# Port Otago Project Next Generation Summary of existing physical coastal environment information and scoping for further studies


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# Executive Summary


This physical coastal environment report is part of a collection of reports addressing the feasibility of progressing Port Otago operations through "Project Next Generation". This report covers aspects of coastal processes including:

- Hydrodynamic factors associated with the tidal and wave environments in the harbour and outside the harbour between Taiaroa Head and Karitane Point.
- Sediment characteristics of material to be dredged from the main harbour channel.
- Sedimentological factors of potential dredge spoil receiving sites, including sediment characteristics of the seabed and potential dispersal of placed dredge sediments.
- Possible effects of the dredging activities, the final dredged channel and the placed dredge sediment on the physical coastal environment and existing Port Otago dredging activities.
- Possible effects on the physical coastal environment of large container ships using the harbour channel.

The general physical coastal environment of Otago Harbour and Blueskin Bay are described. The process environment is dominated by high-energy, southerly swell waves, and a south to north current (oceanic, tidal and wave generated) with an anticlockwise eddy in Blueskin Bay. Sand on the seabed comes from the Clutha River via the nearshore shelf. The sediment transport rate past Taiaroa Head is about moving north at rate of about 1.1 million tonnes per year. Approximately 250,000 m3 to 450,000 m3 of sediment is transported into Otago Harbour each year, and is dredged from the shipping channel and deposited onto disposal sites off Heyward Point, Aramoana Beach and Shelly Beach. In effect, the maintenance dredging operation works to bypass the sediment across the harbour inlet.

The main effects of Project Next Generation on the physical coastal processes of Otago Harbour and Blueskin Bay concern possible changes to the hydrodynamics of the harbour, and the transport of sediment in the harbour and from a possible disposal site in Blueskin Bay.

Results from initial modelling of the harbour hydrodynamics suggest that the effects of a deeper channel will not be significant. The tidal wave is likely to propagate more quickly up the harbour decreasing the time phase difference of high tide between Port Chalmers and Dunedin. There is not likely to be any more than a minor change to the tide elevations (± 20 mm) or to the peak velocity of the tidal currents (± 0.04 m/s). These changes are unlikely to change the pattern of sediment transport onto or off the inter-tidal sand flats or along the margins of the channel within the harbour.

Studies for consents for maintenance dredging have shown that the effects of disposal of dredged sediment at Heyward Point, Aramoana Beach and Shelly Beach has not resulted in significant adverse effect. The addition of up to 5,000,000 $m^3$ of sediment will have a greater effect on the physical coastal environment. An initial constraints mapping exercise indicated that there are sites that could be appropriate for sediment disposal within 10 nautical miles of Port Chalmers.

Studies required to fill significant information gaps that have been identified at this point are:

- Confirm sediment characteristics and level of contaminants (to be scoped by POL) in the areas to be dredged, including the sub-bottom sediments to 15m below msl, and at potential disposal/receiving sites.
- Determine the amount and character of any rock that may need to be removed adjacent to Rocky Point, Acheron Head and Pulling Point (POL)
- Carry out detailed hydrodynamic modelling of the harbour and Blueskin Bay (NIWA).

- Carry out sediment transport modelling for the harbour and Blueskin Bay using the findings of the sediment characteristics study and the hydrodynamic model (NIWA).
- Identify any effects of the deeper channel on wave propagation and ship handling.
- Determine the potential wake and water level surge effects of potential larger vessels using the deeper channel.

The results of sampling and description of the sediment characteristics is required so that estimates of dredging volume, methods and cost can be finalised. The descriptive characteristics are also required as input to modelling sediment transport during disposal and from the disposal site so that the effects of movement of sediment can be assessed.

The outcome of more detailed hydrodynamic modelling may be that further studies are required in specific locations to assess potential effects of the project. With regard to physical coastal processes, these studies may involve assessing changes to the beaches north of Taiaroa Head to Karitane, and to beaches and inter-tidal sand flats within the harbour.

# 1. Introduction

This report is part of a collection of reports addressing the feasibility of progressing Port Otago operations through "Project Next Generation". In essence the project involves preparing Port Chalmers to service large container ships of 6000 to 8000 TEU (twenty foot equivalent units).

The physical coastal environment report covers aspects of coastal processes including:

- Hydrodynamic factors associated with the tidal and wave environments in the harbour and outside the harbour between Taiaroa Head and Karitane Point.
- Sediment characteristics of material to be dredged from the main harbour channel.
- Sedimentological factors of potential dredge spoil receiving sites, including sediment characteristics of the seabed and potential dispersal of placed dredge sediments.
- Possible effects of the dredging activities, the final dredged channel and the placed dredge sediment on the physical coastal environment and existing Port Otago dredging activities.
- Possible effects on the physical coastal environment of large container ships using the harbour channel.

The following section presents a brief description of the physical coastal environment of Otago Harbour and the area from Taiaroa Head north to Karitane Point. Section 3 presents discussion on the bullet points listed above with regard to a deeper channel, dredging to attain the deeper channel and disposing of the dredged sediment. Risk analysis is also presented. Gaps in the information on the description of the physical coastal environment and coastal processes are discussed in Section 4. The final section is a discussion of the feasibility of the project with regard to the physical coastal processes.

# 2. The Physical Coastal Environment of Otago Harbour and Blueskin Bay

### 2.1 General geography of the area

Otago Harbour is the focal point of the Dunedin City area and provides the contemporary and historical link to trade and migration into Otago. Dunedin City (population about 115,000) is located at the south-western end of the harbour. Port Otago is located at Port Chalmers (population about 1,300), on the northern side of the harbour.

Figures 1 and 2 locate places referred to in the text, and show the general location of Otago Harbour and the adjacent coastal area. The two coastal areas at the focus of this report are the harbour and the offshore area from Taiaroa Head to Karitane. This area of open coast is often referred to as Blueskin Bay, a name also used for the estuary southwest of Warrington. In this report, the estuary will always be referred to as Blueskin Bay Estuary, while the general open coast area will be referred to as Blueskin Bay.


**Figure 1** Location map of the Otago Harbour area (from NZMS 260 Series via TopoMap).


**Figure 2** The lower harbour (from NZMS 260 Series via TopoMap).

Otago harbour is approximately 20km long and averages 2.5km in width. The harbour is bounded to the south and east by Otago Peninsula, and to the north and west by the hills of Mt Cargill. The harbour is effectively divided into upper and lower sections by Quarantine Island located between Port Chalmers and Point Quarantine. The harbour has extensive areas of intertidal sand flats, located mainly on the southern side of the harbour, but also extending south from Aramoana (Figure 2).

The long narrow shape of the harbour, and the large intertidal areas, require the port areas of both Port Chalmers and Dunedin to be serviced by an artificially maintained shipping channel. Sediment dredged from the channel is deposited at receiving grounds outside the harbour at Heyward Point, off Aramoana Beach (Spit Beach site) and at Shelly Beach.

The capital dredging proposed for Project Next Generation, is to occur in the main harbour channel in the lower harbour and to the port berth area. The disposal of the sediment is still to be decided, but with a significant proportion of the volume to be disposed of offshore, then a new suitable receiving site will be required. The effects of the dredging and sediment disposal will be considered for both the lower and upper harbour, for the harbour entrance area and Blueskin Bay.

Apart from Port Chalmers, the other main communities located around the lower harbour are Careys Bay and Deborah Bay, just north of Port Chalmers, Aramoana, which lies at the northern side of the entrance to the harbour, the settlements of Otakou and Te Rauone Beach, on the shore of the eastern side of the harbour south of Harington Point, and Harwood, to the southwest of Te Rauone Beach (Figure 2).

Communities of interest in Blueskin Bay and coastal areas that may be affected by disposal of dredged sediment offshore include the settlements of Purakanui, Waitati, Warrington and Karitane, and the shores of Kaikai Beach, Whareakeake (Murdering Beach), Long Beach, Purakanui Bay, Warrington Spit, the rocky shore from Warrington to Puketeraki and Karitane.

## 2.2 Regional Geology and Quaternary history

The geology of Otago has been well documented at a regional scale. Key references include Wood (1969), Bardsley (1972, 1977), Andrews (1973, 1979), Carter *et al.* (1985), Lauder (1991), Bishop and Turnbull (1996). The studies of Scott and Landis (1975), Nicholson (1979), Cournane (1992) and Goldsmith (1995a, 1995b) provide descriptions of the geology at a local scale. Andrews (1973), Carter and Carter (1986), Thomas (1998) and Osterburg (2001, 2006) present interpretations of Quaternary and Holocene landform development.

### 2.2.1 Regional setting

The rocks that outcrop along the Otago coast, including those around Dunedin represent four major stages of geological history. They are:

1) The Basement rock - comprised of Tertiary schist;
2) Two Tertiary sedimentary sequences;
3) Three late Tertiary eruption phases of the Dunedin Volcano; and
4) Glacial and inter-glacial deposits laid down approximately 15,000 to 10,000 years BP.

Figure 3 presents a generalised regional map of the geological make-up of the study area and the wider hinterland, and shows the spatial extent of these four evolutional stages of geological history. From Figure 3 it can be seen that Otago Peninsula and the shoreline to the north to Blueskin Bay estuary is dominated by the Dunedin volcanic complex and modern alluvial deposits. The coastline north of the estuary to Karitane is characterised by Tertiary Sediments and remnants of the volcanic flows that now form the sea cliffs along this section of shore (from Nicholson, 1979: 29).

Otago Peninsula, Dunedin and Otago Harbour now lie on what is thought to be the centre of the Dunedin Volcano. The volcano took several million years to develop, with successive lava flows progressively overlapping in the westward direction upon a surface of low relief that was created by the two Tertiary sedimentary sequences. From Figure 3 it can be seen that the sedimentary sequences truncate the Basement of Otago and Haast Schists. Alluvium was laid down over the volcanic rocks during the Quaternary (last 1.8 million years). Loess deposits are also present and are thought to have been sourced from what is now the seabed, during glacial periods when sea level was significantly lower than today.

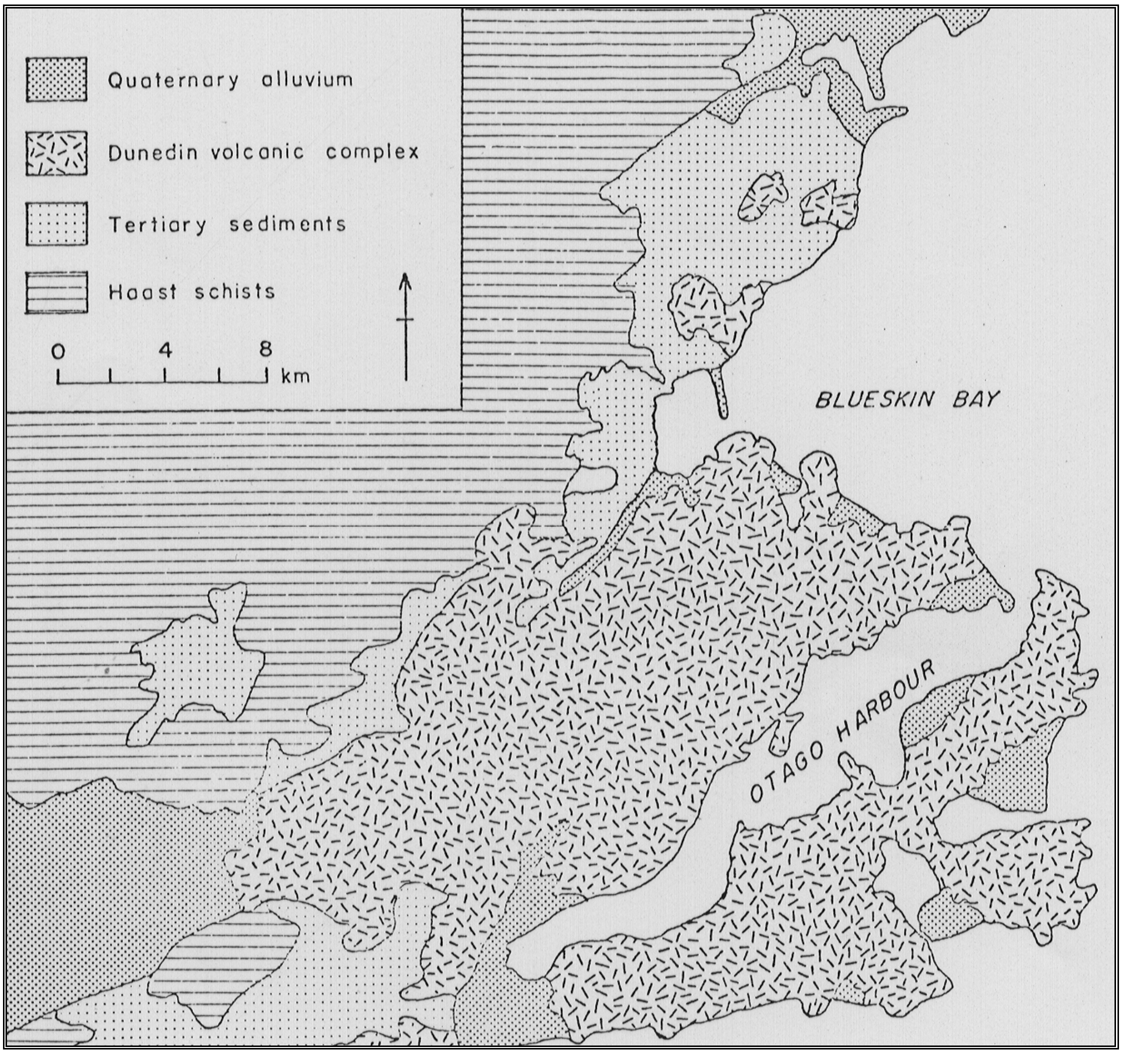


**Figure 3** A generalised map of regional geology of Blueskin Bay and surrounding hinterland.

The glacial and interglacial periods that featured during the Late Quaternary through to the Holocene were the main controlling factors of the morphology of the Otago Shelf. New Zealand's last post-glacial transgression was interspersed with standstills of sea level that were often accompanied by the construction of seaward thinning sedimentary wedges (Carter, 1986). Areas of Otago Harbour now covered with dune sands were probably fully marine less than 6,000 years BP.

### 2.2.2 Seabed sediments

It has long been acknowledged within the literature (Marshall, 1905; Andrews, 1973 and 1976; Bardsley, 1977; Nicholson, 1979; and Williams, 1979) that the quartz sands of the nearshore zone off Otago are derived from Otago Schists, with their ultimate source being the Clutha River and to a lesser extent the Taieri River. Bardsley (1977), Andrews (1973, 1976), and later Williams (1979) specifically described the mineral suite of these nearshore sediments as being made up of quartz, sodic plagioclase, chlorite, epidote, zoisite, garnet, wollastonite, and biotite, many of which are signature minerals of the Haast Schist that the Clutha River transports to the littoral zone south of Otago Peninsula.

Carter (1986) produced a sediment budget for the coast south of Otago Peninsula to Nugget Point. From this budget, he showed that the dominant source for the modern sediment (younger than 6,500 years) is the Clutha River, which delivers in the order of 3.14 million tonnes of sediment to this coastal system each year. In comparison, the much smaller Taieri River provides a mere 0.6 million tonnes per year, with nearshore and biogenic productivity providing 0.4 and 0.25 million tonnes of sediment per year respectively. Carter also noted from his study that suspended mud size particles make up over half of the modern sand input, but little is retained on the Otago nearshore shelf. Of all the sand and gravel sized material delivered to the Otago coast by the Clutha River, approximately half is stored within the large nearshore sand-wedge (Peninsula Spit), with approximately 1.1 million tonnes per year transported north under the influence of wave processes and nearshore currents to be deposited on the beaches and nearshore north of Otago Peninsula.

Figure 4 illustrates the general shelf sediment facets off Otago, where it can be seen that sediments are distributed as an inner shelf belt of modern terrigenous sand; a middle shelf belt of relict terrigenous sand and gravel; and an outer shelf zone of biogenic sand and gravel (Andrews, 1973). Beyond the shelf, relict sandy muds line the submarine canyons and slope bottom (Nicholson, 1979). The distribution of modern sands and muds that lie close to the shore reflect the location of river mouths.

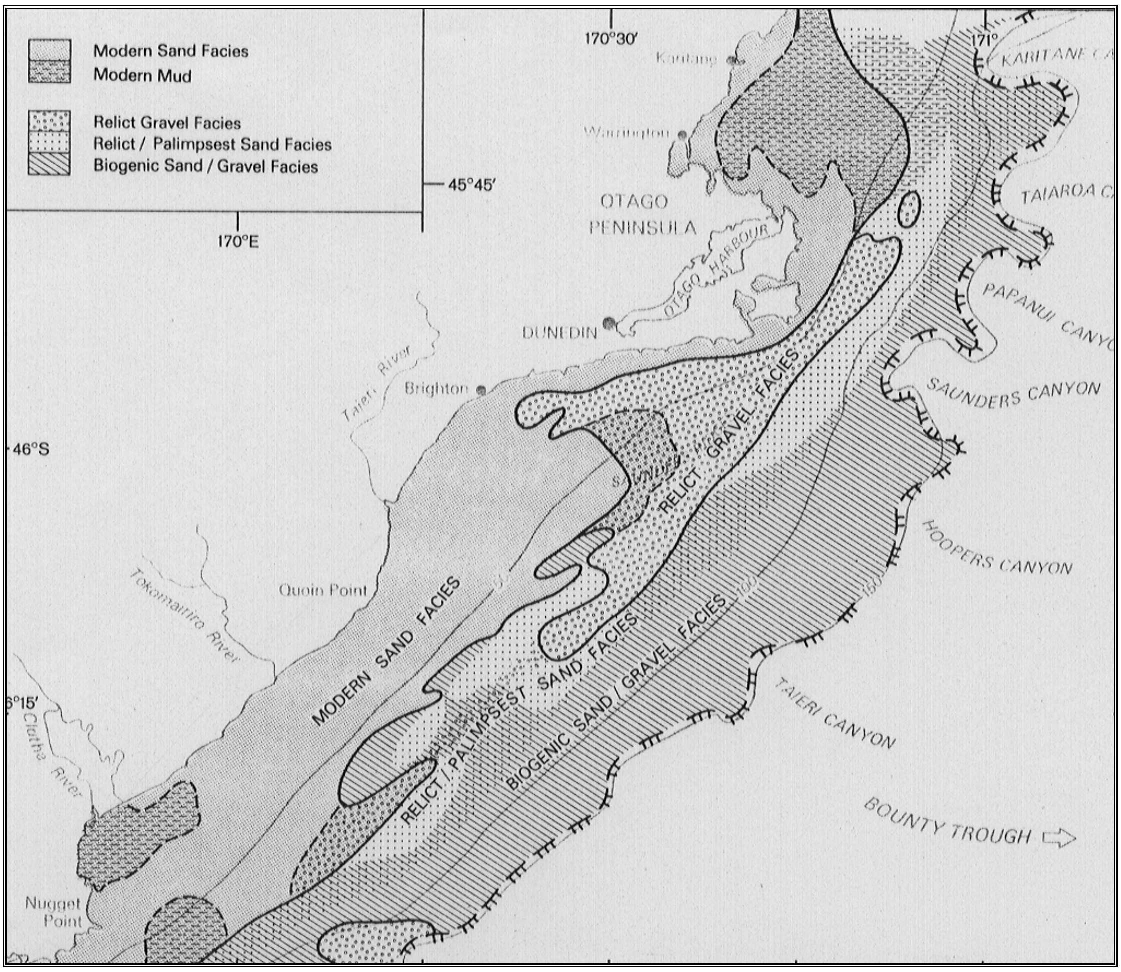


**Figure 4** Spatial distribution of five main sediment facets deposited on the South Otago shelf as identified by Andrews (1973).

A nearshore sand-wedge blankets the inner-mid Otago continental shelf, where the deposition of up to 34 metres of Holocene sediment has accumulated. The wedge appears to have evolved in two main stages. The first being the still-stand between 9,600 and 8,800 years BP when mean sea level was approximately 24 to 27 metres below where it is today. Accumulation lessened with the re-commencement of the Holocene regression and when the sea level stabilised to its present position (about 6,500 years BP), the second stage of the evolution of this sand-wedge commenced with a deposition of modern sands over the lower wedge (Carter and Carter, 1986). The sediments present on the inner shelf have important implications with regard to the type of material found at the beaches of Blueskin Bay, as the source of the beach sediments is almost entirely from offshore.

A submarine feature in the form of a submerged spit is situated off Otago Peninsula (referred to as 'Peninsula Spit' by Carter and Carter, 1986). It is a product of the inner continental shelf sand-wedge. The submerged spit is approximately 25 kilometres long, tapering from 3 to 4 kilometres width where it abuts the northern shore face of Cape Saunders and fades out northwards on the mid shelf off Karitane. Separate to this submarine feature, is the ebb-tide delta of Otago Harbour. The shipping channel truncates the delta.

## 2.3 Otago Roads

### 2.3.1 Wave Environment

Wave energy is the most important physical factor effecting the nature and direction of coastal and inner shelf sediment movement. This is due to waves being the principle process factor with regard to the amount of work done at the shore (a function of wave energy) and the type of work done at the shore (a function of wave shape), whether this is accretional or erosional. Therefore, incident waves play a very important role in short and long-term beach stability, beach form and evolution, and have a direct effect on nearshore processes that are considerably greater than tides, currents and winds.

**Offshore wave environment**

The most frequent wind directions for the area of Blueskin Bay are from the north / northeast and south / southeast. It should be expected that the direction of wave propagation into the bay also be from these directions.

Very few studies have directly measured the wave climate of the nearshore environment within Blueskin Bay. Instead data from local studies of directions of deepwater wave approach obtained from ship records, and hindcast modelling of the wave environment have been used to determine the wave climate of the Otago nearshore area. Many studies, including research by Pattle (1974), and Hewson (1977) have shown that the East Coast of the South Island is dominated by oceanic southerly swell waves, with local waves playing a secondary role. Nicholson (1979) presented a review of data obtained from ship observations, a drilling rig off the North Otago Coast, and those observations made onshore by Hodgson (1966), where he noted that the southerly swell component is generally a longer period wave when compared to other waves that are generated locally. From this data Nicholson calculated that, north-easterly swell occurred 29.2% of the time, with swell arriving from the east (probably either refracted southerly or easterly deepwater waves) occurring 44.7% of the time. The predominate offshore wave height as obtained by Nicholson (1979) was 1.5 - 2 metres (making up 47.3% of all occurrences) with waves of heights between 3 - 6 metres occurring 26.3% of the time. As longer period waves generally have greater energy for a given height, Nicholson concluded that the southerly swell plays the most important role in sediment movement along the inner shelf east Otago Peninsula.

Sanford South Island Ltd (2001) assessed sea state conditions at Taiaroa Head recorded over a 40-year period (1961 - 2001). The data showed that swell waves predominantly propagate from the northeast, and these waves are generally low in height. Southerly swell waves are the second most dominant wave, and are larger than those propagating from the northeast. The data also showed a seasonal trend with occasional large wave energy events with wave heights greater than five metres typically experienced during the autumn and winter months. Such waves propagate from the south and southeast and refract around Taiaroa Head into Blueskin Bay.

**Wave climate of Blueskin Bay**

Recent work by NIWA for Project Next Generation (Oldman, Bell and Stephens 2007) has used a 20-year WAM wave hindcast for an area 3 nautical miles due east of Taiaroa Head at approximately 170.778°E, –45.774°S to represent the wave environment. Based on the hindcast data, the mean significant wave height $H_s$ (average of the highest 1/3$^{rd}$ of waves) was 1.1 m, mean wave approach direction $D$ (coming from) was 125° (i.e. from south-east) and the mean wave period $T_m$ was 6.4 seconds. The distribution of significant wave height ($H_s$) and mean wave period ($T_m$) are shown in Figures 5 and 6 respectively. The directional distribution of the waves at this site is shown in Figure 7.

With the beaches of Blueskin Bay being situated on the leeward side of Otago Peninsula this section of coastline is also leeward from the dominant southerly swell. Although the southerly swell is still a dominant wave within Blueskin Bay, Hodgson (1966) noted that its intensity and effectiveness is considerably reduced by the effect of wave refraction, and that within this leeward area local winds play a more important role in wave propagation.

The movement of nearshore sediment is determined by both the angle at which the waves approach the shore and the amount of energy reserved in the waves from the open sea. The direction of wave approach to the shoreline is dependent upon the direction of the generating winds, and also the configuration of the near-shore environment. The near-shore influences the approaching waves through refraction.

The amount of refraction experienced by longer waves is always much greater than for short waves as they 'feel' the influence of the seabed sooner. As a result swell waves are often seen breaking parallel to the shore.

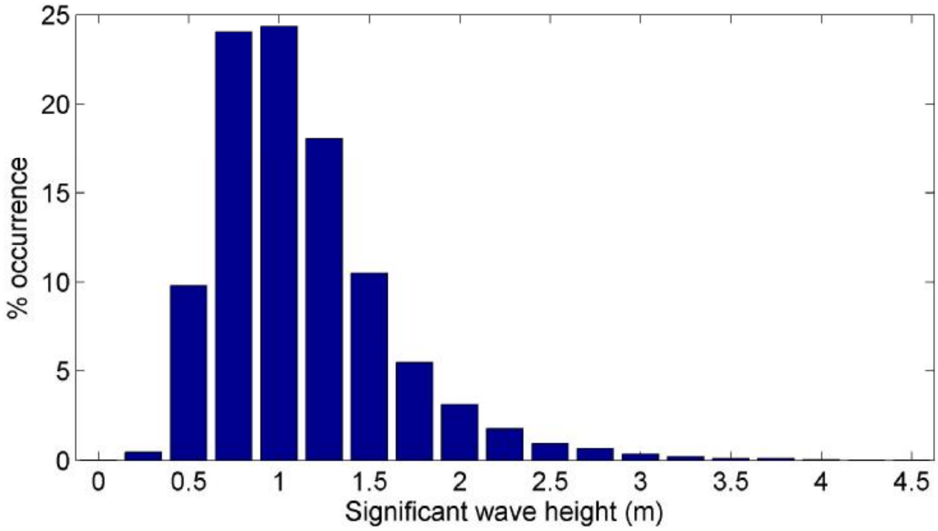


**Figure 5** Distribution of significant wave height from the 20-year (1979–98) wave hindcast model at a site located 3 nautical miles due east of Taiaroa Head.

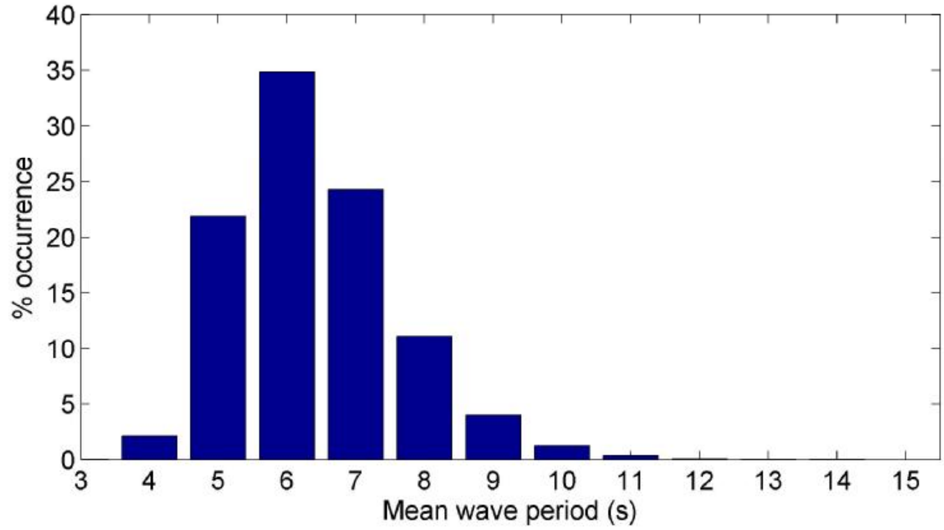


**Figure 6** Distribution of mean wave period from the 20-year (1979–98) wave hindcast model at a site located 3 nautical miles due east of Taiaroa Head.

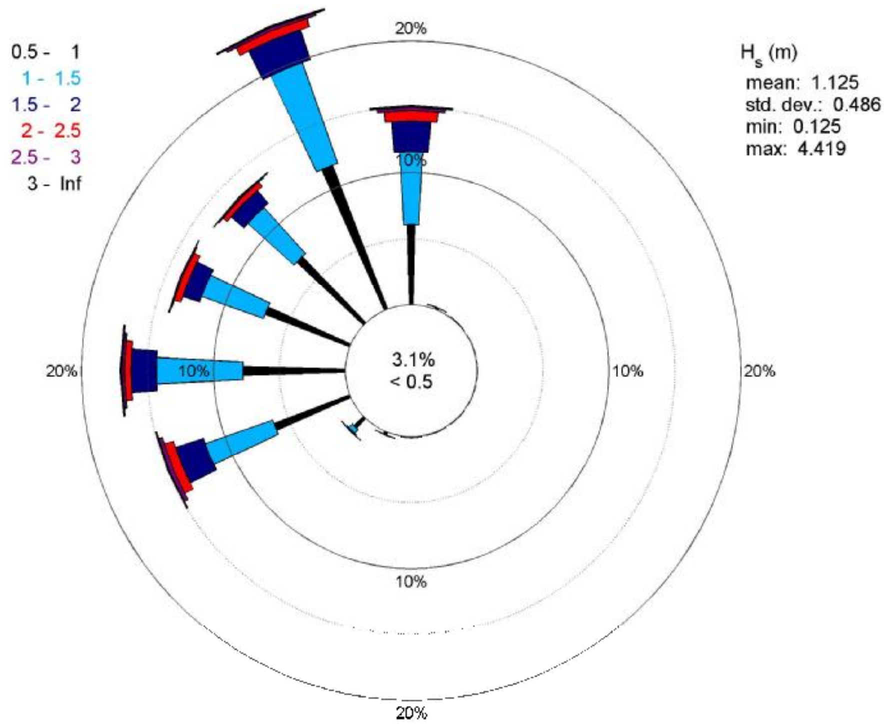


**Figure 7** Wave rose from the 20-year (1979–98) wave hindcast model at a site located 3 nautical miles due east of Taiaroa Head. Directions are shown in the direction to where the waves are travelling.

Refraction is important when considering the amount of energy delivered to the coastline by a given wave train, and is also an important factor with regard to wave energy received by the beaches of Blueskin Bay. The change of wave direction of two or more parts of a wave crest results in convergence or divergence of wave energy. Within Blueskin Bay the submarine contours follow closely that of the shoreline, and hence, wave refraction occurs at different locations at different times. Concentration of energy (greater wave heights) is experienced on headlands, and dispersion of energy (smaller wave heights) occurs within bays.

Nicholson (1979) approximated both factors with the aid of refraction diagrams for the two dominant wave modes. These refraction diagrams are shown here as Figures 8 and 9. Nicholson noted that an 8 second wave (representative of swell waves propagating from the north-east) first felt the seafloor at a water depth of 49.8 metres. The gradual shelf slope that characterizes Blueskin Bay means that the shorter period waves undergo little refraction until close to the shore. Consequently there is little loss of deepwater wave energy as the northeasterly waves move across the shelf. This results in most of the wave energy from this source being expended at the shore. It can be seen from Figure 8 that under these conditions, waves approach obliquely to the shore from Purakanui northwards. South of Purakanui to the Harbour Entrance, wave approach is shore-parallel.

In contrast, the longer period southern swell waves begin shoaling 6 to 7 kilometres offshore. Figure 9 shows a refraction diagram of a 12 second wave that is representative of swell waves emanating from a southerly direction. Such waves first 'feel' the bottom at a water depth of 112.3 metres, thereafter beginning to refract. Although a longer period wave and therefore of higher energy for a given height than the northeasterly wave, the southerly undergoes intense refraction to arrive parallel to the Blueskin Bay beaches. Consequently wave energy levels generally tend to decrease from north to south along the coastline towards Otago Peninsula. It can be seen from Figure 9 that north of Warrington Spit and Seacliff, waves need to undergo less refraction to arrive parallel to the coast and as a result wave energy spent on these beaches is greater than those located further south. This means that an energy gradient is produced thus promoting a northerly transport of sediment under southerly swell conditions increasing in a northeastwards direction.

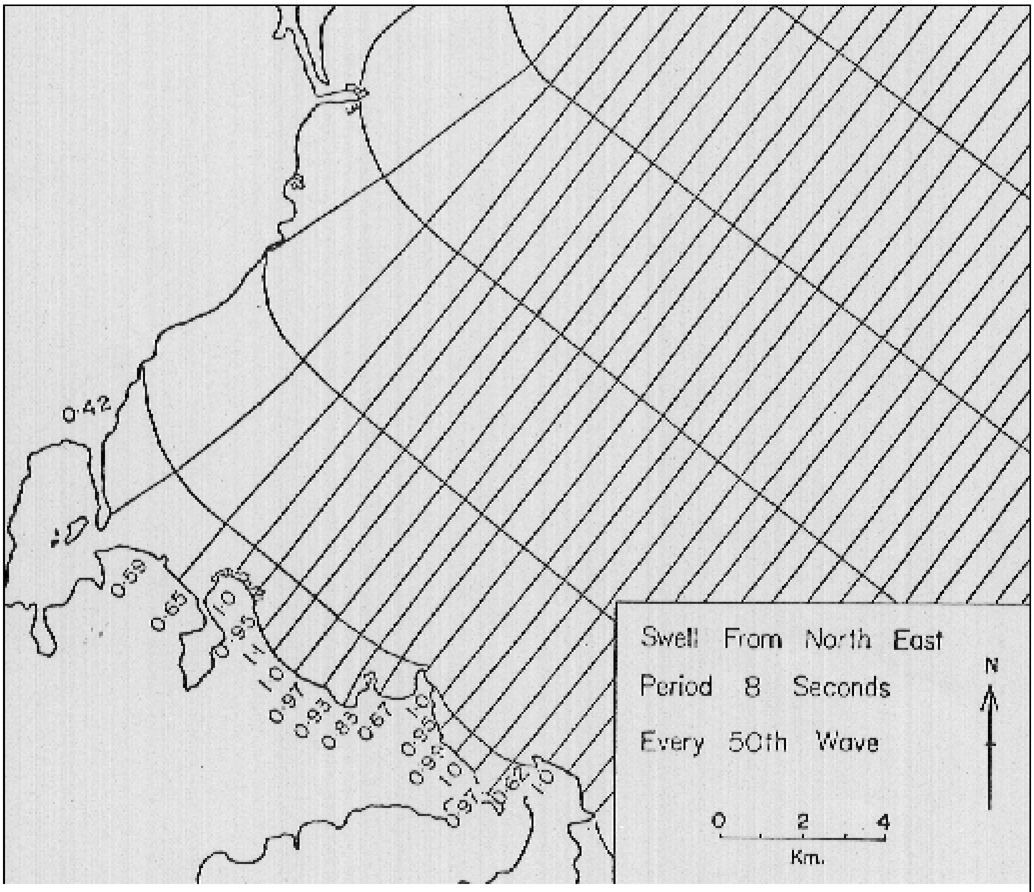


**Figure 8** Wave refraction diagram for a northeasterly swell entering Blueskin Bay with a wave period of 8 seconds. NB every 50th wave is shown (Nicholson, 1979).

The wave climate of Blueskin Bay can be summarised as being 'quieter' than the outer Otago shelf and those beaches south of Otago Peninsula, with the bimodality in local wind conditions being reflected also in the wave environment in Blueskin Bay. Of the waves that do enter the bay, strongly refracted southerly swell dominates but refraction lessens its intensity. The northeasterly locally generated waves are unimpeded within the bay, although they are generally less powerful than the southerlies affecting the outer-shelf. Overall the regime within Blueskin Bay can be described as a low energy coastal environment that experiences periodic high-energy storm waves propagating from the south.

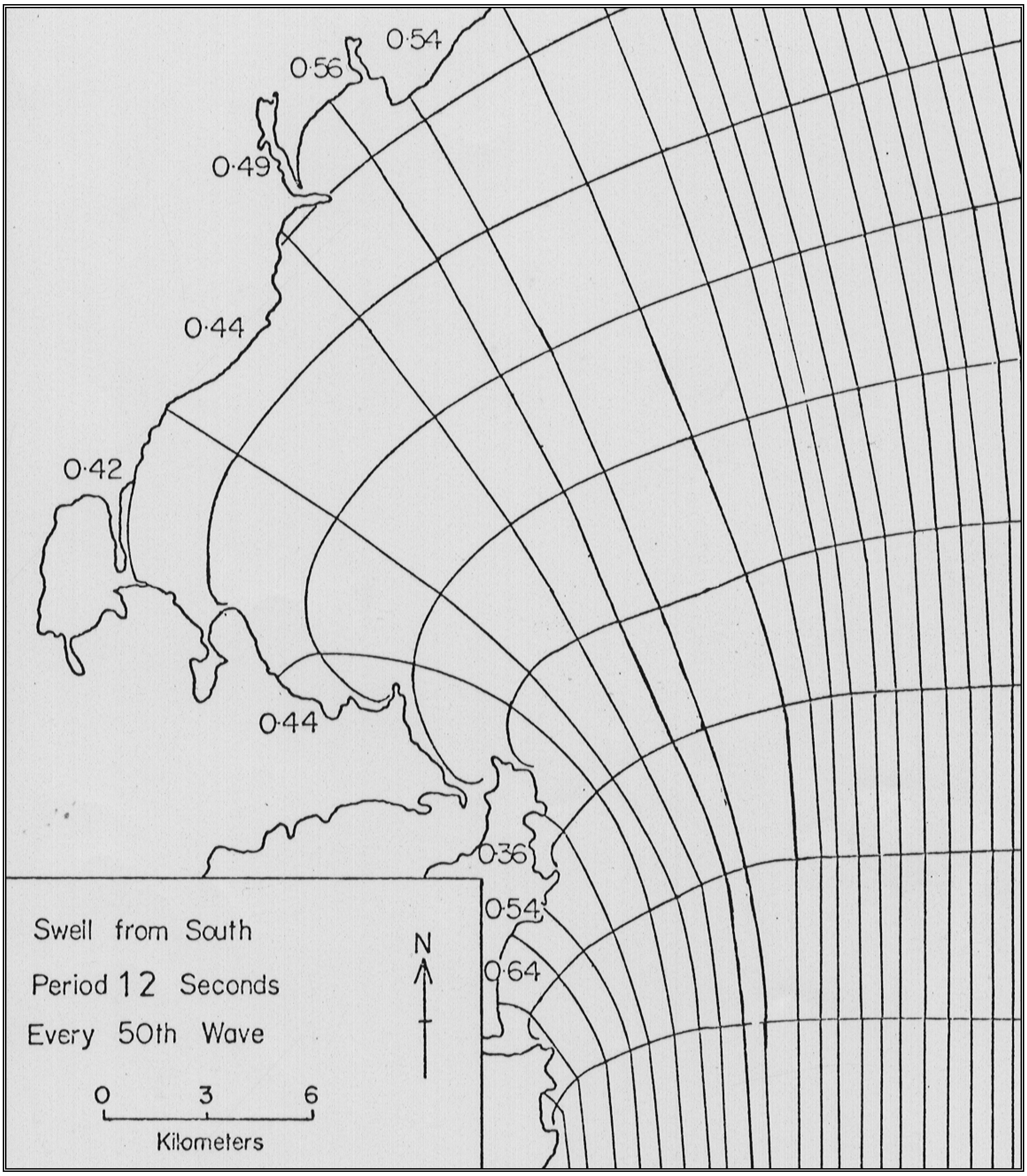


**Figure 9** Wave refraction diagram for a southerly swell entering Blueskin Bay with a wave period of 12 seconds. NB every 50th wave is shown (Nicholson, 1979).

### 2.3.2 Tidal Currents

At a regional scale many reports have described the southern current that moves northwards up the East Coast of the South Island. Also well recognised (Andrews, 1973; Carter, 1986; Carter and Heath, 1975; Nicholson, 1979; and Murdoch *et al.*, 1990) is the disruption that

Otago Peninsula has on this northward current, by forcing an anti-clockwise 'eddy' to form in its lee. This eddy, when considered together with the wind and wave processes has a direct effect on nearshore processes within Blueskin Bay.

At a local scale McLintock 1951 noted the wave currents together with those of the tide combine to transport sediment inshore and eastward along Aramoana and Shelly Beaches. Royds Garden (1990) present results of modelled tidal currents at the harbour entrance and they too recognised these effects of tide and wave generated currents.

Recent studies have examined the tidal currents through the harbour entrance (Old 1998, 1999; Old and Vennell 2001). There is a strong asymmetry between the ebb and flood flow structures. While the ebb flow extends beyond 2km from the entrance, the flood flow is limited to within 600 m of the coast. Further results of these studies are presented in the section on Otago Harbour.

### 2.3.3 Bathymetry

Figure 10 shows the bathymetry of the area offshore from Otago Harbour.

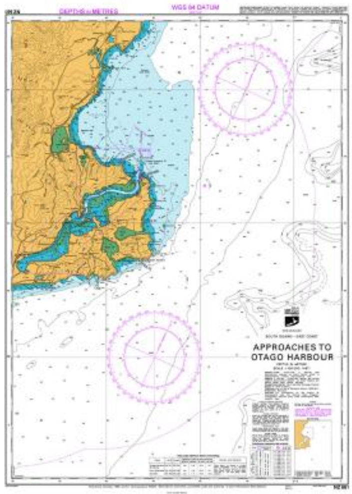


**Figure 10** New Zealand Hydrographic Chart NZ661 Approaches to Otago Harbour (Thumbnail download LINZ.co.nz).

The width of the continental shelf out from Taiaroa Head is approximately 30km. The seabed slopes gently to depths of 100-250m at the edge of the shelf. A series of drowned Quaternary shorelines have been identified across the shelf. The seabed of Blueskin Bay slopes to a depth of 30m at a distance of about 17km from Warrington Spit. The contour at 30m forms a near straight line from south to north starting from about 5.5km offshore of Taiaroa Head. A large submarine “spit” form is located landward of the 30m contour. The crest of this feature grades from about 20m depths at the southern end to 30m depths at the distal end. The depth inshore of the feature is about 30m in an area northeast of the dredged channel. The general slope of Blueskin Bay is towards the northeast.

The dredged sediment disposal grounds at Heyward Point and Aramoana form small sand-hills on the general seabed topography. In 2004, the crest of the Heyward Disposal site was about 9m below MSL, sloping north to the general seabed level of about 11m depths. The change in seabed topography since 1974 is equivalent to about 43% of the total placed dredged sediment (since 1974). The crest of the mound at the Spit Disposal site in 2004 was 5.7m below MSL, sloping gently to the general seabed level of 9m below MSL. There has been slow accumulation at the Spit site since 1983, equivalent to about 44% of the total dredged sediment placed at the site. The accumulation of sediment at the sites includes placed sediment and sediment passing through the area naturally due to nearshore sediment transport processes.

### 2.3.4 Sediment Characteristics

The textual characteristics of the nearshore sediments can be described as medium to fine sand, with a mean diameter between 3Ø-2Ø (0.125mm – 0.14mm), well to very well sorted, and strongly positively (finely) skewed (Elliott, 1958; Andrews, 1973; Hamel and Bar, 1974; Bardsley, 1977; Nicholson, 1973; Rainer, 1981; and Carter ***et al.,*** 1985). Carter ***et al.*** summarised the textual nature of the nearshore as being homogeneous in that

> *"Close inshore the sediment has no discernible textural trend"* p13

The only exception to this textural trend is that of the ebb tide delta situated at the harbour entrance. Andrews (1973) described this local area as being very coarsely skewed.

Single and Kirk (1994) and Sanford South Island Ltd (2001) also describe the sediments as being fine sand 2.51Ø - 1.6 Ø (0.17-0.33mm), well to very well sorted, and either near symmetrical or fine skewed. Kirk (1980) describes a coarser fraction of sediment in the location of the harbour mouth, consistent with Andrews' (1973) description. Furthermore, Kirk observed that the sediments to the north of Otago Peninsula and those further offshore exhibit similar textural characteristics, and proposes that the relatively homogenous nature is consistent with a single dominant source for the material.

Bunting *et al.* (2003a) found that the sediments of the beaches and nearshore between Taiaroa Head and Karitane range from 2.75Ø (0.15mm) to 1.61 Ø (0.33mm) and that these correspond to descriptive classifications of fine sand to medium sand respectively. The most notable feature of these data is that a large proportion (85% of all samples) of the sediments are fine sand size, that is 2.55Ø to 2.08Ø (0.17mm to 0.24mm).

The sediment of the nearshore is predominantly very well sorted, although sorting values range from 0.05Ø (very well sorted) to 0.74Ø (moderately sorted). The spread of values is indicative of varying degrees of energies acting upon the shoreline between Karitane and Taiaroa Head, with anomalies away from the general trend of very well sorted sediment confined to localised areas.

The textural characteristics of the sediments compare well between studies that span 44 years. It can therefore be concluded that the physical nature of the sediments of the coastal system between Taiaroa Head and Heyward Point have not changed significantly over the period since the study by Elliott (1958). The findings of Bunting *et al.* (2003a) also show that the disposal of the sediment dredged from the shipping channel of Otago Harbour offshore at the Shelly, Aramoana, and Heyward Point has not changed the textural nature of the coastal sediments. These areas do not appear to stand out as anomalies from the surrounding seabed.

The above description of the textural characteristics of the beaches and seabed within Blueskin Bay provides a useful mechanism to aid in the understanding of the processes that are responsible for the deposition and transportation of the sediments. This section of the Otago coastline possesses a relatively homogeneous size range of fine sand. This is likely to be a direct effect of two dominant factors. The first is that the main contemporary source of sediment to the coastal system is from one dominant source, the Clutha River. The second is that a relatively consistent and narrow range of energy is received in the nearshore and at the shore. This, together with a single dominant sediment source, is mirrored in the small standard deviation of the sediments and unimodal distribution. Moreover, the finely skewed samples obtained between Heyward Point and Karitane indicate that small streams and the Blueskin Bay Estuary are responsible for the supply of fines to this section of shore. These are additional to the main dominant sediment source. This is also reflected in the slightly less well-sorted material north of Heyward Point.

### 2.3.5 Sediment Transport Paths

Work for dredged sediment disposal consents by Kirk (1980), Single and Kirk (1994) and Bunting *et al.* (2003a, 2003b) determined sources, sinks and transport routes of the nearshore and beach sediments from Taiaroa Head to Heyward Point using a concept of “rollability”. This method considers the sediment from the whole environment in a relative manner. Sources and sinks of sediment can be identified. These indicate where sediment is travelling from and to, respectively. This method can be used to infer transport pathways but not rates or volumes of sediment movement

The main sediment source areas were identified as the shore of Mapoutahi Point (between Purakanui Bay and Blueskin Bay Estuary), Warrington Spit and the beach at the northern end of Long Beach. There are two secondary source areas of sediment. These are the area offshore and the beach at Karitane and the offshore area between Warrington Spit and Brinns Point. The main sink area is north of Taiaroa Head to Heyward Point.

The rollability analysis distinguished two separate coastal compartments. Sediment sources dominate the nearshore between Heyward Point and Karitane Peninsula (the northern compartment). The implied sediment transport direction for the area is movement onshore and alongshore from Karitane to Warrington Spit and also south toward Heyward Point. Where Warrington Spit abuts the hinterland a source area is present. From here a strong gradient exists along the length of the spit to a dominant sink at the tip. This strong gradient is further enhanced with the presence of a large source area at the entrance to the Blueskin Bay Estuary. Such a pattern points to this area as being a very dynamic and active section of the nearshore. Alexander and Cassy's Creeks feed into the estuary and are likely to supply sediments to the estuary in combination with the longshore transport of sediment along the spit to the inlet by Doctors Point.

Sediment sinks dominate the coastal area south of Heyward Point to Taiaroa Head, including the entrance to Otago Harbour. Two strong sink areas exist, one being located between Heyward Point and the Heyward Point disposal site, and the other north of Taiaroa Head, east of the harbour channel. This latter sink is likely to be the product of sediment being deposited into the wider Blueskin Bay coastal system as part of the northward transportation of material up the east coat of the South Island and also the deposition of sediment that has been flushed out from Otago Harbour by the ebbing tide. The rollability analysis also indicates that longshore transport of sediment is dominant over onshore or offshore transport.

The relative role of the northern compartment acting as a source of sediment for the southern compartment between Taiaroa Head and Heyward Point is also indicated from other descriptive sediment characteristics. An increase in sorting, and gradual increase in positive skewness values in a southerly direction was found in the sediment samples.

Overall, both rollability and the sediment textural characteristics show that the northern coastal compartment acts as a source of sediment to the southern compartment together with the southern current that delivers sediment up the east coast. Furthermore the three dredged sediment receiving areas do not appear to feed sediment north into Blueskin Bay Estuary (a concern raised with regard to the disposal of maintenance dredging), nor do they appear to feed sediment into the dredged channel that extends out through the ebb-tide delta from Otago Harbour.

### 2.3.6 Shores

The volcanic rock (prominently basalt) that abuts the shoreline north of Otago Harbour forms a contemporary back-beach cliff at Aramoana, Kaikai, Murdering, and Long beaches. These cliffs were created during the first and second eruptive phases of the Dunedin volcano (Benson, 1969). The presence of well water-weathered, rounded basalt cobble ridges at the foot of these cliffs suggests that the initial source of beach sediment to the coastal system was direct wave attack upon these high basalt cliffs. It is evident that the contemporary quartz sands that make up the beaches have an origin different than that expressed in the local geology. The remoteness of these beaches from active river sources suggests beach sediment is obtained directly from the Otago shelf and has been deposited onshore within the original geological setting. It can be concluded that the present day beaches between Taiaroa Head and Karitane are modern (in geologic time) depositional features.

There are three types of shoreline that make up the study area. These are:

1) Bay-Head Beaches;
2) Spit Complexes; and
3) Sea Cliffs.

Kaikai Beach, Murdering Beach, Long Beach, and Karitane Beach are all bay-head beaches. The morphology of all four of these beaches is very similar. At the southern locations, a sand beach fronts a now fossil, sea-cut cliff. Karitane has a bay-head beach formed in alluvial deposits flanking Karitane Peninsula. Warrington Spit, Purakanui Beach, Aramoana and Shelly Beach at the entrance of Otago Harbour are all sand-spit complexes. Sea cliffs, the third shore type make up the Headlands of Taiaroa Head, the shore from Warrington to Green Point, and Karitane Peninsula.

Collection of Maori artefacts from excavations at the foot of the fossil seacliffs confirms that the beaches are very recent in origin. The artefacts have been the subject of studies by Skinner (1953, 1959) and Lockerbie (1959). Skinner (1958) described a section taken from Long Beach where;

> *"18 inches below the clay lay the bottom of one edge of an earth oven"*
> p400

Skinner noted that the bed between the earth oven and recent clay layer was composed of sand and included fish and bird bones, shells, and a human toe bone. Below the oven was a deposition of wind blown sand that rested upon old beach sand. The old beach was partly quartz sand and sands of volcanic origin, a product of the eroded volcanic cliffs. This evidence of charcoal, earth-ovens, and artefacts suggests that Maori occupied these beaches when the shoreline was at the base of the cliffs. As Maori first occupied New Zealand no more than about 1200 years ago, the evidence provided by these excavations present further confirmation that the beaches within Blueskin Bay have formed within the last 1000 years, and they are a relatively recent feature of this coastal environment.

The nearshore processes of Blueskin Bay are predominantly low energy with respect to the outer Otago shelf. As a result the bay is a depositional environment, acting as a re-entry trap to catch the northeast sediment drift along the Otago shelf.

Once within the coastal system of Blueskin Bay, the sands are reworked by a variety of local processes and transported into the smaller bays and onto the beaches. Within the beaches immediately north of Otago Peninsula, longshore drift occurs in both directions along the shore (northward during southerlies and southward in north-easterlies). Although the net direction of drift is not large, it is in a northward direction.

Nicholson (1979) and Kirk (1980) have described the coastline north of Otago Peninsula as displaying active and rapid progradation. Superimposed on this long-term trend are short-term periods of erosion and deposition, a feature that is typical of sand beaches. With the aid of shoreline surveys and aerial photographs, Nicholson calculated rates of shoreline change for the period between 1863 and 1979 and found considerable rates of progradation at Long Beach and Purakanui Spit. Between 1975 and 1997 progradation was nearly zero and these beaches appear to now be in a state of relative stability.

Table 1 shows the long-term net change to the shoreline position. Long Beach has advanced seaward by about 206 metres since 1863, at a long-term rate of 1.83 metres per year. The seaward face of Purakanui Spit has moved seaward by about 360 metres, at a rate of about 2.7 metres per year. It can also be seen from Table 1 that there appears to be a decline in this rate of shoreline advance in a southeastward direction towards the harbour entrance where Kaikai Beach presents a long-term near-stable beach state, and Murdering Beach is moderately erosional, retreating approximately 173 metres since 1863. These measured rates of change indicate that differential supply of sediment to adjacent beaches is occurring and also different wave energies are spent on the beaches.

Warrington Spit advanced approximately 97 metres between 1967 and 1997 at a rate of about 3.23 metres per year. However this shoreline eroded 28 metres between 1975 and 1997. Some sections of the shore between Warrington and Karitane are known to be erosional, with past erosion at Karitane presenting hazard to a roadway and Karitane School.

**Table 1** Summary of net rates of shoreline change at Warrington Spit, Purakanui, Long, Murdering, and Kaikai Beaches, 1863 to 1997 (adapted from Nicholson 1979 and Bunting *et al.* 2003a).

| LOCATION | NET SHORELINE CHANGE (m) | RATE OF CHANGE (m/yr) |
|---|---|---|
| Warrington Spit (1967-97) | +97.03 | +3.23 |
| Purakanui | +358.8 | +2.68 |
| Long Beach | +206.3 | +1.54 |
| Murdering Beach | -173.5 | -1.29 |
| Kaikai Beach | -18.6 | -0.13 |

NB: + denotes shoreline advance, - denotes shoreline retreat.

Bunting *et al.* (2003a) present an analysis of beach profile surveys carried out at Aramoana, Murdering Beach, Long Beach, Purakanui, Warrington Spit and Karitane between 1990 and 2003. Storm incidence and onshore winds result in short-term changes to the beach profiles in the form of erosion and accretion. Over that time period dune and upper foreshore growth had occurred on all of the beaches except Karitane.

#### 2.3.7 Human Activities

Human activities have modified the physical coastal environment of Blueskin Bay and the approaches to Otago Harbour in three main ways:

1. By modification of the harbour inlet form and stability through construction of the Mole and Long Mac, and by dredging of the harbour channel,
2. Disposal of dredged sediment at the Heyward and Spit sites,
3. Disposal of dredged sediment at Shelly Beach.

Armstrong (1978) and Goldsmith (1995a, 1995b) describe human modifications to Aramoana Beach and the harbour inlet from the 1840s onwards through the construction of training walls and groynes, and dredging of the inlet channel. Between 1846 and 1994, shoreline position and sediment transport at Aramoana was significantly altered by coastal engineering structures. Progradation of Aramoana Beach after the Mole construction indicates sediment has accumulated on the updrift side. The beach area between the mole and Harington Point (Shelly, or Spit Beach) retreated rapidly after the construction of the Mole, indicating the beach is on the downdrift side of the Mole and starved of sediment. The position of the channel has remained effectively fixed because of the training works.

Maintenance and development dredging of the shipping channel in Otago Harbour has been carried out since 1865. Sediment dredged from the channel and port areas has been deposited offshore at the Heyward site since 1930 (Lusseau 1999), the Aramoana (Spit) site since 1983, and the Shelly Beach site since 1987. There is no record of what happened to dredged sediment prior to 1930, but some was used in reclamations around the harbour, and some (possibly up to 1.5 million "hopper yards") was placed in the vicinity of Te Rauone Beach.

Leon (2005b) presents an analysis of the volumes of sediment placed at each site, and the changes to the seabed topography for the period 1974 to 2004. The total dredged sediment placed at the Heyward site over that period is 3,170,000 $m^3$, the total dredged sediment placed at the Aramoana (Spit) site between 1983 and 2004 is 2,650,000 $m^3$, and the total dredged sediment placed at the Shelly Beach site between 1987 and 2004 is 362,000 $m^3$.

In addition to sediment disposal from the maintenance dredging, about 3.2 million $m^3$ of sediment was disposed of in the vicinity of Heyward Point as a result of capital dredging of the lower harbour in 1976 (Lusseau 1999).

Changes to wave refraction over the disposal sites is unknown. There is no documented evidence of localised erosion or changes to the wave environment in the vicinity of the Heyward site or at Aramoana Beach. However anecdotal evidence from fisherman, and from surfers at Aramoana indicate the possibility of some changes to the pattern of breaking waves due to the presence of the disposal sites.

Sediment placed at the Heyward site disperses quickly from the main location of placement (usually in the southeast corner of the site), and there is no direct relationship between the volume of sediment placed at the site and changes to the volume of sediment at the site over time. Sediment accumulation at the Aramoana (Spit) site initially moved shoreward, but then areas of accumulation changed to be near the seaward limit of the site. It is likely that the position of accumulation in any year is related to the position of placement, as dispersal from the placement area is relatively slow. Analysis of historical data shows that Aramoana Beach has been accreting since the construction of the mole. Accumulation of sediment on the disposal site has also occurred during years when no dredged sediment has been placed there. It is likely that a combination of natural and human sediment inputs are occurring at Aramoana.

At Shelly Beach, sediment placement has been carried out in part to provide sand as nourishment to the eroding beach, and in part for economic reasons. A significant erosion hazard was identified for this beach in the early 1990s (Johnstone 1997, Single and Stephenson 1998). Retention of placed dredged sediment on Shelly Beach and in the nearshore south of the Mole has resulted in mitigation of the erosion hazard to the beach (Leon 2005a).

## 2.4 Otago Harbour

Lauder (1991) identified the major geological features and physical systems of the harbour. The geological description of the harbour from Wood (1969) and Scott and Landis (1975) is summarised in the Royds Garden (1990) environmental impact assessment of dredging in Otago Harbour. Figure 11 shows the bathymetric map of the harbour.

The harbour was formed by volcanism during the late Miocene (over 5 millions years BP) and crustal folding of a syncline during this period. During the Holocene and since the end of the last glaciation (about 15,000 years BP), the harbour basin has flooded with seawater and infilled with sediment. Rising sea level between 9,600 and 6,500 years BP swept sand into the harbour from a large spit formed north of Otago Peninsula. South of Otago Peninsula, a tombolo built out from St Clair to join what was an island to the mainland. Lauder (1991) puts the age of the harbour as about 6,000 years, and since its formation has been subject to infilling from sand swept in from the continental shelf and from sediments eroded from the catchment hills.

Scott and Landis (1975) and Cournane (1992) identified the Aramoana tidal flats as a relict feature from 6,000 to 3,000 years BP. From seismic tests, Cournane found that the Tertiary rocks on both sides of the harbour were not continuous under recent harbour sediments, and suggested that the thickness of the sediment layer at Aramoana over the basement rocks was about 85m. Borehole data also indicated significant sub-surface mud layers up to 8m thick in the lower harbour that may become exposed to erosion in the shipping channel at depths greater than 12 to 15m.

**Figure 11** New Zealand Hydrographic Chart NZ6612 Otago Harbour (Thumbnail download LINZ.co.nz).

The tidal compartment of the harbour (the amount of water flowing in during a tidal cycle) is between 69.3 x $10^6 m^3$ and 75 x $10^6 m^3$ (Quinn 1979, Royds Garden 1990). The tidal range is 1.98m Spring and 1.25m Neap at Port Chalmers and 2.08m Spring and 1.35m Neap at Dunedin (HydroLinz website).

Old (1999) and Vennell and Old (1999) have investigated the tidal hydraulics of the harbour. They found that high tide at Port Chalmers occurs around 10-15 minutes after high tide at the Spit, and there was a tendency for the time difference to be slightly smaller during spring tides and slightly larger during neap tides. The time difference for spring low tides between the two sites is up to 50-60 minutes, and for neap low tides the difference is 35 minutes. The tidal time differences are explained by the tide wave travelling up the harbour faster with increased water depth. Therefore it travels faster during neap low tides than during spring low tides. This confirms Wilson's (1989 and Wilson and Sutherland 1991) findings from sensitivity analysis, that depth and frictional resistance have the greatest influence on tidal propagation.

Old (1999) found for the ebb tide, that slack water occurs around the time of high water at Port Chalmers, with a weak eddy present. Consistent ebb flow forms 30 minutes after high water but is confined to within 500 m of the mole tip. An ebb tide jet begins to form around 1 hr after high water, narrowing and strengthening to peak around 3 hrs after high water. During flood tide, peak flows of 1.59 $m.s^{-1}$ occur at the southern end of the spit on the western side of the channel due to constriction between Harington Point and the Long Mac and shallow water. However, no sediment scouring occurs here due to sediment supply from Shelly Beach behind the Long Mac.

On the ebb tide, peak flow velocity of 1.36 $m.s^{-1}$ occurs on the eastern side of the channel near the centre of Harington Bend. A deep scour hole that effectively increases the inlet cross-section area prevents maximum velocities occurring at the narrow entrance of Harington Point, where it would be expected. At the harbour entrance, ebb tide maximum velocity is 1.03 $m.s^{-1}$. On the western side of the channel the flow is sinusoidal over a tidal cycle but the ebb flow has a pulse-like, high velocity nature upon leaving the harbour and the flow across the entrance bar has a strong ebb-dominated asymmetry. Tidal flow has a flood-dominated asymmetry on the eastern side of the entrance near Taiaroa Head (peak velocity = 1.15 $m.s^{-1}$) caused by constrictions of the entrance and ebb flow jet that produces a westward sediment entrainment flow from the eastern side.

The flood tide period is shorter and its flow is stronger than the ebb tide, therefore the harbour is flood dominated and sediment will naturally move into the harbour and infill it. Tidal flows and sediment analysis show that a large volume of sediment can move within the harbour as bedload. Sediment is deposited at Harington Bend during flood tide and removed on the ebb, thus there is some balance between sedimentation and scour in this part of the channel.

Lauder (1991) notes that the harbour has been substantially modified by human activity by reclamation, causeway and jetty construction, dredging and channel stabilisation, catchment modification and lining the harbour shoreline with seawalls. Reclamation has resulted in reduction of the harbour tidal compartment. However Wilson (1989) found that MSL at Dunedin had decreased 40mm since 1888 due solely to channel deepening. He suggested that if the channel had not been deepened, MSL rise over the last century would probably be about 1.4 $mm.y^{-1}$ rather than 1.0 $mm.y^{-1}$ as was previously accepted.

Inflows from modified urban and rural catchments have resulted in changes to the sediment supply and chemistry in parts of the harbour. Baird (1997), Purdie and Smith (1994) and Stevenson (1998) have investigated sediment contaminants and sedimentation within the upper harbour. Lusseau (1999a) presents a summary of their findings. Purdie and Smith found that sediment texture was influential on infaunal organisms and absorption of pollutants. They also found that the amount of heavy metals was low and well within typical levels for other New Zealand inlets. Most trace metal pollutants were sourced to stormwater runoff from the Leith River (Baird 1997). Very little is known about contaminants in the sediments of the lower harbour, although the level of trace metals reduced with distance from Dunedin to the harbour entrance.

Modification of the shoreline, natural and ship wave action within the harbour have resulted in erosion hazards. Erosion and shoreline change at Te Rauone Beach has been investigated by ORC and DCC since the early 1990s, and is the subject of further work in regards identifying options for coastal management project through work being done by Port Otago Ltd (Single 2007). Consultation with the ORC, DCC and the community is underway at the present time.

# 3. The effects of a deeper channel

## 3.1 Introduction

In considering the feasibility of Project Next Generation, it is important to assess the sustainability of the desired finished works and the processes required to attain that outcome. This section first considers the effects of a finished deeper channel from Taiaroa Head to Port Chalmers on the physical coastal process environment of Otago Harbour and the nearshore area around the inlet. Secondly, the effects of the dredging activity are considered. Finally, options for disposing of the dredged sediment are identified, and the effects of disposal at sea are discussed.

## 3.2 14m to 15m channel depth

The exact configuration and bathymetry of the proposed 14 to 15m deep channel has not been finalised. The general configuration will remain along the same line as the existing channel, but the width of the channel will be increased and the bends slightly modified. In addition, the swinging basin at Port Chalmers will need to be extended. Sections of the channel are presently deeper than the desired 15m maximum due to a combination of historical dredging and natural processes, and the depth in these areas will not be changed.

Six types of effects on physical coastal processes have been identified. These are:

1. Changes to hydrodynamics of the channel north of Harington Point
2. Changes to hydrodynamics within the harbour
3. Changes to sediment transport dynamics within the channel
4. Changes to sediment transport dynamics on the tidal flats and channel margins
5. Changes to future maintenance dredging demands
6. Changes to effects of shipping activities.

From earlier work by Wilson (1989), the effects of channel dredging in Otago Harbour are thought to have resulted in a decrease in the mean sea level of the harbour. Theoretical studies show that dredging of a long channel is likely to result in increased asymmetry of the tidal flow, and changes to the tidal range.

Initial modelling of the effects of the new channel depth and configuration has been carried out by NIWA (Oldman, Bell and Stephens in prep). The modelling identifies potential changes to the hydrodynamics within the harbour and in the inlet. Further detailed modelling will be used to identify changes to the potential sediment transport dynamics within the channel and on the channel margins, and the potential effect of the deepened channel on wave propagation across the ebb tidal delta.

The proposed shipping channel depths and configurations were modelled and compared to modelled conditions of the existing channel (12.8m, but rounded to 13m for modelling purposes) situation for a number of different tide and wind conditions. The wind conditions considered were prolonged 20-knot winds from the SW and NE. These directions represent winds that blow along the main axis of the harbour and have been observed to have an affect on tidal wave propagation along the harbour.

The main findings of the modelling with regard to changes to the present channel regime are presented in Appendix 1, and are summarised as follows:

- Tide timing – There are small differences in the timing of high and low tide. The duration of the tidal flows will change by up to ±6 minutes. There is also a small change in the time of high tide, where there will be an advance in the tide time during spring tide conditions by up to 4 minutes at Port Chalmers and Ravensbourne. There is also a possibility of a slowing of the tide time during neap tides under southwesterly wind conditions by up to 5 minutes at Ravensbourne.

- Water level – There is a small difference (up to 0.02m) in the tide range (low to high tide) through most of the harbour for the 15m-depth channel during spring tides. There is a slightly larger increase in the spring tidal range (by about 0.07m) at the Dunedin wharves during calm wind conditions. There is unlikely to be any change to the elevation of msl.
- Harbour currents – There are small absolute changes in peak tidal current velocities for different scenarios. The greatest change is a reduction in the peak ebb tide velocity of 0.04m/s at the Spit tide gauge during neap and spring tide conditions for the 15m-depth channel.
- Different wind conditions cause variations to the degree of change to propagation of the tidal wave up the harbour, such that the difference between the existing situation and the 14m and 15m channel depths varies depending on the wind condition (calm, 20 knot SW or 20 knot NE).

The spatial aspect of the changes to the hydrodynamics is still to be modelled in detail. However the small changes in peak velocities of the tidal currents indicate that there are likely to be only minor effects on sediment transport potential and associated turbidity and biological affect on the channel margins and intertidal sand flats.

Table 2 lists the potential consequences of different effects of the proposed channel.

The effects of the proposed channel configurations at the inlet are not known in detail, but there may be a minor increase in the potential for sediment transport into the channel at the Howletts claim from the ebb tidal delta, and along the channel between the ebb delta and Harington Bend. This sediment may be transported into and then out of the channel over the tidal cycle, but there may be a slight increase in the maintenance dredging demand with the deeper channel.

After a time for adjustment of the channel side slopes, it is likely that the channel configuration will remain stable after the proposed increase in depth and widening of the bends. Apart from adjustment to the intertidal sand flats at the margin of the channel in forming the battered slopes of the channel sides, no changes to the stability or form of the sand flats is expected.

An additional factor that needs to be considered is the effect of vessel wake on the shores of the harbour and other vessels (such as moored yachts). At present, ship wake is a possible agent of beach change including erosion and realignment of the shoreline at Te Rauone Beach. Larger vessels may create a larger wake, and result in a greater affect at the shore. The wake waves can be modelled for the harbour, and will be investigated in particular for Te Rauone Beach. However modern ship designs are resulting in reduced effects of wake waves, so the issue of vessel wake requires a watching brief and monitoring, but may not become a significant issue. Coastal management at Te Rauone Beach will consider the effects of vessel wakes.

The effect of wave propagation across the channel, north of Taiaroa Head, is unknown, but may result in effects on ship handling, pitch and roll. This aspect of the effects of the proposed channel deepening is the subject of further detailed modelling.

**Table 2** Risk assessment and potential adverse effects on the physical coastal environment of the proposed channel.

| POTENTIAL EFFECT | POTENTIAL CONSEQUENCES | ADDITIONAL INFORMATION | SIGNIFICANCE OF EFFECT | | | |
|---|---|---|---|---|---|---|
| | | | SEVERITY | DURATION | PROBA-BILITY | RISK |
| Change to tidal hydrodynamics. | Change in time lag of high tide between Spit and Dunedin. | Initial modelling of the hydrodynamics of Otago Harbour has shown that there is likely to be a small (a few minutes at the most) change in time lag between the Spit tide gauge and Dunedin Wharves. This means that tide time-tables would need to take the change into consideration. | Low | Long-term | High | Low |
| | Changes to flushing of harbour and recirculation of clean water. | Initial modelling of the harbour hydrodynamics has also shown that there may be changes to the residency time of water within the harbour. The detail of any changes is unknown at present, but the planned, detailed modelling will include identification of the flushing times through the harbour. | Medium | Long-term | Low/ Medium | Low/ Medium |
| | Changes to hydrodynamics of upper and lower harbours (tide heights and currents) including areas outside of the main channel. | The initial modelling has shown that the tidal range will increase by up to 0.07m during a spring tide at Dunedin Wharves, but by a lesser amount for all other tidal conditions at Ravensbourne, Port Chalmers and at the harbour entrance.<br>It is important to note that the increase in elevation at high tide, and especially at high water of a spring tide, will not significantly increase inundations hazards around the | Low | Long-term | Low | Low |

| POTENTIAL EFFECT | POTENTIAL CONSEQUENCES | ADDITIONAL INFORMATION | SIGNIFICANCE OF EFFECT | | | |
|---|---|---|---|---|---|---|
| | | | SEVERITY | DURATION | PROBA-BILITY | RISK |
| | | harbour.<br>The initial modelling results show that the peak velocity of tidal currents will be slightly reduced. This means that the potential to move sediment will decrease, so that it is unlikely that scouring of the channel margins or the inter-tidal sand flats will occur. However there is a need for consideration of the potential for unwanted deposition of sediment in areas of lower currents. This will be assessed in detail in further modelling for specific sites. | | | | |
| Instability of channel form and position. | Shipping channel sides are unstable and collapse into the channel requiring significant increases in maintenance dredging. | Deepening the channel may result in over-steepening of the sides. This may necessitate the sides being battered during dredging to a near-stable or stable form. This means the channel form will be close to equilibrium, and maintenance dredging is likely to be within the existing consent conditions of 450,000 m3 per year. | Medium/ High | Short-term/ Medium-term | Low/ Medium | Medium |
| | Shipping channel sides are unstable and intertidal sand flats erode. | Sediment investigation are still to be completed, but information from previous dredging operations in Otago Harbour, and from the maintenance dredging indicate that the channel margins are robust and not susceptible to slumping and erosion. | Medium | Short-term/ Medium-term | Low | Low |

| POTENTIAL EFFECT | POTENTIAL CONSEQUENCES | ADDITIONAL INFORMATION | SIGNIFICANCE OF EFFECT | | | |
|---|---|---|---|---|---|---|
| | | | SEVERITY | DURATION | PROBA-BILITY | RISK |
| | Secondary channels used for recreational purposes, and beaches around the harbour may be affected by deposition of sediment due to altered hydrodynamics | There have been concerns raised about infilling of sections of secondary channels within the harbour, and deposition and shoaling near beaches. These channels include East Channel, Back Beach and the entrance to the Yacht Harbour in the Upper Harbour, the entrance to the slipway at Deborah Bay, the area around Weller's Rock and the area near Pilot Beach.<br>Little is known about the processes leading to the existing deposition of sediment in these areas, but it is known that changes to the channels and beaches of the harbour are occurred during the 1800s.<br>The detailed hydrodynamic modelling can identify any relationship between the proposed dredging activities and the changes in current flows and sedimentation.<br>From the information at hand, the effects of existing sedimentation could be managed by small scale local dredging. These works would however require new consents, as they are not covered by any existing consents or permitted activities. | Medium | Long Term | Low/ Medium | Medium |

| POTENTIAL EFFECT | POTENTIAL CONSEQUENCES | ADDITIONAL INFORMATION | SIGNIFICANCE OF EFFECT | | | |
|---|---|---|---|---|---|---|
| | | | SEVERITY | DURATION | PROBA-BILITY | RISK |
| Change in current velocities at the ebb tidal delta. | Additional sedimentation in area of Howletts Claim. | The initial modelling shows that there is a possibility of changes to the current flows in the outer channel. This may result in additional movement of sediment into and along the outer channel, and/or additional sedimentation within the channel.<br>The result may be that additional maintenance dredging will be required in this area.<br>Rates of sedimentation, and the likelihood of changes to the maintenance dredging demand will be identified in detailed modelling still to be carried out. | Medium | Medium-term/Long-term | Medium/ High | Medium/ High |
| | Infilling of the entrance Channel to north of the end of Mole. | | Medium | Medium-term/ Long-term | Low | Low |
| Modification of wave propagation. | Affect ship-handling, pitch and roll through the inlet. | Deepening the outer channel will modify the propagation of waves passing across or along the channel. Modelling of this area will include information about the existing wave environment and will provide data on the potential wave characteristics within the channel. This will be used to determine the probability, and/or identify synoptic conditions that will result in ship handling problems. | Medium | Long-term | Unknown | Unknown |

| POTENTIAL EFFECT | POTENTIAL CONSEQUENCES | ADDITIONAL INFORMATION | SIGNIFICANCE OF EFFECT | | | |
|---|---|---|---|---|---|---|
| | | | SEVERITY | DURATION | PROBA-BILITY | RISK |
| | Propagation of swell waves into the harbour including onto Shelly and Te Rauone Beaches. | Observations, wave and current measurements at Te Rauone Beach have identified swell propagation into the harbour. The effects on the shoreline of these waves are not fully understood, but these waves are likely to contribute to changes to the beaches and nearshore in this area. Detailed modelling of the wave environment will include propagation of waves into the harbour so that the effects can be assessed. | Medium | Long-term | Unknown | Unknown |
| Increased wake from larger ships. | Erosion of channel sides, intertidal sand flats and beaches of the lower harbour. | Modern ship design is working towards minimum wake effects. However the actual effects of the wake produced by larger ships on the channel margins and beaches near the main harbour channel will need to be investigated further. Initial work will be to identify the wake characteristics from the larger vessels, and then to compare that wake with the wake from vessels using the harbour at present. | Low | Long-term | Low/ Medium | Low |
| | Wake disruption of use of marina and boat ramps at Deborah Bay and Carey's Bay. | | Low | Long-term | Low/ Medium | Low |
| Increase in vessel passages. | Cumulative effect of wake. | The effects of wake from an individual vessel can be determined when the characteristics of the wake are known. However it will also be important to determine the likely number of vessel passages along the channel so that the cumulative effect of those passages can be assessed. | Low | Long-term | Low | Low |

**What we know**

The initial modelling shows that the effects of a deeper channel on the hydrodynamics of the harbour are not likely to be significant. A change in the speed of propagation of the tidal wave along the harbour by a few minutes can be factored into the tidal information for Port Chalmers and Dunedin, as can any variations to the tidal elevations.

The initial modelling allays concerns that the deeper channel could result in raising the level of high tide within the harbour to such an extent that flooding of the harbour margins could result. The work by Wilson (1989) indicates that past channel dredging has suppressed the effects of eustatic sea level rise over the last century. Deepening the channel further could delay or suppress the effects of projected future sea level rise.

Changes to the velocities of the tidal currents are unlikely to be significant within the channel and across the intertidal sand flats.

Ship wake is thought to play a role in causing change at Te Rauone Beach, and may have an effect on moored vessels in Deborah Bay and Carey's Bay. To date no issues have been raised concerning moored vessels, but ship-handling modelling will show the effect of wake waves and water level surge of the larger ships transiting the channel.

**What we don't know**

The detailed changes to current velocities across the intertidal sand flats are unknown. However this issue can be investigated through the finer grid modelling of the harbour hydrodynamics. When areas of greater or lesser velocities are identified, they can be investigated further with regard to sediment transport potential and effect on biota.

The wake waves of larger container ships is unknown, but with development of ship design taking wave generation into account, it is likely that the wake is no greater than, and possibly less than the wake of large vessels already using the harbour.

**Risk factoring**

Table 2 presents a list of possible adverse effects of a deeper channel as identified by the Port Otago Project Team and the Project Consultative Group. Rankings of the severity of the possible consequences, the duration of the effect and the probability of occurrence are given for each effect. An estimate of the risk involved for each adverse effect if the project is progressed to completion is also given.

### 3.3 Dredging activity

The volume of material to be dredged will depend on the exact specifications of the proposed channel alignment, sidewall slopes, areas to be widened and the final depth for different sections of the channel. The degree of difficulty in dredging the material depends on the type of sediment to be dredged, the range of particle sizes, and the likely cohesiveness of the sediment. It is especially important to identify if there is a predominance of clay or rock in the mix. At present the nature of the sediment that would need to be removed from the harbour is not known with precision. However the general characteristics of the material can be described from studies of the harbour (such as Cournane 1992) and the experiences of historical capital dredging and the ongoing maintenance dredging.

The effects of the dredging operation will also depend on the ability of water currents to disperse disturbed sediment in suspension and the nature of the material to be dredged. The tidal hydrodynamics, current velocity profile (speed of water currents at different depths) and spatial distribution of currents within the harbour in the vicinity of the channel provide the energy to move sediments in suspension. The size of the sediment determines how readily it will be moved. Fine cohesive sediments will disperse through the water column very slowly and result in plumes of "dirty" water propagating through the harbour for some distance for some period of time. Coarser material is more likely to settle within the dredge hopper and within the water column quite rapidly.

It is likely that rock outcrops will be encountered adjacent to Acheron Head, Pulling and Rocky Points. It is likely that the rock in these areas is weak and will be able to be removed using a backhoe dredge. However the strength of the rock will need to be assessed to determine if explosives will be required to loosen the rock. Experience from the maintenance dredging suggests that the rock should be able to be removed without the use of explosives (Alan Sutherland, Harbour Services Manager, Port Otago Ltd pers com).

Initial modelling of the changes to the hydrodynamics of Otago Harbour has been carried out by NIWA (Oldman, Bell and Stephens in prep). The hydrodynamic modelling will be linked to a sediment transport model to show the potential development and movement of plumes during dredging. Initial sediment plume modelling is also included in the NIWA report. The results show reasonable dilution of suspended sediment concentrations. The bulk of the sediment plume would move mainly along the channel within the lower harbour, but there could be dispersion over the middle part of upper harbour through the Eastern Channel during prolonged dredging operations.

The duration and extent of any plume needs to be determined by applying a sediment transport model using detailed information about the dredged sediment (in particular size and settling behaviour) to the detailed modelling of the of the hydrodynamics of the harbour. Different scenarios can be modelled to determine the effects of different weather conditions and operational methods. The objective of the modelling will be to assess the potential spread of the effects and the scope and extent of any necessary mitigation.

**Table 3** Risk assessment and potential adverse effects on the physical coastal environment of the dredging operation in the lower harbour and Port Chalmers swinging basin.

| POTENTIAL EFFECT | POTENTIAL CONSEQUENCES | ADDITIONAL INFORMATION | SIGNIFICANCE OF EFFECT | | | |
|---|---|---|---|---|---|---|
| | | | SEVERITY | DURATION | PROBA-BILITY | RISK |
| Slumping of channel margins. | Infilling of channel. | The dredging operation will require information about the nature of the sediment to be dredged. This includes information about the stratigraphic character of the sediments and the likelihood of instability of the channel margins during the dredging operation.<br>The dredging methodology will address the necessary requirements to avoid significant slumping that may disrupt use of the channel. | Low | Short/ Medium-term | Low | Low |
| Plume dispersal. | Loss of water quality. | The dredging activity will result in high turbidity (suspended sediment) the immediate effect of the turbidity is to discolour the water, but suspended sediment will travel within flowing water and disperse and settle along the channel and across other areas of the harbour.<br>Determining the spatial and temporal extent of plumes will be addressed through the detailed hydrodynamic modelling with the addition of information about the sediment characteristics of the dredged material. This work is ongoing, and the results will be discussed in the initial NIWA report on the | Medium/ High | Short/ Medium-term | High | Medium/ High |
| | Fine sediment submergence of intertidal biota. | | Medium/ High | Short/ Medium-term | Low to High Variable in extent | Medium/ High |
| | Fine sediment settling on beaches. | | Low/ Medium | Short/ Medium-term | Low/ Medium | Low/ Medium |

| POTENTIAL EFFECT | POTENTIAL CONSEQUENCES | ADDITIONAL INFORMATION | SIGNIFICANCE OF EFFECT | | | |
|---|---|---|---|---|---|---|
| | | | SEVERITY | DURATION | PROBA-BILITY | RISK |
| | | hydrodynamic modelling (Oldman *et al.* in press). The potential effects on the benthic communities are discussed in more detail in the NIWA report on ecological information and work scoping (James *et al.* 2007). Fine sediment settling on beaches can clog the pore spaces between sand particles and lead to an increased potential for erosion, and change the appearance of the beach. The potential for this to occur will be determined by the detailed hydrodynamic modelling. | | | | |

**What we know**

Cournane (1989) describes the characteristics of the seabed (harbour bottom) and subsurface sediments in sections of the channel by Aramoana. Kirk (1980) determined the sediment characteristics of the seabed in the inlet vicinity and the channel up to Harington Bend. Records from maintenance dredging within the channel can be used to describe the seabed sediment characteristics for the channel and swinging basin. Although it is likely that the sediment character is similar with depth below the seabed, the precise nature and distribution of the subsurface sediments is unknown.

However it is likely that most of the sediment to be removed will be similar to sediment removed during maintenance dredging. The sediment will generally be finer than medium fine sand, and will contain fine silt. It is unlikely that there will be much clay in the dredged sediment. There will be some rock (up to 100,000m3) to be removed from the channel in the vicinity of Pulling Point, Acheron Head and Rocky Point.

Modelling to date shows that a sediment plume will develop, and could move through the harbour and into the upper harbour. It is likely that the plume will persist at least in the immediate area of dredging for the entire duration of the dredging operation.

**What we don't know.**

The precise configuration, alignment and depth of the finished channel are yet to be finalised. The final design will allow for determination of the volume of sediment to be removed and where it will come from within the channel and swinging basin.

The exact characteristics of the sediment to be removed (from about 13m depth to 14 or 15m depth) are unknown and will need to be determined by coring the seabed throughout the area to be dredged. This information is necessary to progress dredging tenders and contracts and to determine more precisely the nature of the dredging operation required, and the effects of the operation.

Detailed modelling, still to be carried out, will provide a more precise picture of the dispersal of sediment plumes during the dredging. The effects of sediment dispersal and settling on the biota of the harbour will be assessed from the modelling results with regard to the ecological character of any affected areas.

**Risk factoring**

Table 3 presents a list of possible adverse effects of a deeper channel as identified by the Port Otago Project Team and the Project Consultative Group. Rankings of the severity of the possible consequences, the duration of the effect and the probability of occurrence are given for each effect. An estimate of the risk involved for each adverse effect if the project is progressed to completion is also given.

### 3.4 Disposal of dredged sediment

There are four main options for disposal of dredged sediment. These are:

- Disposal at sea,
- Reclamation,
- Resource use of the sediment, and
- Storage on land.

Disposal at sea is the most common option undertaken and is the method of disposal used by Port Otago for past capital dredging and for the ongoing maintenance dredging. Seafloor areas around Port Chalmers have also been reclaimed using dredged sediment, while sand sized dredged sediment has been used to nourish beaches within Otago Harbour, at Shelly Beach and recently at Middle Beach, St Kilda. It is likely that in the past, some sand from dredging in Otago Harbour has also been used as landfill. The New Zealand sediment aggregate industry has a demand for coarse sand and gravels for cement etc., but this economic use of dredged sand from Otago Harbour has not been explored in detail. It is likely that storage of the sand on land would require a foreseen future use of the resource. In the Dunedin area, that use may include future beach nourishment (for example at Ocean Beach and Te Rauone.

At present, the demands for sand for beach nourishment would amount to less than about 100,000 $m^3$ of clean, fine to coarse sand per year. This includes approximately 50,000 $m^3$ per year placed at Shelly Beach from maintenance dredging.

The likely market for sand aggregate is the Auckland region. The desired range of sand size is larger than medium sand. The sediment dredged from Otago Harbour is likely to be finer than that required for the aggregate industry.

Reclamation using sand dredged for Project Next Generation has also not been examined, as there are no foreseeable demands for land area in the short term. However some areas of the community have expressed an opinion that additional flat land on the margin of the harbour near Deborah Bay and Careys Bay would be advantageous for enhanced use of the harbour coastal environment.

Therefore disposal of the dredged material at sea is the only option that has been examined in detail, particularly given that a substantial portion of the whole dredge volume seems likely to require disposal at sea. In doing so, an initial broad approach has been taken to identify the possible adverse effects of such disposal with regard to the physical coastal processes, marine ecology and marine resource use.

The specific effects of dredged sediment disposal will depend on the nature of the dredged sediment and the nature of the receiving environment. Disposal of dredged sediment on land will have very different effects to disposal within the coastal environment. Within the coastal environment, the effects of disposal for reclamation are different to the effects of disposal at sea.

The four main types of effect on the physical coastal environment from disposal of dredged sediment at sea are:

1. Effects during transportation to the receiving ground. Increased turbidity along the route may result from accidental loss or leakage of dredged material overboard en-route to the site.
2. Effects on the environment from the act of disposal. These may include turbidity plumes, movement of placed sediment away from the site to the adjacent seabed or channels, or onshore to beaches, estuaries or river mouths, and modification to the seabed sediments and water quality in the vicinity of the site.
3. Effect of the dredged sediment on the receiving environment. These effects are similar to those from the act of disposal, but include a long-term aspect of movement of the placed sediment away from the receiving ground, burying of local flora and fauna, change in the characteristics of the seabed at the disposal site and possible adverse effect from contaminants in the dredged sediment.
4. Effects on the wider environment due to accumulation of sediment in the receiving area. The effect is related to the change in seabed contours that may result in modification of wave propagation across the disposal site and transferred effect to the nearshore and local beaches due to changes in sediment transport by waves, and changes to the breaking wave properties. The effects may include local wave focussing, especially in shallow water (less than about 8m depth).

Table 4 lists the possible adverse effects of reclamation on the physical coastal environment. The main effects of reclamation with regard to the physical coastal environment are modification to the shoreline, and changes to the local hydrodynamics around the reclamation. The modification to the shoreline will affect people's use of the shore amenity. In many ways, the use may be enhanced. For example, additional areas for parking, boat launching and picnicking may be provided, beaches may be artificially constructed, shorelines can be restored, or additional industrial area may result from reclamation adjacent to existing wharves. The effects of the final use of any reclaimed land would also need to be assessed in detail.

Loss of amenity use and changes to the landscape are the main adverse effects of use the shoreline. However modification to the local hydrodynamics can also affect water quality, change sedimentation, and can lead to erosion of adjacent shores and seabed.

The changes to the hydrodynamics can be modelled, and the effects of those changes can be assessed.

Table 5 lists the possible adverse effects on the physical coastal environment of disposal of dredged sediment at sea. The additional possible effects during transportation are presented in Point 1 above, and those effects are in line with the possible effects of the existing maintenance dredging and sediment disposal, although the activity is carried out more intensively over a longer period of time. Adverse effects can be avoided through best international dredging practice (safety, weather, plant integrity for example) with regard to transportation of the dredged sediment to the disposal site.

Turbidity during disposal is unavoidable, but can be limited to as small a footprint as possible by working with knowledge of the wave and current conditions at the disposal site.

For the purposes of identifying and scoping possible locations for a disposal site, the Port Otago Project Team considered a number of factors that would constrain the choice of site. The disposal of up to 5 million $m^3$ of dredged sediment requires a large area of seabed to prevent the construction of a mound. A site size of about 5km by 5km ($25km^2$) was considered. If spread evenly, this area would accommodate the material as a layer 200 mm thick. However an even spread is unlikely to be achieved, so the footprint of the disposal site is large to ensure the effects are contained within a known area.

Four constraints maps were prepared. One considered operational factors of the dredge such as distance from the harbour, weather and depth constraints (shallow areas). A second constraints map considered ecological areas, areas significant to benthic communities and fisheries. The third and fourth maps considered the physical coastal environmental characteristics of seabed sediments and hydrodynamics.

The ideal disposal site would have the same sediment in situ characteristics as the dredged material. From the map of the seabed sediments (Figure 4), the areas of modern sand and mud facies were considered as possible receiving grounds.

Potential movement of sediment from the site was considered by assessing the predominant current directions and known sediment transport paths from previous studies (Andrews 1976, Carter *et al.* 1985, Kirk 1980, Bunting *et al.* 2003a). The ideal site would not result in sediment transport into the dredged channel, into Blueskin Bay estuary, or onto the rocky coast north of Warrington.

The effects of movement of sediment from the disposal site and effects of the accumulation of sediment on the seabed will be assessed through the detailed modelling and field studies.

**Table 4** Risk assessment and potential adverse effects on the physical coastal environment of reclamation in Otago Harbour.

| POTENTIAL EFFECT | POTENTIAL CONSEQUENCES | ADDITIONAL INFORMATION | SIGNIFICANCE OF EFFECT | | | |
|---|---|---|---|---|---|---|
| | | | SEVERITY | DURATION | PROBA-BILITY | RISK |
| Change to local hydrodynamics. | Loss of circulation of clean water. | The main change to the physical coastal environment from reclamation is the change to the configuration of the shoreline and nearshore. This can result in changes to the flows of water in the nearshore and the interactions of that flow with nearshore and beach sediments.<br>Any reclamation would require a full assessment of the effects on the adjacent coastal environmental processes. This would include modelling of the situation before and after the reclamation, and calibration of the model through measurement of currents, and sediment characteristics in the area. | Medium | Long-term | Medium | Medium |
| | Localised sedimentation. | | Medium | Long-term | Medium | Medium |
| | Localised scouring. | | Medium | Long-term | Medium | Medium |

**Table 5** Risk assessment and potential adverse effects on the physical coastal environment of disposal of dredged sediment at sea.

| POTENTIAL EFFECT | POTENTIAL CONSEQUENCES | ADDITIONAL INFORMATION | SIGNIFICANCE OF EFFECT | | | |
|---|---|---|---|---|---|---|
| | | | SEVERITY | DURATION | PROBA-BILITY | RISK |
| Deposition at the disposal site. | Turbidity. | The main change to the physical coastal environment from reclamation is the change to the configuration of the shoreline and nearshore. This can result in changes to the flows of water in the nearshore and the interactions of that flow with nearshore and beach sediments.<br>Any reclamation would require a full assessment of the effects on the adjacent coastal environmental processes. This would include modelling of the situation before and after the reclamation, and calibration of the model through measurement of currents, and sediment characteristics in the area. | Low/ Medium | Short-term | High | Medium |
| | Submergence of benthic communities. | | Medium | Long-term | Medium | Medium |
| Sediment movement from the disposal site. | Turbidity. | The seabed of Blueskin Bay is a dynamic environment. Oceanic, tidal and wave currents work together to move sediment on the seabed. Different areas of the seabed are more mobile than others, and different sizes of sediment will move under different environmental process conditions.<br>Sediment movement will have effects on benthic communities. James *et al*. (2007) discuss these effects in detail. | Low/ Medium | Short-term / Medium-term | Medium/ High | Medium |
| | Submergence of benthic communities. | | Medium/ High | Short-term / Medium-term | Medium/ High | Medium |
| | Movement of sediment into dredged channel. | | Low | Short-term / Medium-term | Low | Low |
| | Movement of sediment into Blueskin Bay Estuary or beaches north of the harbour. | | Low/ Medium | Medium-term / Long-term | Low/ Medium | Low |

| POTENTIAL EFFECT | POTENTIAL CONSEQUENCES | ADDITIONAL INFORMATION | SIGNIFICANCE OF EFFECT | | | |
|---|---|---|---|---|---|---|
| | | | SEVERITY | DURATION | PROBA-BILITY | RISK |
| | | Sediment may also move onshore, and can modify beach and estuarine sedimentation, or could move into the dredged channel, necessitating additional maintenance dredging. Previous studies have indicated the nearshore sediment transport in the vicinity of the existing disposal grounds (Bunting *et al*. 2003a). These studies show movement of sediment from the disposal sites away to deeper water and alongshore. Patterns and rates of sediment transport will need to be determined for the sediment type that is disposed for the wider Blueskin Bay seabed. This will be achieved through modelling work by NIWA using wave and current information (calibrated with field data) and the characteristics of the sediment, and calibrated for the existing seabed sediments by rollability analysis using the same technique as earlier studies. The results of these studies will be used to identify optimal disposal areas. | | | | |

| POTENTIAL EFFECT | POTENTIAL CONSEQUENCES | ADDITIONAL INFORMATION | SIGNIFICANCE OF EFFECT | | | |
|---|---|---|---|---|---|---|
| | | | SEVERITY | DURATION | PROBA-BILITY | RISK |
| Refraction of waves. | Focusing of wave energy onto beaches. | Waves interact with the seabed, modifying the speed of the wave through friction (wave refraction). A variable seabed will affect different parts of the wave so that some parts move more slowly than others. This will cause parts of the wave to change direction, and the energy within the wave to focus or disperse along the length of the wave.<br>The effect of the sediment in the receiving ground on wave refraction will be modelled by NIWA to determine possible inshore effects associated with changes to the form of the wave.<br>In addition, the detailed hydrodynamic modelling will also assess the potential for waves from different directions interacting to form large, or “rogue” waves. | Low/ Medium | Medium-term / Long-term | Low | Low |
| | Disruption of surf breaks. | | Low | Medium-term / Long-term | Low | Low |
| | Rogue wave formation at sea. | | Low | Medium-term / Long-term | Low | Low |

When the constraints maps were put together, the resulting map showed potential areas where the operational factors would be most optimal and the adverse effects would be minimised. This map is shown in Figure 12.

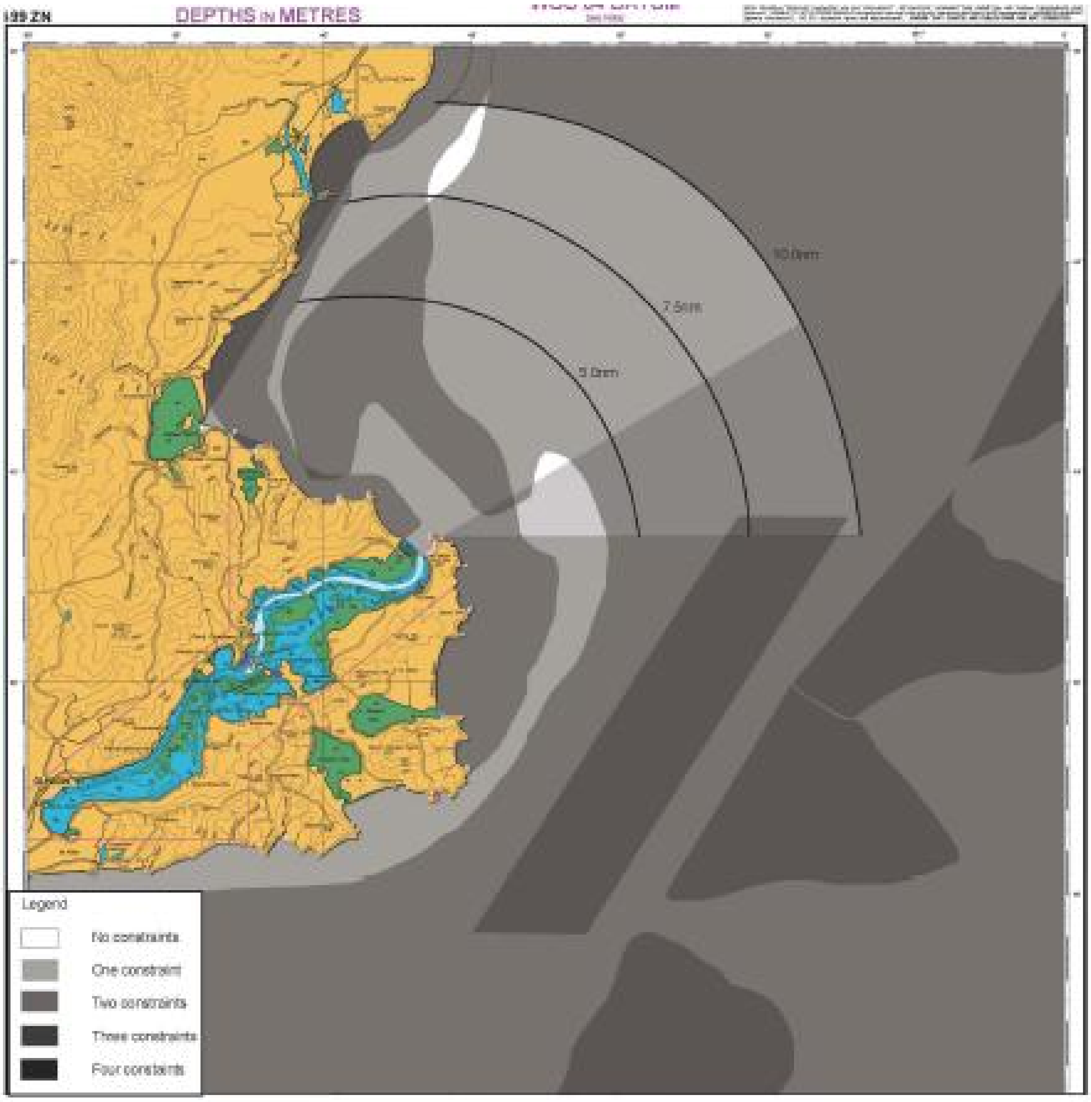


**Figure 12** Results of constraints mapping exercise. Lighter areas have fewer constraints.

Further information is required to assess the possible sites with regard to sedimentology and ecological cover, and with regard to potential sediment transport by waves and currents. Modelling by NIWA (Oldman, Bell and Stephens 2007) gives an approximation of the hydrodynamics of Blueskin Bay. The model synthesized the available information on waves in the waters offshore from Taiaroa Head and provides an approximate estimate of wave conditions and their frequency that would be sufficient to re-suspend material from the offshore dredge spoil ground, and determines the approximate directions the re-suspended fine-sand material would be transported.

**What we know**

Previous studies give a broad picture of the hydrodynamics processes and sedimentology of the seabed of Blueskin Bay so that an appreciation of the effects of placing the dredged sediment can be ascertained. The NIWA modelling shows that the median size sediment at a potential disposal site 3nautical miles off Taiaroa Head would be re-suspended by waves 14% of the time in total, during an average of 23 separate events per year. The finer sand fractions are expected to be re-suspended by waves 23% of the time, during an average of 31 separate events per year. Finer sediments (silts) were not considered in the model but will need to be considered in the detailed modelling.

The predominant current off Taiaroa Head is to the north, so re-suspended sand and sand moving as bedload along the seabed will be winnowed out of the accumulated disposal mound and moved mostly north to northeast.

Bunting et al. (2003a) show that the beach systems from Kaikai north to Purakanui Bay have not been adversely affected by nearly 30 years of placement of maintenance dredged sediment, and capital dredged sediment from the 1970s placed near Heyward Point.

**What we don't know**

At present we do not have detailed knowledge of the seabed sediments at the possible disposal sites identified by the constraints mapping. There is also a need for further modelling to refine the hydrodynamics of Blueskin Bay and to determine sediment transport potential from the site under different weather and disposal mound scenarios.

**Risk factoring**

Table 5 shows that the risk of significant adverse effects is medium to low. It is important to note that the modelling and seabed surveys of sedimentological and ecological factors will provide for certainty of the effects.

# 4. Information gaps and additional studies

Despite the number of coastal management, process and sedimentological studies undertaken in the Otago Harbour and Blueskin Bay, there are gaps in our knowledge that require further studies before a full assessment of potential effects can be made. Some additional studies will also be important to provide adequate baseline data so that any significant effects can be monitored and assessed as the project progresses. Studies required to fill significant information gaps that have been identified at this point are:

- Confirm sediment characteristics and level of contaminants (to be scoped by POL) in the areas to be dredged, including the sub-bottom sediments to 15m below Chart Datum, and at potential disposal sites.
- Determine the amount and character of any rock that may need to be removed adjacent to Rocky Point, Acheron Head and Pulling Point (POL)
- Carry out detailed hydrodynamic modelling of the harbour and Blueskin Bay (NIWA).
- Carry out sediment transport modelling for the harbour and Blueskin Bay using the findings of the sediment characteristics study and the hydrodynamic model (NIWA).
- Identify any effects of the deeper channel on wave propagation and ship handling.
- Determine the potential wake and water level surge effects of potential larger vessels using the deeper channel.

## 4.1 Description of seabed and sub-bottom sediment characteristics

Kirk (1980), Single and Kirk (1994), Bunting et al. (2003a) and Jonker (2003) have carried out sediment sampling from the seabed at a number of sites within the study area. The locations of sites that have been sampled are shown in Figure 13. Also shown in the figure are locations where new samples should be collected for analysis to describe the seabed in more detail so that the assessment of the effect of the dredge sediment placement within the wider Blueskin Bay environment can be determined.

Sampling outside the harbour should be carried out in conjunction with seabed benthic surveys. Sampling inside the harbour requires specialist equipment for boreholes, sediment coring, water jetting, preparation and documentation of sample collection and testing for contaminants. This work is a first priority as the results are required for input into other decision-making and modelling work.

Seismic surveys of the areas adjacent to Rocky Point, Acheron Head and Pulling Point to identify the position and character of rock underlying the harbour sediments is likely to be carried out as a joint exercise between Otago University Geology Department and Port Otago Ltd.

## 4.2 Modelling hydrodynamics and sediment transport

NIWA has prepared a proposal for modelling oceanographic, hydrodynamic and sediment transport. The key questions to be addressed are:

1. What will be the effects of deepening and widening the shipping channel on the hydrodynamics of the harbour especially tide levels, currents, wind waves and long waves?
2. Where will be the effects from suspended-sediment plume movement, dilution and settlement during both the dredging and sediment disposal operations, especially on aesthetics, benthic communities, fisheries, water clarity?

3. What is the pattern of potential movement of sediment from proposed disposal sites? Will it contribute to infilling the main shipping channel? Will it affect the coastal beaches and Blueskin Bay estuary?
4. What is the potential effect of channel deepening on nearby features and morphology, including the stability of Te Rauone and Omate Beaches, Aramoana sand flats and ecological reserve, subsidiary harbour channels, Shelly Beach and The Spit?

The NIWA proposal includes process measurements (waves and currents) for calibration of the model.

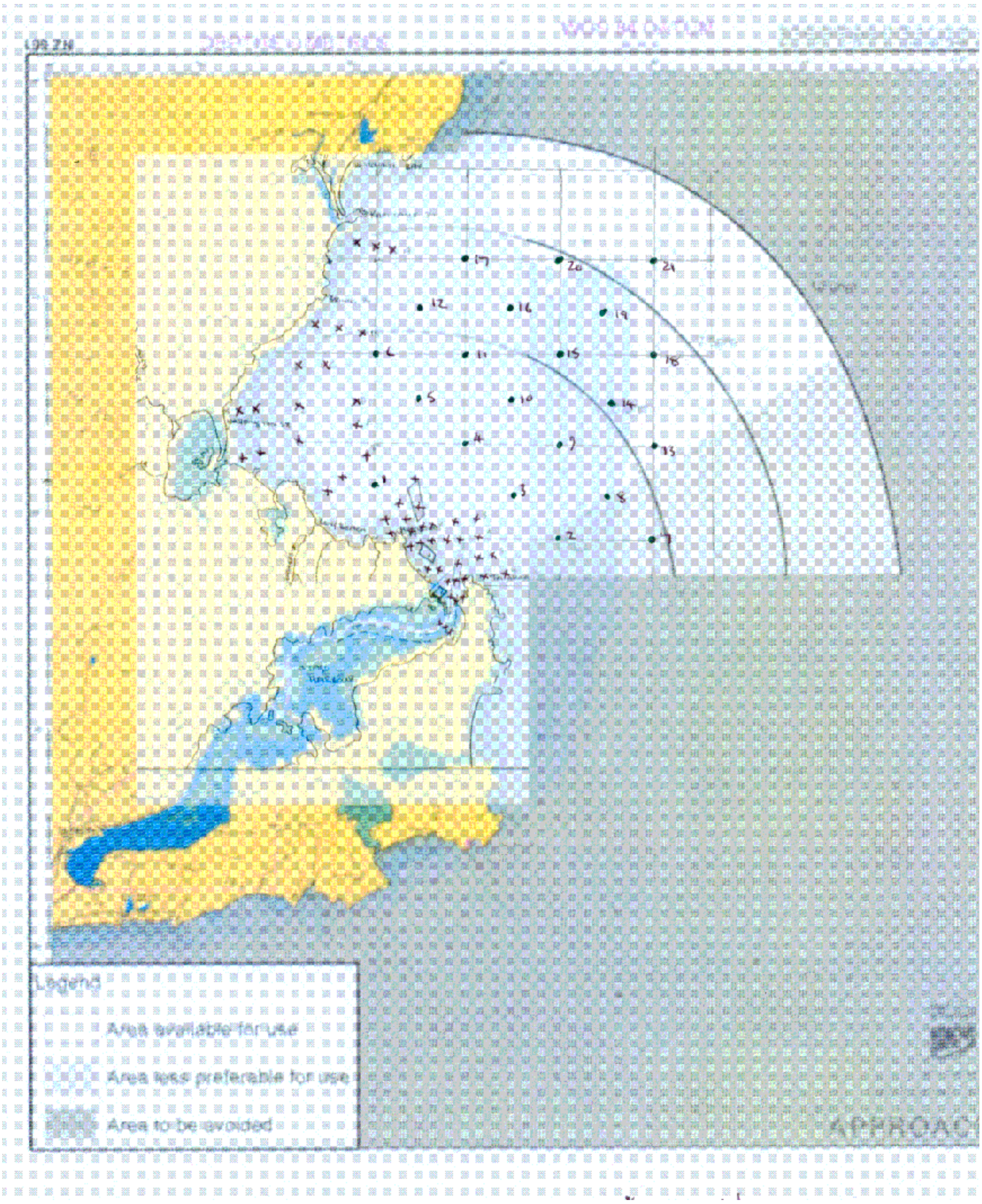


**Figure 13** Sediment sampling sites. X marks sites of samples from 1980 to 2003, and for which the descriptive characteristics are known. The numbered dots indicate potential new sample sites.

The results of the sediment studies and the hydrodynamic modelling may identify further areas of study relating to sediment transport across ecologically significant sites, or to changes in wave propagation and shoaling that may affect human use of the coastal resource.

### 4.3 Ship handling

The NIWA model will provide data that can be used to determine any potential effects on ship handling through the outer channel in particular. The effect of swell and locally generated wind waves on ship pitch and roll will need to be determined for the potential large vessels using the deeper channel. This work is to be carried out by naval architects.

In addition, future management of vessels will likely necessitate real-time wave data in the area of the entrance channel so that pilots and masters of ships can safely plan entry and exit from the harbour. To this end, POL is investigating the installation of wave measuring equipment deployed at or near the existing landfall tower. The real-time data would be used for the safe management of vessel transit. The equipment could also be used to collect wave and current process data for calibration of the NIWA hydrodynamic modelling.

# 5. Conclusions on feasibility of Project Next Generation regarding the physical coastal environment

The potential effects of dredging the Otago Harbour channel from Port Chalmers to the fairway to a depth of up to 15 m on the physical coastal processes concern possible changes to the hydrodynamics of the harbour and the transport of sediment in the harbour and from a possible disposal site in Blueskin Bay.

Results from initial modelling of the harbour hydrodynamics suggest that the effects of a deeper channel will not be significant. There is likely to be a change to the time phase difference of high tide between Port Chalmers and Dunedin by up to about 6 minutes, with the tidal wave propagating more quickly up the harbour. There is not likely to be any more than a minor change to the tidal range (± 70 mm) or high tide height (+30mm). The peak velocity of the tidal currents will change by up to 5% (decrease of -0.04m/s), with the dominant change being a slowing of the peak tidal velocity in the main channel. These changes are unlikely to change the pattern of sediment transport onto or off the inter-tidal sand flats or along the margins of the channel within the harbour.

Further work is required to determine the nature of the sediments to be dredged and the nature of the sediments on possible receiving sites. The results of sampling and description of the sediment characteristics is required so that estimates of dredging volume, methods and cost can be finalised. The descriptive characteristics are also required as input to modelling sediment transport during disposal and from the disposal site so that the effects of movement of sediment can be assessed.

Studies for consents for maintenance dredging have shown that the effects of disposal of up to 400,000 $m^3$ of dredged sediment at Heyward Point, Aramoana Beach and Shelly Beach has not resulted in significant adverse effect. The addition of up to 5,000,000 $m^3$ of sediment, although in deeper water, will have a greater effect, but site selection will be conditional on any adverse effects being avoided or mitigated. The initial constraints mapping exercise indicated sites that could be appropriate.

Further work is required to identify the seabed sediments and the currents and potential sediment transport patterns at possible offshore sediment disposal sites.

The outcome of more detailed hydrodynamic modelling may be that further studies are required in specific locations within the harbour to assess potential effects of the project at a site-specific level. With regard to physical coastal processes, these studies may involve assessing changes to the beaches north of Taiaroa Head to Karitane, and to beaches and inter-tidal sand flats within the harbour.

The review of literature on the physical coastal processes and environment of Otago Harbour and the wider Blueskin Bay have shown that there is a need for further detailed study on sediment characteristics and hydrodynamic processes so that the effects of the proposed dredging can be fully assessed. However from the work to date including the initial modelling, there do not appear to be any significant adverse effects relating to the physical coastal environment that cannot be avoided, mitigated or remedied.

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# 7. Appendices

## 7.1 Appendix 1 Summary of main changes to the hydrodynamics of the harbour under different shipping channel configurations compared to the present situation.

**Table 1a** Spit Tide Gauge summary of main changes to the hydrodynamics of the harbour under different shipping channel configurations.

| Scenario | Tide | Winds | Height of High Tide (m) | Height of Low Tide (m) | | Flood Tide Duration (hrs) | Ebb Tide Duration (hrs) | Peak Flood Velocity (m/s) | Peak Ebb Velocity (m/s) |
|---|---|---|---|---|---|---|---|---|---|
| Present (13.0m) | Neap | Calm | 1.73 | 0.48 | | 6.45 | 5.80 | 0.65 | 0.65 |
| | | 20 knot SW | 1.72 | 0.47 | | 6.42 | 5.85 | 0.64 | 0.65 |
| | | 20 Knot NE | 1.74 | 0.49 | | 6.47 | 5.80 | 0.66 | 0.65 |
| | Spring | Calm | 2.05 | 0.24 | | 6.42 | 6.05 | 0.95 | 0.85 |
| | | 20 knot SW | 2.04 | 0.23 | | 6.42 | 6.07 | 0.96 | 0.86 |
| | | 20 Knot NE | 2.05 | 0.25 | | 6.42 | 6.05 | 0.94 | 0.84 |
| 14m | Neap | Calm | 1.73 | 0.48 | | 6.47 | 5.80 | 0.64 | 0.63 |
| | | 20 knot SW | 1.72 | 0.47 | | 6.42 | 5.85 | 0.63 | 0.63 |
| | | 20 Knot NE | 1.74 | 0.49 | | 6.45 | 5.80 | 0.65 | 0.64 |
| | Spring | Calm | 2.05 | 0.24 | | 6.42 | 6.05 | 0.95 | 0.83 |
| | | 20 knot SW | 2.04 | 0.23 | | 6.40 | 6.07 | 0.96 | 0.84 |
| | | 20 Knot NE | 2.06 | 0.25 | | 6.42 | 6.07 | 0.94 | 0.83 |
| 15m | Neap | Calm | 1.73 | 0.48 | | 6.45 | 5.82 | 0.63 | 0.62 |
| | | 20 knot SW | 1.72 | 0.47 | | 6.40 | 5.85 | 0.62 | 0.62 |
| | | 20 Knot NE | 1.74 | 0.49 | | 6.45 | 5.80 | 0.64 | 0.62 |
| | Spring | Calm | 2.05 | 0.24 | | 6.42 | 6.05 | 0.94 | 0.81 |
| | | 20 knot SW | 2.04 | 0.23 | | 6.40 | 6.07 | 0.95 | 0.82 |
| | | 20 Knot NE | 2.06 | 0.25 | | 6.42 | 6.07 | 0.92 | 0.81 |

**Table 1b** Spit Tide Gauge differences from 13m-channel situation

| Scenario | Tide | Winds | Difference in Height of High Tide (m) | Difference in Height of Low Tide (m) | Difference in time of High Tide from 13m situation (mins) | Difference in Flood Tide Duration (mins) | Difference in Ebb Tide Duration (mins) | Difference in Peak Flood Velocity (m/s) | Difference in Peak Ebb Velocity (m/s) |
|---|---|---|---|---|---|---|---|---|---|
| 14m | Neap | Calm | 0.00 | 0.00 | 1.0 | 1.0 | 0.0 | -0.01 | -0.01 |
| | | 20 knot SW | 0.00 | 0.00 | 0.0 | 0.0 | 0.0 | 0.00 | -0.01 |
| | | 20 Knot NE | 0.00 | 0.00 | -1.0 | -1.0 | 0.0 | -0.01 | -0.01 |
| | Spring | Calm | 0.00 | 0.00 | 0.0 | 0.0 | 0.0 | 0.00 | -0.02 |
| | | 20 knot SW | 0.00 | 0.00 | -1.0 | -1.0 | 0.0 | 0.00 | -0.02 |
| | | 20 Knot NE | 0.00 | 0.00 | 0.0 | 0.0 | 1.0 | 0.00 | -0.02 |
| 15m | Neap | Calm | 0.00 | 0.00 | 0.0 | 0.0 | 1.0 | -0.02 | -0.03 |
| | | 20 knot SW | 0.00 | 0.00 | -1.0 | -1.0 | 0.0 | -0.01 | -0.03 |
| | | 20 Knot NE | 0.00 | 0.00 | -1.0 | -1.0 | 0.0 | -0.02 | -0.03 |
| | Spring | Calm | 0.01 | 0.00 | 0.0 | 0.0 | 0.0 | -0.01 | -0.04 |
| | | 20 knot SW | 0.00 | 0.00 | -1.0 | -1.0 | 0.0 | -0.02 | -0.04 |
| | | 20 Knot NE | 0.01 | 0.00 | 0.0 | 0.0 | 1.0 | -0.01 | -0.04 |

**Table 2a** Harrington Bend summary of main changes to the hydrodynamics of the harbour under different shipping channel configurations.

| Scenario | Tide | Winds | Height of High Tide (m) | Height of Low Tide (m) | | Flood Tide Duration (hrs) | Ebb Tide Duration (hrs) | Peak Flood Velocity (m/s) | Peak Ebb Velocity (m/s) |
|---|---|---|---|---|---|---|---|---|---|
| Present (13.0m) | Neap | Calm | **1.75** | **0.47** | | **6.47** | **5.80** | **0.59** | **0.56** |
| | | 20 knot SW | **1.73** | **0.45** | | **6.45** | **5.82** | **0.59** | **0.56** |
| | | 20 Knot NE | **1.77** | **0.49** | | **6.47** | **5.78** | **0.60** | **0.56** |
| | Spring | Calm | **2.07** | **0.23** | | **6.47** | **6.03** | **0.86** | **0.72** |
| | | 20 knot SW | **2.05** | **0.21** | | **6.52** | **5.95** | **0.87** | **0.73** |
| | | 20 Knot NE | **2.08** | **0.25** | | **6.47** | **6.05** | **0.85** | **0.72** |
| 14m | Neap | Calm | **1.75** | **0.47** | | **6.45** | **5.82** | **0.59** | **0.55** |
| | | 20 knot SW | **1.73** | **0.45** | | **6.40** | **5.83** | **0.59** | **0.56** |
| | | 20 Knot NE | **1.77** | **0.49** | | **6.50** | **5.75** | **0.60** | **0.56** |
| | Spring | Calm | **2.07** | **0.23** | | **6.50** | **5.93** | **0.86** | **0.72** |
| | | 20 knot SW | **2.06** | **0.21** | | **6.43** | **6.03** | **0.87** | **0.73** |
| | | 20 Knot NE | **2.08** | **0.25** | | **6.53** | **6.00** | **0.86** | **0.72** |
| 15m | Neap | Calm | **1.76** | **0.47** | | **6.50** | **5.77** | **0.58** | **0.55** |
| | | 20 knot SW | **1.73** | **0.45** | | **6.38** | **5.83** | **0.58** | **0.55** |
| | | 20 Knot NE | **1.77** | **0.49** | | **6.48** | **5.77** | **0.59** | **0.55** |
| | Spring | Calm | **2.07** | **0.23** | | **6.50** | **5.95** | **0.85** | **0.71** |
| | | 20 knot SW | **2.06** | **0.21** | | **6.50** | **5.98** | **0.86** | **0.72** |
| | | 20 Knot NE | **2.09** | **0.25** | | **6.48** | **5.98** | **0.85** | **0.71** |

**Table 2b** Harrington Bend differences from 13m-channel situation

| Scenario | Tide | Winds | Difference in Height of High Tide (m) | Difference in Height of Low Tide (m) | Difference in time of High Tide from 13m situation (mins) | Difference in Flood Tide Duration (mins) | Difference in Ebb Tide Duration (mins) | Difference in Peak Flood Velocity (m/s) | Difference in Peak Ebb Velocity (m/s) |
|---|---|---|---|---|---|---|---|---|---|
| 14m | Neap | Calm | 0.00 | 0.00 | -1.0 | -1.0 | 1.0 | 0.00 | 0.00 |
| | | 20 knot SW | 0.00 | 0.00 | -3.0 | -3.0 | 1.0 | 0.00 | 0.00 |
| | | 20 Knot NE | 0.00 | 0.00 | 2.0 | 2.0 | -2.0 | 0.00 | 0.00 |
| | Spring | Calm | 0.00 | 0.00 | 2.0 | 2.0 | -6.0 | 0.00 | 0.00 |
| | | 20 knot SW | 0.00 | 0.00 | -5.0 | -5.0 | 5.0 | 0.00 | 0.00 |
| | | 20 Knot NE | 0.00 | 0.00 | 4.0 | 4.0 | -3.0 | 0.00 | 0.00 |
| 15m | Neap | Calm | 0.00 | 0.00 | 2.0 | 2.0 | -2.0 | -0.01 | -0.01 |
| | | 20 knot SW | 0.00 | 0.00 | -4.0 | -4.0 | 1.0 | -0.01 | -0.01 |
| | | 20 Knot NE | 0.00 | 0.00 | 1.0 | 1.0 | -1.0 | -0.01 | -0.01 |
| | Spring | Calm | 0.01 | 0.00 | 2.0 | 2.0 | -5.0 | -0.01 | -0.01 |
| | | 20 knot SW | 0.01 | 0.00 | -1.0 | -1.0 | 2.0 | -0.01 | -0.01 |
| | | 20 Knot NE | 0.01 | 0.00 | 1.0 | 1.0 | -4.0 | -0.01 | -0.01 |

**Table 3a** Pulling Point summary of main changes to the hydrodynamics of the harbour under different shipping channel configurations.

| Scenario | Tide | Winds | Height of High Tide (m) | Height of Low Tide (m) | | Flood Tide Duration (hrs) | Ebb Tide Duration (hrs) | Peak Flood Velocity (m/s) | Peak Ebb Velocity (m/s) |
|---|---|---|---|---|---|---|---|---|---|
| Present (13.0m) | Neap | Calm | **1.79** | **0.45** | | **6.43** | **5.90** | **0.63** | **0.61** |
| | | 20 knot SW | **1.74** | **0.41** | | **6.45** | **5.85** | **0.66** | **0.59** |
| | | 20 Knot NE | **1.84** | **0.48** | | **6.38** | **5.93** | **0.61** | **0.65** |
| | Spring | Calm | **2.12** | **0.22** | | **6.53** | **6.02** | **0.89** | **0.79** |
| | | 20 knot SW | **2.07** | **0.19** | | **6.58** | **5.93** | **0.87** | **0.82** |
| | | 20 Knot NE | **2.16** | **0.26** | | **6.55** | **6.00** | **0.91** | **0.77** |
| 14m | Neap | Calm | **1.79** | **0.44** | | **6.42** | **5.90** | **0.62** | **0.60** |
| | | 20 knot SW | **1.74** | **0.41** | | **6.45** | **5.80** | **0.65** | **0.58** |
| | | 20 Knot NE | **1.84** | **0.48** | | **6.45** | **5.83** | **0.61** | **0.64** |
| | Spring | Calm | **2.12** | **0.22** | | **6.53** | **6.03** | **0.88** | **0.78** |
| | | 20 knot SW | **2.07** | **0.19** | | **6.58** | **5.95** | **0.87** | **0.81** |
| | | 20 Knot NE | **2.17** | **0.26** | | **6.53** | **6.05** | **0.90** | **0.76** |
| 15m | Neap | Calm | **1.80** | **0.44** | | **6.43** | **5.88** | **0.62** | **0.60** |
| | | 20 knot SW | **1.75** | **0.41** | | **6.42** | **5.85** | **0.65** | **0.58** |
| | | 20 Knot NE | **1.84** | **0.48** | | **6.40** | **5.90** | **0.60** | **0.63** |
| | Spring | Calm | **2.12** | **0.22** | | **6.52** | **6.05** | **0.88** | **0.78** |
| | | 20 knot SW | **2.08** | **0.18** | | **6.60** | **5.93** | **0.86** | **0.81** |
| | | 20 Knot NE | **2.17** | **0.25** | | **6.52** | **6.03** | **0.90** | **0.76** |

**Table 3b** Pulling Point differences from 13 m channel situation

| Scenario | Tide | Winds | Difference in Height of High Tide (m) | Difference in Height of Low Tide (m) | Difference in time of High Tide from 13m situation (mins) | Difference in Flood Tide Duration (mins) | Difference in Ebb Tide Duration (mins) | Difference in Peak Flood Velocity (m/s) | Difference in Peak Ebb Velocity (m/s) |
|---|---|---|---|---|---|---|---|---|---|
| 14m | Neap | Calm | 0.00 | 0.00 | -1.0 | -1.0 | 0.0 | -0.01 | -0.01 |
| | | 20 knot SW | 0.00 | 0.00 | 0.0 | 0.0 | -3.0 | -0.01 | -0.01 |
| | | 20 Knot NE | 0.00 | 0.00 | 4.0 | 4.0 | -6.0 | -0.01 | -0.01 |
| | Spring | Calm | 0.00 | 0.00 | 0.0 | 0.0 | 1.0 | -0.01 | -0.01 |
| | | 20 knot SW | 0.00 | 0.00 | 0.0 | 0.0 | 1.0 | -0.01 | -0.01 |
| | | 20 Knot NE | 0.00 | 0.00 | -1.0 | -1.0 | 3.0 | -0.01 | -0.01 |
| 15m | Neap | Calm | 0.00 | 0.00 | 0.0 | 0.0 | -1.0 | -0.01 | -0.01 |
| | | 20 knot SW | 0.00 | 0.00 | -2.0 | -2.0 | 0.0 | -0.01 | -0.01 |
| | | 20 Knot NE | 0.00 | -0.01 | 1.0 | 1.0 | -2.0 | -0.01 | -0.01 |
| | Spring | Calm | 0.01 | -0.01 | -1.0 | -1.0 | 2.0 | -0.01 | -0.02 |
| | | 20 knot SW | 0.01 | -0.01 | 1.0 | 1.0 | 0.0 | -0.01 | -0.02 |
| | | 20 Knot NE | 0.01 | -0.01 | -2.0 | -2.0 | 2.0 | -0.01 | -0.01 |

**Table 4a** Point Chalmers summary of main changes to the hydrodynamics of the harbour under different shipping channel configurations.

| Scenario | Tide | Winds | Height of High Tide (m) | Height of Low Tide (m) | | Flood Tide Duration (hrs) | Ebb Tide Duration (hrs) | Peak Flood Velocity (m/s) | Peak Ebb Velocity (m/s) |
|---|---|---|---|---|---|---|---|---|---|
| Present (13.0m) | Neap | Calm | **1.78** | **0.46** | | **6.47** | **5.82** | **0.41** | **0.41** |
| | | 20 knot SW | **1.74** | **0.43** | | **6.45** | **5.82** | **0.44** | **0.39** |
| | | 20 Knot NE | **1.81** | **0.48** | | **6.45** | **5.83** | **0.38** | **0.43** |
| | Spring | Calm | **2.09** | **0.23** | | **6.63** | **5.90** | **0.58** | **0.54** |
| | | 20 knot SW | **2.06** | **0.20** | | **6.48** | **5.98** | **0.55** | **0.56** |
| | | 20 Knot NE | **2.12** | **0.25** | | **6.62** | **5.93** | **0.60** | **0.52** |
| 14m | Neap | Calm | **1.78** | **0.45** | | **6.47** | **5.85** | **0.40** | **0.40** |
| | | 20 knot SW | **1.74** | **0.43** | | **6.47** | **5.83** | **0.43** | **0.39** |
| | | 20 Knot NE | **1.81** | **0.48** | | **6.45** | **5.83** | **0.38** | **0.43** |
| | Spring | Calm | **2.10** | **0.22** | | **6.58** | **5.92** | **0.57** | **0.53** |
| | | 20 knot SW | **2.06** | **0.20** | | **6.50** | **5.97** | **0.55** | **0.56** |
| | | 20 Knot NE | **2.13** | **0.25** | | **6.58** | **5.98** | **0.59** | **0.52** |
| 15m | Neap | Calm | **1.78** | **0.45** | | **6.47** | **5.82** | **0.39** | **0.39** |
| | | 20 knot SW | **1.74** | **0.43** | | **6.50** | **5.80** | **0.42** | **0.38** |
| | | 20 Knot NE | **1.81** | **0.48** | | **6.47** | **5.80** | **0.36** | **0.43** |
| | Spring | Calm | **2.10** | **0.22** | | **6.57** | **5.93** | **0.55** | **0.53** |
| | | 20 knot SW | **2.07** | **0.19** | | **6.48** | **6.00** | **0.53** | **0.56** |
| | | 20 Knot NE | **2.13** | **0.24** | | **6.60** | **5.93** | **0.58** | **0.51** |

**Table 4b** Port Chalmers differences from 13 m channel situation

| Scenario | Tide | Winds | Difference in Height of High Tide (m) | Difference in Height of Low Tide (m) | Difference in time of High Tide from 13m situation (mins) | Difference in Flood Tide Duration (mins) | Difference in Ebb Tide Duration (mins) | Difference in Peak Flood Velocity (m/s) | Difference in Peak Ebb Velocity (m/s) |
|---|---|---|---|---|---|---|---|---|---|
| 14m | Neap | Calm | 0.00 | 0.00 | 0.0 | 0.0 | 2.0 | -0.01 | -0.01 |
| | | 20 knot SW | 0.00 | 0.00 | 1.0 | 1.0 | 1.0 | -0.01 | -0.01 |
| | | 20 Knot NE | 0.00 | 0.00 | 0.0 | 0.0 | 0.0 | -0.01 | 0.00 |
| | Spring | Calm | 0.00 | 0.00 | -3.0 | -3.0 | 1.0 | -0.01 | -0.01 |
| | | 20 knot SW | 0.00 | 0.00 | 1.0 | 1.0 | -1.0 | -0.01 | 0.00 |
| | | 20 Knot NE | 0.00 | 0.00 | -2.0 | -2.0 | 3.0 | -0.01 | -0.01 |
| 15m | Neap | Calm | 0.00 | 0.00 | 0.0 | 0.0 | 0.0 | -0.02 | -0.01 |
| | | 20 knot SW | 0.00 | 0.00 | 3.0 | 3.0 | -1.0 | -0.02 | -0.01 |
| | | 20 Knot NE | 0.00 | 0.00 | 1.0 | 1.0 | -2.0 | -0.02 | -0.01 |
| | Spring | Calm | 0.01 | -0.01 | -4.0 | -4.0 | 2.0 | -0.02 | -0.01 |
| | | 20 knot SW | 0.01 | -0.01 | 0.0 | 0.0 | 1.0 | -0.02 | 0.00 |
| | | 20 Knot NE | 0.01 | -0.01 | -1.0 | -1.0 | 0.0 | -0.02 | -0.01 |

**Table 5a** Ravensbourne summary of main changes to the hydrodynamics of the harbour under different shipping channel configurations.

| Scenario | Tide | Winds | Height of High Tide (m) | Height of Low Tide (m) | | Flood Tide Duration (hrs) | Ebb Tide Duration (hrs) | Peak Flood Velocity (m/s) | Peak Ebb Velocity (m/s) |
|---|---|---|---|---|---|---|---|---|---|
| Present (13.0m) | Neap | Calm | **1.85** | **0.41** | | **5.95** | **6.35** | **0.36** | **0.27** |
| | | 20 knot SW | **1.74** | **0.33** | | **6.13** | **6.17** | **0.38** | **0.26** |
| | | 20 Knot NE | **1.96** | **0.50** | | **5.95** | **6.37** | **0.34** | **0.28** |
| | Spring | Calm | **2.20** | **0.22** | | **5.88** | **6.65** | **0.48** | **0.33** |
| | | 20 knot SW | **2.09** | **0.14** | | **5.90** | **6.63** | **0.46** | **0.35** |
| | | 20 Knot NE | **2.31** | **0.31** | | **5.83** | **6.70** | **0.50** | **0.32** |
| 14m | Neap | Calm | **1.86** | **0.41** | | **5.93** | **6.38** | **0.36** | **0.27** |
| | | 20 knot SW | **1.74** | **0.33** | | **6.12** | **6.23** | **0.38** | **0.26** |
| | | 20 Knot NE | **1.96** | **0.50** | | **5.97** | **6.33** | **0.34** | **0.29** |
| | Spring | Calm | **2.21** | **0.22** | | **5.87** | **6.67** | **0.49** | **0.33** |
| | | 20 knot SW | **2.09** | **0.14** | | **5.98** | **6.55** | **0.46** | **0.35** |
| | | 20 Knot NE | **2.31** | **0.30** | | **5.85** | **6.68** | **0.51** | **0.32** |
| 15m | Neap | Calm | **1.86** | **0.41** | | **5.93** | **6.38** | **0.36** | **0.27** |
| | | 20 knot SW | **1.74** | **0.33** | | **6.07** | **6.27** | **0.38** | **0.27** |
| | | 20 Knot NE | **1.96** | **0.50** | | **6.00** | **6.33** | **0.34** | **0.29** |
| | Spring | Calm | **2.21** | **0.21** | | **5.92** | **6.63** | **0.49** | **0.34** |
| | | 20 knot SW | **2.10** | **0.14** | | **5.95** | **6.57** | **0.47** | **0.35** |
| | | 20 Knot NE | **2.32** | **0.30** | | **5.85** | **6.68** | **0.51** | **0.32** |

**Table 5b** Ravensbourne differences from 13m-channel situation

| Scenario | Tide | Winds | Difference in Height of High Tide (m) | Difference in Height of Low Tide (m) | Difference in time of High Tide from 13m situation (mins) | Difference in Flood Tide Duration (mins) | Difference in Ebb Tide Duration (mins) | Difference in Peak Flood Velocity (m/s) | Difference in Peak Ebb Velocity (m/s) |
|---|---|---|---|---|---|---|---|---|---|
| 14m | Neap | Calm | 0.00 | 0.00 | -1.0 | -1.0 | 2.0 | 0.00 | 0.00 |
| | | 20 knot SW | 0.00 | 0.00 | -1.0 | -1.0 | 4.0 | 0.00 | 0.00 |
| | | 20 Knot NE | 0.00 | 0.00 | 1.0 | 1.0 | -2.0 | 0.00 | 0.00 |
| | Spring | Calm | 0.00 | 0.00 | -1.0 | -1.0 | 1.0 | 0.00 | 0.00 |
| | | 20 knot SW | 0.00 | 0.00 | 5.0 | 5.0 | -5.0 | 0.00 | 0.00 |
| | | 20 Knot NE | 0.00 | 0.00 | 1.0 | 1.0 | -1.0 | 0.00 | 0.00 |
| 15m | Neap | Calm | 0.00 | 0.00 | -1.0 | -1.0 | 2.0 | 0.00 | 0.00 |
| | | 20 knot SW | 0.00 | 0.00 | -4.0 | -4.0 | 6.0 | 0.00 | 0.01 |
| | | 20 Knot NE | 0.00 | -0.01 | 3.0 | 3.0 | -2.0 | 0.00 | 0.00 |
| | Spring | Calm | 0.01 | -0.01 | 2.0 | 2.0 | -1.0 | 0.00 | 0.00 |
| | | 20 knot SW | 0.01 | -0.01 | 3.0 | 3.0 | -4.0 | 0.01 | 0.00 |
| | | 20 Knot NE | 0.01 | -0.01 | 1.0 | 1.0 | -1.0 | 0.00 | 0.00 |

**Table 6a** Dunedin Wharves summary of main changes to the hydrodynamics of the harbour under different shipping channel configurations.

| Scenario | Tide | Winds | Height of High Tide (m) | Height of Low Tide (m) | | Flood Tide Duration (hrs) | Ebb Tide Duration (hrs) | Peak Flood Velocity (m/s) | Peak Ebb Velocity (m/s) |
|---|---|---|---|---|---|---|---|---|---|
| Present (13.0m) | Neap | Calm | **1.84** | **0.42** | | **5.85** | **6.47** | **0.11** | **0.08** |
| | | 20 knot SW | **1.71** | **0.29** | | **6.00** | **6.32** | **0.47** | **0.41** |
| | | 20 Knot NE | **1.99** | **0.53** | | **5.87** | **6.45** | **0.40** | **0.44** |
| | Spring | Calm | **2.18** | **0.24** | | **5.72** | **6.82** | **0.18** | **0.11** |
| | | 20 knot SW | **2.06** | **0.10** | | **5.78** | **6.77** | **0.54** | **0.21** |
| | | 20 Knot NE | **2.34** | **0.33** | | **5.70** | **6.83** | **0.43** | **0.46** |
| 14m | Neap | Calm | **1.86** | **0.40** | | **5.87** | **6.45** | **0.12** | **0.09** |
| | | 20 knot SW | **1.71** | **0.28** | | **6.02** | **6.30** | **0.47** | **0.41** |
| | | 20 Knot NE | **1.99** | **0.52** | | **5.83** | **6.48** | **0.40** | **0.44** |
| | Spring | Calm | **2.18** | **0.24** | | **5.72** | **6.82** | **0.18** | **0.11** |
| | | 20 knot SW | **2.06** | **0.10** | | **5.78** | **6.77** | **0.54** | **0.21** |
| | | 20 Knot NE | **2.34** | **0.33** | | **5.70** | **6.83** | **0.43** | **0.46** |
| 15m | Neap | Calm | **1.86** | **0.40** | | **5.88** | **6.43** | **0.12** | **0.09** |
| | | 20 knot SW | **1.71** | **0.28** | | **6.02** | **6.30** | **0.47** | **0.41** |
| | | 20 Knot NE | **1.99** | **0.52** | | **5.83** | **6.47** | **0.40** | **0.44** |
| | Spring | Calm | **2.21** | **0.20** | | **5.73** | **6.80** | **0.19** | **0.12** |
| | | 20 knot SW | **2.07** | **0.09** | | **5.80** | **6.73** | **0.54** | **0.21** |
| | | 20 Knot NE | **2.35** | **0.32** | | **5.70** | **6.83** | **0.43** | **0.46** |

**Table 6b** Dunedin Wharves differences from 13m-channel situation

| Scenario | Tide | Winds | Difference in Height of High Tide (m) | Difference in Height of Low Tide (m) | Difference in time of High Tide from 13m situation (mins) | Difference in Flood Tide Duration (mins) | Difference in Ebb Tide Duration (mins) | Difference in Peak Flood Velocity (m/s) | Difference in Peak Ebb Velocity (m/s) |
|---|---|---|---|---|---|---|---|---|---|
| 14m | Neap | Calm | 0.01 | -0.02 | 1.0 | 1.0 | -1.0 | 0.01 | 0.00 |
| | | 20 knot SW | 0.00 | 0.00 | 1.0 | 1.0 | -1.0 | 0.00 | 0.00 |
| | | 20 Knot NE | 0.00 | 0.00 | -2.0 | -2.0 | 2.0 | 0.00 | 0.00 |
| | Spring | Calm | 0.00 | 0.00 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 |
| | | 20 knot SW | 0.00 | 0.00 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 |
| | | 20 Knot NE | 0.00 | 0.00 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 |
| 15m | Neap | Calm | 0.02 | -0.03 | 2.0 | 2.0 | -2.0 | 0.01 | 0.00 |
| | | 20 knot SW | 0.00 | 0.00 | 1.0 | 1.0 | -1.0 | 0.00 | 0.00 |
| | | 20 Knot NE | 0.00 | -0.01 | -2.0 | -2.0 | 1.0 | 0.00 | 0.00 |
| | Spring | Calm | 0.03 | -0.04 | 1.0 | 1.0 | -1.0 | 0.01 | 0.01 |
| | | 20 knot SW | 0.01 | -0.01 | 1.0 | 1.0 | -2.0 | 0.00 | 0.00 |
| | | 20 Knot NE | 0.01 | -0.01 | 0.0 | 0.0 | 0.0 | 0.00 | 0.00 |