# Annotated Bibliography:

## Coastal and Continental Shelf Processes of Otago Harbour and Blueskin Bay


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## Introduction

This report reviews literature on coastal and continental shelf processes of Otago Harbour and Blueskin Bay. The work was commissioned by Port Otago Ltd in order to assist in identifying the effects of proposed capital dredging activities in Otago Harbour associated with "Project Next Generation" on the physical coastal environment. The aim of this literature review is to identify major recent research that has been undertaken in the Otago Harbour area, to summarise the main understandings of coastal and shelf processes in the study area, and to identify any significant gaps in the current knowledge base.

Chronologically, the review focuses on literature produced since about 1990 although earlier significant reports are also reviewed. For the purposes of this study, it was considered that most material produced before 1990 has been summarised in many previous reports (Kirk 1982, Single and Kirk 1994, Bunting *et al*. 2003a). Smith (1994, 1999) and Tonkin and Taylor Ltd (2000) for example, provided substantial bibliographic reference lists relating to the Otago Coastal environment.

Spatially, the area covered by the review concentrates on the nearshore shelf between Otago Harbour and Karitane and Otago Harbour. Where relevant, literature pertaining to regional scale processes such as oceanic currents and sedimentation on the Otago continental shelf have also been reviewed.

The literature that has been reviewed is representative of most of the major recent and historical coastal and shelf research that has been undertaken in the study area. There may be other items of research that have not been included in this report due to lack of relevance, repetitiveness or the research not being accessible in the time-frame allowed.

### Literature Types and Sources

A plethora of relevant information has been produced on the study area. This has come about due to Otago Harbour being intensely urbanised and a being major shipping port. Thus, the harbour has high economic, environmental and recreational importance to Dunedin City. Because of this, coastal-marine processes and the ecology of the Otago Harbour and its surrounds have been studied from many perspectives. For example, research has been undertaken by several university departments (e.g. Marine Science, Geology, Geography, Surveying, Chemistry, Applied Science, Engineering), local authorities (Otago Regional Council, Dunedin City Council, Port Otago Ltd and their predecessors), the Department of Conservation, and numerous private consulting companies. Research from these organisations has covered marine and terrestrial geology, geomorphology, sedimentology, hydrology, oceanography, biology, water and sediment quality, anthropogenic changes, planning/management and recreational aspects amongst others. Also, as Otago was one of the earliest areas in New Zealand to be settled by Europeans, many local history accounts have also been produced.

The reviewed literature can be divided into the following three main sources: A) Papers published in scientific journals; B) Client based technical reports produced by consulting companies, university staff and post graduate students, and C) Post graduate research theses, diplomas and dissertations. Some information was also gathered from general history accounts (e.g. Church *et al.* 2007). Most of the journal information was obtained from the Canterbury University library, whilst most of the post graduate research studies were obtained from various libraries at Otago University. Copies of many of the technical/client reports were gathered from university staff members (Canterbury and Otago Universities) and Port Otago Ltd.

The reviewed literature is categorised into the following broad topics of research:

1. Regional coastal environment – including Otago continental shelf evolution and sedimentation (e.g. Andrews 1973; Carter *et al.* 1985; Orpin 1992; Osterburg 2001)
2. Oceanographic processes - (e.g. Barnett *et al.* 1988; ; Wilson 1989; Old 1999; Whitefield 2004; Vennell and Old *in press*)
3. Holocene coastal evolution and shore development - (e.g. Elliot 1958; Witman 1974; Goldsmith 1995; Thomas 2000; Leon 2005a)
4. Sediments of Blueskin Bay and Otago Harbour - (e.g. Kirk 1980; Single and Kirk 1994; Bunting *et al.* 2003a; Carter 1986; Hicks and Shankar 2003; Dignan 2005; Smith 1999b; Tonkin and Taylor 2000; Leon 2005b; Ramsay 2005)
5. Otago Harbour coastal environment -
6. Coastal hazards - (e.g. Otago Regional Council 1991; Johnstone 1997; Tonkin and Taylor 1997, 1999; Smith 1999a; Berryman 2005)

## Bibliography Format

The bibliography contains both published and unpublished information. Material presented within the above categories is arranged alphabetically by author. Each review describes the focus of the research, methods used, and the main findings. Brief descriptions of the major figures, tables and appendices are then given. In a few cases, the complete original reports were not available for review at the time of writing. In such cases, either the abstract has been quoted verbatim (e.g. Old and Vennell 2001; Vennell and Old *in press*) or it has been noted that figures etc. are yet to be obtained (e.g. Old 1999; Sabetian 1998). An alphabetically arranged reference list of the material reviewed is also provided at the end of the annotated bibliography.

## Further Research

Despite there being general agreement on most aspects of the physical coastal environmental processes, there are some areas where differing opinions have been identified, or there is a distinct lack of information available. These areas warrant further investigation. Most authors have provided recommendations for further research relating to their particular fields of interest but the list of Bunting *et al.* (2003b) is particularly relevant to any dredging activities in Otago Harbour. These recommendations include:

And in addition:

1. The coastal and Otago Harbour sediment budgets need to be refined For example, Smith (1999b) suggested there was a deficit of coastal sediment, attributable to the sand storage behind the Roxburgh and Clutha Dams. However, Tonkin and Taylor (2000) stated the there was still a sand surplus to the coastal sediment budget, despite the dams. Added to this, recent calculations of the Clutha sediment discharge volumes provided by Hicks and Shankar (2003) are considerably lower than those used as the basis for the sediment budgets of Smith (1999b) and Tonkin and Taylor (2000).

2. Measurements of currents and waves are required in Blueskin Bay. As noted by Bunting *et al.* (2003b), very little measurements have been made of nearshore currents and waves in the Blueskin Bay area. These processes are crucial to dredge spoil dispersal, coastal sedimentation and ship handling in the outer channel.

3. The effects of projected climate change need to be examined for Otago Harbour. Many reports have produced data and information on Holocene sea level rise, and others have provided very general statements regarding the effects of future sea level rise. Barnett *et al.* (1988), Wilson (1999), Wilson and Sutherland (1991) and Tomlin (2002) have examined with regard to inundation hazards, the effects of projected future sea

level rise associated with climate change. However there are likely to be other effects relevant to harbour sedimentation, hydrodynamics, and dredge spoil dispersal and ship handling.

## Acknowledgements

Thanks are extended to Lincoln Coe (Port Otago Ltd) and the following people at Otago University for arranging and allowing access to much of the literature reviewed: Professor Keith Probert and Dr Abby Smith (Marine Science Dept); Dr Andrew Gorman (Geology Dept), and the librarians of the University of Otago and University of Canterbury.

# Annotated Bibliography

## Regional coastal environment

**Bardsley WE (1977):** Dispersal of some heavy minerals along the Otago-Eastern Southland Coast. *New Zealand Geographer* 33 (2): 76-79.

Twenty one beach sediment samples containing natural heavy tracer minerals were used to determine the sediment transport directions along the coastal zone between Porpoise Bay (Southland) and the Pleasant River (East Otago). Two types of sediment sample were used: *'Plutonics'* (parent rocks from Stewart Island and Western Southland) and *'Volcanics'* (parent rocks from the Dunedin area). The Plutonics showed a simple NE dispersal pattern along the coast: There was a distinct drop in heavy minerals at Kaka Point, mainly due to the influence and inputs of the Clutha River, and a possible local southerly drift. Allans Beach appeared to be the main Volcanic source. High content of Volcanics from Allans Beach northwards was consistent with NE sediment movement and a point source. Secondary sources included Long Beach and Warrington Beach. Generally, the northerly dispersal of both types of minerals was consistent with the northerly direction of the Southland Current and dominant southerly swell. As sand is concentrated in a narrow belt close to the coastline through wave action, its transport is governed by neritic water rather than the true Southland Current. North of Dunedin, sand transport is more complex. As sand follows the coastline into Blueskin Bay, the influence of the northward current decreases and cannot move north of Cornish Head due to the gyre (eddy) circulation system.

*Figures:* Location of lithological types and oceanic currents in the study area; Detail of Otago Peninsula (Dunedin Volcanics), ocean currents and offshore sand limits. Two sets of graphs show the % heavy mineral/distance along coast (km) for the Plutonic and Volcanic mineral assemblages.

**Church I; Strachan S; Strachan J (2007):** Blueskin days: A history of the Waitati, Evansdale, Warrington and surrounding districts. Blueskin History Steering Society. 367p.

A general history account of the area but some references are made to coastal stability. Notes erosion on the western side of the spit at Warrington which exposed Maori archaeological sites, but the northern end of the spit and dunes were generally stable, as $^{14}C$ dates showed various Maori occupations between 1370 and 1620. Eroding edge of bay at Waitati exposed several archaeological sites. An exception to erosion in this area was at the site of the former Waitati River mouth, which had silted up long before European times, and artifacts from the moa-hunter period have been found.

*Figures:* Many historical photographs, maps and sketch maps of the area reproduced from Hocken Library, Otago Museum and private collections.

**Gibb JG (1986):** A New Zealand regional Holocene eustatic sea-level curve and its application to determination of vertical tectonic movements; a contribution to IGCP-Project 200. *Royal Society of New Zealand Bulletin* 24: 377-395.

82 radiocarbon dates obtained from various sea level indicators (e.g. shells, peat, brackish carbonaceous muds, beach ridges and cheniers), and collected from eight very low uplift/downthrown areas, were used to determine a Holocene eustatic sea level curve for New Zealand. Radiocarbon samples and dating methods are described, as well as definitions of eustacy, tectonic uplift, and paleo-sea level indicators. Also described are tectonic stability of each site, the separation of tectonic and eustatic effects, and the sea level trend over the last 10

000 years in detail. Blueskin Bay was described as enclosed by a 2 km long Holocene sandspit, emerging from loess capped marine terrace at northern end. Underlying the loess are beach gravels and sand extending up to 2.7 m above MHWS (These deposits are assumed to be 120 to 125 ka). 10 radio carbon dates were obtained from the NE section of Blueskin Bay and based on these it was concluded that the bay had been tectonically stable over the last 120-125 ka. Thus Blueskin Bay was used as a type locality for New Zealand, as the 10 dates for Blueskin Bay were inferred to be eustatic.

_Figures and Tables:_ Photos of various sample locations including Blueskin Bay soil profiles. Two sea level curve figures (general NZ Curve and curves for eight sample sites including Blueskin Bay). Data tables of radiocarbon sample locations; dates; Holocene beach formations and relative sea levels.

**Hodgson WA (1966):** Coastal processes around the Otago Peninsula. *New Zealand Journal of Geology and Geophysics* 9 (1/2): 76-90.

This paper describes the development of the sand spits on the north and south sides of the Otago Peninsula, based on daily wave observations made between December 1963 and December 1964 (Daily wave period and direction observations from Taiaroa Head Lighthouse and daily swell observations from Cape Saunders Lighthouse). Wave height and period observations for 3 and 4 weeks periods were also made from St Clair and St Kilda respectively. Describes generalised conceptual models from international research and summarises previous research (mainly Elliot 1958). Wave patterns for each beach are described in detail: Dominant southerly swell, backed by a lesser northerly swell under local conditions. Swell period ranged from 4 to 25 seconds but 81% of the time the period was between 6 and 12 seconds. Mean period deceased from 12 seconds at St Clair to 8.5 sec at Taiaroa Head. No explanation given. Deep water wave heights ranged from 1.5 to 9.5 ft, giving breaker heights at the beach of 3 to 11 ft. Average wave height increased from 3 to 4 ft from summer to winter. S-SW waves incompletely refracted on north side of peninsula and local NE winds important in promoting NE wave approach directions. Between Taiaroa Head and Warrington Spit breakers are a product of N-NE winds and are much more variable than dominant ocean swell. Mean NE sea conditions at Warrington: T= 2-6 seconds; Wind velocity =10-16 knots; wave heights up to 5 ft based on fetch of 20-170 miles; Little refraction of NE waves therefore approach shore at high angles (30-40$^{o}$). Shells identified N to S littoral drift along Warrington Spit (500lb coloured sand tracer not found in beach drift experiment)

_Figures and Tables:_ Map of beach locations – St Clair to Warrington; wave refraction diagrams for southerly swells (10 and 15 second periods). Air photos of Warrington and Spit beaches. Graphs of wave energy and swell periods.

**Nicholson DC (1979):** MA Thesis (Geography, Canterbury University). Sand beaches in southern Blueskin Bay. 185p.

Holocene-Present beach morphology and coastal changes of Purakanui Beach, Long Beach, Murdering Beach and Kaikai Beach are examined, and links are made between the Otago shelf sediments and those on the beaches of Blueskin Bay. Methods used included reviewing coastal processes literature, analysis of air photos, old cadastral surveys and bathymetric charts, beach and back-beach cross section surveys, sub surface surveys based on digging pits, offshore profile surveys (based on echo soundings), analyses of beach surface, subsurface and offshore sediment samples. Significant findings were: (1) Blueskin Bay sand beaches were found to be a product of very recent and rapid progradation (last 200-500 yrs), due to changes in the Otago shelf sediment supply. Sediment supply rates may have changed due to climatic and anthropogenic changes or a combination of both. Sediment changes were not related to base level changes (i.e. Tectonic uplift of land, drop in sea level or both); (2) Sand transport confined to narrow nearshore zone defined by a terrace slope at 15 m depth – this probably defined the seaward extent of beach system sand transport; (3) Wave induced gyre circulation probably more important for sand transport in Blueskin Bay than *"eddies in coastal currents and the orbital action of waves".* Eddies in bay are weak and not consistent with patterns of shoreline growth; (4) Purakanui Beach accretionary (-3.2 m.y$^{-1}$, +370.4 m over 116 yrs); Long Beach accretionary (-+1.83 m.y$^{-1}$, +211.8 m over 116 yrs); Murdering Beach erosional (-0.89 m.y$^{-1}$; -103.1 m over 116 yrs; Kaikai Beach stable (-0.15 m.y-$^{1}$, -18.6 m over 116 yrs). Short term fluctuations superimposed on these trends.

Figures, Tables and Appendices: Maps of general location; geology; coastal landforms; wave refraction diagrams; ocean currents; sediment sample locations; shoreline positions. Graphs of Pleistocene–Holocene sea level changes; wind speed and direction; beach-back beach-offshore cross section profiles; beach volume changes. Tables of pre/post glacial sea level fluctuations; beach characteristics; direct current measurements; sediment sample analyses; coastal erosion/accretion rates. Numerous general site photos.

**Orpin AR (1992):** Authigenic carbonate chimneys as possible conduits for fluid explosion, on the outer Otago shelf. MSc Thesis (Geology, Otago University. 110p plus appendices.

This thesis describes carbonate chimneys on the upper most continental-shelf, east of the Otago Peninsula. A summary of Otago shelf sedimentation is given (based on Carter *et al.* 1985), and descriptions of the chimneys and sea floor are presented, based on photography from a Remote Operated Vehicle (ROV). Detailed analyses of the chimneys' geochemical and petrographic compositions are also given. The chimneys were interpreted as exhumed relict features that were originally cemented just below the sediment-water interface. The chimney cement was interpreted as aquifer forced ground water, marine in character, and sourced from the exposed inner-middle shelf during glacially lowered sea level. Radiocarbon dating suggests a maximum age of 33 000 ± 550 yrs BP. The chimneys' chemical composition and location at the head of off shore canyons indicate coastal dewatering was widespread during the last period of lowered sea level. The aquifer forced explanation contrasts with the tectonically induced fluid flow proposed for vent sites on convergent margins.

Figures and Tables: Location map and numerous photos of the chimneys. Tables of geochemical composition. Appendices: Current shear velocity equations; bathymetric information – outer shelf; x-ray diffraction and fluorescence analyses; seismic profiles; Electron microprobe analysis; video of sea floor.

**Orpin AR (1997):** Dolomite chimneys as possible evidence of coastal fluid explosion, uppermost Otago continental slope, southern New Zealand. *Marine Geology* 138: 157-167.

This paper provides a summarised version of the methods, main findings and conclusions of Orpin (1992). See above.

Figures and Tables: Location map and numerous photos of the chimneys. Table of geochemical composition.

**Otago Regional Council (2005):** Environmental status of the nearshore coastal environment: 68p.

This report presents a 'State of Environment' report for Otago's Coastal Marine Area (CMA). It focuses on water quality issues of the urban Dunedin and Harbour areas. The physical aspects of the CMA in terms of coastal processes get very little mention. However, coastal sediments are monitored in terms of contaminants (heavy minerals and feacal colliforms), especially in the harbour and around the Green Island sewer outfall. It is recognised there is no formal or coordinated monitoring programme of the CMA and that data collection relies mostly upon that collected through resource consent applications and monitoring. Sites, methods and regularity of consent monitoring are given. The storm water outfall at Portobello Rd caused significant heavy mineral contamination in the area due to the local, low wave energy which did not disperse the heavy minerals, allowing them to settle out in the sediments. Contamination could be traced through the sediment profile to the 1960s when the pipe was installed. Based on this, sedimentation rates in the Portobello area were 3.0 - 3.5 $mm.y^{-1}$.

*Figures and Tables:* Maps of Otago Region and CMA locations, weekly water quality monitoring sites. Numerous graphs and tables show water quality and heavy mineral/colliform concentrations, and International standards/guidelines.

**Rasch IL (1987):** Dissolved silicon in the marine environment. MSc Thesis (Chemistry? Otago University). 175p.

This thesis investigated two possibilities: First, was the possible removal of dissolved silicon in sea water by adsorption onto particulate matter (relevant to nutrient removal in the ecosystem), and secondly, of more importance to Project Neptune, using dissolved silicon/sediment tracers to determine tidal circulation in Blueskin Bay. The hydrology and geology of Blueskin Bay are summarised and the field sampling and laboratory techniques are described in detail. Adsorption experiments in Blueskin Bay indicated that in sediments with high $SiO_2$, silicon would desorb from the solid matter. Based on intensive surface sampling of sediments and analysing the dissolved silicon content, little evidence was found to support the gyre counter-current in Blueskin Bay. The dissolved silicon was found to be very useful in identifying differing water masses

*Figures:* Most of the figures are graphs are contour maps of sediment, salinity and water temperature parameters of Blueskin Bay. Maps of general location; proposed surface flow directions (ebb and flood tides); traditional gyre flow directions; sediment sample locations.

**Smith AM (1994):** Proposed regional coastal plan for Otago. Background Report 4: Eastward to the sea: A scientific review of the Otago Coastal Marine Area. Otago Regional Council. 83p.

Report provides a brief overview of all aspects of the Otago Coastal Marine Area, with brief descriptions of the geology, geography, biology, water chemistry, ocean currents, shelf sediments, pollution, conservation and management. Describes coastal stability at various locations: Shag River to Pleasant Valley = very little erosion; south of Pleasant River = accretion; Karitane-Warrington coast subject to landslides due to mass movement of unstable lithologies. General sea level rise effects discussed (based on IPCC) and what local effects these may have on coast. Locations of historical beach sand mining and dredging/dumping are identified. Dredging undertaken since 1884: current rate approximately 240 000 $m^3.y^{-1}$. Reclamation of Otago Harbour = 363 ha since 1862. Main observations from previous research: Sediment wedge up to 15 m thick; Clutha River main supplier; waves, winds, currents dominantly move NE along coast; swell heights usually between 1.5 and 2.5 m but can be much higher; Most large swells and storm waves from SE; Southland Current flow rate between 20 and 80 $cm.s^{-1}$. Southerly gales may cause storm surge of 60 cm. Spring tide = 2.1 m above datum; Tidal range is 1.5 to 1.8 m; semi permanent eddy at Blueskin Bay leads to sand deposition; current speeds in Otago Harbour main channel up to 75 $cm.s^{-1}$ (1.5 knots) but more usually 50 $cm.s^{-1}$ (1.0 knot). Extensive reference list divided into following groups: (1) Maps and charts; (2) Field guides and general books; (3) Scientific literature (marine chemistry and pollution; physical oceanography; meteorology, hydrology; marine biology and conservation; management reports. The individual references are not summarised.

*Figures:* Maps of Otago Peninsula; bathymetry; coastal geology; offshore sediments and transport directions; satellite photos of offshore waters; current and wind directions; coastal erosion/accretion, sand mining, dredge areas, spoil dump; coastal structures; areas vulnerable to sea level rise.

**Smith AM (1999a):** Coastal erosion issues in Otago: Literature review. Report to Tonkin and Taylor Ltd. 8p plus appendix.

This brief report was the first in a series (see below) that examined coastal erosion issues in Otago. It provides brief overviews of the Otago coastal setting (beach types, composition, orientation etc); changes to sediment budgets from littoral drift, rivers, dams and flooding, beach stability/shoreline changes, and the effect of human activity on the shoreline. A substantial bibliographic list is provided, covering a wide range of subjects relating to coastal issues, sourced from newspaper reports, general histories, university projects and theses, to professional technical reports.

*Figure and Appendix:* Location map of Otago Coast. Appendix = bibliography list.

**Smith AM (1999b):** Coastal erosion issues in Otago: Draft sediment budget. Report to Tonkin and Taylor Ltd. 31p.

A sediment budget is developed for the Otago coast between Nugget Point and Karitane, and extending offshore to the edge of the modern sand wedge. These boundaries were chosen as they probably reflected the natural boundaries of sand transport from the Clutha River. General sediment budget concepts are described and these are applied to the Otago coast: Sediment sources, storage, transport, and removal along the coast are identified and quantified. The main conclusions were: (1) The Clutha is the main source of coastal sediment in Otago – if not dammed it would provide 58% of total output; (2) The sediment load of the Clutha is reduced from 594 444 $m^3.y^{-1}$ to 69 444$m^3.y^{-1}$ due to damming, which significantly affects the volume delivered to the coast; (3) Dredge spoil added 21% of the total sediment supply to the east Otago Coast but the benefits are only on beaches north of the harbour – most probably ends in Blueskin Bay; (4) Biogenic carbonate is the next most important sediment source but the volume is unknown; (5) The modern offshore sand wedge stores 52% of all sediment in storage and the total average supply is only 69% of the storage volume. Very little sediment escapes the East Otago system (sand wedge storage and Blueskin Bay eddy) into North Otago; (6) Only about 16% of total input is removed from the system – sand mining and dune blowouts are minimal losses; carbonate attrition may be responsible for most loss; (7) A net deficit was identified – storage and removal were 62% greater than the supply rate.

*Figures and Tables:* Otago coast sediment budget maps, and budget component diagrams; nearshore sand wedge model. Tables: Historical events relevant to East Otago sediment budget; East Otago sediment budget model parameters; coastal sand body inventory for East Otago; nearshore sand wedge volume calculations; sediment budget control model.

**Smith AM (2000a):** Coastal erosion issues in Otago: Past, present, and future. Report to Tonkin and Taylor Ltd. Marine Science Department, Otago University. 16p.

This report builds on the sediment budget report (see above), which was based on time averaged data over 100s-1000s of years. In this report, factors that affect the sediment budget (natural and human influences) are considered over various time scales of 1000 yrs BP, present day, 100 yrs from now (predicted). Main findings were: (1) In all three models supply is inadequate to support storage - this may lead to the net deficit recorded; (2) Sediment supply to the coast increases over time due to increased erosion from changing land use practices, potential effects of climate warming (more rain = potentially more sediment discharge), and dredge spoil dumping in the coastal system. The fluvial contribution remains high throughout and biogenic carbonate is also important; (3) The nearshore sand wedge is the most important storage area. However, trapping of sediment behind the Clutha dams now accounts for about 33% of all sediment budget storage; (4) Sediment removal remains nearly constant over time; (5) Sediment deficit is improving over time with increased supply and a slower increase in sediment storage; (6) Much more detailed field data was needed to better quantify the individual elements of the East Otago sediment Budget.

*Figures and Tables:* Map of Otago shelf showing shelf and sand wedge limits. Graph comparing three sediment budgets over time. Tables: Smith's (1999) sediment budget; sediment budgets over three time scales.

**Smith AM (2000b):** Coastal erosion issues in Otago: Gaps in our knowledge. Report to Tonkin and Taylor Ltd. Marine Science Department, Otago University. 9p.

Gaps in the knowledge of Otago's coastal sediment budget were identified with three main areas being suggested for further research and quantification. These were a Clutha bedload study, an onshore sediment transport and storage study, and a sub-tidal sediment storage and transport study. A number of field and data gathering techniques for each study are suggested.

*Figure and Table:* Otago coast/shelf map and sediment budget table reproduced from Smith's previous reports.

**Steger KK (2002):** Environment of the Otago shelf recorded in skeletal carbonate of *Otionellina spp.* (Bryozoa: Chilostomatida). MSc thesis (Marine Science, Otago University). 127p.

Factors governing the distribution and abundance of carbonate producing taxa on the Otago continental shelf were examined between Tow Rock and Wickliffe Bay on the south side of the Otago Peninsula. However, the relevance to Project Neptune is that an up-to-date sediment analysis of nearby Otago shelf sediments is provided, and the shelf sediment facies theme originally proposed by Andrews (1973) and Carter *et al.* (1985) is reviewed and developed upon. 42 day grab sediment samples were collected across three shelf transects ranging in depth from 13 m to 137 m. Each transect was 14 km long and these were located at Wickliffe Bay, Cape Saunders and Tow Rock (i.e. just to the north and south of Papanui and Hooper's inlet respectively). Standard laboratory techniques were used to analyse the sediment, and sediment composition and textural changes across each transect are described. Based on this analysis, three major sediment facies were identified. These were: (1) The inner-shelf fine terrigenous sand facies (mean water depth = 20 m; depth range = 0 m to 40 m) was composed of 100 wt% well sorted sand. This facies was strongly influenced by constricted shelf bathymetry, the Southland Current and local storms which created an area of high hydraulic energy and thus well sorted sediments; (2) The mid-shelf sandy-gravelly facies (mean water depth = 66 m; depth range = 40 m to 90 m) was composed of 60 wt% gravel, 38 wt% sand and 2 wt% mud, all poorly sorted. The poor sorting of this facies indicated that it was from a moderate energy environment and not heavily influenced by storm events; (3) The outer-shelf (mean water depth = 113 m; depth range = 90 m to 137 m), extending to the shelf break, was composed of 21 wt% gravel and 79 wt% sand, and was poorly sorted. Again, the poor sorting suggested an area of low to moderate energy. Organic content of the sediment facies increased with depth.

*Figures and Tables:* Location map showing transects, sediment sample locations and bathymetry; Sediment facies map. Numerous graphs and tables present data on sediment sample location, composition and textural analysis, plus biotic data. Photos of equipment used.

**Tonkin and Taylor (2000):** Contact Energy Ltd: Clutha consent programme – Coastal erosion issues. Report for Contact Energy Ltd. 80p.

This substantial report focuses on the effects that sediment trapping of Roxburgh Dam (and to a lesser extent Clyde Dam) have had on coastal stability and sediment budgets on the East Otago coast, since the construction of Roxburgh Dam in 1956. The study area covers the coast from Nugget Point to Waikouiti and the continental shelf between those points. The report is in 5 major sections. The introductory section presents the background, aims and objectives of the study. Then general descriptions are given of the coastal, shelf and river environments and processes (geomorphology, geology, hydrology, oceanography), and sediment budget concepts, based on previous research. Also presented is a breakdown of a major bibliographic reference list containing 702 entries (presented in Appendix A of the report). It was noted that only 12 professional papers on Otago coastal stability were recorded. The second section examines East Otago coastal sediments (sources, storage, transport, removal, sediment budget) describing each of these parameters and the methods of how they were quantified. The next section discusses changes in the sediment budget over various time scales (1000 yrs BP; immediately prior to 1956; current situation and 100 yrs into the future. Historical shoreline movements based on previous research and this study are examined in the fourth section of the report. This includes historical erosion and accretion rates, measurement and interpretation techniques, site selection and data sources, and error sources. The final section of the report provides conclusions on the sediment budget, shoreline movements and gaps in the knowledge. Major findings include: (1) Major sediment supply changes relate to historical land use changes (alluvial mining, dredge spoil dumping, damming of the Clutha); (2) Sediment storage changed little over last 1000 yrs – main change in Otago Harbour storage area due to dredging and an increase in sediment storage in northern beaches; (3) Clutha historically the main sediment supplier to the coastal budget; (4) Coastal sediment budget losses small compared to supply rate, with most sediment held in storage in the nearshore sand wedge; (5) Still a sediment budget surplus despite Roxburgh Dam, therefore reduction in supply taken up by loss in sediment storage volume, rather than net erosion; (6) Possible sediment budget deficits on coast were probably greater before human intervention than they are currently with the damming of the Clutha; (7) Dredge spoil dumping is the main sediment supplier to the beaches north of the Harbour. Therefore changes in Clutha sediment supply and storage mainly affects area south of Dunedin beaches and peninsula; (8) Generally no changes in trends of shoreline movement – suggests Otago coast is relatively stable with normal short term fluctuations occurring; (9) Higher erosion rates since 1982 at some sites probably El Nino driven in this period; (10) Comparison of pre/post Clutha damming coastal changes showed either reduced erosion, increased accretion or change from erosion to accretion; (11) Still uncertain if coastal sediment budget has had time to adjust to Roxburgh Dam.

*Figures, Tables and Appendices:* Maps of study area, determination sites for shoreline change analysis, sediment budget flows and volumes. Graphs of shoreline change rates: Tables relating to sediment budget parameters, control model and changes over time; Shoreline changes pre/post Clutha damming and during 2 periods of post damming. Appendices: Extensive bibliographic listing; historical events relating to sediment budget changes; coastal sand bodies; calculations of nearshore sand wedge volume; shoreline movement determination sites; photos and plans etc used to determine shoreline change

## Oceanographic processes

**Jonker R (2003):** The stability of the sea bottom in Blueskin Bay. B.Surv. dissert. (Surveying, Otago University). 55p.

Dissertation examines the conditions that lead to the dispersal of dumped dredge spoil at Blueskin Bay. A general history of dredge dumping is provided in Chapter 1. Chapter 2 provides a theoretical background (numerous equations) into estuary hydraulics (waves, tides, currents) and sea bed stability criteria. The project site is described in Chapter 3, which details the sediment sample sites, sediment descriptions, bathymetry, dredging activities, and the hydraulic regime (tides, currents, waves, temperature, salinity.) Chapter 4 describes the calculation methods used (based on time series wave data) to determine critical shear stress, design waves and the influence of currents. The results are presented in graphic and tabular form in Chapter 5 and these are discussed in Chapters 6 and 7. Main findings were: (1) Most sediment samples were very fine sand which become muddier towards the centre of the bay, and are well sorted; (2) Movement of dredge spoil ranged from >1% of monitored days in deep water to 25% of days in shallow water; (3) Water depth appeared to be the dominant factor in whether or not bottom sediments were disturbed; (4) Disturbance is dominantly caused by wave action – tidal currents have very little influence; (5) Northerly to Easterly waves cause most bottom disturbance; (6) Results indicative only as most were based on existing data and not direct measurements.

*Figures and Tables:* Study area and sediment sample location maps; hydrographical map. Graphs of sediment parameters (size and sorting); wave and current velocities and directions; shear stress/mean grain size relation; diffraction and shoaling rates. Tables present wave and sediment data.

**Murdoch RC; Proctor R; Jillet JB; Zeldis JR (1990):** Evidence for an eddy over the continental shelf in the downstream lee of Otago Peninsula, New Zealand. *Estuarine, Coastal and Shelf Science* 30: 489-507.

Paper provides quantitative oceanographic evidence of an eddy on the north side of Otago Peninsula to confirm previous reports of the eddy which were based largely on biological evidence. Study was based on detailed hydrographic surveys (1978-1982), satellite imagery (LANDSAT and CZCS visible bands) and a simple depth-averaged numerical model. The three methods are discussed. The main findings were: (1) Two distinct water masses flow over the Otago Shelf – the Southland Current (outer shelf at surface but confined to near bottom at mid shelf; Neritic waters over the inner shelf); (2) Satellite images show low salinity water flows northward past Cape Saunders but it sheds a southerly counter current (eddy) into Blueskin Bay; (3) Numerical model showed that asymmetrical tidal flow around peninsula induced the counter clockwise eddy. Eddy was enhanced by the northward flow of the Southland Current meandering at the Karitane Canyon and alongshore wind stress from the NE. Strong Northerlies and SW winds (of several days duration) broke the eddy down. Wind data indicate the eddy is a relatively persistent oceanographic feature.

*Figures and Tables:* Otago shelf and hydrographic survey lines; Grid used of numerical model. LANDSAT and CZCS images of suspended sediment and dissolved material along Otago coast. Numerical model current direction vectors. Numerous graphs showing water surface/column salinity and temperatures; Graph of Clutha discharge/sea salinity relationship.

**Old CP (1998):** Otago Harbour tidal jet and channel flow. Report for Port Otago Ltd. Marine Science Department, Otago University. 80p

The tidal jet and channel flow of Otago harbour were investigated with particular reference to sediment transport and future dredging operations in the shipping channels - a better understanding of tidal flows would allow more precise and thus, cheaper dredging to occur. A brief description of the local harbour geography is given (e.g. Two drowned valleys, divided into upper and lower harbour, most sediment is from Clutha and littoral drift), and a more detailed description of the historical development of the entrance region is also provided (pre and post European shorelines, human alterations such as groynes, walls, reclamations, dredging). The report was based on data collected for Old's thesis (Old 1999), from an Acoustic Doppler Current Profiler (ADCP), of which the methods of data collection and analysis are discussed in detail (also see Old 1999 and Vennell and Old 1999). The main findings included: (1) 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; (2) Flood Tide characteristics – 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 scouring occurs here due to sediment supply from Shelly Beach behind the Long Mac (i.e. bypasses the groyne); (3) Ebb Tide characteristics – peak velocity of 1.36 $m.s^{-1}$ occurs on the eastern side of the channel near the centre of Harington Bend – this suggests the flow is unable to scour down to an equilibrium level at this point (a deep scour hole which effectively increases cross section area prevents maximum velocities occurring at the narrow entrance of Harington Point, where it would be expected). Sediment is deposited on the bend during flood tide and removed on the ebb, thus there is some balance between sedimentation and scour on the bend. At the harbour entrance (just outside 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; the flow across the entrance bar has a strong ebb dominate asymmetry; (4) 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 which produces a westward entrainment flow from the eastern side; (5) Tidal flows and sediment analysis show that a large volume of sediment can move within the harbour as bedload; (6) Options for optimising dredging: Dredging the outer channel in the summer and winter months would be the most efficient times when weather patterns are more stable – it was found that most sediment is moved into the shipping channel during large storm events and neap tides: in Dunedin the smallest tides occur between June and July, and December and January, and most storm events occur during spring and autumn. Another dredge optimising method for the outer channel would be to dredge the bar down to a level where swell scour is negligible – the down side of this however would be the volume of material to be moved and finding a suitable dump site. At Howlett's Point storm events are likely to move sediment from here towards Harington Point, where it is likely to be moved into the harbour on flood tides – it was suggested that dredging is probably best carried out at Howlett's Point just prior to the largest annual tides in March and September. There was little evidence of sediment build up through Harington Bend although it may require periodic dredging; (7) Groyne developments could improve scour – two options were presented. The first was that the Long Mac could be extended towards the Mole – this would constrain the flow to the shipping channel and remove the flow curvature at the Mole end, thus increasing velocity and scour. Side effects of this would be for the bar to move westward which could alter the position of the existing channel westward. This would increase flood flow past Harington Point and could destablise Harington Bend. Storm swell would also force ships towards the groyne. The second option was to build groynes from the Mole towards the channel to deflect the flow beyond the Long Mac into the channel. The advantages of this were in reducing the entrance width and would help to break waves before they reached Shelly Beach, potentially reducing erosion.

*Figures, Tables and Appendices:* Figures: Location map and survey lines; numerous plots/diagrams of velocity vector fields, along and across tidal jet plots; contour plots of maximum ebb and flood tide current magnitudes; estimated tidal residual currents for measured tidal cycles; estimated bottom stresses for maximum ebb and flood flows; bedload transport for maximum ebb and flood flows; movable grain size as a time function for various locations; comparisons of measured and theoretical velocities; possible sand transport paths at harbour entrance; historical harbour plans and proposed groynes for improving entrance conditions. Photos of equipment. Tables: survey and survey location data; ebb and flood tide data; sediment size and type (from Single and Kirk 1994). Appendices: Position data for survey lines; ADCP heading correction data; Plots of velocity profile positions for all surveys

**Old CP (1999):** The structure and dynamics of an ebb tidal jet. PhD thesis (Marine Science, Otago University). 277p.

This thesis describes in detail the two dimensional structure and dynamics of the ebb tidal jet in Otago Harbour, based on data gathered from a broadband Acoustic Doppler Current Profiler. Observations of the measured tidal jet velocities are compared to plane jet models and observations from the literature, to develop a conceptual model of the time development of the ebb tidal jet. The analyses showed that the ebb tidal jet was developed in three stages. The first stage of flow development occurred from when the flow first begins to ebb, up to when the separation of the coastal boundary layer occurs. In the next stage, separation eddies and the jet-like structure are developed. The final stage is the release of the vortex pair as a free dipole during the deceleration of source flow. From these development stages, a conceptual model of the time development of the ebb tidal jet is defined. The results of this thesis are also discussed in other papers/reports (For example, see reviews of Old 1998; Old and Vennell 2001; Vennell and Old 1999).

*Figures, Tables and Appendices:* Appendices: Mathematical appendices of classical jet-plane equations; classical jet-plane dynamics; derivation of the modified jet-plane model; time averaged harmonic equation. Data Appendices: Survey co-ordinates; heading corrections; velocity profile positions; spatial distribution of estimated harmonic coefficients; time series of ebb tidal jet development; profiles of interpolated velocity components.

**Old CP; Vennell R (2001):** Acoustic Doppler Current Profiler measurements of the velocity field of an ebb tidal jet. *Journal of Geophysical Research – Oceans:* 106 (C4): 7037 - 7049.

*Note: This paper was not readily available from Canterbury University's Physical Science Library therefore the review is a direct quote of the paper's abstract. No Figures, Tables or Appendices reviewed.* A broadband acoustic Doppler current profiler was used to measure the velocity field of the ebb tidal jet formed at the entrance to Otago Harbour, South Island, New Zealand. Four separate surveys were conducted where various sets of transects were run continuously over a 13 hour period, producing time series of velocity profiles with 1 hour sampling over a grid with an across-jet resolution of 20 m and an along-jet resolution of 150 m. The velocity field of the ebb tidal jet is phase locked to the tidal response of the harbour, making it possible to combine the data from separate tidal surveys to produce synoptic maps of the depth-averaged velocity field. The spatial structure of the ebb tidal jet at the time of peak flow exhibits many features of a classical plane jet. There is a strong asymmetry between the ebb and flood flow structures; the ebb flow extends beyond 2km from the entrance, while the flood flow is limited to within 600 m of the coast. The flow along the jet axis becomes pulse-like in time with distance from the entrance. The formation of a propagating eddy observed along the eastern side of the jet suggests that this momentum pulse may be associated with the pair of separate eddies generated by the accelerating ebb tidal flow.

**Vennell R; Old C (1999):** Acoustic Doppler Current Profiler measurements of tidal currents in Otago Harbour channel: Landfall Tower to Harington Bend. Report to Port Otago Ltd. Marine Science Department, Otago University. 3p plus appendices.

This booklet provides much raw data (as numerous appendices) on tidal measurements in the Otago Harbour channel. The measurements were based on Old's (1999) thesis data. The method of data collection was described - a vessel mounted Acoustic Doppler Current Profiler measured currents at 0.5 m depth intervals every 3 seconds on moving boat, of which its position was accurately surveyed. Six areas of the channel were covered once per hour for 13 hours so a complete flood/ebb spring tidal cycle was covered. The data were spilt in to two groups covering the approach channel (Landfall Tower to Mole) and the entrance channel (Beacon 11 to Harington Point). The measurements were adjusted so all times were relative to high water at Port Chalmers for a spring tide of 2 m tidal range. Further details are given on the data breakdown and presentation. Data showed that: (1) 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 (>2.0 m) and slightly larger during neap tides (<1.7 m); (2) The time difference for spring low tides (<1.0 m) between the two sites is up to 50-60 minutes, whilst for neap low tides the difference is as low as 35 minutes. The tidal time differences are explained by tide wave traveling up the harbour faster with increased water depth. Therefore it travels faster during neap low tides than during spring low tides; (3) For the ebb tide, 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. Ebb tide jet begins to form around 1 hr after high water, narrowing and strengthening to peak around 3 hrs after high water - Maximum current velocity of 2.19 k between Harrington Point and Taiaroa Head around the same time. Ebb flow upstream of the Mole contracts and strengthens as it passes the Mole tip to form the jet; (4) For the flood tide, slack water just in side the entrance occurs 6.5 hrs after high tide (or 25 minutes after low tide). Flood flow already started at Taiaroa Head at this time and residual flow from ebb tidal jet still seen at Landfall Tower. Peak flood current velocity of 2.4 k occurs around 10 hrs after high water, or 2 hrs 55 minutes after low water, downstream of No. 1 Beacon. Flow converges strongly and strengthens around the Mole tip and Taiaroa Head. At Mole tip, flows at channel centre are along the lead line – flood flows have a significant eastward component across the leads to the south of No. 1 Beacon.

*Figures and Appendices:* Graph comparing tides at Spit Wharf and Port Chalmers. Numerous appendices (tabular) of raw data.

**Vennell R; Old C (in press – abstract only):** High resolution observations on the intensity of secondary circulation along a curved tidal channel. *Journal of Geophysical Research (accepted 2007).*

*Note - This review is a direct quote of the accepted paper's abstract:* High horizontal resolution moving vessel ADCP observations of the spatial pattern of cross-stream velocities in a curved tidal channel show radially outward surface velocities of up to 10 $cms^{-1}$ which are maximum mid-channel, consistent with helical secondary flow in a vertical plane normal to the depth averaged velocity. The 30 m cross and 150 m along-channel resolution observations are from a 2700 m long section of a 350 m wide horizontally and vertically well mixed tidal channel with a radius of curvature of 1-5 km. The along-channel resolution allows the intensity of the curvature induced secondary flow to be estimated from the linear correlation between the observed cross-channel component of vertical shear and the shear estimated from the stream velocity and its varying curvature using an existing analytical model. The two shears are highly correlated and the regression line slope demonstrates that the observed curvature induced secondary flow is 30% more intense than that predicted by the model for a typical bottom drag coefficient. The secondary flow is 505 more intense than the predicted using the drag coefficient which best fits the stream velocity profile. Numerical solutions demonstrate that the intensity of the secondary flow is sensitive to small changes in the shape of the eddy viscosity profile, hence intensity may be sensitive to the way turbulence is modeled. Lagged correlation of the observations showed that the secondary flow adapts to changes in curvature and primary flow over a 300 m length scale, or 20 m water depths, consistent with the existing model and laboratory studies.

*Figures:* Channel cross section and plan of flow outward directions.

**Whitefield JD (2004):** A comparison between velocities and echo intensities in an ebb tidal jet. MSc Thesis (Marine Science, Otago University). 79p.

In previous investigations an Acoustic Doppler Current Profiler (ADCP) had been used to gather data on tidal velocities and back scattered Echo Intensities (EI) in Otago harbour. However, only the velocity data were analysed, so this thesis used the EI data to determine the spatial structure of the Otago Harbour tidal jet and to compare this structure with that found from the velocity data previously analysed. Normalised depth profiles were calculated and plotted across jet transects in time series – these plots were used to search for variations in jet structure with depth, along with comparisons to topographic contour plots. These methods showed there was negligible change to the jet structure with depth. Time series plots of EI and velocities showed the velocity flow changed from sinusoidal at the harbour entrance to pulse–like further along the jet axis. The points at the edges of the survey lines showed small variations with time, though some points on the outer set had high EI values (similar to the jet axis). As these values corresponded to a flow reversal, it was suggested the EI data can pick out the eddy structure. Space-time diagrams combined with time series plots showed that suspended sediment does not change in the same way as velocities – at slack low water some sediment remains in suspension and appears during the flood tide. It was also shown that suspended sediment forms a wider structure than velocities, although a good correlation existed between the two. The best fit curve for the Otago jet is of Gaussian form during ebb flow – there are virtually no currents in the along-jet direction. This meant there is reduced suspended sediment during flood tides. Plots showed the velocities and EI behaved differently but both data sets showed the existence of a two stage jet with a clear region of development and another of jet flow. The study showed that the ADCP was a useful tool for the analysis of the spatial structure of the tidal jet, but the EI data cannot be used alone, as the velocity structure differs from the EI structure.

*Figures and Tables:* Location map of study area. Theoretical jet structure; numerous EI data profiles and graphs for various locations and depths; time series plots for EI and velocities (ebb and flood tides); Gaussian best fit curve for EI and velocities; Amplitude and calculated half width for EI and velocity. Aerial photos of the Otago Harbour jet. Tables of geodetic data; high and low water times in relation to surveys; time and circuits of maximum ebb and flood flows; EI data for maximum ebb and flood flow and EI values from cross sections; $C_o$ values from cross sections/time series analysis; Calculated values for amplitude and half width of the ebb tide jet structure.

## Holocene coastal evolution and shore development

**Andrews PB (1973):** Late Quaternary continental shelf sediments of Otago Peninsula, New Zealand. *New Zealand Journal of Geology and Geophysics* 16 (4): 793 -830.

This detailed paper, based on bathymetry and analysis of surficial sediments (263 samples) and benthic assemblages, describes sedimentary composition, distribution and history of over 1190 $km^2$ of the Otago Shelf between Cornish Head and the Taieri River. The paper describes the bathymetry of the continental shelf, continental slope and submarine canyons; coastal currents (Southland Current dominant – details given), tides and tidal currents (clockwise rotation of tide described); NE and SW wind equally prevalent but SW stronger (most likely to influence sediment transport and erosion). Sediments and benthic assemblages are discussed in detail and based on these the history of sedimentation is presented. Main findings are: (1) Otago shelf sediments (pebbles and sand) predominantly from Otago Schist, delivered to coast by Clutha River and transported northward by combined action of Southland Current and longshore drift from southerly swell; (2) 5 prominent modes of sediment – sandy pebble gravel in mid shelf deposited in the early-mid phase of post-glacial sea level rise and distributed northwards by Southland Current; then fine sand deposited (corresponding to temporary halt in sea level rise from 8000-9000 years BP, associated with pebbles and gravels deposited in Clutha catchment). Since current sea level attained 6000 yrs BP, only very fine sand and silt deposited on inner shelf. Holocene sand and muddy sand dominate inner shelf; middle and outer shelf dominated by organic skeletal debris except where pebble gravel occurs, indicating negligible Holocene sedimentation in these areas. Thus, middle and outer shelf sediments are relict features from earlier and lower sea level stands.

<u>Figures and Tables:</u> Otago shelf and bathymetry (based on soundings in 1950); shelf cross section profiles (from bathymetry); sediment sampling sites; sediment distribution and composition; Distribution maps of organic skeletal distribution, detrital gravel; Sediment maps (median diameter, mean diameter; standard deviation; skewness); Graphs of frequency-size distribution; several sediment mode size maps; Tables of sedimentary data and benthic fauna assemblages.

**Andrews PB (1976):** Sediment transport on the continental shelf, east of Otago – a reinterpretation of so-called relict features: Comment. *New Zealand Journal of Geology and Geophysics* 19 (4): 527-531.

This short comment paper was produced in response to Schofield's (1976) paper of the above title (same issue of NZ J G and G); Schofield questioned if some of the shelf features described by Andrews (1976), such as gravel deposits, 'drowned shorelines' and the 'drowned spit' were in fact relict, or modern. Andrews defends his interpretations in this comment paper and provides several lines of evidence: (1) Andrews thinks Schofield has the timing of gravel deposition confused as Schofield refers to the gravels as both modern, yet 'lag' deposits. Therefore, if lag deposits, they must be relict deposits argues Andrews; (2) Based on Carter and Heath (1975), Andrews claims the modern Southland Current alone does not have the energy to transport modern coarse sand and gravel along the shelf at depths Schofield was considering. However, Andrews suggests that some limited post sea level rise reworking of relict features has occurred, based on evidence from contemporary sedimentation patterns of the Clutha River mouth, which Schofield entirely ignored; (3) Based on geographical distribution and sedimentary composition (grain size, texture etc), Andrews largely dismisses Schofield's account of the development of the drowned shorelines and the drowned spit feature on the Otago Shelf (4) Andrews concluded both relict and modern features are discernable on the shelf and that many relict features have undergone, or are undergoing modification by modern processes.

_Figures:_ Two sediment grain size contour maps (% detrital gravel and median grain size) for shelf area between south Otago Peninsula and Shag Point area.

**Armstrong MR (1978):** Erosion of Spit Beach, Aramoana, Otago. Post Grad. Dip. Sci. (Geography, Otago University). 29p.

This report explains possible causes for the coastal erosion that was occurring at Aramoana at the time of writing, based on bathymetric maps, aerial photographs and literature reviews (published papers and old harbour board reports). A general history of the development phases of the mole, railway embankment and other seawalls is given (based on old harbour board reports from the 1880s onwards, with some good early quotes about sand erosion and accumulation), then coastal/beach changes in relation to these structures are described and/or hypothesised. Erosional phases around New Zealand are compared to the site. Successive bathymetry maps were superimposed and isobaths showed a significant deepening (sediment removal) in immediate offshore area between 1941-1975. Tide and wave conditions are explained and attributed to offshore sand movement through beach and nearshore steepening (higher waves could break closer to shore). Erosion of spit's seaward face directly related to condition of the spit training wall. Beach erosion (vegetation line retreat) between 1975-1978 was measured at 60 ft in three years (from air photos). Precise period of change from historical accretion to recent erosion was difficult to identify due to few permanent residents reports; infrequent storm damage made overall trends hard to identify; erosion was reasonably slow and there were few distinctive landmarks to make beach comparisons.

_Figures and Appendices:_ Very simple and basic sketch maps (drawn free hand – no scales) showing coastal structures, historical beach changes, and flood tide flow directions. Two more detailed maps (appendices) show the shoreward migration of the offshore isobaths at 5 yr intervals between 1941 and 1975.

**Carter L; Carter RM (1986):** Holocene evolution of the nearshore sand wedge, South Otago continental shelf, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 29: 413-424.

High resolution seismic profiling over 550 line km was used to map the structural sequence continental shelf sand wedge between Nugget Point and Otago Peninsula. Additional information was provided by lower resolution profiles, surficial sediment samples and piston core samples. The regional setting of the wedge is defined and four distinct shore parallel sediment facies described, based on Andrews (1973) and Cater *et al.* (1985). These are described as: (1) Wedge morphology (surface features and narrows from 18 km at Molyneux Bay to 1-3 km wide in Taieri Bight); (2) Seismic structure and stratigraphy (5 units – Basement Torlesse and Cretaceous-Cenozoic sedimentary rocks; Pleistocene sedimentary unit; Fluvial unit; Early post-glacial transgressive unit; Holocene wedge). These units are described in detail. Two distinct stages of wedge development corresponded to major sea level standstills 9600-8800 yrs BP (sea level -27 to -24 m) and 6500 yrs BP, when sea level reached its present elevation. The older, lower wedge accumulated faster than the modern wedge, presumably in response to a greater sediment supply accompanying major changes in early Holocene climate and oceanographic conditions.

_Figures and Tables:_ Map of shelf location, bathymetry and seismic profiles; map of sand wedge sediment facies; seismic cross sections; postulated shorelines and isopachs of wedge (Clutha to Otago Peninsula; Evolution of the wedge. Table of wedge volume data.

**Elliot EL (1958):** Sandspits of the Otago Coast. *New Zealand Geographer* 14: 65-74.

Sand spit development between Brighton and Waikouaiti is discussed. Coastal processes such as wave size and direction, ocean current directions and velocities, sediment supplies and transport directions are described. Clutha River considered the main sediment source and dominant coastal drift from SW to NE. However, most of the main spits are orientated southwards due to wave refraction and eddies in the lees of headlands, and because of the shelter the headlands provide from southerly waves, NE waves are important in the development of southerly directed spits.

*Figures and Tables:* Location/geomorphology map (cliffs, various relict and modern beach features); Aramoana Spit development (1879, 1900, 1950); Coastal features between Taieri River and Brighton. Table summarises wind velocities and directions at Taiaroa Head and Waikouaiti (1937-1945).

**Goldsmith MJ (1995a):** Morphological change of sandy beaches at the entrance to Otago Harbour. MSc thesis (Geography, Otago University). 165p.

Comparisons of shoreline changes between human–modified sandy beaches at the Otago Harbour entrance and a control beach were investigated in this thesis. The main objectives were to determine the morphological responses of sandy beaches to natural environmental conditions, and the extent of human influence in modifying morphological response. Natural and human morphological changes were examined on several time scales ranging from storms of a few days duration, seasonal and annual changes, to changes over the last 150 years. Long term changes were determined from aerial photographs and historical charts, whilst short term changes during the study period were monitored by regular surveying. The human influence on beach modifications and morphology was determined by comparing changes pre and post coastal structure, and comparing these to the unmodified control beach. The main findings were: (1) Long Beach was characterised by apparent progradation between 1871 and 1994. This progradation most likely resulted from a steady supply of longshore sediment combined with a low energy wave regime; (2) Between 1846 and 1994, shoreline position and sediment transport at Aramoana was significantly altered by coastal engineering structures – 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. Progradation of Aramoana Beach after the Mole construction indicates sediment has accumulated on the updrift side; (3) Between January 1993 and March 1994, large NE approaching storm waves lead to rapid erosion of all beaches – in general volume losses were greater on human modified beaches, particularly Spit Beach. Accretionary phases occurred during period of moderate wave energy (either low NE swell or large southerly swell refracted by the peninsula). Human modified beaches recovered more quickly after erosion phases, especially when dredge dumping occurred concurrently; (4) The magnitude of profile shape and volume changes was greatest in the human modified beaches being generally largest at Spit Beach and smaller at Aramoana Beach - these changes were larger than at the control beach; (5) Dredge dumping in significant quantities appeared to reduce volume losses during erosion phases at Spit and Aramoana beaches and promoted sediment accumulation during accretion phases. As the Aramoana dump site is further offshore and in deeper water than the Spit Beach site, it as not likely to be as effective in beach renourishment as at Spit Beach.

*Figures, Tables and Appendices:* Figures (most are graphs): Location maps of study beaches and survey locations; conceptual coastal/beach models; wind rose (Taiaroa Head 1961-1977); wave refraction diagrams (southerly and NE swell); wind and wave diagrams; beach positional changes over various time scales (MHWM and beach contours); beach volume changes over various time scale; ocean currents. Tables: Sediment grain size classification; sediment grain size analysis results; beach erosion/accretion volumes; total beach volumes; swell frequency and height data; wind data; plan scale errors; dredge dumping volumes. Appendices: Cross section plots and digital terrain models (DTMs).

**Goldsmith MJ (1995b):** Shoreline changes at the entrance to Otago Harbour. Report to report the Beach-haven Earth Trust. 15p.

This report was based on Goldsmith's (1995) thesis (above) and discusses coastal changes and causes around Spit Beach/Aramoana by natural processes, construction of the Mole and training wall, and dredging. Beaches described as low wave energy (due to highly refracted southerly swell and low magnitude northerly waves). Therefore profile changes generally small. Rapid positional and profile changes occurred at Aramoana after construction of mole in 1885. Aramoana accreted as NW to SE sediment drift trapped: Spit Beach retreated as this supply cut off. Greatest volume losses associated with high magnitude, low frequency NE storms (locally generated). Short term volume gains associated with low magnitude southerly and NE swell. Training wall is becoming less effective at sand trapping: Raising of the beach has allowed sand to pass over wall into channel or onto head of spit. Dredge spoil dumping was considered to contribute to deposition on Spit Beach when done on a regular basis and in sufficient quantities. However, it was difficult to separate artificial and natural effects, especially on a short term basis.

*Figures:* Beach location; wind rose (Tairoa Head 1961-1977); wave refraction diagrams (S and NE swell); shoreline changes (1850, 1884, 1909, 1933, 1951, 1985); ocean currents; cross section profile locations (10 profiles between training wall and Long Beach; cross section and profile changes; dredge dumping grounds

**Leon JP (2005a):** Coastal evolution of Shelly Beach, Otago Harbour: A composite approach to examining the morphodynamic behaviour of a human-modified sand spit. MSc Thesis (Geography, Canterbury University). 216p.

*Note: This summary adapted from Martin Single summary for POL.* Thesis investigated the long-term dynamics of sediment transport on Shelly Beach. He used a combination of techniques including field measurements of processes (waves, currents and winds) and morphology (dune, beach and nearshore seabed profiles and sediment characteristics), along with computer modeling of currents and sediment transport paths. He also analysed changes to the bathymetry in conjunction with dredge spoil disposal data for the period between April 1987 and April 2004. Was found that there is a fine balance of the mainly low energy wave and tidal processes acting on the medium well-sorted sands resulting in a nominally equilibrium form to the bay. Changes to the energy levels due to storms (wave and wind energy) will move sand on the nearshore, beach and dunes resulting in changes to the equilibrium state of the morphology. The natural long-term state of Shelly Beach is erosional. The principal source of sediment is from the Clutha and Taieri Rivers via the seabed south and east of Otago Peninsula. Tidal currents have maximum velocities during mid-tides and slack water at high and low tides. Ebb flows are dominant. Long period southerly swell waves are affected by diffraction and refraction around Taiaroa Head and the ebb-tide delta of the harbour. This effectively dissipates most of the energy from these waves before they reach the shore at Shelly Beach. North-easterly waves are less affected by refraction and diffraction, and so contribute significant energy to the beach. During high energy conditions, currents flow from the middle of the beach to each end. Beach and nearshore sediments are easily entrained by wave and tidal currents in the nearshore, and wind on the beach and dunes during most conditions. A morphodynamic framework was applied to Shelly Beach, and was found that morphological transitions can be effectively predicted according to the relative tide range, breaking wave height, period and high tide sediment velocity. Under prevailing conditions in the embayment, the beach profile of the sub-aerial beach will show characteristics of a reflective high tide beach and a more dissipative low tide terrace (a steep upper beach and low gradient lower beach). During storm events with waves greater than 1.5m, the beach will develop a very steep profile. This will reflect energy offshore, and will result in transport of sediment offshore. Process based empirical models of sediment transport and long-term morphological evolution were developed to investigate the effects of the supply of sand to the nearshore area of the embayment. It was found that the introduced sediment moved onshore from the inner nearshore towards the sub-aerial beach and along the surf-zone in both directions. In the sub-aerial beach, sediment is transported by wind and accumulates in the dunes. During storm conditions, currents are developed which transport sediment offshore along the flanks of the embayment (along the North Mole and Long Mac groyne). A total of 362 000 $m^3$ of sand has been placed in the nearshore of Shelly Beach. An initial high rate of placement occurred between 1986 and 1989 (average 36 000 $m^3.y^{-1}$), while between 1996 and 1999 there was a relatively low rate of placement (about 5 000 $m^3.y^{-1}$). At other times, the average rate of placement was about 20 000 $m^3.y^{-1}$. Sediment volume in the nearshore has increased by approximately 200 000$m^3$, while the increase in the sub-aerial zone was 35 000$m^3$. The sediment characteristics of the nearshore have not changed since dredge spoil placement commenced in 1986. Dredge spoil is rapidly dispersed within the inner nearshore but only moves slowly onshore and then into the dune system. There is a lag period of about 3 to 4 years between increases to the sediment volume of the nearshore and increases in the sediment volume of the sub-aerial beach. The dune volume is relatively stable, but has increased since 1993. This has resulted in growth of the dunes. A sediment budget was developed for Shelly Beach. This showed that the nearshore is infilling rapidly and the sub-aerial beach (especially the dune part) is growing due to placement of dredge spoil in the nearshore. Findings of the sediment budget analysis showed that dredge spoil placement in the nearshore is effectively infilling the coastal system and not appreciably re-entering the navigation channel. Nourishment is positively affecting the sub-aerial beach sediment balance and is mitigation against long-term erosion of the dunes. Human actions have resulted in the formation of Shelly Beach and subsequent erosion hazards at the site due to stabilisation of the harbour entrance and channel, and use of the backshore and dune area. Nourishment of the system with dredge spoil placement in the nearshore has resulted in mitigation of the erosion hazard without increasing the dredging demands for the navigation channel. It was suggested that further monitoring of nearshore waves and currents during a range of conditions would lead to a better understanding of the relationships between the main processes and sediment transport. These could also be related to longer term climatic changes such as El Nino/La Nina phases, Interdecadal Pacific Oscillation and projected sea level rise. Ongoing yearly monitoring of the nearshore and sub-aerial beach by bathymetric and beach profiles was seen as essential for continued assessment of the effectiveness of the dredge spoil placement.

*Figures and Tables:* 121 figures in total (maps, photos, flow charts, graphs, schematic diagrams, DTMs). Most relevant figures (for Project Neptune) show various views of the study area; conceptual models of the study area; morphodynamic models; wind, tide and current directions and velocities; wave refraction/diffraction plots; sediment budgets; sediment volumes and transport directions, DTMs of changing bathymetry. Tables present data on NZ wave parameters; El Nino effects; measured ocean currents; general grain size characteristics; sediment sample locations and analyses; beach profile changes.

**Osterburg EC (2001):** Late Quaternary evolution of the Otago Margin. MSc thesis (Geology, Otago University). 172p.

This thesis combines the results of 200 line km of high resolution seismic profiling (over 220 $km^2$), radiocarbon dating of sediments, sea floor and core sediment samples, sea floor photography and video, to establish a Late Quaternary chronostratigraphic model for the Otago Shelf. Describes the shelf's sediment sources and supplies, based on Andrews (1973) and Carter *et al.* (1985). Methods of seismic profiling and model development and calibration are described in detail, taking factors such as compaction into account (due to sediment, ice and water loading). The two models (one was rejected) were compared to sea level curves from remote locations around the world. The proposed chronostratigraphic model *"includes fluvially incised sequence boundaries eroded during marine isotope stages 2, 4, and 6, bounding three sequences subdivided into low stand, transgressive and high stand/regressive tracts".* The sea level low stands of stages 2, 4, 6 obtained maximum depths of 126-131 m, 101-111 m and 116-135 m respectively. These low stands produced sequence boundaries, landward pinching deltaic wedges on the outer shelf, and submarine canyon incision. During marine transgressions of stages 6-5, 4-3, and 2-1, clastic shallow marine wedges and back-barrier valley fill deposits accumulated. The Late Quaternary sequence of the Otago shelf was volumetrically dominated by deltaic and strandline units deposited during high stands, though falling sea levels (stages 5-4, 3-2, 1). This was contrary to traditional stratigraphic models. There was discrete evidence for higher order (~20 ka) sea level fluctuations influencing sedimentation on the shelf.

*Figures, Tables and Appendices:* Appendices: Navigation data for seismic profiles (direction, depth, speed etc); 18 high resolution seismic profiles lines; 4 sequence stratigraphic interpretations of seismic reflection lines; 2 shelf sequence models.

**Osterburg EC (2006):** Late Quaternary (marine isotope stages 6-1) seismic sequence stratification evolution of the Otago continental shelf, New Zealand. *Marine Geology* 229: 159-178.

This very detailed paper presents the main findings of Osterburg's (2001) thesis, summarised above.

*Figures and Tables:* Location map showing Otago shelf, seismic profile lines, bore hole locations, bathymetry and sediment flow directions; Several photographic/schematic seismic profile cross section figures. Sea level graphs for two model scenarios and comparisons to other locations. Three data tables relating to Otago shelf subsidence rates; Table describing stratigraphic columns and chrono-stratigraphy under the two models.

**Schofield JC (1976):** Sediment transport on the continental shelf, east of Otago – a reinterpretation of so-called relict features. *New Zealand Journal of Geology and Geophysics* 19 (4): 513-525.

This paper reassess the findings of previous works, particularly that of Andrews (1973), in relation to Otago Shelf sedimentation. Schofield (1976) disputes Andrews (1973) claims of relict (drowned) shorelines, a spit, and relict gravel deposits on the Otago shelf, and believes these features (in up to 100 m water depth) are modern and formed mainly by the Southland Current. He describes the Southland Current (direction, velocities and depths at various locations); the offshore gravel belt (between 40-100m depth, separated from the shore by a fine sand belt); 'Drowned shorelines' and 'Drowned Spit' and the nearshore sand belt (as defined by Andrews 1973). Schofield compares these features to the shelf in Foveaux Straight. For the Otago Shelf, Schofield concludes that: (1) The Southland Current is capable of sea floor erosion, deposition and sediment transport at depths of up to 100 m - Based on the absence of shallow water benthic species connected with the so-called drowned shorelines; the relationships between lag-gravels and known velocity currents and sea floor profiles; (2) Southland Current transports offshore sediment like longshore drift – deposition occurs when velocity drops, forming large submarine bars (not drowned spits); (3) The nearshore fine sand belt is deposited where nearshore and offshore currents partially nullify themselves, and as offshore gravels are deposited by Southland Current, therefore not relict deposits; (4) At times, it is assumed coarse sediment must move shoreward from the deep offshore gravel belt, across the fine nearshore sand belt. This happens in other parts of the country. See review of Andrews (1976) for response comment.

*Figures and Tables:* Basic offshore current map; offshore gravel distribution map; Simplified offshore erosion model (based on Zenkovich 1967); Foveaux Straight bathymetry. Graphs of Hjulstrom curve and grain size-frequency curves.

**Thomas D (1998):** Late Holocene radiocarbon ages from Blueskin Bay Estuary: Relevance to local eustatic sea-level during the last 7000 yrs. *Geological Society of New Zealand Miscellaneous Publication 101A*. p226.

Single paged conference abstract. Used 18 radiocarbon dates to determine eustatic sea levels in Blueskin Bay over the last 7000 years (10 published radiocarbon dates from Gibb 1986 plus 8 unpublished dates). The envelope limits of paleosea-level dataset are consistent with a post-glacial transgression after 6.5 ka, followed by a minor regression of -2.0m at 5.5 to 5.0 ka, followed by a minor transgression of 1.9 m between 5.0 and 3.2 ka. Timing and magnitude of the minor regression and transgression differs from Gibb (1986) who found a minor regression of -0.4 m between 5.0 and 4.5 ka, followed by a minor transgression of 0.6 to 0.9 m between 4.5 to 3.5 ka. Also compared data from Weiti River estuary (another of Gibb's control sites) and concluded that the comparison of local sea levels between the two reference sites suggested local variations in eustatic sea levels may be significant.

*Figures and Tables:* None.

## Sediments of Blueskin Bay and Otago Harbour

**Bunting K; Single MB; Kirk RM (2003a):** Sediment transport pathways around Otago Harbour and north to Karitane Peninsula. Report for Port Otago Ltd. Land and Water International Ltd. 75p.

Sediment transport pathways between the Otago Harbour and Karitane were investigated, with particular reference to the sediment dispersal patterns at the three dredge spoil dumping grounds used by Port Otago Ltd (Shelly Beach, Aramoana and Heyward Point). The report was primarily based on the rollability analysis of 64 sediment samples taken from the seabed at Aramoana Beach, Shelly Beach, Murdering Beach, Long Beach, Purakanui Beach, Warrington and Karitane beaches. Information from previous investigations was also incorporated. Sediment volumes at the dump sites were examined and compared to previous studies by Kirk (1980) and Single and Kirk (1994), to identify changes over time and determine the effect the spoil dumping was having on sedimentation processes at Shelly Beach, Aramoana and Heyward Point. The main findings were: (1) The coastal environment between the Harbour entrance and Karitane acts as two separate compartments – the northern nearshore compartment between Karitane and Heyward Point (to about 15 m depth) acts as a sediment source to the southern nearshore compartment, between Taiaroa Head and Heyward Point; (2) Dredge spoil at the three dump sites has not changed the textural nature of the sediments from the surrounding seabed sediments; (3) There was no evidence to show that spoil from the Heyward Point site was moving north into Blueskin Bay, nor was spoil from the three sites directly re-entering the harbour; (4) Spoil is quickly removed from the three dump sites and spread over the nearshore, although a significant volume is retained in the Aramoana site, which forms a mound at the southern end of the site. The report concludes with a number of recommendations relating to future research and monitoring of coastal sedimentation, beach changes and nearshore tidal currents throughout the study area, and land use practices and sediment runoff around Blueskin Bay and Purakanui Inlet.

*Figures and Tables:* Map showing location of site, sediment sample sites and dredge dump grounds. 3 nearshore sediment rollability contour maps. Graph of dredge volumes 1975-1997. Tables: Dredge discharge quantities 1975-2002; sediment sample analysis (Folk Parameters; numeric and descriptive); Shelly Beach volumetric change (1986-1998)

**Bunting K; Single MB; Kirk RM (2003b):** Effects of dredge spoil at Shelly Beach, Otago Harbour. Report for Port Otago Ltd. Land and Water International Ltd. 31p.

This report was produced to accompany that of Bunting *et al.* (2003a) and assesses the effects of dumping dredge spoil at Shelly Beach in an effort to re-nourish the beach and mitigate coastal erosion. Sediment transport paths are identified, a sediment budget for Shelly Beach is developed, and local beach morphodynamics are discussed. The report was based on site visits; analysis of sediment samples from the upper foreshore and nearshore, to duplicate Kirk (1980) and Single and Kirk (1994) so direct comparisons could be made; a literature review; photographs and cross section surveys; bathymetric soundings. Significant findings were: (1) Shelly Beach is highly dynamic and rapidly responsive to sediment supply changes; (2) Sand fences and dredge disposal have been effective a combating erosion; (3) Shelly Beach dredge disposal site is both a sediment sink and source, whilst the beach itself is a depositional zone (sink) for dredge disposal material – Dredge spoil is quickly dispersed from the Shelly Beach dump site which renourishes the whole beach, especially the base of the mole; (4) Minor sediment sink at Long Mac indicates southerly sediment drift along Shelly Beach; (5) Present management of Shelly Beach not having an adverse effect on dredging programme, despite some sediment from here indirectly re-entering the harbour; (6) Sediment budget for nearshore between the Mole and Long Mac was near stable between 1987-1998; small volume gain of 77 000$m^3$ at a rate of 700 $m^3.m^{-1}$ of beach, which was considered a positive effect; (7) Knowledge gaps: Include nearshore wave, tide and current conditions – previous investigation relied on deep water conditions; cross-section survey and sounding data were scarce/absent. Recommendations included: Resurveying the nearshore environment; continuing to use Shelly Beach as a dredge disposal site; beach cross section surveys be updated; direct eave environment study of the are, rather than inference from the deep water environment.

*Figures and Tables:* Maps of site location, dredge dumping grounds and sediment sample collection; Rollability contours (Kirk 1980; Single and Kirk 1994; current study). Graph of cumulative dredge requirements at harbour entrance (1975-1997). Tables: Dredge discharge volumes (1975-2002); Sediment analysis results – Taiaroa Head to Heyward Point (Folk's statistical parameters and descriptions); Shelly Beach volume change (1986-1998).

**Carter L (1986):** A budget for modern-Holocene sediment on the South Otago continental shelf. *New Zealand Journal of Marine and Freshwater Research* 20: 665-676.

This paper quantifies sediment inputs and outputs on the Otago shelf sedimentary wedge between Nugget Point and Cape Saunders, south of the Otago Harbour. However, some discussion is given to the Blueskin Bay area. The general Otago shelf area is described, as are the assumptions used to estimate sediment volumes (bedload to suspended load ratios; volume-mass conversions; sediment age; Roxburgh Dam effects). Main findings were: (1) Sediment inputs were from the Clutha River (3.14 $Mt.y^{-1}$); Taieri River (0.6 $Mt.y^{-1}$); Southland Shelf (0.4 $Mt.y^{-1}$); Biogenic productivity (0.25 $Mt.y^{-1}$); coastal erosion inputs were negligible; (2) Sediment storage: Littoral storage rate (0.04 $Mt.y^{-1}$) therefore insignificant; Shelf storage rate between Nugget Point and Cape Saunders = 1.35 $Mt.y^{-1}$; (3) Sediment outputs included bedload losses through northerly drift past Otago Peninsula (up to 1.06 $Mt.y^{-1}$); Suspended load losses – most mud moves offshore but about 10% of sediment in Molyneux Bay and Blueskin Bay is mud. Holocene mud accumulation on outer shelf slope up to 50 $mm.y^{-1}$; attrition loses based on Gibb and Adams (1982) and Gibb (1979) = 25% of Clutha gravel (0.15$Mt.y^{-1}$) is destroyed before it reaches Otago Peninsula, leaving a residual of 0.11 $Mt.y^{-1}$; (4) Clutha supplies 76% of material to shelf and shelf wedge absorbs nearly half of total bed load input. Rest drifts NE and is stored in beaches and dunes (south of Peninsula), and Peninsula Spit and beds and beaches of Blueskin Bay and shorelines further north; (5) Total Blueskin Bay accumulation volume over last 9600 years estimated at 0.4 x $10^9m^3$ (0.7 x $10^9$t), at a rate of 0.07 $Mt.y^{-1}$.

*Figures and Tables:* Location and shelf sand wedge bathymetry; sediment budget map; cross sections of Holocene sand wedge. Tables of shelf cross section data and bed load/suspended load data

**Carter RM; Carter L; Williams JJ; Landis CA (1985):** Modern and relict sedimentation on the South Otago Continental Shelf, New Zealand. *New Zealand Oceanographic Institute Memoir* 93. 43p.

A very detailed account of Otago shelf sedimentation based on 1500 line km of high resolution, continuous seismic profiles; 170 line km of side-scan sonographs; 18 core samples; 14 box core samples; underwater photographs (6 locations); data from 500 surficial sediment samples historically gathered; selected samples analysed for grain size, $CaCO_3$ and heavy mineral content, and faunal components; literature review. The general physical characteristics of the shelf environment are described including the hydraulic regime (Southland Current, local semi-diurnal tide, persistent southerly "ground swell" generated by storms in the Southern Ocean), local winds, sediment supplies (Clutha, Taieri, Tokomairiro rivers, coastal erosion) and transport directions are quantified. The bulk of the paper identifies and describes 4 prominent offshore sediment facies and their development over the Quaternary Period. Facies include modern and relict features: (1) Modern terrigenous sand facies – seaward thinning wedge on the inner shelf, composed mainly of Haast Schist from the Clutha and Taieri River; minor sources of plutonic and volcanic rocks from Southland and Dunedin respectively; (2) Relict terrigenous gravel facies on middle shelf – derived from Clutha. Contains relict molluscs, an association with drowned estuarine deposits, and large gravel ridges that are out of equilibrium with modern currents; (3) Relict/palimpsest sand facies on mid to outer shelf; Fine to medium sands of Southland (Foveaux Straight-Western Province) and Haast Schist (Clutha, Taieri, Tokomairiro) origin; (4) Biogenic sand/gravel facies - most widespread on outer shelf, composed of both relict and modern species. Sediment facies developed in response to various sea level standstills during post glacial transgression and have been modified by the modern hydraulic regime. Standstills defined as: (a) 18 000-20 000 yrs BP - Last maximum lowering of sea level represented by distinct terrace veneered with relict sand and mollusc debris at -110 to -120 m deep; (b) Next standstill ~15 000 yrs BP - Sediment wedge at -75 m deep equating to relict sand facies (c) Shoreline again stabilised at ~12 000 yrs BP at -55 m depth - Nearshore ridges of relict terrigenous gravel facies developed in association with estuarine deposits and sand wedges (d) Sea level stabilised at modern level about 6 500 yrs BP - Modern sands introduced and dispersed NE by combined effects of southerly swell, tides, Southland Current and storm induced motions. Much of the modern sand accumulates on the northern (lee) side of the Peninsula where it forms an extensive sand wedge and submarine spit. Modern mud depocentres in Molyneux Bay and Blueskin Bay. Modern hydraulic processes have resulted in the mixing and burial of facies in some locations.

*Figures and Tables:* Maps of detailed bathymetry (Nugget Point to Karitane); tracks of bathymetry; high-resolution seismic and side-scan sonar surveys; sediment sample areas; sediment facies: Numerous photographs of sea bed. Satellite photos of Clutha sediment plumes. Photos of sediment core samples: Numerous seismic cross section profiles: 3D schematic diagram of hydraulic and sedimentary processes over Otago Shelf: Schematic cross sections of Blueskin Bay and Molyneux Bay based on seismic profiles.

**Dewdney R (2001):** Floating sand in Blueskin Bay estuary. BSc Hons Dissert (Geology, Otago University). 49p.

Detailed sediment sample and mineralogical analyses were undertaken and comparisons were made between the 3.5 Ø fraction of floating and shore sand samples from the tidal channel in Blueskin Bay to establish heavy mineral distribution, sedimentation patterns and rates. Methods included sieving, mineral separation analysis, Scanning Electron Microscope (SEM) analysis, thin sections and point count analysis, captive bubble tests and microprobe analysis. Main findings were: (1) A suite of heavy minerals with a density greater than quartz and feldspar (> 2.769), common to both shore and floating sand samples, was identified; (2) Whilst all samples contained the heavy mineral suite, the relative concentrations of the heavy minerals fluctuated along the length of the tidal channel, with slightly less fluctuation rates occurring in the floating samples; (3) An area of approximately 0.7 ha with a relatively high concentration of heavy minerals was identified between the tidal channel and Warrington Spit (between 1.0 and 1.3 km from the channel mouth); (4) The floating sand was preferentially sorted by the floatation process and generally contained a higher weight % of heavier minerals: The angularity of the heavy minerals could be a significant factor in the floatation sorting process, while 'wet ability' of the mineral surface probably plays a less significant role; (5) Transportation by floatation appeared to be a one way process and was probably responsible for the relatively high heavy mineral concentration found between Warrington Spit and the tidal channel. The relationship between the tidal channel morphology and sea breeze tidal dependence, may establish a system where floating sand is deposited regularly in the area found to have a higher concentration of the heavy minerals (between the channel and the spit); (6) It was estimated that 14 $t.y^{-1}$ (maximum floating sand flux) of sand are transported by floatation towards the head of the estuary; of this 182 $kg.y^{-1}$

are of the heavy mineral suite identified; (7) It was recommended that more sediment shape, hydrophobicity, and hydrodynamic analyses be undertaken to determine the importance of grain shape in the floatation process, the reasons for heavy mineral fluctuations along the tidal channel, and to better define the concentrations of heavy minerals within the estuary.

*Figures, Tables and Appendices:* Location map and maps of estuary features. Figures of wind directions, calm water zone, photos of sedimentary structures (mega ripples, sand rafts etc). Photographs of equipment used. Graphs of sedimentary (chem. and phys) parameters. Tables of raw data from sediment analyses. Appendices: Sediment sieve analysis, weight % and point count data, SEM images.

**Dignan C (2005):** A sediment budget for Blueskin Bay estuary, south east New Zealand. Post Grad. Dip. Sci. (Marine Science, Otago University). 48p.

A sediment budget for Blueskin Bay was developed, based on: (a) The comparison of suspended sediment samples from Waitati Creek and Carey Creek (the two creeks flowing into Blueskin Bay) to sediment samples from within the estuary itself; (b) A literature review of sedimentary processes in the bay; (c) Comparisons of air photos from 1951 and 2001. A total of 24 suspended water samples were taken from the two creeks over three weeks, and these were correlated to ORC stream flow data ($l.s^{-1}$) to find the annual volume of fluvial sediment ($kg.y^{-1}$) entering the estuary. Surface sediment samples form the estuary were taken from two transects, beginning at the mouth of each creek (5 samples from each transect). Both the suspended and surface samples were analysed (ANOVA) to determine differences within and between the sites. Air photos were compared to identify morphological and land use changes over the last 50 years. It was found that: (1) Approximately 8000 $kg.y^{-1}$ of suspended sediment enters the estuary from the two main creeks; (2) surface sediment samples had between 10 and 63% mud suggesting a large proportion of suspended sediment from the streams settles in the delta systems within the estuary; (3) Suspended load input from the nearshore was dominant but fluvial input was more significant in times of heavy rainfalls; (4) Combining all sediment sources and sinks gave an annual storage in the estuary of 23 198 $kg.y^{-1}$; (5) Sea level rise may move the sediment budget towards equilibrium – air photos show land use has changed little over 50 years but there have been significant morphological changes (accretion and erosion); (6) With a monitoring programme and good management, ecological and environmental values of Blueskin Bay can be conserved.

*Figures and Tables:* Location maps and air photos of Blueskin Bay; maps of sediment sample sites; sediment sorting; Blueskin Bay eddy; coastal changes; rainfall and river flow data. Graphs of sediment analysis results. Sediment budget diagrams. Tables: Raw sediment data; rainfall data; stream discharge data; sediment budget sources and sinks.

**Ensor MJ (1986):** Sedimentology of Blueskin Bay. MSc thesis (Marine Science, Otago University). 155p.

This thesis examines modern sedimentation processes in Blueskin Bay as well as the effects of Holocene sea level rise, climatic fluctuations, and European settlement on sedimentation patterns. Twelve transect lines were established from the estuary margin to Rabbit Island, and from these, over 200 surface sediment samples were collected and analysed, along with core samples collected from the marginal channels, offshore samples (from Blueskin Bay and Otago Harbour), and other surficial samples from the Clutha River, Carey Creek and Waitati Creek. Current and tide data from Blueskin Bay were gathered and analysed and historical air photos were compared to determine recent morphological changes. The main findings were: (1) Various sedimentary zones (mineralogical and textural) exist around the bay – surficial sediments on the inner shelf for example, can be divided in zones of mica, skeletal debris and mud zones; (2) Sediment transport on the inner shelf is produced by a combination of refracted southerly swell, and locally induced swells which are mostly produced by NE winds of unlimited fetch; (3) North of Taiaroa Head, surficial sediments up to 30 m depth are transported on the inner shelf by southerly swell; (4) 4 km north of Murdering Beach and 6 km east of Warrington Beach, at 15 to 20 m depth, bottom sediments are relatively protected from this high energy inner shelf transport – this may correspond to the centre of the gyre circulation system in the bay as sediments in this area have high mica, mud and skeletal debris concentrations; (5) The Clutha was considered the main sediment source, followed by the Dunedin volcanics, Southland plutonics, and onshore movement of relict sediment from the mid to outer shelf; (6) Grain sorting values ranged from typically poorly sorted within 500 m of the deltaic margins of Waitati and Carey Creeks, to extremely well sorted sands on the bar and spit environments; (7) Highest flow velocities were in the main channel (180 $cm.s^{-1}$) and decreased to 0.0 $cm.s^{-1}$ at the estuary margins – bedform morphology confirmed this; High energy flood orientated symmetrical mega-ripples in the channels, tide dependent asymmetrical cuspate ripples on platform sands near Rabbit Island and low energy low amplitude linear ripples at the estuary margins; (8) Warrington Spit accretion rates on the seaward side over last 400 yrs range between 0.5 to 1.6 $m.y^{-1}$. Erosion on the estuary side of the spit over same period was <0.7 $m.y^{-1}$. Large dunes on southern half of spit relatively unstable over previous 30 yrs. Greatest changes over last 120 yrs were along estuary margins adjacent to Evansdale and Waitati deltas, where 100 to 150 m of margin retreat had occurred. Reclamations, railway construction and river mouth alterations in the 1870s caused significant channel migrations; (9) Radiocarbon dates show a Holocene sequence of upper core progradation and degradation (sand and gravels) commencing around 2850 ± 150 yrs. Below this are phases of discontinuous sedimentation from around 3760 ± 430 yrs (shelly sands, muds), and below this are black muds from around 5880 ± 230 yrs. The interpretation of this sequence was given as sea level raised to slightly above its present level around 6000 yrs BP and offshore derived muds were deposited in the deltaic environments – Sea level then dropped around 4000 yrs BP and deltaic sediments advanced in to the estuary covering the bottom muds. Around 2800 BP sea level raised to its present level. Core samples coarsening upwards near Rabbit Island were relatively recent features and probably deposited by extreme storm surge conditions.

_Figures:_ Maps and aerial photos of Blueskin Bay; sediment sampling areas; sediment size and sorting distribution. Ground photos of the estuary, landforms, and landmarks of measurement. LANDSAT images showing Holocene estuary channels. Wind and wave conditions and directions. Stratigraphy of core samples. Numerous fauna photos.

**Hicks DM; Shankar U (2003):** Sediment from New Zealand rivers. NIWA Chart. *Miscellaneous Series* No 79. SCALE 1: 750 000.

This chart shows the annual volume of suspended sediment discharged to the continental shelf from New Zealand's rivers. It is the most up to date and probably most accurate information of its kind. Sediment yield figures were based on empirical models that were calibrated by river sediment gauging. The map breaks the NZ coast line into regions and sediment yields from the major rivers and regions are presented. The map also shows: (1) Which catchments were gauged for sediment discharge, (2) Which catchments are dammed by hydro and natural lakes (3) Terrestrial sediment yields based on colour codes (4) Basic description of the sediment yield calculations. The Clutha River was calculated as discharging 0.39 x $10^6$ $t.y^{-1}$ of suspended sediment to the shelf, and the Taieri River 0.32 x $10^6$ $t.y^{-1}$. It should be noted that these figures are much lower than previous estimates such as Griffiths and Glasby (1985), and those used by Smith (1994) and Tonkin and Taylor (1999) in their Otago coastal sediment budgets.

_Figures:_ Single map (Chart) with text boxes as described above.

**Kirk RM (1980):** Sand transport processes at the entrance to Otago Harbour: Report to the Engineer's Department, Otago Harbour Board. 57p.

This report identifies and defines the sediment characteristics (Folk's parameters and rollability), volumes and distribution patterns at the Otago Harbour entrance channel, ebb tide delta, shipping channel and associated inter-tidal flats: The sediment characteristics are then correlated to harbour and coastal hydraulic conditions. The report was the first to deal exclusively with nearshore shelf processes in the area, as previous reports had examined the mid-outer shelf region. The hydrology (tides, waves, currents, inlet stability) was based largely on previous research (especially Heath 1975) and discussion with Otago Harbour Board engineers. Coastal processes as described by Elliot (1958) and Andrews (1973) are discussed. 44 sediment samples were analysed from the specific areas mentioned above (provides detailed accounts of collection and analysis methods). Sediment volume changes were calculated from digitised sounding charts (bathymetry maps) – maps at 5 yr intervals between 1945 and 1975 were used. Significant findings were: (1) 63 500 $m^3.y^{-1}$ of sand is stored in the ebb tide delta, in addition the 400 000 $m^3.y^{-1}$ that is dredged; (2) Ebb tide delta volume was 7.6 x $10^6$ $m^3$ in 1975. Had grown >2 x $10^6 m^3$ in around 33 yrs; (3) Annual drift past harbour ~450 000 – 500 000 $m^3.y^{-1}$ – about 14% of this gets stored in delta, rest ducted into harbour or transported to northern beaches; (4) Sand storage in delta is larger than dredging operation; (5) Independent reports showed accumulation in harbour and Blueskin Bay about equal; (6) Narrow harbour throat entrance the main reason for harbour sedimentation – acts like a pump and brings material in from the inner shelf on flood tide – if entrance area increased, sedimentation rates would decrease, but this would involve more dredging; (7) Dredge spoil from Heyward dump ground moves N and NE into Blueskin Bay – generally doesn't accumulate at site or move south to re-enter harbour entrance/channel; (8) No suitable sites to the seaward of the Mole for a sand trapping operation – Aramoana and Harington Bend best for this as they are strong sediment receiving areas, have strong axial flow, and there is room to construct a trapping structure; (9) Mixture of fine, modern fluvial sand and relict mid shelf sand deposited in harbour; (10) Dominant sand transport direction is northward and shoreward; (11) Dredging has more effect on sand storage over periods up to 5 yrs, rather than long term effects.

<u>Figures and Tables:</u> Location map of shipping channel and sediment sample areas; Contour maps of rollability values and sand size fractions. Graphs of tidal compartment/entrance cross-section relationship; changes in ebb tide delta volume (1941-1975); gross volume change (%) between surveys. Tables of tidal velocities in harbour; grain size summaries (statistical and descriptive); rollability analysis; sieve sizes; rollability values; sediment volumes (between various depths and between surveys); contour changes.

**Leon JP (2005b):** Changes in seabed elevation of dredge spoil sites at Heyward Point, Aramoana and Shelly Beach, Otago Harbour. Report to Port Otago Ltd. Geography Department, Canterbury University. 26p plus appendices.

Changes in seabed topography at the three Port Otago Ltd dredge spoil dumping grounds were determined from a detailed GIS analysis of digitised bathymetric charts and digital terrain models (DTMs). The methods are described in detail. For the Heyward Point site, it was found that accretion had occurred at a rate of 52 000 $m^3.y^{-1}$ since 1978. The retention rate/unit area of disposal site = 0.024 $m^3.y^{-1}.m^2$. This equated to 43% of cumulative dredge spoil placed. There was no direct relationship between dredge spoil placement and disposal site volume. Sediment is dispersed very rapidly from the site. At The Spit site the accretion rate since 1984 (when dumping commenced) was 56 000 $m^3.y^{-1}$. The retention rate/unit area of disposal site = 0.089 $m^3.y^{-1}.m^{2.}$, which equated to 44% of the cumulative spoil placed. However, natural accumulation had also been occurring in this area since the late 19th century, so it was not possible to determine the natural and dumped proportions of the retention volume. At the Shelly Beach site, sediment accumulated at rate of 11 350 $m^3.y^{-1}$ between 1987 and 2004 which equated to 53% retention of the cumulative spoil placement (0. 028 $m^3.y^{-1}.m^2$) – this included the retention of natural littoral sediments. Unlike the other two sites, most of the accretion At Shelly Beach occurred in the first year and has fluctuated since, due to the more dynamic seabed there. Also, as a negative sediment budget had been previously identified here, it was concluded that most of the sediment accumulation in the nearshore was a result of dredge dumping. It could be expected that about 50% of the dredge spoil at the site would be retained in the sub-aerial beach and dunes, or recirculate offshore. This was a positive impact as it reduced beach erosion.

*Figures and Appendices:* Numerous DTMs of bathymetry at different time scales for the three dump sites. Graphs of dredge spoil placement/disposal site volumes.

**Litchfield NJ; Lian OB (2004):** Luminescence age estimates of Pleistocene marine terrace and alluvial fan sediments associated with tectonic activity along coastal Otago, New Zealand. *New Zealand Journal of Geology and Geophysics* 47: 29-37.

Luminescence dating methods (optical dating of K-feldspar and thermo-luminescence of quartz) were used to determine the Pleistocene faulting history of the Titiri and Akatore Faults systems in coastal Otago. The sampling methods and analytical techniques are described in detail. Seven luminescence dating samples were collected from the study area, including two from Warrington Beach (northern Blueskin Bay). Raised beach terrace at Warrington was described as slightly deformed, tilted to the NE and offset 1.0 m by a small NW striking fault. Dating samples came from modern marine cliff at Warrington: One sample from loess underlying a beach gravel layer and one from the beach sand overlying the gravels (Figure 2 of report). It was assumed the sand would approximate the terrace age and the underlying loess would give a maximum age. For the Warrington samples it was concluded that despite some anomalies, there was enough evidence to support the deposition of the raised beach sand during the 125 ka sea level high-stand. This age estimate was consistent with Gibb (1986) and indicated the area has been tectonically stable since that time.

*Figures and Tables:* Location map of sediment sample sites and local faults. Stratigraphic logs for luminescence ages (includes 2 Warrington sites); Optical and radiation properties of sediment samples. Tables of chemical composition of samples; doses/fading ratios and optical ages; data from this study compared to previous investigations.

**Witman JD (1974):** Sedimentological and ecological studies of Blueskin Bay estuary. Dip. Sci. Dissertation (Geology, Otago University). 108p.

Historical and contemporary sedimentary processes of Blueskin Bay are presented, based on the analysis of surficial and sub-surface sediment samples (Folk parameter analyses) micro-macro organism analysis, and wind, wave and tidal data. The stratigraphy from numerous pits dug along transects across the bay are described individually then correlated to present an overall Holocene sedimentary history of the bay. It was found that: (1) Sediment grain size and sorting are very limited and the majority of sediment is very well to well sorted fine sand. Extreme Folk parameter values (size, sorting, skewness, kurtosis) relate to quartz and schist gravel in the sediment; (2) The zone of highest energy occurs adjacent to the tidal inlet and the zone of lowest energy occurs in the upper reaches of the estuary; (3) Various faunal species were found to correlate to sediments of a particular grain size – grain size was more important to fauna than the other parameters such as sorting or skewness; (3) A sequence of two loess layers and a mixed loess/solifluction layer stratigraphically separated by 2 sand sequences was tentatively correlated to 3 ice advances and two interstadials of the Otira Glaciation; (4) During Kumara 2/1 stage, Blueskin Bay was thought to be an embayment of the South Pacific Ocean, partially protected from the open ocean by a small promontory or headland on the north shore. Later (early Flandrian), a small sand spit formed at this location. Sand, cobble and shell beds above present day sea level in the low cliffs bordering the estuary, and sand layers beneath Rabbit Island are thought to be sand and cobble beaches deposited during the westward transgression of the Flandrian sea. It was proposed that Rabbit Island originated as a Flandrian sand plain and was selectively degraded by Waitati River and Carey Creek.

*Figures, Tables and Maps:* Location maps of site and sediment samples; sediment structures; paleogeography; transects; Folk parameter distribution (size, sorting, skewness, kurtosis); shell bed distribution. Diagrams of stratigraphic units along the transects. Graphs of Folk's parameters (statistical plots). Aerial photos of Blueskin Bay study area. Ground photos of sediment structures (ripples etc) and photos of pit stratigraphy along the transects.

## Otago Harbour coastal environment

**Baird V (1997):** Trace metals in some marine sediments. MSc thesis (Chemistry, Otago University). 100p.

Trace metals in marine sediments of Otago Harbour (and Doubtful Sound, Fiordland) were collected and analysed, and the effects of storm events on Otago Harbour trace metal distribution was also investigated. A range of chemical procedures, along with sediment size analysis, Inductively Coupled Plasma (ICP) and Graphite Furnace Atomic Absorption (GFASS) spectrometry, X-ray diffraction and fluorescence, and gamma-ray spectrometry, were used to analyse the sediment samples. The significant findings (in relation to Port Otago Ltd dredging activities) were: (1) A definite sediment size gradient exists along the length of Otago Harbour which may be due to the influences of the Leith River and sandy material entering the harbour from coastal waters; (2) Trace metals followed a similar distribution gradient along the harbour; Pb levels increased towards Dunedin (influenced by the Leith River stormwater drainage), Cr was transported across the harbour from Sawyers Bay and Cr levels increased slightly towards Dunedin; (3) Comparisons on natural sediment cores to laboratory storm experiments showed that for Site A (Stormwater outlet, Anderson Bay), natural sediments appeared to be undisturbed by storm activity (i.e. stable) which meant the site was a good control site to monitor anthropogenic pollution. At Site B (Dunedin Wharf) and Site C (Burns Point), the impact of storms could not be distinguished from the sediment mixing which occurs naturally at these sites. $^{210}$Pb studies demonstrated that storm activity may be important in re-suspending and re-distributing trace metals at some sites in the Upper Harbour.

*<u>Figures and Tables:</u>* Maps of location, sediment sampling sites, ebb and fold flow patterns in harbour. Many tables and graphs of chemical analysis and sediment sample characteristics.

**Barnett AG; Victory SJ; Bell RG; Singleton AL (1988):** Otago Harbour hydrodynamic model study. Report to Otago Harbour Board. Barnett Consultants Ltd. 152p.

This detailed report was produced with the aims of establishing basic tidal flows and levels in Otago Harbour, to predict potential changes to these once the second container terminal at Port Chalmers was built and channel realignments were undertaken, and to identify sediment transport paths in the harbour and possible dredge spoil dumping areas. The report was based on: (a) Review of current information; (b) Intensive field data collection (Tide gauge recordings, continuous current metering, velocity vertical profiling, Drogue Tracking, climate data and hydrographic surveying), and (c) A two dimensional hydrodynamic model developed from the Danish Hydraulic Institute's System 21 model. Three levels of model resolution were used: A coarse grid at 150 m resolution for the entire harbour; a 75 m grid covering the shipping channels around Port Chalmers, and a 25 m grid covering the swinging basin and berthing area at Port Chalmers. The main findings in relation to shipping were: (1) A persistent southward current past No 2 Container Berth and a local clockwise eddy moving offshore at the container berths at slack high tide; (2) Sediment pathways were found to form closed loops – there was little evidence of net transport in or out of the harbour. Possible sediment deposition areas were identified on the north side of Harington Bend and at No 2 Container Berth; (3) There was no evidence of a longshore current outside of the harbour; (4) Normal tidal currents alone will not move fine-medium sand at the spoil ground – under combined wave and current action it can move slowly towards the Mole; (5) Sea level rise of 0.5 m was recommended for long term planning use; (6) The main effects of sea level rise on the harbour would be an equivalent rise in high and low tides plus a decrease in the tidal time lag from Tairaoa Head to Dunedin. The sediment regime in the harbour would also be changed, particularly in the intertidal areas and increased dredging may be necessary.

*Figures and Tables:* Maps of harbour, tide and current recording sites. Medium Grid data collection components. Examples of velocity profiles. Measured and predicted tidal levels. Numerous tide level and current direction and velocity diagrams (actual and predicted, and comparisons of the two). Photos of equipment used (tide gauge, S4 meter, Braystoke current meter). Tables: Current meter sites; physical characteristics of harbour; comparisons of main tidal harmonic constants (Landfall, Pilots Beach, N0. 5 Beacon) and spring and neap tidal ranges; averaged maximum tidal currents, flow directions and tidal periods at Port Chalmers-Halfway Islands; S4 deployment statistics at Landfall Tower; tidal ranges on gauging dates; charts used for digitising bathymetry.

**Barrell DJA (2002):** Geological stability assessment of the Port Otago tide gauges, Otago Harbour, New Zealand. Report prepared for port Otago Ltd. Institute of Geological and Nuclear Sciences. *Science Report* 2001/21. 19p plus appendices.

The stability of the tide gauges at Port Chalmers and Dunedin Port are assessed. The assessment is based on the analysis of local geology, and detailed investigations of: (1) Port development: (2) location of tide gauges and benchmarks: (3) foundation materials: (4) foundation conditions below the tide gauges and benchmarks. Tide gauging has been carried out at Dunedin Port since 1899 and at Port Chalmers since the 1970s. The Dunedin gauge has been relocated at least three times (1922 = Birch St; Dec 1982 = below new POL office; June 1983 = Victoria wharf). There are no POL files of tide gauging before 1922 (Hannah 1988 refers to gauging going back to 1899). Port Chalmers gauge is being monitored in a nation wide GPS survey programme to determine sea level changes and tectonic stability. Otago Harbour described as drowned valley – volcanic bedrock overlain by a layer of firm valley fill deposits (gravels etc), then a very soft post-glacial mud/sand/shell layer. Both tide gauges appear to be very stable, with their foundations being set in the very firm valley fill material and the whole Dunedin/Otago Peninsula has a very slow vertical uplift rate of around $0.0 \pm 0.2$ mm.$y^{-1}$.

*Figures, Tables and Appendices:* Numerous maps/figures of local geology and faults; harbour surface sediments; reclamation areas; tide gauges and benchmarks; harbour structures (rockfill, piles, caissons, wharves etc); maps of borehole locations. General photos of Port Chalmers and Dunedin Port. Appendices of core log data and descriptions.

**Bennett NM (1995):** Otago Harbour: Development and Development control and the effects of these on the environment. MSc thesis (Marine Resource Development and Protection, Institute of Offshore Engineering, Heriot-Watt University, Edinburgh). 138p.

This thesis focused on the historical legislation, development controls and management of Otago Harbour. The harbour was chosen because of being an enclosed site with definite boundaries and had been subject to continual development and alteration, and conflicting interests. Although focusing on historical management, this study provides general historical chronologies of harbour reclamations and dredging, construction of structures and channel/shoreline changes. Numerous old harbour charts and plans from the Hocken Library are reproduced.

*Figures, Tables and Appendices*: Numerous historic maps and photos of the harbour are reproduced (from 1846 onwards); numerous ground and aerial photos from around the harbour (Figures in text and appendices). Plans of historic reclamations. Tables and graphs of reclamation data.

**Cournane S (1992):** Seismic and oceanographical aspects of Lower Otago Harbour. MSc thesis (Marine Science, Otago University). 216p.

A number of techniques are used to identify and describe the geology, geomorphology, sedimentology and oceanography of the Lower Otago Harbour. Methods included current meter experiments, water temperature and salinity recordings, high resolution seismic profiling and bore-hole data. It was found that: (1) Current meter experiments (3 days long) located on the inside of Harington Bend, close to the shipping channel, during a neap tide showed that the mean flow was ebb dominated and concentrated in an E-SE direction (dictated by the slope of the Aramoana tidal flats), with a maximum velocity of 0.58 $m.s^{-1}$. Flood velocities reached 0.47$m.s^{-1}$ and were concentrated in a W-SW direction in the shipping channel; (2) Sediment entrainment was likely to occur only in the height of the ebb tide. This was supported by geomorphological evidence of the Aramoana tidal flats. The ebb sediment transport directed away from Aramoana suggests that the Aramoana sediments are relict features (6000 to 3000 yrs BP) and are experiencing contemporary erosion; (3) Holocene tidal ridges at Aramoana are a post formation of a spit feature that must have been higher than the present spit (i.e. they indicate a similar tidal direction as today, during a period of deeper water than present); (4) Generally, bed forms of the Lower Harbour shipping channel ranged from small ripples (27 cm wave length) to long period sand waves up to 60 m long, but usually less than 1.0 m high. Dune features at Halfway Islands and Harington Point appear to relate to constrictions and accelerated flow – the constrictions also cause large scour holes and tidal colks. Scour holes at Ohinetu Point and Te-U-Mukuri result from artificial constrictions (groynes). Sand waves (generally 6 to 30 m length) were found in areas of moderate to fast flow, around both sides of Halfway Island tidal calk, south side of Deborah Bend, Hamilton Bay and just south of Howletts Point. Most sand waves are flood orientated at all stages of the tide (contrary to the dominant ebb tide flow) and there is little evidence of re-orientation within a tidal cycle. Scour and three dimensional bed form features usually occur in areas of high velocity as on the outside of bends in the shipping channel, although in some cases, the very outer limits of the bends were featureless; (5) Seismic evidence showed that Tertiary rock units on both sides of the harbour are not continuous under the recent harbour sediments – this was supported by aerial photo evidence and borehole samples. Previous seismic investigations may have misinterpreted the reflector layers. Seismic reflectors in the harbour centre near Aramoana flats suggests 85 m thickness of sediment to basement rock – this is much thicker than previously thought (e. g. 30 m suggested by Scott and Landis 1975); (6) Borehole data shows significant sub surface muds (up to 8 m thick) in the Lower Harbour which may be exposed to erosion in the shipping channel at depths greater than 12 to 15 m. The environment for mud deposition was interpreted as a barrier enclosed lagoon. A fossil crab found at 15 to 18 m below MSL suggested a rapid burial event during barrier closure, most likely a result of a catastrophic rainfall event causing substantial terrestrial derived sedimentation. A number of recommendations in relation to data gathering and storage are provided including more side-scan radar and seismic profiling, and underwater photography of bed features, especially around the harbour entrance channel.

*Maps, Tables and Appendices:* Main diagrams are large scale maps (back cover) showing sub-bottom features and bed forms; Harington Point side scan sonar plot; AUTOCAD of side scan sonar; bore hole data from Aramoana. Also graphic diagrams of wind and tide data etc. Much of the raw data are presented as Tables in the appendices and include navigational and positional data; Tide and wind data; computer notes; sediment types and locations; raw current meter data.

**Johnstone N (1997):** Consequences of breaching of Aramoana Spit sand dunes. Unpublished memorandum to the Otago Regional Council. 4p plus appendices.

This brief report briefly discusses the construction history of the Mole and Long Mac, the associated beach changes around the Aramoana area, the erosional effects of coastal storm damage in 1986 and 1992, and remedial options available to prevent further erosion. It was noted that the Mole increased lateral sand movement and build up in the vicinity of the spit and the Long Mac was constructed to prevent the eastward growth of the spit and maintain an efficient channel. The Long Mac had suffered storm damage but was still serving its purpose. Historical evidence showed that whilst the Long Mac was effective in trapping sand and building up the beach locally, it had negligible impact along most of the length of Spit Beach. The 1986 storm resulted in houses having to be relocated whilst the 1992 storm initiated dune restoration work (dune fences, planting etc). The beach had prograded between 1992 and 1997. The major consequences of breaching or severe erosion appeared to be the integrity of houses at the eastern end of the spit, the possible loss of vehicular access should the track behind the dunes washout, and potential loss of recreational values should the beach become inaccessible. Possible erosion mitigation options included the increased dumping of dredge spoil in the South Spit dumping area, groyne construction along the spit between the Mole and Long Mac, continued dune planting and sand fence construction, and upgrade the Long Mac training wall.

_Figures and Appendices:_ Appendix: Pre-Mole maps of the Spit Beach. No one seems to have copies of figures or appendix.

**Lauder GA (1991):** Otago Harbour: Coastal Inlet and Shoreline Processes**.** Report to the Physical Systems and Ecosystems Working Group of the Otago Harbour Planning Study. Department of Conservation, Southland. 20p.

The geological and geomorphological origins of Otago Harbour and human modifications to it are summarised in this report. The report was based on a literature review and was part of a larger a planning investigation. The geographical setting of the harbour and Holocene to contemporary inlet and shoreline processes/sedimentation are summarised, and management and research priorities are identified. For each section of the report, key references are given (many of the more recent references have been summarised in this literature review for Project Neptune). Areas requiring further research were identified as: (1) Flow patterns and processes of the shallow upper harbour area (key recreational parts of the harbour) and water exchanges, ecology and sediments in the truncated embayments (from railway and road causeways; (2) Individual and net effects of reclamations on Harbour hydrology (e.g. tidal flows and tidal prisms); (3) Very little is known of catchment sediment influxes to the harbour – this has implications for sediment budgets, nutrient and pollutant inflows; (4) Inlet trapping investigations of water, sediment, nutrients, heavy metals etc, especially in areas away from the main channels, for which most data related; (5) Classifying, categorising and mapping shoreline types (e.g. cliffs, rocky beaches, sandy beaches, sand flats, artificial walls etc); (6) Material composition of shorelines around the harbour – Information exists for some areas but not the whole harbour; (8) Harbour shoreline processes –information is site specific and no overall account has been presented.

_Figures and Tables:_ No figures. Table of proposed shoreline typology.

**Lusseau D (1999a):** Port Otago Ltd. Dredge spoil relocation: A literature review. Report for Port Otago Ltd. Zoology Department, Otago University. 38p.

This report provides a general overview of relevant literature relating to the Otago Harbour dredging operation produced to that time. It considers physical (harbour geology, sedimentology, hydrology, water quality) and biological (faunal communities and health) aspects. The report is divided into two main sections. The first provides background information on Otago Harbour and its physical and environmental characteristics, spoil relocation areas and biological communities. The second part of the report provides assessments of physical conditions, water and sediment quality and harbour biology. Physical processes (sediment origins and transport etc) are mainly summarised from Kirk (1980), Royds Garden (1990), Purdie and Smith (1994), Single and Kirk (1994) and Goldsmith (1995). Hydrological aspects are summarised mainly from Carter *et al.* (1985), Royds Garden (1990), and Old (1998). Sediment quality information was from Purdie and Smith (1994) and Stevenson (1998). As all of these references are reviewed in the present report, details are presented in those specific reviews. However, the main conclusions of Lesseau (1999a) were: (1) Spoil from the dredge dumping ground generally disperses alongshore to the north and onshore and was found to be beneficial for erosion mitigation at South Spit Beach: Dumping at Heyward Point may not affect the morphology of Blueskin Bay even though some Heyward Point material moves onshore. 18% of material is retained in the Aramoana dump site annually, forming a mound which may protect the beach; (2) Harbour sediments are dominantly medium sand to mud with occasional gravel and soft rock sediments – the Clutha and Taieri rivers are the main sources, brought north by the Southland Current and southerly swell. Southland Current splits at the peninsula and forms the Blueskin Bay gyre and southerly drift, north of the harbour. Fine muds and silt in the harbour come from local runoff, stormwater discharges and Leith River. Sediment characteristics of the relocated (dumped) sediments are the same as native surrounding sediments; (3) Apart from a few highly localised sites of high heavy mineral and hydrocarbon concentrations (un-dredged areas), sediment quality in the harbour is well within the national guideline ranges. The contaminants can be potentially re-suspended during dredging, and wind, wave, tide and storm action. Stormwater and agricultural runoff appear to be the two main sources of sediment pollution in the harbour; (4) Dredge material is unlikely to be contaminated with feacal bacteria as their density decreases rapidly from the sewage outfall. However, contamination of relocated sediments is a possibility. Dredged material contained various contaminants depending on the sediment site origin. No data exists on the re-suspension of contaminants at the disposal sites and their consequent availability to flora and fauna; (5) Dredge disposal keeps benthic communities at the disposal sites in the early colonising stage, affecting their diversity, abundance and composition.

*Figures and Tables:* All figures reproduced from reports mentioned above. Maps of sediment types and distribution; rollability values; ocean currents; harbour entrance morphology; bathymetry; heavy metal types and distribution. Tables describing disposal site locations; sediment types; heavy metal composition and location. Also numerous maps, tables and graphs relating to benthic fauna and water quality data.

**Lusseau D (1999b):** A review of dredging activities in Otago Harbour and their relocation 1899-1998. Report for Port Otago Ltd. Zoology Department, Otago University. 4p plus appendices.

This report provides very detailed data on historical dredging and dredge disposal in the Otago Harbour since 1872. The detailed data for the period between 1899-1998 are based on monthly reports from the various historical harbour authorities. It was noted that information quality has been very consistent between 1934 and 1998, but before 1934 it was more variable. The report focuses on data presentation for the five following issues: (1) Variation in dredged volumes from the harbour for maintenance and development of the shipping channels; (2) Variations in annual volumes of dredge spoil dumped at each relocation site; (3) Volumes of reclaimed dredge material; (4) variations in annual volumes of dredged material taken from each claim in Otago Harbour; (5) Data from 1977-1998 was presented in more detail, correlating to the period of lower channel deepening. A brief history of the dredging and channel development is given, along with volumes of material removed and relocated, and channel lengths and depths at each stage of development. It was found that maintenance dredging has historically always increased after development (capital) dredging stages, then decreased as the area (channel slopes and basin) stabilised. For maintenance dredging and relocation consents, it was considered impractical to accurately predict the volumes required as weather and sea conditions made sediment movements in the harbour highly variable.

*Figures, Tables and Appendices:* Location map of harbour, cannels and dredge/dump sites. Descriptive table of harbour developments and dates. Appendices (the bulk of the report) are an extensive compilation of graphs and tables of the historical dredge and spoil data for various sites around the harbour.

**Otago Regional Council; Dunedin City Council (1991):** Otago Harbour planning study – Stage One: Report on the ecosystems and physical systems working group. *ORC and DCC Joint Discussion Series* 2. 210p.

This report provides general overview of physical and ecological systems in the Otago Harbour, prepared for ORC and DCC planning purposes. The main physical points were: (1) Otago Harbour is a drowned valley, 22 km long, 2.3 km average width, 400 m wide mouth. Divided roughly in half by Goat and Quarantine Islands. Total area at high water = 4 600 ha, with about 30% being inter-tidal; (2) Present shoreline development commenced 15 to 17 000 yrs BP at the beginning of the post glacial sea level rise, when sea level rose to slightly higher than present. Subsequent sea level fall and stabilisation around 6500 yrs BP causes beaches to migrate

seawards as deposition took place at the shorelines. Pleistocene sediment 1-3 m thick cover much of the volcanic base rock; (3) Otago Harbour formed on a NE trending fault zone no longer considered active, although nearby Akotere Fault Zone is active; (4) First map of 1826 showed harbour to have a serpentine channel of 5-7 fathoms deep and sandbanks which were navigable at high water; (5) Harbour hydraulics are dominated by the main channel ebb and flood flows; (6) Aramoana sand flats thought to have developed from a sand influx between 6000 and 4000 yrs BP. Therefore, Aramoana sand flat probably relict, over 3000 yrs old and probably not a site of current active sedimentation; (7) Two distinct water quality regions in the harbour – North of Halfway Islands water is homogeneous, south of islands the water is mixed and stratified with freshwater inputs from Leith Stream; (8) Uncertain as to the volume and distribution of sediment introduced to harbour through stormwater and natural water courses; (9) Relationships between sedimentation, hydraulics, reclamations and erosion still largely unknown, apart from around main shipping channel; (10) Effects of anthropogenic modifications (reclamations, seawalls, causeways, urbanization, dredging etc) on harbour hydraulics has not been fully evaluated; (11) Main sediment source for harbour is fine sediment moving northwards along coast from the Clutha River, then flood tide brings sediment into the harbour which is deposited because the flood tide is stronger than the ebb tide – estimated deposition rate is 800 000 $t.y^{-1}$. Therefore dredging essential to maintain navigable channels; (12) Sediment input from the Clutha is expected to decrease due to effects of Clutha damming; (13) Harbour siltation will be an ongoing problem; (14) Sea level rise may have the following harbour effects – inundation of low lying harbour margins; modification of the hydraulic regime, shoreline processes, morphology and characteristics of the intertidal sand flats in the harbour.
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*Figures and Tables:* Maps of hydrodynamic features; sedimentation patterns; geology; channel cross sections (Taiaroa Head to Heywards Point: 1871, 1925, 1951). Numerous graphs on wildlife and ecology data. Table of shoreline classifications.

**Purdie J; Smith AM (1994):** Heavy metals and hydrocarbons in Otago Harbour sediments. Report to Otago Regional Council. Department of Marine Science, Otago University. 51p.

The concentrations and distribution of heavy metals and hydrocarbons in the Upper Otago Harbour were determined by the textural and chemical analyses of 41 sediment samples collected from 15 sites. Texturally, the samples fell into three main groups: (1) Slightly gravelly muds (mainly silts with some shell material) were found at Sawyers Bay, Lantham Bay, Mac Andrew Bay and the inner Harbour Basin; (2) A sometimes gravelly well sorted fine sand was typical of the middle reaches of the upper harbour (Broad Bay to Ravensbourne); (3) Variable poorly sorted, mixed muddy sands and gravels characterised the inner most sediments (Anderson's Bay mouth of Leith River and Burkes. Sediment texture was influential on infaunal organisms and adsorption of pollutants. In all cases, mean values for heavy metals were low and well within typical levels of other NZ inlets. There was a strong correlation between heavy metal concentration and sediment size in coarse sediments. In finer sediments, distance from source and other factors controlled concentrations. The highest hydrocarbon concentrations were found at the mouth of the Leith River, near the boat harbour. Hydrocarbon concentrations were found to be 1-3 orders of magnitude higher in sediment than in sea water, showing that hydrocarbons are adsorbed and concentrated in the marine sediments. Pollutants reach the harbour through the Leith River, storm water runoff, sewage and industrial effluent outfalls and harbour activities. The effects of these pollutants on fauna and flora were unknown at the time of writing.

*Figures, Tables and Appendices:* Location map of Harbour; maps of sediment sample sites; grain size and texture; maps of various heavy metal concentrations around the harbour and sources of pollutants; hydrocarbon distribution. Graphic correlations of heavy metals/hydrocarbon and sediment size/texture. Tables of sediment sample locations and textural data; heavy metal sources, concentrations and toxic levels. Appendices: Results of sediment texture, heavy metals and hydrocarbons analyses.

**Quinn J (1979):** Report on further studies on the hydrology of Otago Harbour. Report to Otago Harbour Board. Marine Science Department, Otago University. 6p plus Appendices.

Previous hydrological research undertaken by Quinn (1978) in Otago Harbour had focused on the main shipping channel, so this investigation was undertaken to produce a composite picture of hydrological processes over the wider harbour area. Type II current pole drogues were released at points of interest and at various tidal phases and their movements monitored in terms of time and position. The main results were: (1) On a medium flood tide water of outer coastal origin extends to beyond Halfway Islands to the upper harbour – the following ebb tide flushes most of this out. However, water on the eastern side of the harbour (near Portobello) remains in the harbour on the ebb tide; (2) This resident water body in the lower harbour accounts for the fact that water up-harbour of Halfway Islands can be flushed from the harbour on a medium ebb tide despite the fact that the harbour's tidal compartment (69.3 x $10^6 m^3$) is less than the high tide volume of the Lower Harbour (86.2 x $10^6 m^3$) on a medium tide. Due to the circulatory flow of the Portobello area, this water should be homogeneous with the rest of the Lower Harbour at high tide; (3) In the eastern channel, tidal displacements and velocities are much smaller than corresponding values in the shipping channel; (4) Therefore, most of the upper harbour flow occurs in the shipping channel and the eastern channel flow is more likely to be resident flow; (5) Based on tidal observations at Ravensbourne, none of the Upper Harbour water moves beyond the Halfway Islands on the ebb tide. Subsequently, this water is not subject to the gyre and deflection currents observed in this region and it is thus more resident than the more down-harbour water, and is more prone to environmental modification.

*Figures and Appendices:* 4 maps of drogue plots at various location and tidal phases. Sketch of Type II Drogue. Appendix: Current velocities a fertiliser works.

**Ramsey S (2004):** The application of RTK GPS to high density beach profiling and precise bathymetry for sediment renourishment assessment at Shelly Beach, Otago Harbour, New Zealand. Post Grad. Dip. Sci. (Surveying, Otago University). 121p.

High density, Real Time Kinematic GPS (RTK GPS) surveying and drafting techniques were used to identify and accurately quantify small sediment changes (volumes and transport directions) both above and below the ocean/land interface at Shelly Beach: a 10 m grid was used for the digital terrain models (DTMs) over the beach and 10 m line spacing over the spoil ground The purpose of the research was to assess the effects of dredge spoil beach renourishment more accurately than had been done in the past. The 3D DTMs produced allowed very accurate beach and nearshore volumes to be calculated, beach and nearshore morphology changes to be quantified, and provided much improved graphics allowing easier visualisation of the processes and changes occurring on Shelly Beach and the nearshore bathymetry. The methods used have thus established a high density baseline for future monitoring of long term morphological changes. Despite the limitations of the investigation (time, relatively small spoil volume discharged during the study period, lack of post disposal bathymetric surveys) some important conclusions were made. These were: (1) During typical environmental conditions the sub-aerial sand spit is in equilibrium despite measurable sand movement occurring – erosion and accretion of sand is balanced across the littoral zone; (2) The beach is particularly susceptible to 'atypical' conditions, especially large NE swells that are not deflected by the Mole. Under these conditions up to 10 000 $m^3$ of sand was lost during one month, with most of this loss occurring in a few stormy days; (3) The dredge spoil displayed sediment dispersion during the research period – the data showed a 'sediment in suspension' loss of approximately 25% for the spoil ground site. The mound heights subsided in the order of 0.4 m during the two weeks between surveys. The spreading of this sediment showed no significant change in the total spoil of all the areas analysed for volume change, although time analysis of the volume change data showed a decreasing trend in the total retained spoil at the site; (4) The formation of sand waves at the western side of the spoil ground showed that dispersed spoil was likely to travel as wave trains following initial settlement; (5) Net sand *movement* is easily identified by a path perpendicular to sand wave crests/troughs but there is uncertainty as to the *direction* of sediment travel: It could be dispersed offshore with the ebb tide of the harbour inlet, or inshore in response to the flood tide and typical swell direction – An 8% increase in sediment volume in the offshore analysis area may indicate the net discharged sand movement is offshore; (6) The effectiveness of the spoil in beach renourishment across the extents of the spoil grounds is questioned – Successful renourishment may be only achieved with nearshore, shallow discharges; (7) Swell energy is the primary energy source for sediment transport within, and just off shore of the intertidal zone. Fine tuning of the method was considered for future research (higher density, continuous time data collection). To assess the renourishment programme in the future, it was recommended that high density beach surveys be conducted annually and bathymetric surveys be undertaken at precise given times after spoil dumping.

_Figures, Tables and Appendices:_ Numerous maps and DTMs of Otago Harbour, Shelly Beach, spoil ground bathymetry (and changes); GPS grid and line survey network (beach and offshore), photos of equipment used. Graphic information on survey profiles and results, volumetric changes, sand wave migration etc. Numerous data tables on spoil discharge volumes; survey grid co-ordinates; beach and spoil ground volume changes between various survey periods and survey sites (spaces); % of discharge retained at various sites.

**Royds Garden Ltd (1990):** Environmental impact assessment: Dredging and dredge spoil relocation; Port Otago. Report for Port Otago Ltd. Royds Garden Ltd 43p.

This report accompanied the water right applications for maintenance dredging and dredge spoil dumping in and around Otago Harbour, and focuses on water quality and ecology issues. The dredging operation is discussed in terms of: (1) Historical dredging/dumping methods and volumes; (2) Physical characteristics, coastal processes, hydrology and ecology of the harbour area; (3) Environmental characteristics of the source and dumped sediments; (4) Potential pollutants of the dumped sediments; (5) Impacts of dredging and dumping in and around the harbour. The report is based on previous investigations and sediment sampling from 5 sites (mainly for benthic fauna and pollutant analysis; 90% of sand analysed was fine sand). Shelf sediment sources and oceanic hydrology are summarised mainly from Andrews (1973) and Carter *et al.* (1985), whilst beach stability and nearshore sediment transport is summarised from Kirk (1980). The overall conclusion was that dredging and relocation of sediment (spoil dumping) had been ongoing for 125 years, and apart from very localised impacts, the dredging and dumping operation had no detrimental effects on the physical environment or ecology on the harbour or dumping areas, nor on recreational and commercial activities.

_Figures, Tables and Appendices:_ Location maps of sediment sample sites; dredge dump sites; Aramoana shoreline changes 1880-1980; shelf sediment facies (from Andrews 1973); ocean currents (peninsula – Blueskin Bay); relative rollability values (from Kirk 1980). Diagrams of flood/ebb tide circulation, wind rose (Taiaroa Head). Graphs of current velocity and direction at dump site. Tables for dump ground coordinates (Heyward Point, Spit and Shelly beaches); dredge and dump volumes (1979-1989); sediment and heavy mineral analysis results.

**Sabetian A (1998):** Effect of Dredge Spoil on Benthos and Sediments. BSc Hons Dissertation (Marine Science, Otago University). 53p.

The effects of dredge spoil dumping on benthos and nearshore sediments at the Aramoana dump site are investigated; the results of the benthos/sediment sample analysis from the dump sites are compared to a control site. This dissertation provides a geographic description of Otago Harbour and an overview of the dredging and dumping operation. It is noted that the Aramoana dump site was a dispersive site (where sediment is actively dispersed after dumping), not a contaminant site (where dumped sediments would remain in situ). General coastal processes are described (from other reports). It was concluded that at sediment spoil had caused a change in grain size and composition at the Aramoana dump site (more mud) which in turn reduced the variety of species which inhabited the site.

**Scott GL; Landis CA (1975):** Ecology of Aramoana: Geological development of Aramoana. Report to Dunedin Metropolitan Regional Planning Authority. Geology Department, Otago University. 23p.

This project describes the geological development of the Aramoana area. It is based on the findings of three months field investigations (surficial and bore hole sediment sampling/analysis, biological analysis) and previous reports. The report is in three main sections. The first examines local lithology and stratigraphy (beach, dunes, tidal flats, sediments); the second section looks at geomorphic and geological processes (wind, waves, swells, sediment supply, sea level changes, biological controls on sedimentation rates), and the third part describes the evolution of the spit (pre-historical development, historical development, present day situation). Four geomorphologically active zones were identified. These included the beach, dunes, inter-tidal flats (including the salt marsh), and harbour channel. Also identified were three inactive (i.e. fossil) environments. These consisted of fossil tidal flats, beach (or tidal current) ridges, and fossil dunes. The harbour was described as an estuarine lagoon as the offshore influence of sedimentation was dominant and the sediment contribution from the Leith and other sources was minimal. It was found that the Aramoana area is underlain by uniform, well sorted, fine sands up to 30 m thick. Most of this sand arrived more than 5000 yrs BP via a three stage process – a) Transported to the sea by the Clutha and other rivers; b) Marine processes transported the bulk northwards during a period of lower sea level and c) As sea level rose, sediment was transported westward (landward) across the continental shelf. Since then, wind, waves, tidal currents and biogenic activity have redistributed the sediment in the Aramoana coastal and nearshore zones. It was concluded that the Aramoana area has been dynamically changing for at least 10 000 yrs and this is expected to continue in the future, as indicated by very active erosional and depositional processes that were occurring at the time of writing.

*Figures and Tables:* Map: Several of area, showing general location; basic bathymetry/shelf limits; historical maps of Harbour (1826, 1845, 1850, 1879, 1880); current flow directions; sediment grain size distribution. Sketch diagrams of a representative beach cross section; wave refraction; wind rose; Sea level curve. Two aerial photos (dates?). Table: Correlation of Aramoana and Thames Estuary ridges.

**Single MB; Stephenson WJ (1998):** South Spit Beach assessment of erosion mitigation. Report for Port Otago Ltd. Land and Water Studies International Ltd. 10p.

This report addresses the effects of maintenance or modifications to the Long Mac training wall on the south side of Spit Beach, and recent erosion of the beach and sand dunes between the Mole and Long Mac Training Wall. Spit Beach is described as having a $110^{o}$ bearing and $0.4^{o}$ slope; 500 m wide (above MSL); backed by single dune line 15-20 m wide; sheltered form northerly waves by the moles and from southerly waves by Taiaroa Head. From previous authors, the historical development and modifications of the beach are described (since construction of the Mole), and contemporary changes based on ground/air photos and cross section surveys (23 ORC profiles) are described: Highly dynamic environment (fluctuates between erosion and accretion) influenced by sediment supply. There had been 5 significant erosion episodes in the previous 23 yrs. Coastal processes (waves and tidal currents, wind-borne sediment transport, sand sediment budgets) are briefly described, based largely on Nicholson (1979) and Goldsmith (1995). Issues and options for coastal erosion management are then described. It was concluded that erosion was ongoing, episodic and mainly caused by storm waves and thus, Long Mac wall was not directly responsible for erosion. Dune vegetation removal may have also increased erosion due to blowouts. Erosion is important issue for Port Otago Ltd, as removed beach/dune sand ends up in shipping channel. Was suggested that erosion would be reduced if clean sand from dredge spoil continued to be dumped in the nearshore zone and construction of sand dune fences and dune planting was undertaken. Although maintenance of Long Mac wall would not stop erosion of Spit Beach, it would prevent sediment re-entering the shipping channel.

A combination of several erosion management methods by the ORC, Port Otago Ltd and local residents was considered the best long term solution.

*Figures and Tables:* None.

**Single MB; Kirk RM (1994):** Impact of dredge spoil discharge at the entrance to Otago Harbour – sand transport processes. Report for Port Otago Ltd. Land and Water Studies International Ltd. 35p.

The impacts of dredge spoil dumping are covered in this report as part of Port Otago's dredge consent monitoring programme. Consent allowed dredge dumping at Heyward Point, Aramoana Spit (200 000 $m^3.y^{-1}$ for each beach), and Shelly (a.k.a. South Spit Beach; 50 000 $m^3.y^{-1}$). The physical environment and coastal processes are described, based on previous investigations (especially Elliot 1958; Hodgson 1966; Kirk 1980). Sediment characteristics and analysis (Folk's statistical parameters and rollability) for 42 samples near the dredge disposal sites (Aramoana, Spit and Pilot beaches) are then described and compared to Kirk (1980) results. Also discussed are the tidal inlet hydrology, sediment transport patterns and local beach assessments. Analysis of soundings charts was undertaken to establish sediment volumes of the ebb tide delta between the Mole and the Tiphead. It was found that: (1) Sediment textures of the dredge spoil was basically indistinguishable from the native sediments of the inner shelf, near-by beaches and the samples analysed by Kirk (1980): There was a narrow range of size and sorting values (fine to medium sands; 0.19 to 0.4 mm). The channel deposits were slightly coarser as higher velocity current in the throat area winnowed out finer sediments; (2) Rollability analysis identified five major sink areas (sediment receiving sites) and the major lag areas. Strong receiving areas included the northern and southern margins of the ebb tide delta – these represent transport along the inner shelf and onshore from deeper water. Tidal flats of the lower, inner harbour receive sediment transported into the harbour through the channel; channel itself appears a strong lag (source) deposit but probably acts more like a conduit for transportable sediments. In general, dredge spoil moves northwards; Heywards site spoil moves onto Blueskin Bay beaches; Aramoana spoil sediment separated – some moves onto Aramoana Beach, some remains (~ 31 250 $m^3.y^{-1}$) and forms a nearshore mound. At South Spit, spoil sediment moves onto beaches and has negated erosion by building up beaches at the Mole, the Long Mac and beach; (3) The harbour area is too large for the throat (out of equilibrium) thus harbour, channel and tidal flat sedimentation occurs through a combination of tidal and bar by-passing; (4) Dredge spoil impacts at Aramoana Beach negligible, but much more significant at South Spit Beach where beach renourishment from the spoil has been effective – deepening and erosion from the nearshore has been reversed. It was concluded that the dredge spoil was having no adverse effects on the beaches – it was not re-entering the channel and continued to move predominantly northward along the inner shelf and nearshore, contributing to sedimentation on beaches north of the harbour. At Aramoana and South Spit Beach, dredge spoil mitigated against erosion without adversely affecting the natural character of the beaches.

*Figures and Tables:* Location map (site, dredge dumping grounds and sediment sampling sites; major shelf sediment facies (Andrews 1973); rollability values (Kirk 1980 and this study); NZ inlet area/tidal prism relationship and tidal prism/alongshore transport/inlet stability relationship. Tables: Dredge volumes (1975-1993); sediment analysis descriptions and statistics (Kirk 1980 and this study); inlet stability calculations (Harington Point).

**Smith AM; Croot PL (1994):** The role of the shipping channel in flushing Otago Harbour. Report to Otago Regional Council. Marine Science Department, Otago University. 31p.

The Upper Otago Harbour is vulnerable to pollution events and spills and as such, this lead to a study of tidal flushing patterns in the Upper Otago Harbour with particular attention being paid to the role the shipping channel plays in this (i.e. dispersal, dilution and removal of potential pollutants). The study was undertaken as part of the Otago Harbour Investigation Programme and was confined to the area SW of Ravensbourne and The Cove – the most vulnerable area.

Rhodamine dye was released from boat in the middle of the main shipping channel at the mouth of the Leith and the dye dispersal patterns (time and distance) was surveyed to within ± 1.0 m. It was found that the main shipping channel is capable of moving and diluting sea water and associated material very rapidly, with most movement appearing to be the result of strong tidal currents in the narrow channel. Wind and waves were not important in the initial spread of the tracer dye but may be in dilution and dissipation. Vertical mixing is rapid and complete in the shallow area. There was rapid and significant flood flow through the main channel but the ebb flow moved more slowly though the main channel and smaller eastern channel. The main channel was flushed rapidly (1-2 days) by tidal currents and wind induced motion. Dye dilution rates indicated that at least 15 x $10^6$ $m^3$ of water was available to dilute the dye – the Upper Harbour is therefore well mixed and constantly invaded by new, clean sea water. In the event of a pollution spill, flushing of the shipping channel could be confounding – the rapid flood tide could hamper attempts to contain contaminants and force them further up the harbour towards Dunedin, whilst the ebb tide could flush the pollutants seaward through the main channel and shallow eastern channel.

Figures and Tables: Numerous time series aerial photographs of tracer dye dispersal in Otago Harbour; schematic diagrams of dye circulation. Tables include tide and weather conditions at dye release; flourometric results

**Stevenson M (1998):** An investigation into sediment of the upper harbour basin and Andersons Bay inlet. Otago Regional Council. 137p.

This report examined the nature and extent of sediment build up in Andersons Bay inlet and upper harbour basin in the Portsmouth Drive area. The report aims were to quantify the nature of the sediments in the area and to identify causes of sediment contamination, to quantify the extent and rate of sedimentation in the area and to identify reasons for changes and options for reversing undesirable trends, and to make recommendations for remedial actions. Andersons Bay inlet and the upper harbour sea floor are sediments consist of fine particulate matter creating the muddy characteristics of the area. The main source of this material is land runoff via storm water and drains, especially after high rainfall. Mean sediment size decreases from west to east supporting an anti-clockwise tidal circulation: the fastest tidal velocities flow up Victoria Channel and decrease as the water circulates from west to east, leading to progressive deposition of fine suspended sediments. Bed level trends in the Upper Basin were described as: 1909 to 1985 – generally lowering from dredging for reclamation work; 1985 to 1997 – average build up of 40 mm but this was within the survey error margin, so non decisive. Any build up since 1985 may be due to response of dredging for reclamation of the southern endowment and increased runoff from the highly urbanised/industrialised catchment. As the build up was having no adverse physical or recreational effects, dredging was not considered as justified at that stage. At Andersons Bay, 20 000 $m^3$ of sediment was deposited between 1978 and 1997 (1052 $m^3.y^{-1}$) and building up at 8 $mm.y^{-1}$ though this was not uniform across the inlet - most had occurred in the eastern corner of the inlet. Wave energy in the inlet was reduced by shelter from surrounding hills (less wind) and man made structures. Sediment most likely settles out at low tide when the bay is almost stagnant. The sediment build up in Andersons Bay was reducing aesthetic and recreational values and dredging was recommended at the eastern corner of the inlet where build up was worst. In general sediment contamination was not a problem, although heavy mineral concentrations were above recommended values at the storm water discharge at Portobello.

Figures and Tables: Location maps of harbour and sediment/water sampling sites; distribution of heavy minerals; tidal circulation in the harbour. Cross section surveys of Andersons Bay and Upper Harbour. Ground photos of various locations in the study area. Tables present data on sediment aggradtaion and degradation; sediment and water quality site names; water quality (nutrients) and heavy mineral data.

**Watson S (1992):** Coastal zone management in Otago Harbour, New Zealand: Use of a Geographic Information System for a survey appraisal of the Portobello area. MSc Thesis (subject?), Otago University. 94p plus appendices.

A GIS analysis of biotic and physical features in the Portobello – Halfway Islands area was undertaken to develop a coastal marine area management plan, focusing on ecosystems although some physical information is presented. Pre-management background information was gathered on special marine, terrestrial and historical features in the area, as well as human activities, jurisdiction, potential threats and impacts. Intertidal and sub tidal surveys were gathered to establish physical parameters and ecosystems. Maps, charts and air photos were digitised and stored on the GIS (MapInfo) and data from the field surveys were also transferred to the programme which were then spatially referenced to allow direct comparisons of change, distribution etc to be made. Five shoreline types were identified – Cobble shores and sandy bottom sediments were the most common coastal forms identified. The GIS programme was found to be very useful for information storage and presentation as the data could be expanded and updated easily and quickly, and direct overlays or comparisons of biological and physical features could be made.

Figures and Tables: Location map. Wind rose. Colour photos of shore types, harbour bottom, various species. Many contour maps of species distribution density. Many tables of biota data

**Wilson G (1989):** A two dimensional numerical model of Otago Harbour. ME thesis (Civil Engineering, Canterbury University). 176p

A two dimensional numerical model for the entire Otago Harbour (from the entrance to Dunedin) was developed to assess the effects of the tidal regime brought about by port developments and future climatic changes (i.e. sea level rise). The model was based on a hydrodynamic system developed the Rand Corporation (USA), using detailed bathymetric data and set up on a 150m$^2$ grid system. A 21 hr computer simulation of tidal motion was then run. The model was calibrated and verified with intensive field data (continuous current and tidal elevation metering; channel gauging; bathymetric surveying; drogue tracking; meteorological data). Calibration and verification produced excellent agreement between observed and computed values: Standard deviations ranged from 18-30 mm for water levels and 6-22 cm.s$^{-1}$ for depth averaged velocities, and tidal prism agreement was within 5%. Main findings were: (1) Sensitivity analysis showed that depth and frictional resistance (Manning’s n) have the greatest influence in tidal propagation in Otago Harbour; (2) MSL at Dunedin decreased 40mm since 1888 due solely to channel deepening. If channel deepening removed, true historic MSL rise would probably be about 1.4 mm.y$^{-1}$ (1.0 mm.y$^{-1}$ was the previously accepted increase); (3) Sea level rise will allow deeper draft ships to enter the harbour, and will allow for easier piloting. However, increased sea level will cause stormwater discharge problems at Dunedin, especially at high tide; (4) Enlarging the Halfway Islands (Goat and Quarantine Islands) restriction by 20% would have little effect in the hydraulic behaviour of the harbour – local velocities would decrease (assisting pilots) but reduced velocities may alter complex sedimentation patterns in the area; (5) Deepening Victoria Channel by ≥9.7 m has several advantages – it reduces tidal elevations slightly (20mm at Dunedin), increases tidal prism by ~1% which increases velocities in lower harbour by 2%. This would assist in maintaining channel depth. Alternative suggestion is 0.45 km$^2$ be reclaimed to maintain present tidal prism - dredge spoil can be used for this (reduces transportation cost) – seems unlikely this would affect Victoria Channel; (6) Preliminary investigation of currents at Spit Beach Dump Ground showed residual velocity towards harbour entrance. However, tidal velocities are inadequate to promote any significant sediment transport, but wave action will initiate sediment movement and tidal currents will transport suspended sediment.

Figures, Tables and Appendices: Several maps of Otago Harbour showing location of investigation area, current recording meters and tidal gauges, Braystoking stations, current roses, ebb and flood tide drogue plots, model grid pattern. Schematic diagrams of two dimensional model principles, wind rose (Taiaroa Head). Photos of the equipment used. Many tables and graphs showing data and plots of recorded and modeled tides and currents, water levels and velocities at harbour entrance, Port Chalmers and Dunedin, comparisons of 1888-1988 tide levels. Appendices provide data tables on model calibration and verification for changes in sea level rise, Victoria Channel depths, enlarged tidal cross section at Goat/Quarantine Island, bathymetry, tidal prism conditions, sensitivity analysis.

**Wilson G; Sutherland AJ (1991):** Numerical Modelling of Otago Harbour. Coastal Engineering – Climate for Change. *10th Australasian Conference on Coastal and Ocean Engineering,* Auckland. 2-6 December 1991: 481-486.

This conference paper summarises Wilson's (1989) thesis (see above).

*Figures:* Otago Harbour and tide gauges location map. Graphs comparing modeled data and field data (stage, direction and velocity); 1888 and 1988 sea levels at Dunedin.

## Coastal hazards

**Berryman KR (2005):** Review of tsunami hazard and risk in New Zealand. Report for Ministry of Civil Defence and Emergency Management. Institute of Geological and Nuclear Sciences. 139p.

This report presents the first national scale probabilistic tsunami risk assessment undertaken in New Zealand: The report was based on existing data and information and used a GIS approach. Empirical data were embedded in the GIS for tsunami wave and loss (life, property, $value) modeling purposes. It identified and combined a variety of physical parameters and models in an attempt to estimate/calculate the tsunami hazard and risk for each region and for major individual urban areas. The report focuses on the human/social side of tsunami hazards although physical information is given (NZ local tectonic setting and position in the Pacific, causes of tsunami generation on local, national and international scales etc). For Dunedin, the greatest hazard and risk came from large earthquakes generated on the west coast of South America. Tsunami wave heights from local, distant and combined sources respectively were given as: Dunedin 100 yr return = 0.6 m; 1.3 m; 1.3 m. East Otago Coast 100 yr return = 0.0 m to 2.0 m for local, distant and combined sources. Dunedin 500 yrs return = 1.2 m; 2.5 m; 2.5 m. East Otago Coast 500 yr return = 0.0 m to 2.0 m; 2.0 m to 4.0 m; 2.0 m to 4.0 m. Local coastal landslides and earthquake were considered low tsunami generation risk to Dunedin and the East Otago Coast, although coastal landslides at Highcliff, Lawyers Head, St Clair and Tunnel Beach could cause waves at coastal suburbs.

*Figures, Tables and Appendices*: Maps, plans and cross section diagrams of the New Zealand's tectonic setting (local ocean floor, subduction zones around the Pacific and local examples, continental shelf etc). Maps of various tsunami scenarios and wave height return periods (100 yr; 500 yr; 2500 yr) for New Zealand coast and urban areas. Graphs and tables on wave height and predicted losses of life and property. Appendices contain descriptive tables on historical tsunamis and paleo-tsunami deposits in NZ; probabilistic model methodology; bollide frequency and magnitude; earthquake source data and references; modeling tsunami propagation; limitations of the risk assessment.

**Otago Regional Council (1991):** East Otago coastal hazard mapping: Discussion document. Otago Regional Council, Dunedin. 42p plus maps.

Report describes basic coastal processes and hazards in the Otago Region, and the basic concepts of coastal hazard mapping. East Otago coast is divided into 13 areas, extending from the Taieri River in the south to the Pleasant River in the north. Of relevance to the current report are the areas defined as Taiaroa Head to Heyward Point (6km, excluding the Mole): Otago

Harbour (66km): Heyward Point to Mapoutahi Peninsula (11km): Mapoutahi Peninsula to Warrington (4km): Warrington to Puketaraki (9km): Puketaraki to Cornish Head (10km): Cornish Head to Pleasant River Mouth (6.5km). For each of these areas rates/trends of coastal erosion/accretion are noted (based mainly on Gibb 1978 and Kirk 1979), threatened assets are identified and the potential effects of sea level rise briefly discussed. Beach cross section profiles were established in February 1990 at Spit Beach (2 profiles); South Spit Beach ("a series of profiles have been surveyed from June 1987…"); Long Beach (2 profiles); Warrington Beach (2 profiles); Puketaraki Beach (2 profiles); Waikouaiti Beach (2 profiles).

*Figures:* General location of east Otago coast; 2 basic small scale, descriptive hazard maps (one for north of the harbour entrance, one for south of the entrance). Numerous ground and aerial photographs of the beach/coastal environment.

**Otago Regional Council (1997):** Floodplain management report, Dunedin City: Long Beach flooding and drainage issues. 24p.

This report deals with flooding issues at Long Beach settlement (causes and remedial options), and although it focuses on terrestrial processes, brief mention is given to marine and beach process that lead to flooding. It was noted from previous reports that under northerly wind conditions, southerly drifting beach sand would block the mouth of Drivers Creek, leading to significant backwater flooding issues in the settlement and surrounding areas. The creek mouth had to be artificially breached on numerous occasions to alleviate the backwater flooding. It was also noted that if a spring tide coincided with a northerly wind, it was known for the sea to enter the low lying farm land upstream from the settlement if the storage area was not full of freshwater.

*Figures:* Location map of Drivers Creek and Long Beach catchment. Surveys and long sections of various drainage areas (Figures are in Appendix 1).

**Tomlin JL (2002):** Wetland response to sea level rise: Response of the Merton Arm, Karitane Estuary to sea level rise. B.Appl. Sci. thesis, Otago University. 69p.

This is one of the few investigations to consider the effects of sea level rise (SLR) on the East Otago coast in detail. The thesis aimed to model the effects of SLR on the saltmarsh at Merton Arm, Karitane Estuary, and to establish the ability of the salt marsh to migrate inland as a result of the sea level rise. The study used the mid-range SLR predictions of IPCC (2001) which were 0.31 m and 0.49 m by 2100 AD. The estuary was surveyed with a total station then the data were entered in to Surfer 8 software where a series of different inundation scenarios were generated. It was found that under normal tidal conditions combined with a 0.49 m SLR the majority of the salt marsh would be inundated and around 78% of the marsh would be lost. The marsh has little chance to migrate landward to survive, as it would encroach on to good quality agricultural land, which most likely would not be allowed to happen. It was concluded that unless the wetland was properly managed and conserved, it would be replaced by either estuarine intertidal flats or pastoral farmland, depending on what course of action is taken by the current and subsequent landowners.

*Figures and Tables:* Figures: Conceptual development models. Location maps of Karitane Estuary and survey points used; vegetation and swamp areas (historical and contemporary); topographic maps; contour maps of various SLR scenarios combined with spring tide events. Aerial and ground photos highlighting various features. Tables: Various SLR scenarios; Dunedin climate data; Dunedin tidal gauge data; projected sea levels with projected areas of inundation.

**Tonkin and Taylor Ltd (1997):** Otago Region tsunami and storm surge study: Final report. Report for Otago Regional Council. 47p plus appendices.

This scoping report assessed historical and potential tsunami and storm surge hazards along the Otago Coast between the Clutha River and Oamaru. The main aim of the report was to develop credible maximum scenarios for tsunami and storm surge and describe what effects these may have on the Otago Coast. The report outlines the methodology used to review the historical information, develop the scenarios, and map the potential impacts. Tsunamis are assessed by outlining their general properties, reviewing the historical records for Otago (newspaper/historical reports; tidal data from Bluff to Timaru; meteorological records, local geology reports), then presenting maximum credible scenarios for both far-field and near-field tsunamis. Storm surges are examined in a similar manner. The results of the potential impact mapping for the maximum credible scenarios are then presented. The limitations of the study are discussed and conclusions drawn, leading to the identification of further research to better define tsunami and storm surge hazards. The main findings were: (1) Max tsunami scenario = 3.9 m above MSL on southerly oriented open coasts; 2.8 m above MSL on northerly open coasts and 1.7 m above MSL at Dunedin; (2) Tsunami return period of this magnitude best guessed at 350 yrs; combined with high tide = 4000 yrs; (3) Extreme risk inundation areas = Taieri Estuary, Tikoraki Point, Port Chalmers to Aramoana Rd (all below 3 m above MSL); High risk areas were south facing coasts with ground elevations < 4 m above MSL and north facing coasts, estuaries and harbour areas with elevations < 3 m above MSL; (4) Maximum storm surge scenario was 0.7 m - 0.9 m above tidal level (~double that recorded in Dunedin). Scenario maximum surge combined with High Spring Tide gave a maximum still water elevation of 1.7 m above MSL, leading to wave run-up height of 6-8 m above scenario still water level on steep beaches and 2-3 m for flat beaches; (5) No sites at extreme inundation risk; High inundation risk sites were Kakanui, Karitane Estuary, Parakanui Inlet (all have ground elevations < 2m above MSL); High run-up risk sites were Dunedin, Port Chalmers, Spit Tip (Aramoana), Moeraki, Oamaru, Tikoraki Point.

_Figures, Tables and Appendices:_ Location map. Graphs of May 1960 tsunami water levels in Otago Harbour; May 1960 tsunami water levels at Oamaru, Dunedin, Bluff; predicted high tide elevations at Port Otago between February and July 1960. Numerous data tables showing tsunami magnitudes; water levels and wave heights; components of storm surge; comparisons of calculated and recorded storm surge; predicted max scenario storm surge; areas at risk from tsunami and storm surge direct inundation and wave run-up overtopping. Appendices include chronological listings of the affects of past tsunami and storm surge events; a report and map of the offshore Quaternary faults; the calculations used to determine areas of potential impact from the tsunami and storm surge scenarios.

**Tonkin and Taylor Ltd (1999):** Otago Regional Council – Otago Harbour storm surge study, Stage 1: Estimation of extreme water levels. Report for Otago Regional Council. 60p.

This report follows on from Tonkin and Taylor (1997), providing more specific details about storm surge and extreme water levels in Otago Harbour. Historical tide, water levels and meteorological records (air pressure (Inverted Barometric effect – IB), wind velocities, directions, durations) were used as the basis for modelling extreme water levels at Taiaroa Head, Port Chalmers and Dunedin Port. This methodology was used to address the limitations identified in the 1997 report (e.g. The water levels used in the storm surge scenario were calculated from wind stress and barometric lift components for open coast locations, not in the harbour; no account was made of wind direction, wave refraction in harbour and a uniform nearshore slope was used). Analyses were made of the frequency of storm surge heights, comparisons of actual surge to calculated surge, and return periods and harbour effects. The data were discussed for each individual site then compared between the three sites. Main findings were: (1) Peak surge heights identified for Taiaroa Head, Port Chalmers and Dunedin were 0.56 m, 0.5 m and 0.65 m respectively; (2) Peak water levels above MSL for the same sites were 1.37 m, 1.61 m and 1.84 m respectively; (3) Damaging southerly storms with large wave heights are not good indicators of storm surge in the harbour basin; Surge can occur from a range of conditions. NE gales blowing down the harbour are a significant secondary source of surge. IB effect most influential individual component of surge but not all extremely low air pressure systems produced surge in the harbour. General trend was that surge height at Port Chalmers and Dunedin were 35% and 15% respectively lower than at Taiaroa Head. However, there was a poor correlation between the sites and surge height could not be accurately extrapolated from one site to another. Also a poor correlation exists between recorded and calculated surge.

*Figures and Tables:* Location map. Numerous graphs showing: surge/IB effect relationship; calculated and actual surge levels at 3 sites; recorded surge dates and heights; comparisons of surge levels between 3 sites. Numerous data tables including: Wind speed/direction/return period; extreme surge and water levels at the 3 sites; comparisons of actual and calculated surge and water levels; prediction equations and surge levels for extreme return periods; surge/extreme tide return periods. Appendices also contain numerous similar, data tables.

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