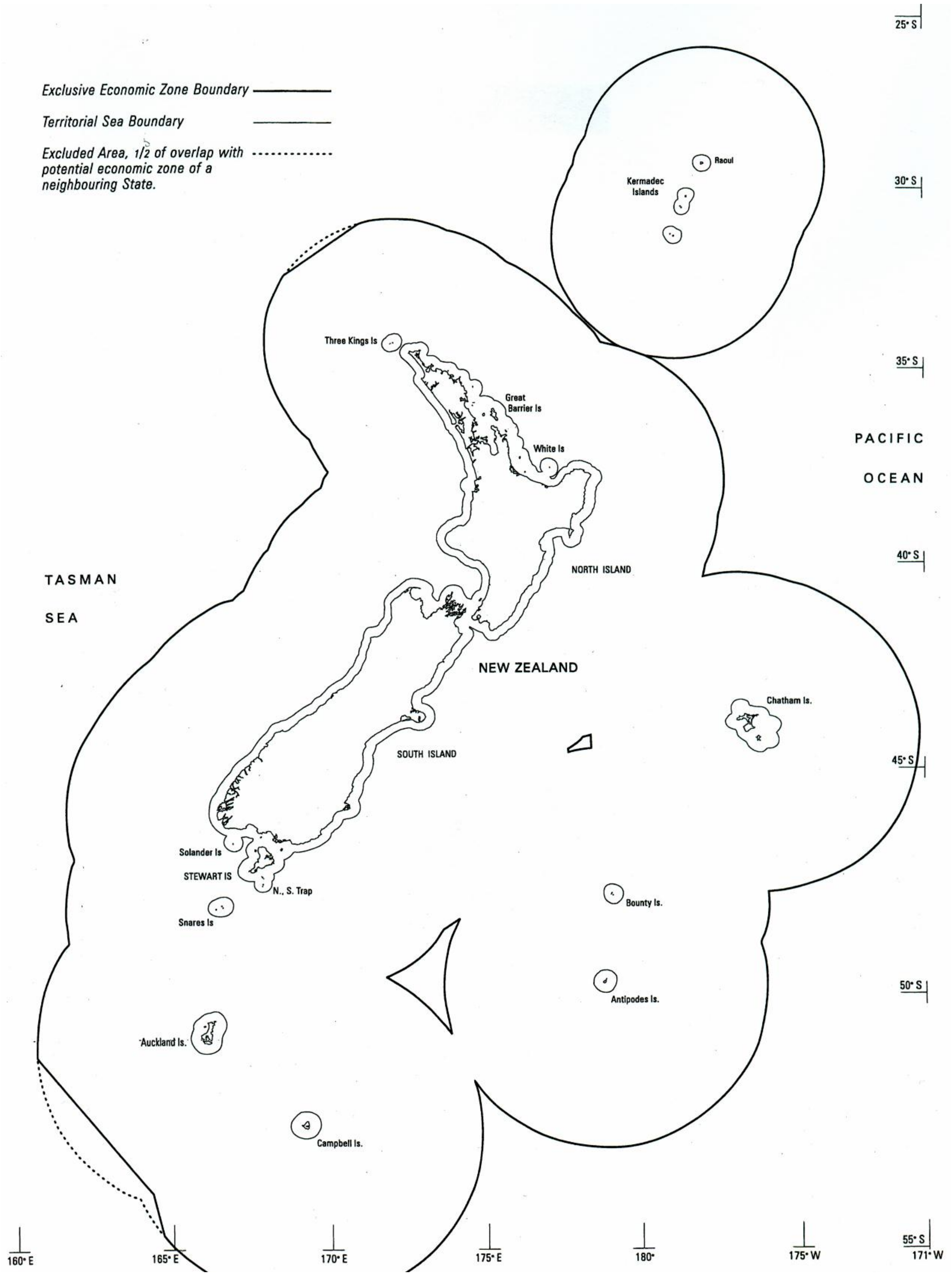


Figure 3. New Zealand Territorial Sea and Exclusive Economic Zone (EEZ).

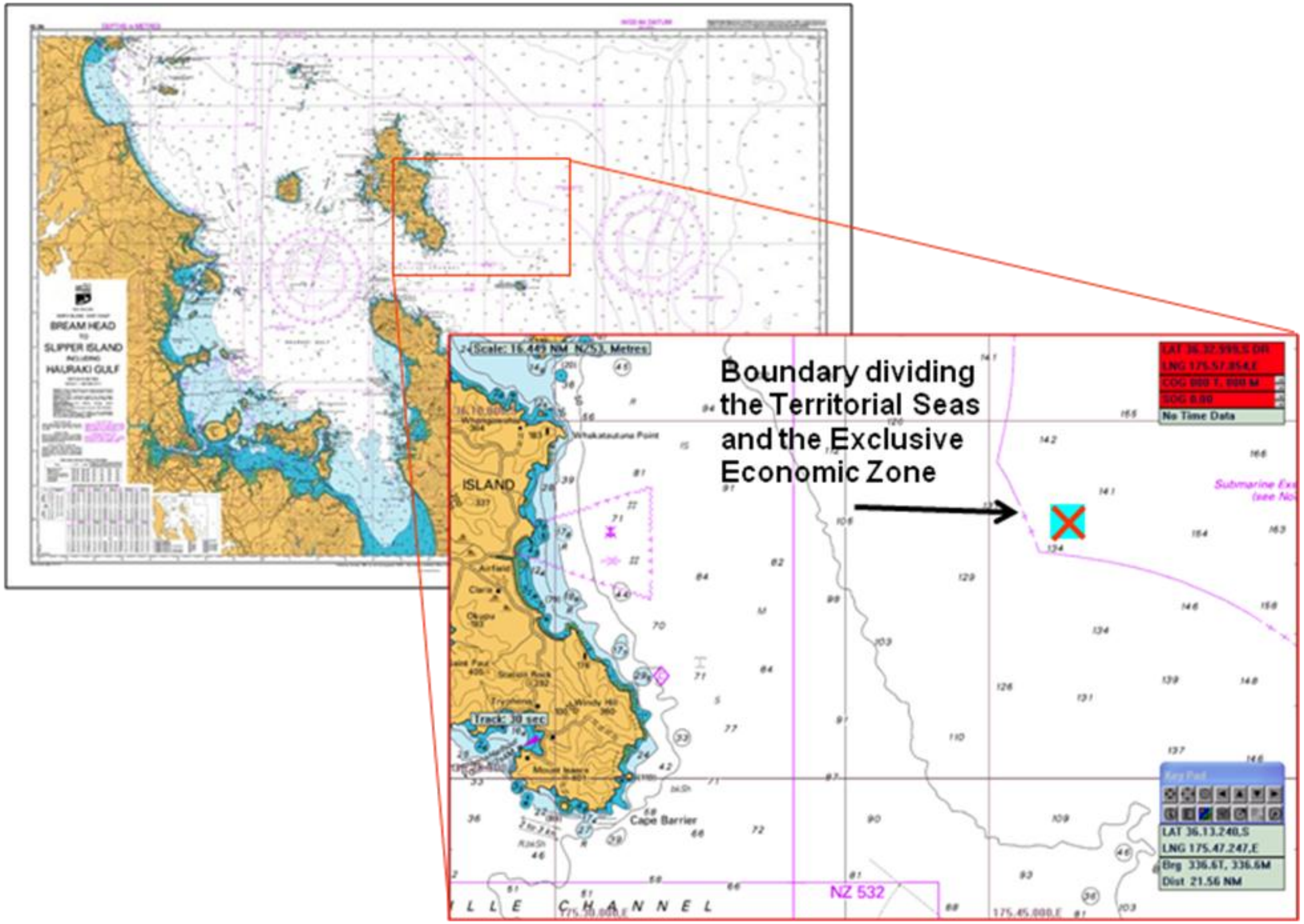


Figure 4. Hydrographic chart of the north-east coastal region of New Zealand (inset: location of the proposed disposal site ~2 km within the EEZ boundary). (Source: Frisken, 1992).

For these reasons, an investigation of the initially proposed site is currently being undertaken in order to identify a suitable option for dredge spoil disposal operations for ports and marinas in the Auckland region (Figure 5). If hydrodynamic and biological features identified at the site indicate that impacts of disposal operations will be minimal, it is expected that this site can also be made available to other interested ports and marinas in the Auckland region.

Figure 5. Possible Auckland area sources for dredged sediment to be disposed at the proposed site. (Source: Google Earth).

2.5 Initially proposed site

The proposed site at 175º 47'.00E and 36º 13'.00S was chosen for the following general features:

- It is located within the EEZ boundary
- It is located outside of the Hauraki Gulf Marine Park (Figure 1)
- It is located beyond the boundaries of the proposed Great Barrier Marine Reserve (Figure 6)
- It is located on the continental shelf (a topographically flat terrace)

- The seafloor sediment is mud to sandy/mud (similar to that which will be dredged from the ports and marinas)
- The water depth will decrease the likelihood of turbulence generated on the seafloor from wind and waves
- There is the capacity to implement an effective monitoring program
- It is accessible to the Auckland and Coromandel areas
- There are no nearby reefs or ecological zones of special significance
- The ecosystem at the site is non-sensitive
- There is no obvious site of cultural significance

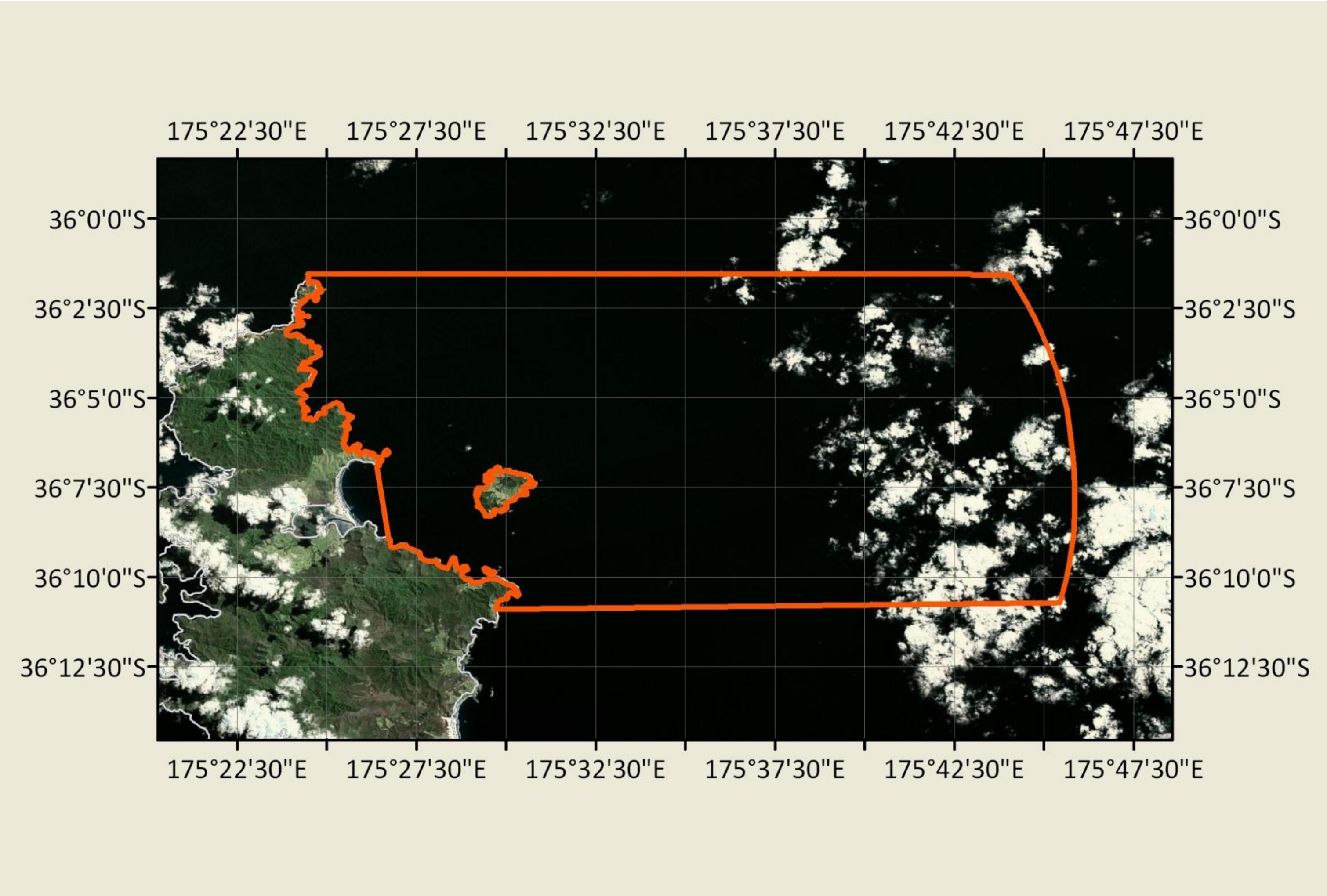


Figure 6. Boundaries of the proposed Great Barrier Marine Reserve. (Source: Department of Conservation).

3 DREDGED MATERIAL CHARACTERISATION

3.1 Origins

Ports and marinas interested in accessing the proposed site for dredged sediment disposal include: Pine Harbour Marina, Ports of Auckland, Westpark Marina, Half Moon Bay, and Clevedon Marina, all of which are located in the Auckland area (Figure 5). Additionally, from the Coromandel region, access to the proposed site may be requested by the marina operators at Whitianga and Whangamata

3.2 Sediment type

In a sediment assessment report by Golder Kingett Mitchell (2007) prepared for Pine Harbour Marina, it was 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 found to be silt (0.004-0.063 mm) with a minimal fine sand component (Golder Kingett Mitchell, 2007), whereas, 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 they areas undergoing the fastest infilling at Pine Harbour Marina and are, therefore, the areas that are most likely to be targeted for maintenance dredging.

Similar 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 marine 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 suspension and winnowing by vessels in the fairway (Loomb, 2001).

3.3 Chemical characteristics

It is likely that the dredged sediments will be partially contaminated. It is expected that there may be some concentrations of heavy metals as well as other undesirable contaminants in these sediments as a result of storm water outfalls. The extent of the contamination of the sediments to be disposed of will need to be determined from the toxicity testing records undertaken on a regular basis at these ports and marinas. The slight level of contamination in these sediments is one reason why on-land disposal of dredgings is not a viable option.

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 dominant sediment texture present in each area referred to in the previous section (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. As the sediments in the entrance of Pine Harbour marina are finer than those of those of the approach channel, it is appropriate that heavy metal concentrations are higher in the entrance.

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 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 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., similar 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 2.

Table 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 those inside the marina. The approach channel is the area of Pine Harbour Marina subject 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.

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 Williamson and Wilcock (1994), Long *et al*., (1995), and Smith *et al*., (1996). All three guidelines have a threshold level, or a biological effects level low (ER-L) where effects on the marine environment are minimal, and also 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 2.

Table 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.

According to the previously discussed studies on the chemical characteristics of the sediments to be dredged in Pine Harbour Marina and Westpark Marina, adverse effects from the presence of heavy metals in the dredged materials will be minimal when these sediments are disposed at a proposed disposal site on the continental shelf east of Great Barrier Island.

3.4 Biological characteristics

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 the majority of these individuals will be destroyed in the dredging, transport, and disposal operations.

As a result of the presence of these and other benthos, such as benthic diatoms and bacterium, it is expected that there will be a significant amount of colloidal proteins occurring as a superficial coating and as a matrix throughout the dredged sediments. Depending upon the dredging method used, these colloidal proteins may 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 at the proposed disposal site. Typically, cohesive sediments are made of flocs which move as a “lump” rather than separately, as non-cohesive sandy sediments do. This will be beneficial in the disposal process because less sediment will be available for dispersion and advection in the water column during the descent of the sediment load.

3.5 Quantities

Dredged sediment to be disposed 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.

4 SITE DESCRIPTION

4.1 Location

The proposed site is located approximately 25 km east of Great Barrier Island directly north of Cuvier Island (Figure 4) outside the territorial seas located in the EEZ at 175º 47’.00E and 36º 13’.00S.

4.2 Geology and geomorphology

4.2.1 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 Kermadec Ridge, respectively (Figure 7). The Kermadec Ridge is adjacent to the Kermadec trench. At 9000 m, this bottom feature is thought to be one of the deepest parts of the world’s oceans (Harris, 1985).

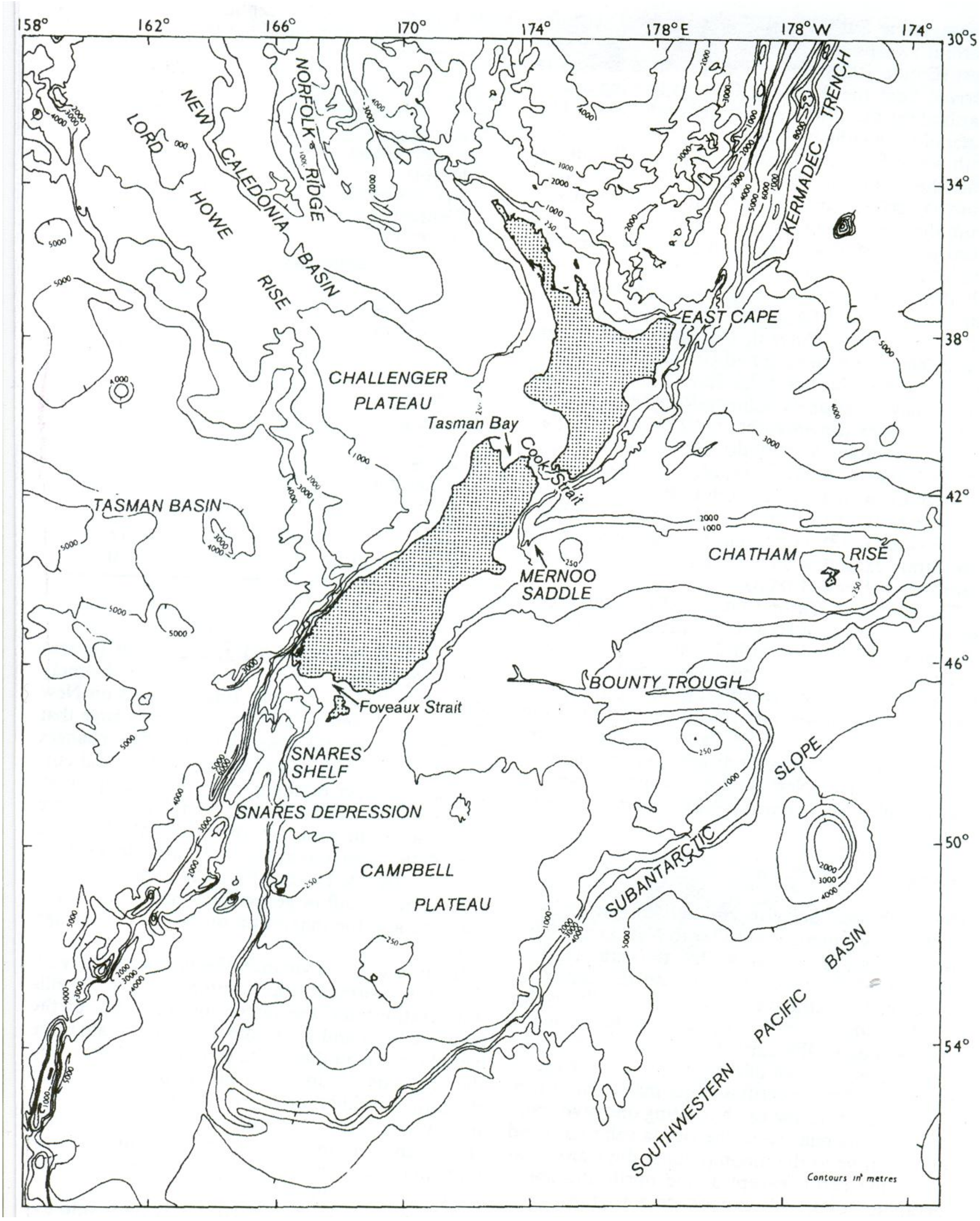


Figure 7. Bottom topographic features surrounding New Zealand. (Source: Heath, 1985).

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 7). 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.

4.2.2 Bottom topography at the 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 50 km off shore can be seen in Figure 8. The black 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 8 (Figure 9).

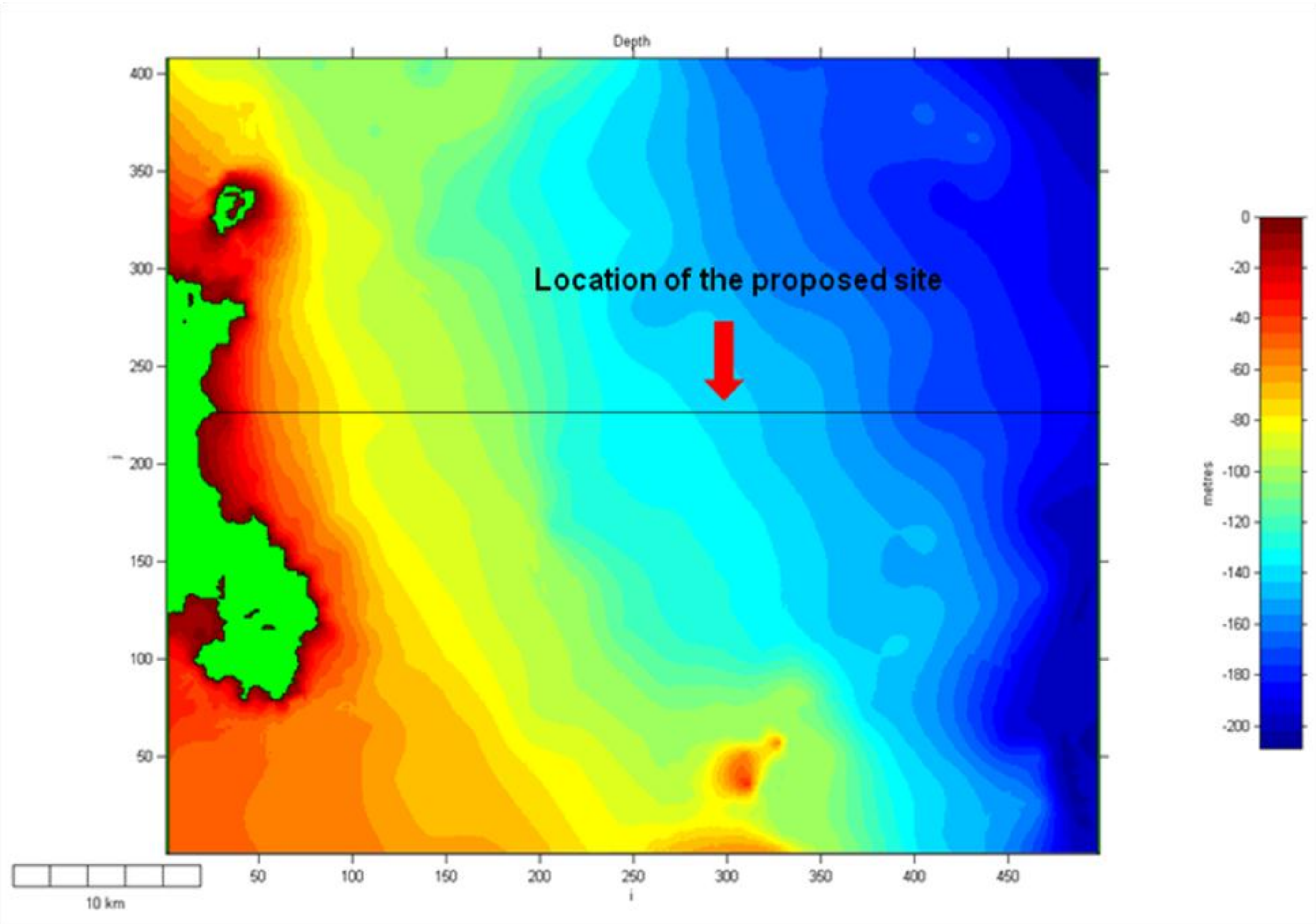


Figure 8. Bathymetry of the regions surrounding the proposed disposal site from the eastern side of Great Barrier Island to ~50 km off-shore. The black line included represents a transect of the continental shelf profile which is plotted in Figure 5.

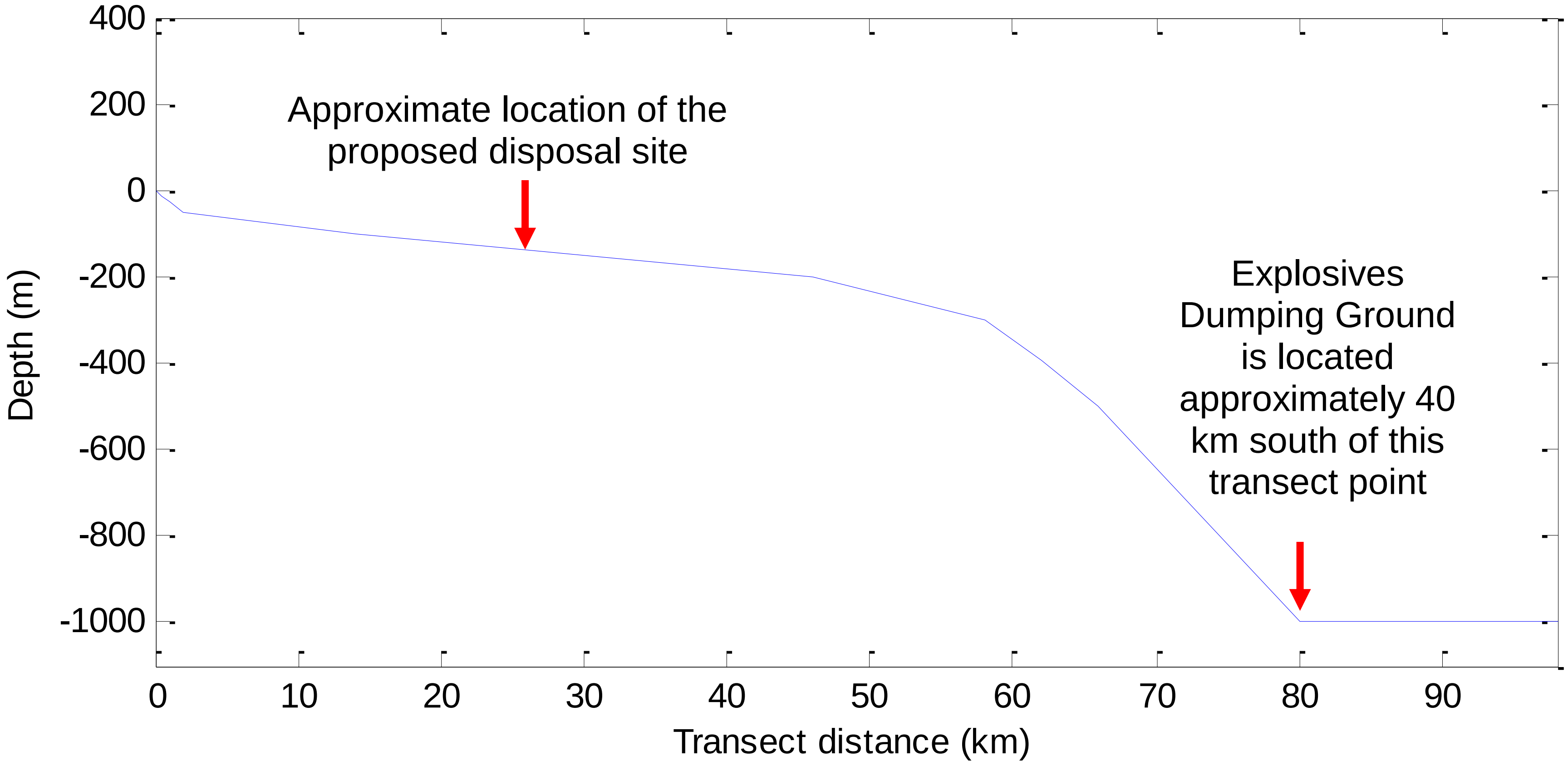


Figure 9. Profile of the continental shelf extending from the east coast of Great Barrier Island past the shelf break (vertical exaggeration= 50)

Initial site inspection on 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.

4.2.3 Sediment type at the proposed site

As recorded by The New Zealand Oceanographic Institute, the sediments mapped at the mid-shelf depths in the area of the proposed site are typically muddy/sand to sandy/mud (Carter, 1980) (Figure 10). Preliminary sampling, in November, 2007, at the proposed site, confirmed the reported sediment types. Observations of samples (without accurate textural analysis) indicate that the sediment at the site is muddy/sand to sandy/mud and varies very little throughout (Figure 11). The sediment sample in Figure 11 is from the sample location in the centre of the proposed site, but characteristics apparent to the naked eye were consistently similar for all sediment samples retrieved.

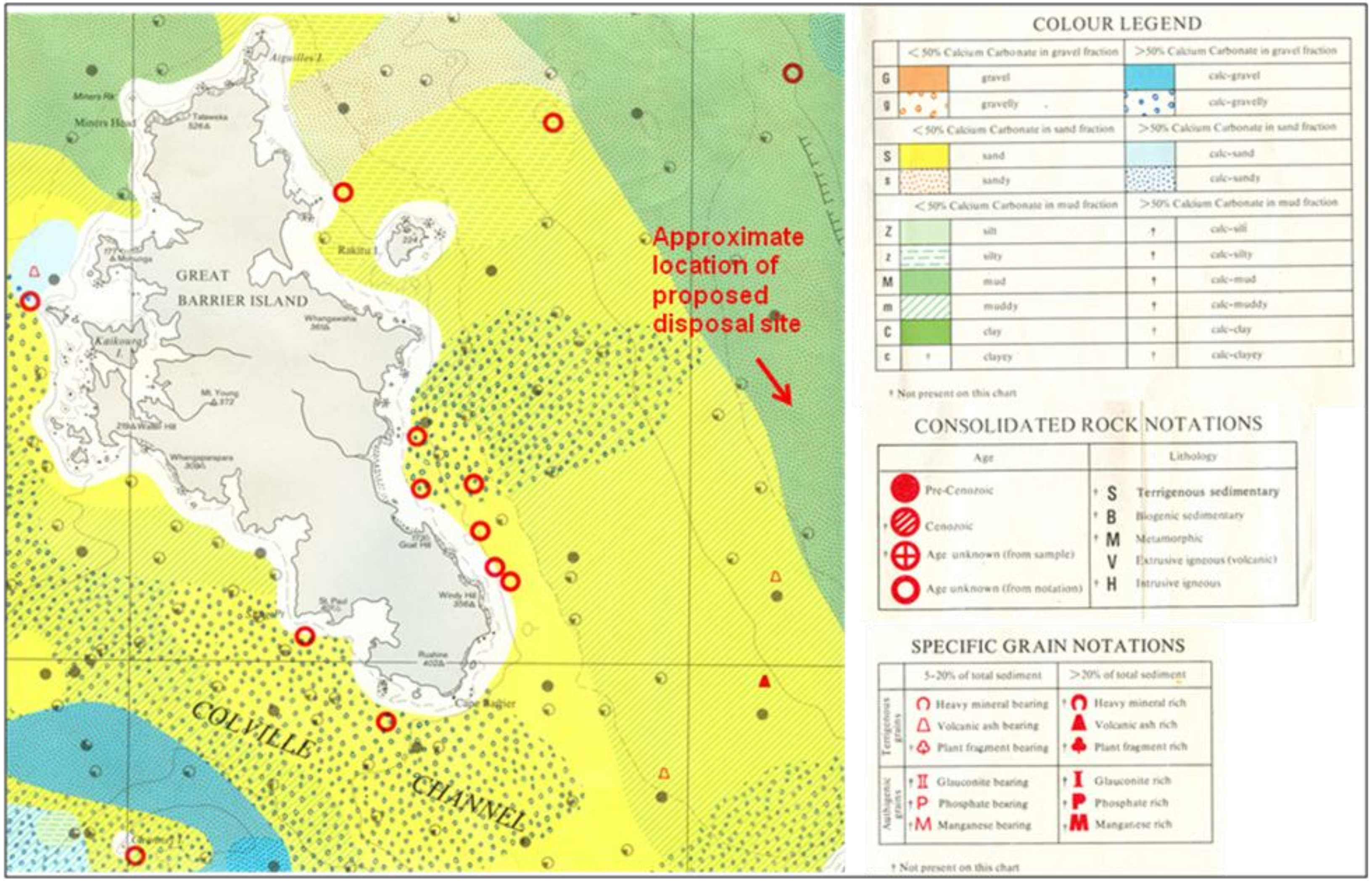


Figure 10. Sediment map of regions east of Great Barrier Island. (Source: Carter and Eade, 1980).

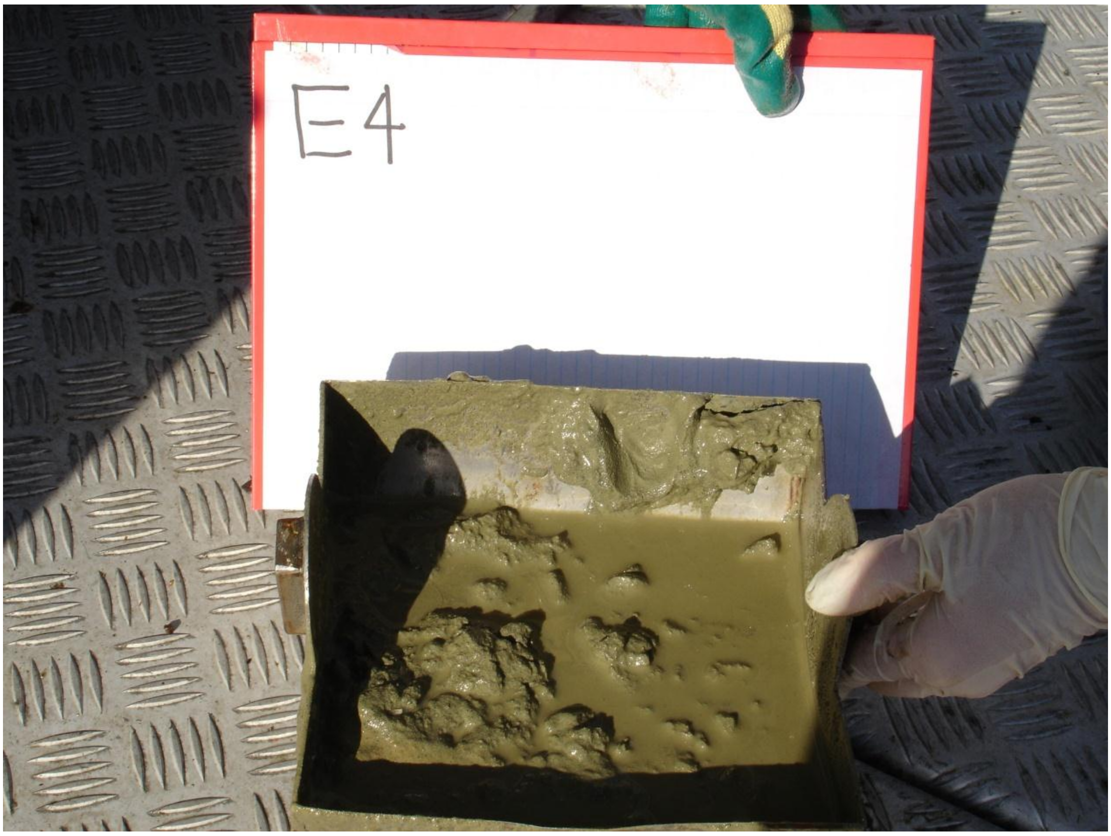


Figure 11. Sediment retrieved during the November, 2007 survey, from the centre sample location of the proposed disposal site (subsequent sample locations yielded sediment visually consistent with that of the centre location).

4.3 Water properties

4.3.1 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 depth, 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).

4.3.2 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 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 relatively high considering that there are no freshwater inputs to this region so distant from land.

4.3.3 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 12a and 12b.

During the study, chlorophyll a concentrations in the north-east coast and continental shelf were elevated in the winter and reached a maximum in spring (September-October) (Figure 12a) (Murphy *et al*., 2001). The minimum concentrations in this region occurred at the end of summer (February-March) (Figure 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.

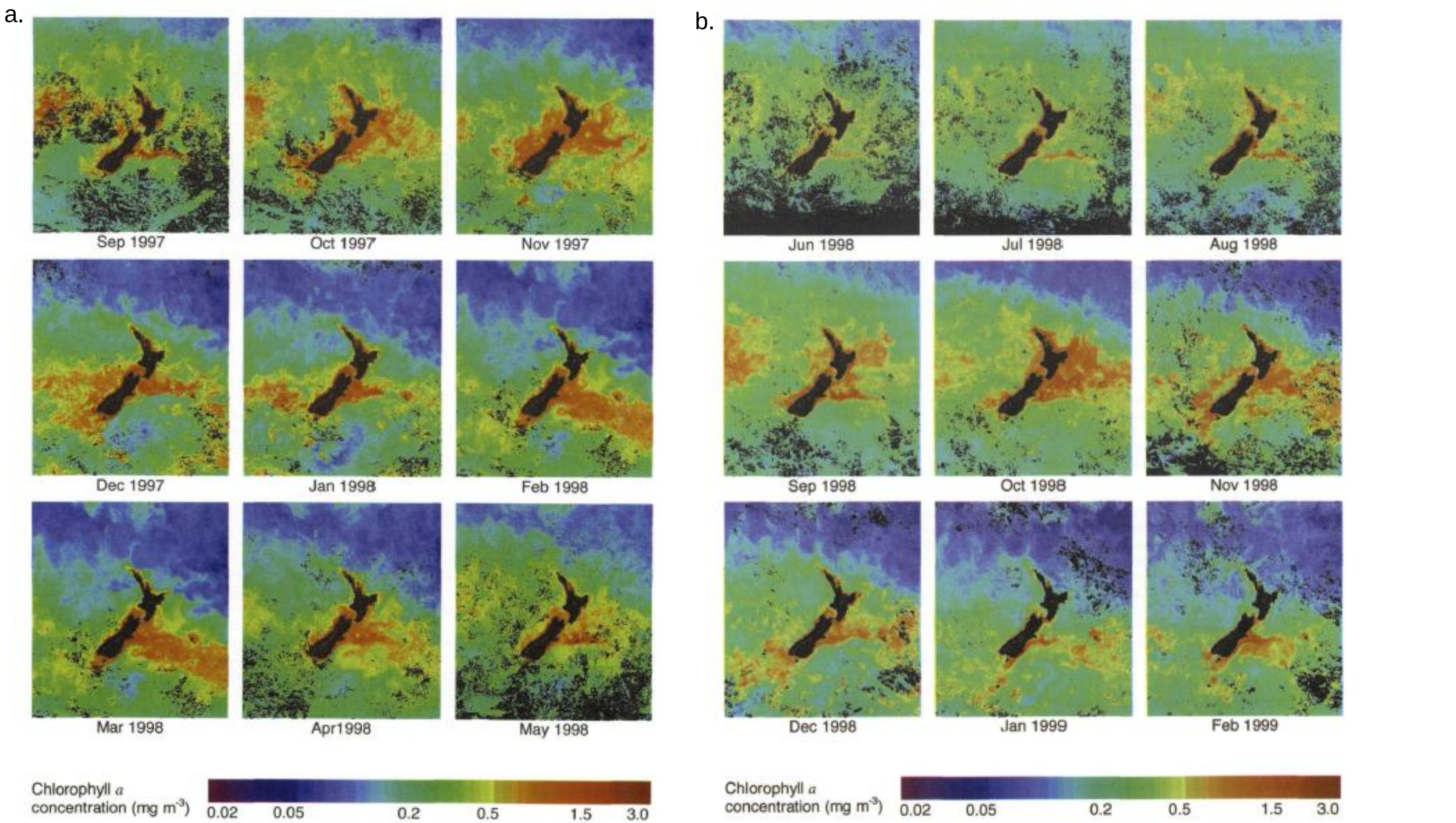


Figure 12. Monthly chlorophyll a concentrations in the coastal waters of New Zealand from (a) September 1997- May 1998 and (b) June 1998- February 1999. (Source: Murphy *et al.*, 2001).

4.4 Hydrodynamics

4.4.1 Tidal characteristics

The waters of the north-east continental shelf of New Zealand are influenced by several tidal waves of varying amplitude and significance. In general, most 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, the M2 tidal component velocities are found to be only 5-10 cms^{-1} whereas overall 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 7) 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 shoreward, 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 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. Ongoing research includes deployment of detailed bottom current recording instruments to obtain data to better understand the effects of an internal wave near the proposed site, and include in numerical models of the oceanographic hydrodynamics.

4.4.2 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).

Once in contact with the New Zealand land mass, the flow decreases in velocity somewhat to form the East Auckland Current (EAUC) (Figure 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).

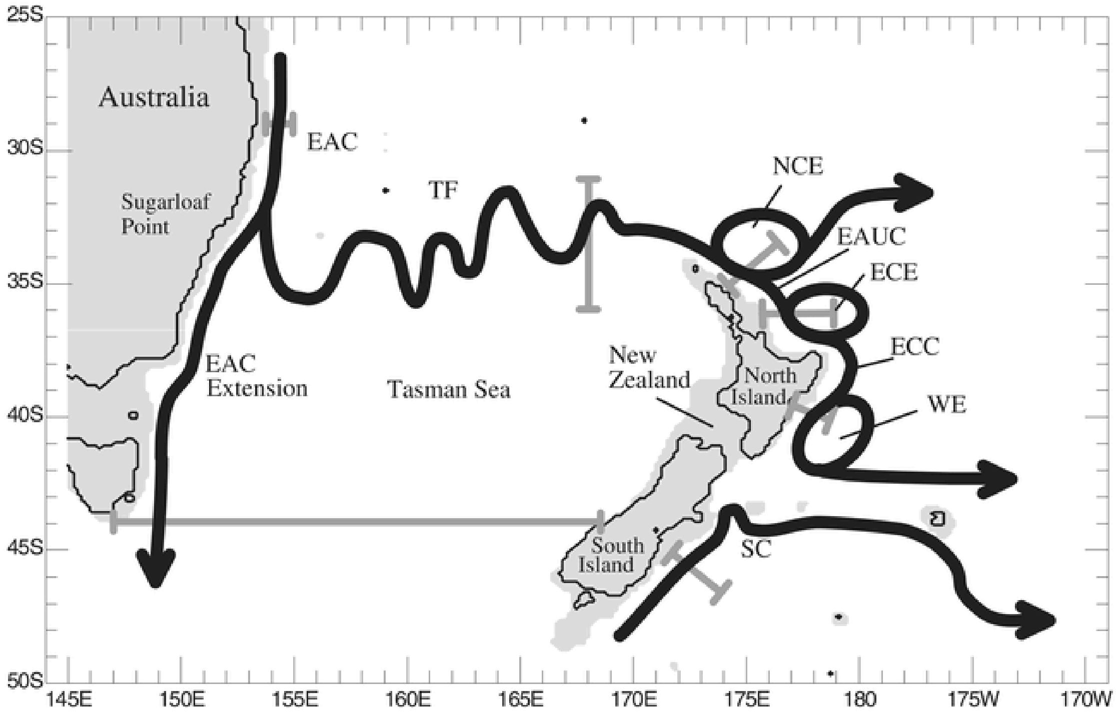


Figure 13. East Australian Current (EAC) system forming the East Auckland Current (EAUC) on the north-east coast of New Zealand showing the approximate locations of the Tasman Front (TF), North Cape Eddy (NCE), East Cape Eddy (ECE), East Cape Current (ECC), Wairapa Eddy (WE) and the Southland Current (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 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 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. Further measurements at the proposed site, will assist understanding for the potential for advection and dispersal of dredge spoil released into the water column.

4.4.3 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 can be summarised with the generalisation 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. Typically, 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 opposite is true in the northern hemisphere.

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, 20-30cms^{-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, additional 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). It was 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).

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 would be affected. Detailed measurements of temperature, nutrients and currents will determine whether upwelling at the site will create significant environmental impacts as a result of disposal operations.

4.4.4 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 moves. 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 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 1m. 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 negligible.

4.4.5 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. Generally, 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 9). 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 shows 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 9). 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 14). The critical velocity of entrainment of sediments from the seafloor (discussed in more detail in section 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 disposed site.

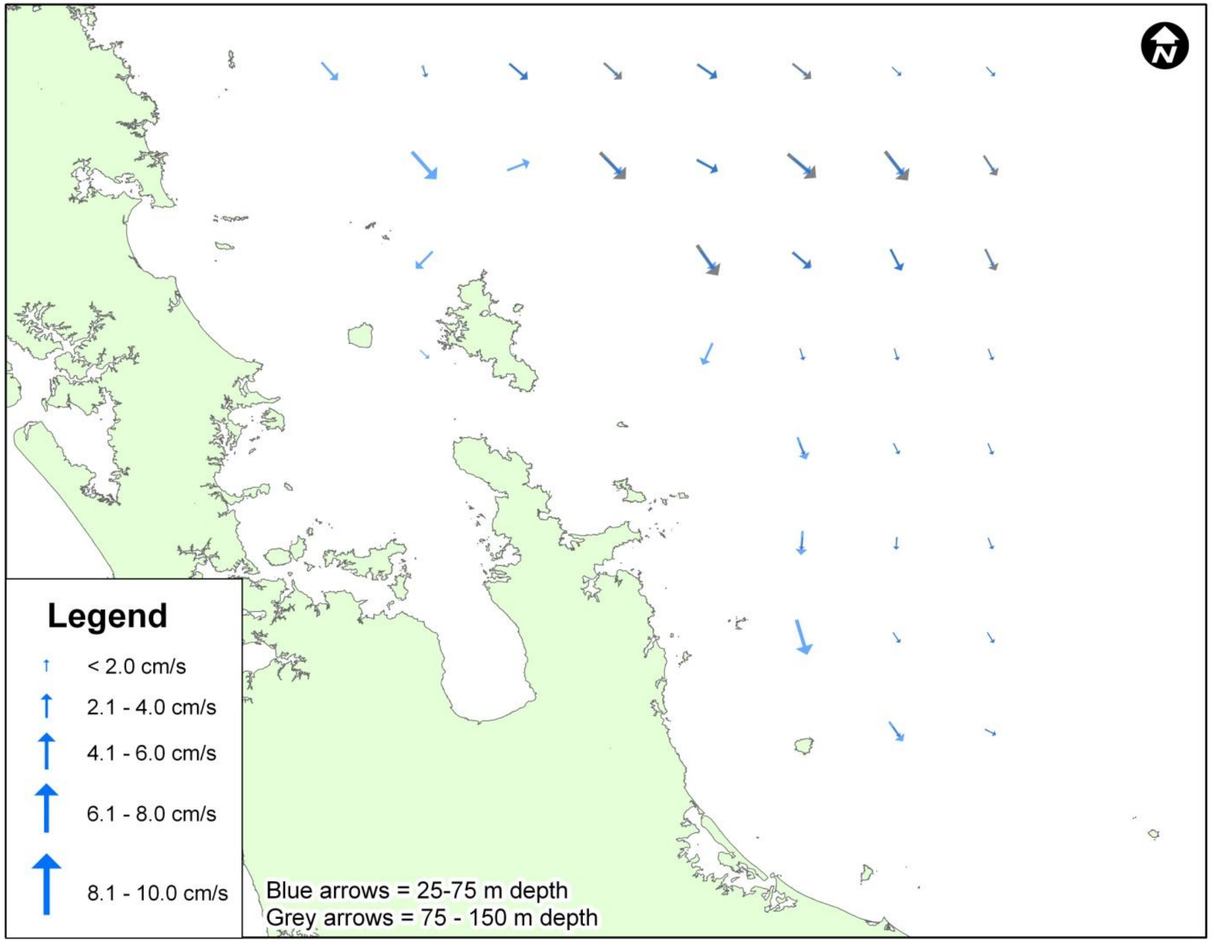


Figure 14. Model output from the Ocean Circulation and Climate Advanced Modelling (OCCAM). Annual averaged currents from October, 2003 to October, 2004 where blue arrows indicate the mid-depth (25-75 m) directional current flow and the gray arrows indicate the bottom (75-150 m) directional current flow. (Source: Peter Longdill, 2007).

4.5 Biological composition and activity

4.5.1 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 proposed site because water depth can be limiting factor for many 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.

There was one survey in particular that endeavoured to classify benthic activity at depths greater than 80 m. In 2002, the Department of Conservation (DOC) commissioned a study of benthic biological composition and activity in areas east of Great Barrier Island for the purposes of establishing a marine reserve in that area. 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 100m (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 4). Therefore, benthic features at study sites sampled near the outer limit of the DOC survey are likely similar to those at the proposed 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 to features that may occur at the proposed disposal 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 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 4. 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 proposed disposal 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) and 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 2.

Table 5. 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, based of the trend observed by Sivaguru and Grace (2002) that species diversity is related to depth, the proposed disposal site can be expected to have an even lower diversity as the depth ranges from 10 – 20 m deeper than the sites sampled in the DOC survey.

Initial observations of benthic fauna recovered from grab samples taken at the site in November, 2007 are that there is very little evidence of significant diversity or abundance. The main taxa recovered, was that of Polychaeta, but only totalling approximately 2-3 individuals per grab sample. These samples require further investigation and identification, but initial conclusions are that there are very few benthic species inhabiting the site.

4.5.2 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 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 100m below the sea surface (Figure 15).

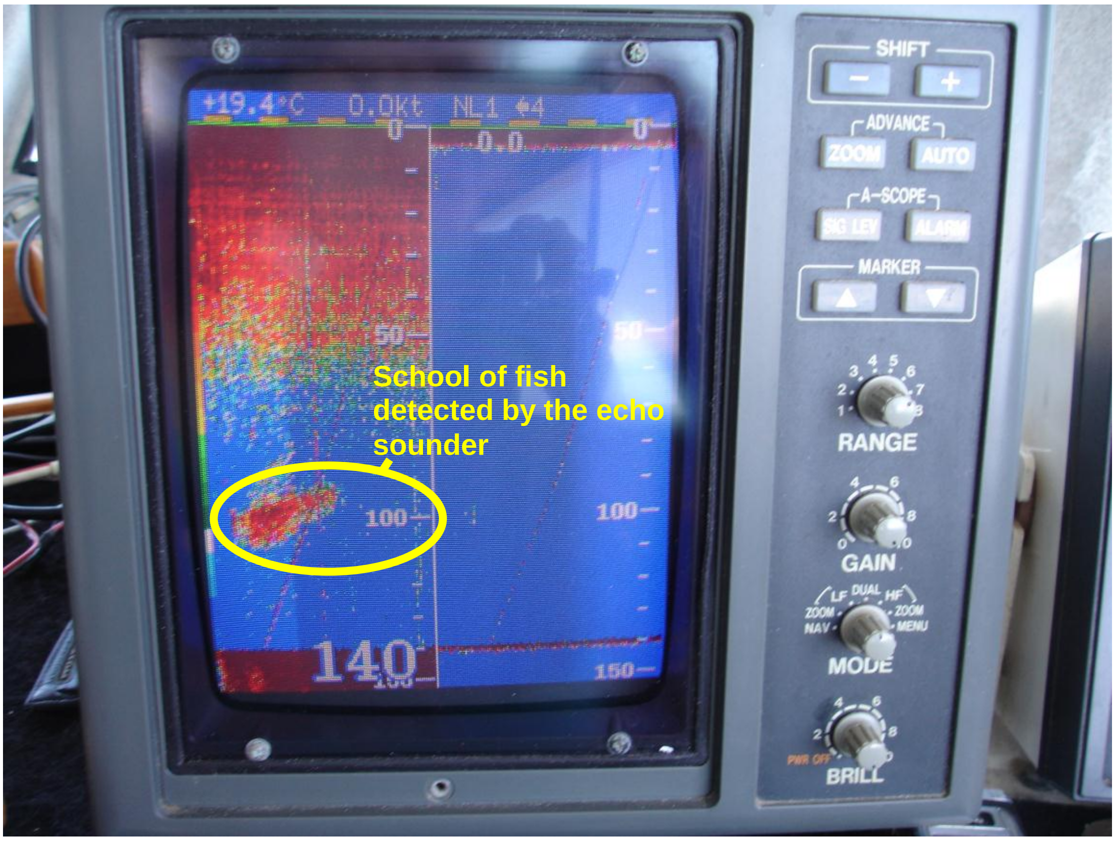


Figure 15. School of fish detected by the echo sounder in approximately 100m of water during the November, 2007 survey.

Table 6. 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

Despite the lack of specific data on the exact species composition and abundance of fishes 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). 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 and large pelagic species may migrate in during warmer seasons, but these occurrences are likely to be rare and mostly seasonal, but as detected by the echo sounder, schools of fish do pass by in the water column of the proposed disposal site.

4.5.3 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. 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 4 includes the findings of this year long study.

Table 7. Findings of a baleen whale song study off the north-east coast 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	Off shore	

		September	(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 except perhaps for transient passage at the proposed 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 a survey taken on November 30, 2007, 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 SITE 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, spread evenly over the proposed site, would result in a ~20 mm layer of material on average over the site. However, it is unlikely that an even layer could be achieved allowing for different synoptic current conditions, so that in practice most of the material disposed would be toward the central part of the disposal site, and might conceivably create a mound 1-2 m high.

6 DISPOSED MATERIAL MOBILITY

6.1 Descent

When dredged material is released from a hopper, it descends through the water column as a fluid-like jet (Figure 16) (Truitt, 1988). Depending on the cohesive properties of this sediment, there may be large clumps of cohesive sediment within this jet, especially as biological activity in the sediment to be dredged will result in more sediment cohesion. Turbulent forces in the water column may cause water to be entrained within the jet (Truitt, 1988).

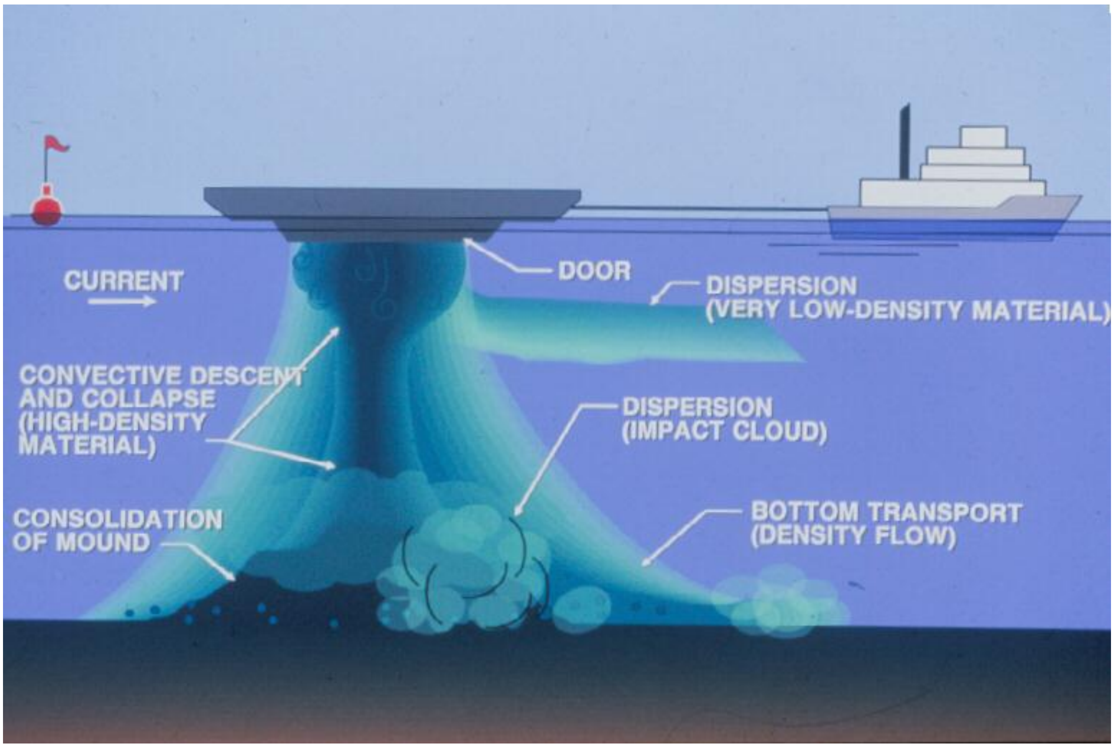


Figure 16. Dredge spoil descent. (Source: Gailiani and Smith for the US Army Corps of Engineers dredge spoil disposal program).

6.2 Advection (horizontal displacement)

Entrainment of water in the descending jet of dredge 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 16). It is expected that the East Auckland Current (EAUC) will cause some horizontal displacement of material during the descent process. 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 outside. However, numerical model simulations are required to properly account for other hydrodynamic features in the area, such as tides, and to determine the residual current direction at the site.

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 17 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 difference in horizontal displacement between a large quantity of sediment descending at once and an individual particle. These calculations indicate that a dredge spoil load of 900 m^3 as a unit will be displaced by horizontal currents very little compared to singular sediment grains.

Calculations show that a small floc of floating sediment 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).

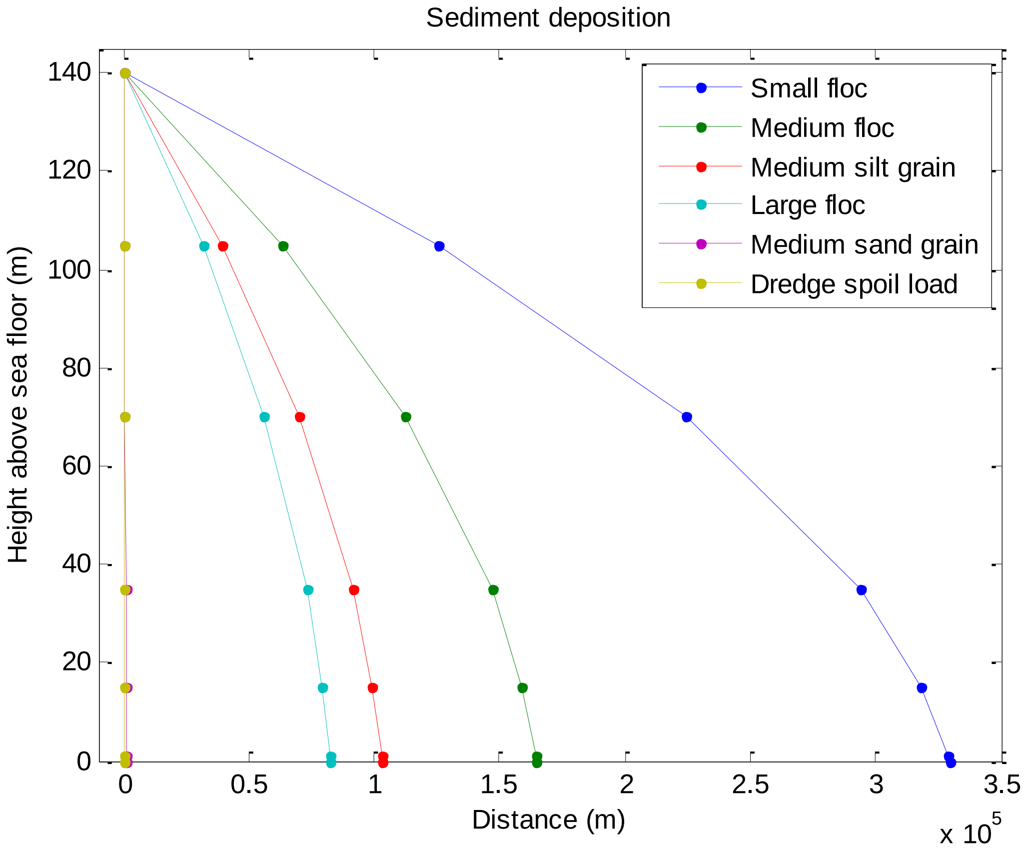


Figure 17. Displacement of sediment particles by horizontal currents during descent to the seafloor.

6.3 Re-entrainment

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) (Appendix 1) was used to estimate u_*. This was determined to be 0.02 (dimensionless) based on a medium sized silt particle of 0.03 mm.

A velocity profile of Equation 1 is plotted in Figure 18. 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.

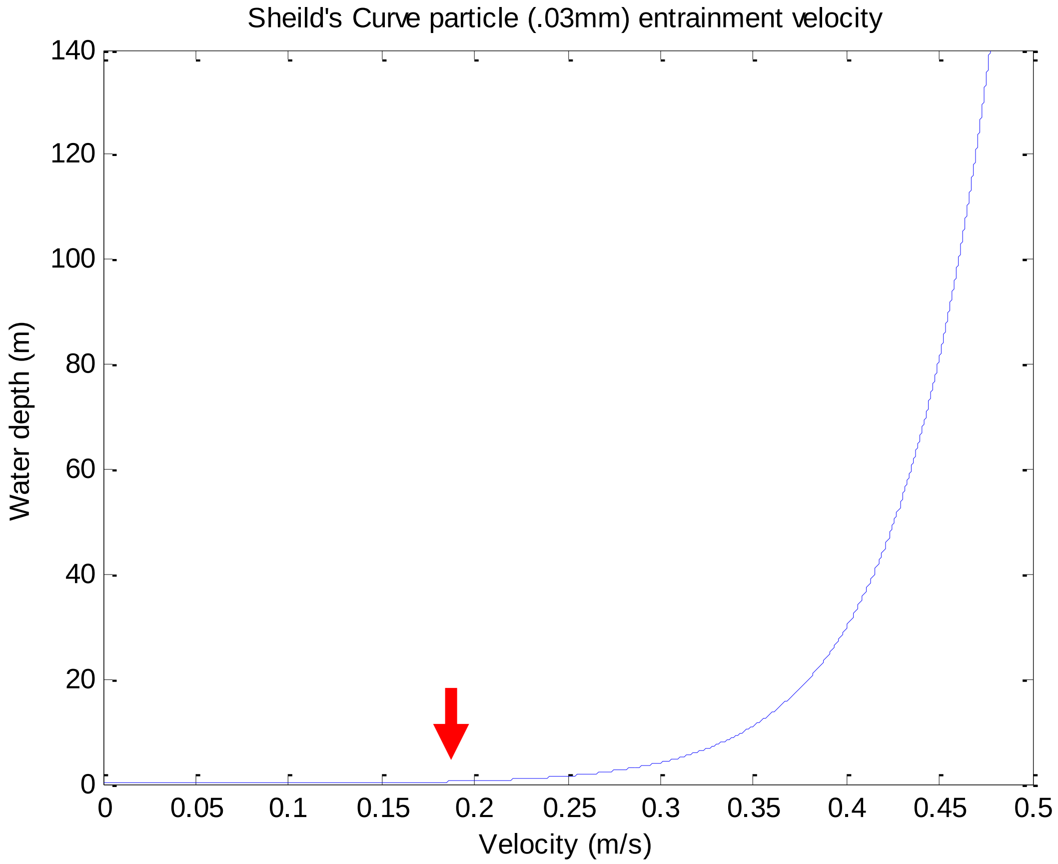


Figure 18. Velocity profile based on a sediment threshold u predicted using Shield's curve. The arrow indicates the nearbed velocity taken to be the critical velocity for sediment movement.

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 18).

Hjulström (1935) determined this critical velocity for the same sized particle to be greater than 20 cms^{-1} (Figure 19). 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.

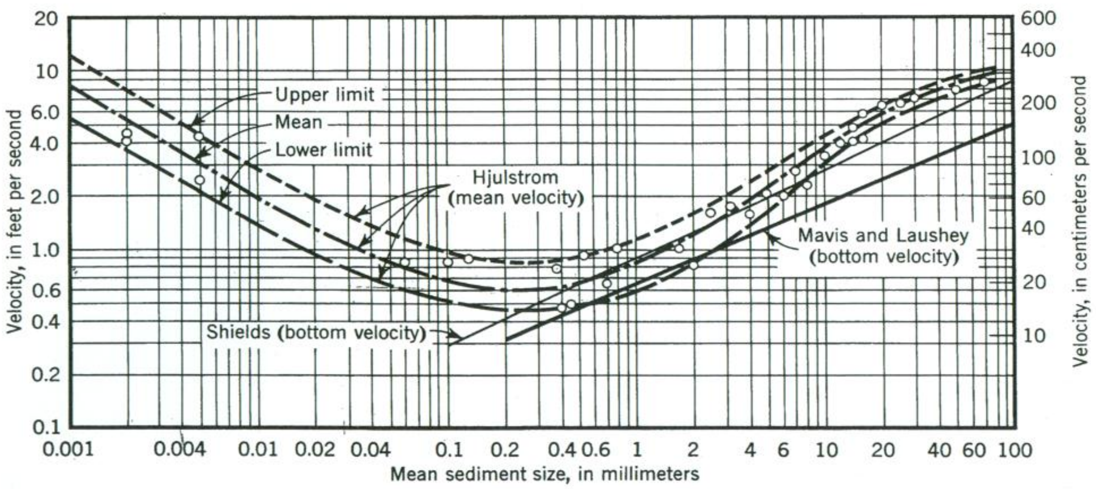


Figure 19. Critical water velocities for quartz sediment as a function of mean grain size. (Source: Hjulström, 1935).

6.3.2 <u>Waves</u>

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.

In 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 used by 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 19), 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 because subsequent consolidation of the sediment increases the velocity required to induce sediment motion.

Subsequently, the sediment cohesion will increase – and the entrainment velocity will likewise increase - due to biogenic production of colloidal proteins from re-colonising worms as reported by Warren (1992) for the dredgings disposal site on the shelf off Tauranga Harbour. This process occurred within two to three months at that site.

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 20 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).

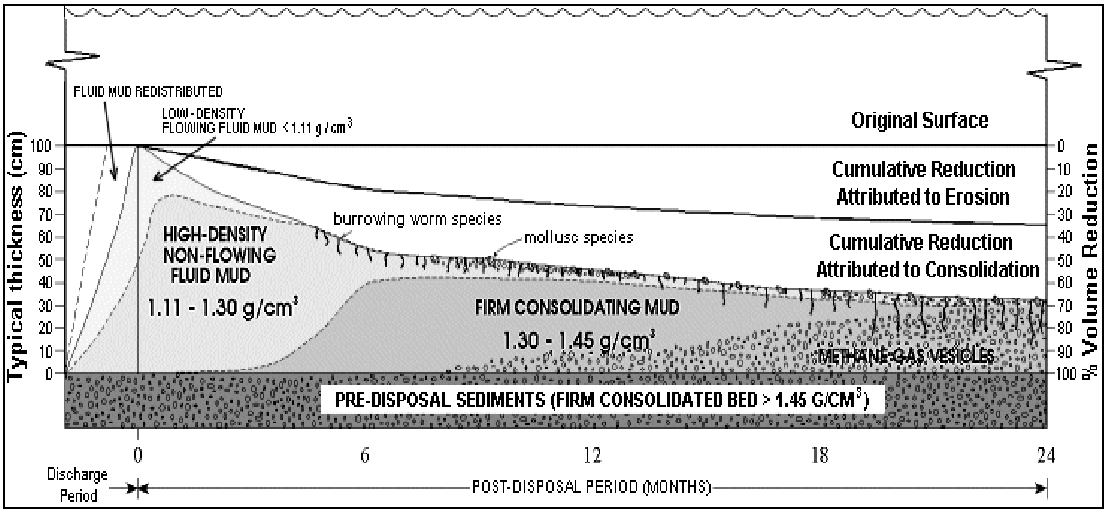


Figure 20. Volumetric and biological change of a dredge spoil mound over time. (Source: Maryland Geological Survey, 2008).

7 EVALAUATION OF POTENTIAL IMPACTS

7.1 Water quality in surrounding areas

As previously stated, on 1-5% of the sediment load is expected to be lost by dispersion in the water column upon descent (Truitt, 1988). It is likely that this lost material will cause the quality of the water in the immediate area to be affected by transient pulses of fine sediment flux from the disposal operations. The water may be turbid temporarily and any contaminants bound in the sediments will be exposed to float freely in the water column. While this is not ideal for the surrounding areas, the impact of a small amount of slightly contaminated sediment in the water column will be small.

Typically, species associated with muddy environments, such as those surrounding the proposed disposal site, are highly tolerant of sediment suspensions especially (DRMP, 1978), if they are only occurring as transient pulses of turbidity as they would during disposal operations.

7.2 Movement of 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 above), as are the tidal and shelf currents. Moreover the dredged material is cohesive, and thus little migration of the dredge dump 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 disposal, 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 proposed disposal site, which 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 occasionally, movement of the spoil mound at the proposed disposal site is expected to be minimal.

7.3 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.

Investigations by the Dredged Material Research Program (1978), a US Army Corps of Engineers research group were conducted using the clam *Rangia cuneata*, the grass shrimps *Palaemonetes pugio* and *P. kadiakensis*, and the worms *Neanthes arenaceodentata* and *Tubifex* sp.. Heavy metals that were routinely measured in these investigations were iron, manganese, copper, cadmium, nickel, lead, zinc, chromium, and mercury. It was found that uptake of heavy metals by organisms was minimal and variable and the impacts resulting from heavy metal bioaccumulation was not evident. However, they did find that bioaccumulation potential appeared to be related to the physical and chemical form that heavy metal occurs in (DMRP, 1978).

Contaminated sediment is no longer considered to always be toxic (DMRP, 1978). It has been found that contaminants are not as easily desorbed from sediments as previously thought and are therefore, less toxic to the environment bound into sediments, than in a free state (DMRP, 1978).

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.

7.4 Benthic fauna mortality and recovery rates

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 smothered in the dredging and/or disposal operations. Likewise, the individuals inhabiting the sediments at the disposal site will also be smothered 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 due mostly likely 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 (DMRP, 1978). If the material disposed is of similar quality to that of the sediment these benthic species previously inhabited, their chances of survival are great (DMRP, 1978).

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 because it would mean that after the first disposal operations are underway 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 of dredged sediment at the proposed site.

7.5 Fin fish and mammal disruption

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. 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 evident.

8 SUMMARY OF POTENTIAL IMPACTS

Based on current knowledge, the proposed site is suitable for disposal operations. However, 3 years of detailed monitoring is recommended in order to accurately determine what, if any, long term impacts the disposal operation is having on the environment. It is also recommended that during this initial 3 year monitoring period, that disposal is limited to approximately 50,000 m^3 of dredged material per year. After this period, a further assessment of appropriate annual disposal volumes can be undertaken.

It is recommended that the following effects are monitored and assessed:

- **Water quality in surrounding areas:** Monitoring should confirm that turbid waters resulting from the disposal plume are not persisting for an extended period of time after a disposal of dredged material has occurred.

- **Chemical content of sediment:** Analysis of the chemical content of the sediment at the disposal site should not show a significant increase in heavy metal concentrations where adverse effects on benthic organisms are occurring.

- **Formation of a spoil mound:** Monitoring is to confirm that the formation of a large and tall mound has not occurred. Such a mound could be problematic for naval operations in nearby areas.

- **Movement of the spoil mound:** Monitoring should confirm that migration of the spoil mound especially in the north-west direction (the direction of the proposed Aotea Marine Reserve) beyond the boundaries of the disposal area is not occurring.

- **Impacts on surrounding areas:** Monitoring should confirm that loads are hitting the target area and the surrounding benthic populations are not impacted.

- **Benthic fauna recovery rates:** Monitoring should confirm that partial recovery of benthic fauna communities is occurring within the initial monitoring time frame of 3 years. This is the key indication to confirm that any contamination levels are at an acceptable level and that no adverse effects are arising.

9 MONITORING

A specific monitoring plan will be developed as features of the site are investigated during future surveys. The initial monitoring plan is suggested as follows:

9.1 Baseline surveys

Before disposal operations begin, a survey of the site should be undertaken in order to properly assess the impacts after disposal operations start. Monitoring results will also be used to determine the carrying capacity of the site. The capacity available will determine the appropriate long-term usage of the site. The survey should include:

9.1.1 Side-scan sonar

Side-scan sonar surveying should be used to determine the initial sediment classification of the site. Through acoustic technology, this instrument can provide visual verification of the types of sediment that may be present at the site by plotting the distinctive backscatter responses associated with each sediment type.

9.1.2 Multibeam survey

A multibeam bathymetric survey should be used to develop a detailed bathymetric map of the site. Similar to side-scan sonar, the multibeam uses acoustic technology to measure distance to the seafloor. Including this in the baseline survey will produce valuable data on the natural features of the site.

9.1.3 Sediment sample retrieval

Preliminary sediment sampling should be used as ground-truthing for the side-scan survey and also to determine the natural assemblage of the benthic infauna found at the proposed site. Additionally, sediment sampling will be used to confirm that the sediment at the site is texturally similar to the sediment that may eventually be disposed there.

9.1.4 Drop camera

Video of the seafloor habitat at the proposed site can be helpful in evaluating the ecological situation at the site. Comparing the video of the site in its natural form to video taken after disposal operations begin can indicate any change in the ecological health of the habitat.

9.2 Proposed monitoring after disposal of 50,000 m^3 of dredged material

After the initial disposal of 50,000 m^3 of dredged material multibeam and side-scan surveys of the site will be repeated. Comparison of these two surveys will be an invaluable indicator as to the impacts disposal operations may be having on the site and in what capacity the site can be operated in the long-term.

9.2.1 Side-scan sonar

Comparing the initial baseline side-scan sonar data to that after disposal of 50,000 m^3 will show whether there is formation of a significant spoil mound and also whether it is migrating away from the disposal site and in what direction. The extent of development of a spoil mound can be used to estimate the capacity of the site for long-term usage.

9.2.2 Multibeam survey

Similar to the side-scan survey, a multibeam survey can be used to confirm the formation of a spoil mound, how tall it is, and if it is in fact migrating out of the designated site by comparing it to the initial survey taken at the site.

9.2.3 Sediment sample retrieval

Sediment sampling after disposal of 50,000 m^3 will give an indication as to the health of the ecosystem. By sampling the sediment, benthic fauna composition and abundances can be compared to the data taken from the initial survey. Significant changes in the composition and abundance of the benthic fauna may possibly be attributed to disposal operations, although other factors such as seasonal variations should be accounted for as well. Additionally, the samples should be analysed for heavy metal concentrations and compared to the initial sediment analysis to confirm any changes.

9.2.4 Drop-camera

Underwater video taken after disposal after disposal of 50,000 m^3 can be used to examine the health of the ecosystem (i.e. is there evidence on the seabed surface of biological activity?) Additionally, video footage may also be used to visualize the spoil mound. Any significant changes that weren't apparent in the initial video footage may indicate impacts resulting from disposal activities, but, again, it will be important to consider natural seasonal variations as well.

9.3 Proposed monitoring after 150,000 m^3 of dredged material disposal

Repeat the survey methods taken after disposal of 50,000 m^3. Compare the findings of this survey to that of the baseline survey and the post-50,000 m^3 survey. At this point, a review of the monitoring programme should be undertaken considering the results of the three previous surveys. If it is apparent that adverse effects are occurring it is recommended that disposal operation methods and frequency be re-evaluated.

9.4 Proposed monitoring 6 years after commencement of disposal operations or after disposal of 300,000 m^3 of dredged material

Repeat the side-scan sonar, multibeam, sediment sample retrieval and drop-camera surveys. Compare the findings to the baseline survey, the post-50,000 m^3 survey, and the post-150,000 m^3 survey. If adverse effects resulting from disposal operations are apparent, re-evaluation of disposal operations and site area is recommended.

9.5 Future monitoring

If after 6 years of monitoring, no adverse environmental impacts have been identified, it is recommended that the monitoring program be reviewed. This review may include a new plan for on-going operations. It is recommended that this plan include a multibeam survey for detection of spoil mound movement, and sediment sampling which will be analysed for benthic fauna composition and abundance as well as for contaminant concentrations

10 OPERATIONAL PLAN FOR DISPOSAL OF DREDGINGS OVER THE DISPOSAL SITE

10.1 No RSNZ submarine exercises occurring

When the Royal New Zealand Navy is not using the vicinity of the site for submarine exercises, the disposal operators should abide by the following operational plan for disposal of dredging over the disposal site.

1. Navigate by DGPS.
2. Electronically plot their position and track within 10km of, and over the disposal site.
3. Electronically plot the point at which dredging disposal commences and the point at which the disposal is essentially complete.
4. Maintain an electronic plot record of cumulative tracks of the dredging disposal vessel within 10 km over the disposal site.
5. Submit the records of the disposal operations to Maritime New Zealand on a 3-monthly basis.

10.2 During RSNZ submarine exercises

When notified by the Royal New Zealand Navy and in consultation with MNZ, all disposal operations would be suspended for the agreed upon period so that submarine exercises in the vicinity of the site may proceed unhindered.

11 LITERATURE CITED

ANZECC, 2000. Australia and New Zealand guidelines for fresh and marine water quality 2000. Australia and New Zealand Environment and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand.

Auckland Regional Policy Statement. *Auckland Regional Council*. Sections 7.4.22-7.4.24.

Bioresearches, 1993. Pine Harbour Marina: Post commissioning survey no. 4, October 1993. pp. 7-38.

BOCZAR-KARAKIEWICZ, B.; BONA, J. L., and PELCHAT, B., 1991. Interactions of internal waves with the seabed on continental shelves. *Continental Shelf Research*, 11(8-10), pp. 1181-1197.

BOLAM, S. G. and REES, H. L., 2003. Minimizing impacts of maintenance dredged material disposal in the coastal environment: a habitat approach. *Environmental Management*, 32, pp. 171-188.

BYE, J. A. T.;HEATH, R. A., and SAG, T. W., 1979. A Numerical Model of the Oceanic Circulation Around New Zealand. *Journal of Physical Oceanography*, 9 (5), pp. 892-899.

Cardno Lawson Treloar, 2007. Tauranga bridge marina wave study sea and swell. Report prepared for Tauranga Bridge Marina Ltd. Report no. LJ2618/R2342, 28 March, 2007.

CARTER, L.; EADE, J. V. 1980: Hauraki sediments, New Zealand Oceanographic Institute chart, coastal series 1:200 000.

DAVIS, R. A. 1985. *Coastal sedimentary environments* (2nd ed.). New York, Springer-Verlag New York Inc. pp.101-104.

DENHAM, R. N.;BANNISTER, R. W.,GUTHRIE, K. M., and CROOK, F. G., 1984. Surveys of the East Auckland and East Cape Currents, New Zealand. *Australian Journal of Marine and Freshwater Research*, 35, pp. 491-504.

Disposal Options Advisory Group (DOAG), 1994. Assessment of the options available for the disposal of dredged material from the Port of Auckland, Part 1, 2, 3, 4, and 5.

Dredged Material Research Program (DMRP), 1978. Effects of dredging and disposal on aquatic organisms. Dredged Material Research Program, US Army Corps of Engineers, Technical Report No. DS-78-5, pp. 1-41.

DYER, K. R., 1986. *Coastal and estuarine sediment dynamics*. Chichester, John Wiley & Sons, Ltd. pp. 209-216.

FOREMAN, M. G. G.;BELL, R. G.;CHERNIAWSKY, J. Y., and BECKLEY, B., 2004. Tides and sea-level variability in the south-west Pacific from TOPEX/Poseidon. *New Zealand Journal of Marine and Freshwater Research*, 38, pp. 649-669.

FRANCIS, M. P., 1996. Geographic distribution of marine fishes in the New Zealand region. *New Zealand Journal of Marine and Freshwater Research*, 30, pp. 35-55.

FRANCIS, M. P.; WORTHINGTON, C. J., SAUL, P., and CLEMENTS, K. D., 1999. New and rare tropical and subtropical fishes from northern New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 33, pp. 571-586.

FRISKEN, W. D. 1992: New Zealand North Island east coast: Breamhead to Slipper Island including Hauraki Gulf 1: 200 000. Auckland, Hydrographic Office of the Royal New Zealand Navy.

GARNER, D. M., 1969. The geopotential topography of the ocean surface around New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 3, pp. 209-219.

GASKIN, D. E., 1968. Distribution of Delphinidae (Cetacea) in relation to sea surface temperatures off eastern and southern New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 2, pp. 527-534.

Golder Kingett Mitchell, 2007. Pine Harbour Sediment Assement. Report prepared for Pine Harbour Marina Ltd, Report no., PINHAAKL002.

GORMAN, R. M.;BRYAN, K. R., and LAING, A. K., 2003. Wave hindcast for the New Zealand region: deep-water wave climate. *New Zealand Journal of Marine and Freshwater Research*, 37, pp. 589-612.

GORMAN, R. M., and STEPHENS, S. A., 2006. Extreme wave predictions around New Zealand from hindcast data. *Journal of Marine and Freshwater Research*, 40, pp 399-411.

HALKA, J.; PANAGEOTOU, W., and SANFORD, L., 1991. Consolidation and erosion of deposited cohesive sediments in Northern Chesapeake Bay, USA. *Geo-Marine Letters*, 11, pp. 174-178.

HARRIS, T. F. W., 1985. *North Cape to East Cape aspects of the physical oceanography*. University of Auckland Department of Physics and Marine Laboratory, Leigh.

HARVEY, M.; GAUTHIER, D., and MUNRO, J., 1998. Temporal changes in the composition and abundance of the macro-benthic invertebrate communities at dredged material disposal sites in the Anse à Beaufils, Baie des Chaleurs, eastern Canada. *Marine Pollution Bulletin*, 36 (1), pp. 41-55.

Hauraki Gulf Marine Park Act, 2000. Public Act 2000 No 1. *Department of Conservation*, pp. 3-21.

HAYWARD, B. W.; BROOK, F. J., GRACE, R. V., and BULL, V. H., 1982. Soft bottom macrofauna and sediments off Rakitu Island, north-east New Zealand. *Tane*, 28, pp. 149-162.

HAYWARD, B. W.; GRACE, R. V., and FRANCIS, M. P., 1986. Sediments and benthos of the northeastern Great barrier Island, New Zealand. *Journal of the Royal Society of New Zealand*, 16(4), pp. pp. 347-355.

HEATH, R. A., 1977. Phase distributions of tidal constituents around New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 11(2), pp. 383-392.

HEATH, R. A., 1980. Eastwards oceanic flow past northern New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 14 (2), pp. 169-182.

HEATH, R. A., 1985. A review of the physical oceanography of the seas around New Zealand- 1982. *New Zealand Journal of Marine and Freshwater Research*, 19, pp. 79-124.

HJULSTRÖM, F., 1935. Studies of the morphological activity of rivers as illustrated by the river Fyris. *Bulletin*, Geological Institute of Upsala, XXV, Upsala, Sweden.

INTERNATIONAL MARITIME ORGANISATION, 2006: Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972. *Office for the London Convention and Protocol*. http://www.imo.org.

INTERNATIONAL MARITIME ORGANISATION, 2006: London Protocol 1996. *Office for the London Convention and Protocol*. http://www.imo.org.

KAROLY, D. J., 1989. Southern hemisphere circulation features associated with El Niño-southern oscillation events. *Journal of Climate*, 2, pp. 1239-1252.

KELLY, J. and MARSHALL, B., 1996. *Atlas of New Zealand Boundaries*. Auckland University Press, 13p.

KOMAR, P. D. and MILLER, M. C., 1973. The threshold of sediment movement under oscillatory waves. *Journal of Sedimentary Petrology*, 43, pp. 1101-1110.

LONG, E. R.; MACDONALD, D. D., SMITH, S. L., and CALDER, F. D., 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marina and estuarine sediments. *Environmental Management*, 19 (1). pp. 81-97.

LOOMB, C. A. M., 2001. Muddy sedimentation in a sheltered estuarine marina, Westpark Marina, Auckland, New Zealand. *Unpublished Msc Thesis*, Department of Earth Science, University of Waikato. pp. 33-60.

Maryland Geological Survey- Coastal and Environmental Geosciences- Dredged Sediment Studies (http://www.mgs.md.gov/coastal/dredge/sedstudy.html) accessed January, 2008.

MATTHEWS, J., 1997. Morphologic changes of the tidal deltas and an inner shelf dump ground from large scale dredging and dumping, Tauranga, New Zealand. Phd thesis. University of Waikato, Hamilton, New Zealand, pp. 223-303.

MCDONALD, M. A., 2006. An acoustic survey of baleen of whales off Great Barrier Island, New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 40, pp. 519-529.

MCKNIGHT, D. G., 1969. Infaunal benthic communities of the New Zealand continental shelf. *New Zealand Journal of Marine and Freshwater Research*, 3, pp. 406-444.

MERCER, S. F. M., 1979. Hydrology of the North-east Coast of the North Island 1973-1974. Wellington: New Zealand Ministry of Agriculture and Fisheries, No. 17, pp. 3-23.

MILLER, M. C.; MCCAVE, I. N., and KOMAR, P. D., 1977. Threshold of sediment motion under unidirectional currents. *Sedimentology*, 24, pp. 507-527.

MURPHY, R. J.; PINKERTON, M. H., RICHARDSON, K. M., BRADFORD-GRIEVE, J. M., BOYD, P. W., 2001. Phytoplankton distributions around New Zealand derived from SeaWiFS remotely-sensed ocean colour data. *New Zealand Journal of Marine and Freshwater Research*, 35, pp. 343-362.

NEUMANN, D. R.; LEITENBERGER, A., and ORAMS, M. B., 2002. Photo-identification of short-beaked common dolphins (*Delphinus delphis*) in the north-east New Zealand: a photo-catalogue of recognisable individuals. *New Zealand Journal of Marine and Freshwater Research*, 36, pp. 593-604.

Parliamentary Commissioner for the Environment (PCE), 1995. Dredgings disposal in the Hauraki Gulf. Final report of the technical review panel.

PICKRILL, R. A. and MITCHELL, J. S., 1979. Ocean wave characteristics around New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 13 (4), pp. 501-520.

Pine Harbour Marine permit submission to the Auckland Regional Council for resource consent to undertake re-agitation dredging (1999).

ROBERTS, R. D.; GREGORY, M. R., FOSTER, B. A., 1991. The Rangitoto spoil ground: impact of dumping dredge spoil from the Port of Auckland on a shallow seafloor. "Coastal Engineering- Climate for Change", 10th Australasian Conference on Coastal and Ocean Engineering, Auckland, pp. 35-40.

SAUNDERS, P. M.; COWARD, A. C., and DE CUEVAS, B. A., 1999. Circulation of the Pacific Ocean seen in a global ocean model: Ocean Circulation and Climate Advanced Modelling Project (OCCAM). *Journal of Geophysical Research*, 104 (C8), 18, 281-18, 300.

SIVAGURU, K. and GRACE, R., 2002. Habitat species diversity of deep reefs and sediments at Great Barrier Island. Report for the Department of Conservation, Auckland Conservancy.

SHARPLES, J., 1997. Cross-shelf intrusion of subtropical water into the coastal zone northeast of New Zealand. *Continental Shelf Research*, 17(7), pp. 835-857.

SHARPLES, J., and GRIEG, M. J. N., 1998. Tidal currents, mean flows, and upwelling on the north-east shelf of New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 32, pp. 215-231.

SHIELDS, A., 1936. Application of similarity principles and turbulent research to bed-load movement. Mitteilungen der Preussischen Versuchanstalt für Wasserbau und Schiffbau, Berlin. *In*: Ott, W. P.; van Uchelen, J. C. (translators). *California Institute of Technology, W. M. Keck Laboratory of Hydraulics and Water Resources. Report 167*.

SMITH, S. L.; MACDONALD, D. D., KEENLEYSIDE, K. A., and GAUDET, C. L., 1996. The development and implementation of Canadian sediment quality guidelines. *Journal of Aquatic Ecosystem Health.*

SMITH, S. D. A. and RULE, M. J., 2001. The effects of dredge-spoil dumping on a shallow water soft-sediment community in the Solitary Islands Marine Park, NSW, Australia. *Marine Pollution Bulletin*, 42 (11), pp. 1040-1048.

STANTON, B. R., 1981. An oceanographic survey of the Tasman Front. *New Zealand Journal of Marine and Freshwater Research*, 15, pp. 289-297.

STANTON, B., and SUTTON, P., 2003. Velocity measurements in the East Auckland Current north-east of North Cape, New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 37, pp. 195-204.

SZOEKE, R. A. D., 1987. On the wind-driven circulation of the South Pacific Ocean. *Journal of Physical Oceanography*, 17, pp. 613-630.

TILBURG, C. E.; HURLBURT, H. E., O'BRIEN, J. J., and SHRIVER, J. F., 2001. The dynamics of the East Auckland Current System: The Tasman Front, the East Auckland Current, and the East Cape Current. *Journal of Physical Oceanography*, 31, pp. 2917-2943.

TOMCZAK, M., and GODFREY, J. S., 1994. *Regional oceanography: an introduction*. Oxford: Elseveir Science Ltd., pp. 53-56.

TRUITT, C. L., 1988. Dredged material behaviour during open-water disposal. *Journal of Coastal Research*, 4 (3), pp. 489-497.

VISSER, I. N., 2000. Orca (*Orcinus orca*) in New Zealand waters. Ph.D. Dissertation. University of Auckland, Auckland, New Zealand. pp. 200.

WALTERS, R. A.;GORING, D. G., and BELL, R. G., 2001. Ocean tides around New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 35, pp. 567-579.

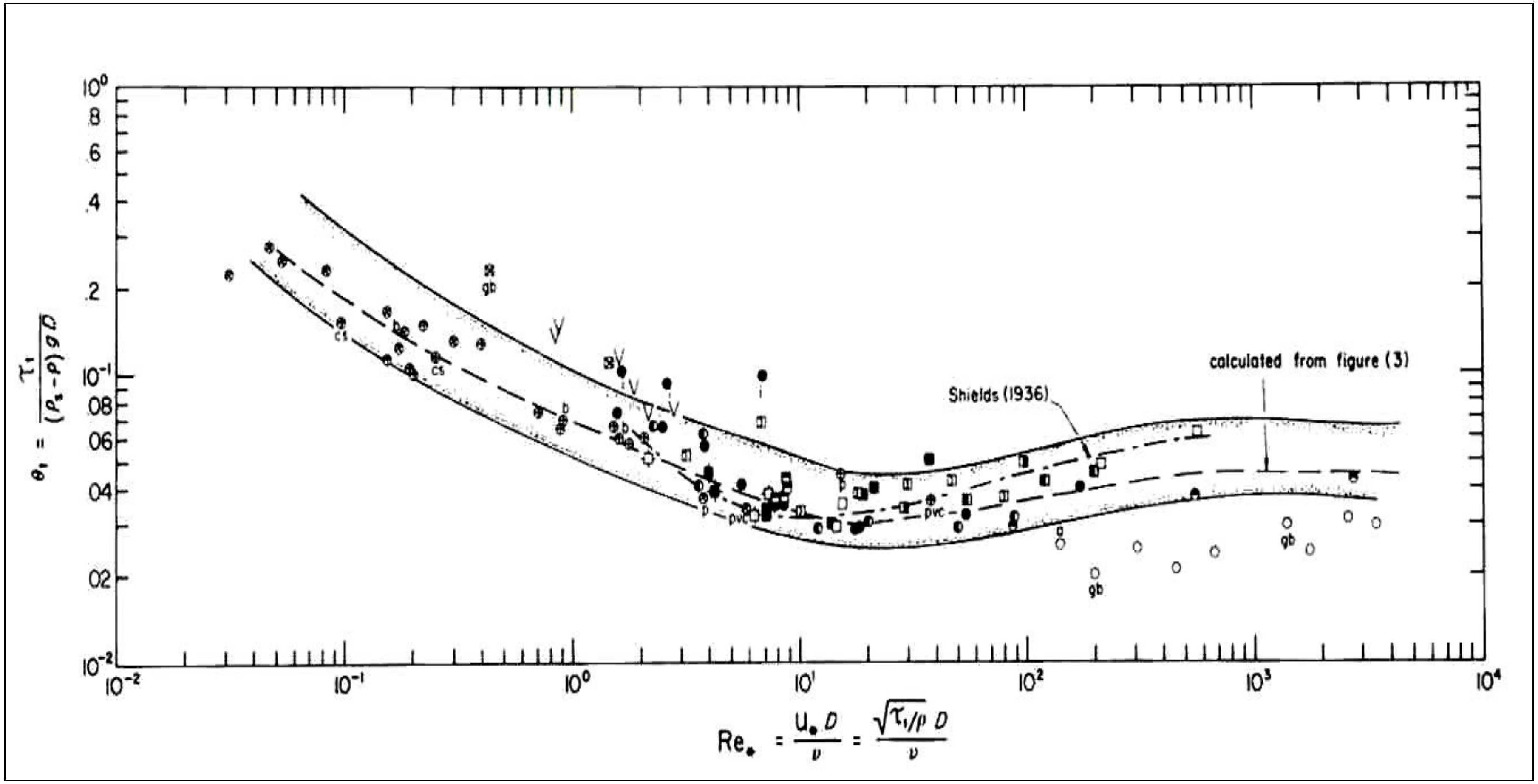
WEBB, D. J.; DE CUEVAS, B. A., and COWARD, A. C., 1998. The first main run of the OCCAM global ocean model, internal report of James Rennell Div., Southampton Oceanography Centre, 50 pp., Southampton, England, U. K..

WILLIAMSON, R. B., AND WILCOCKS, R. J., 1994. The distribution and fate of contaminants in estuarine sediments. NIWA Consultancy Report No. ARC109/3. 67p.

ZELDIS, J. R.; WALTERS, R. A., GREIG, M. J. N., IMAGE, K., 2004. Circulation over the northeastern New Zealand continental slope, shelf and adjacent Hauraki Gulf, during spring and summer. *Continental Shelf Research*, 24 (4-5), pp. 543-561.

12 APPENDICES

12.1 Modified Shields Curve



(Source: Miller *et al*., 1977)