OCEAN BEACH RESTORATION PROJECT: ANNOTATED BIBLIOGRAPHY OF COASTAL PROCESSES AND SHORELINE CHANGES

REPORT FOR
Dunedin City Council

DATE
June 2009

CLIENT REFERENCE
122.DCC.1153.Ocean Beach

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Dunedin City Council

CONTENTS

1. Introduction

This report is the first of the investigations stage of the Dunedin City Council Ocean Beach Restoration Project. The aim of the report is to present a summary of the "state of the knowledge" on the coastal processes and shoreline change within the Ocean Beach embayment. The purpose of the report is to ensure that information gaps required for our understanding of the coastal processes are addressed while at the same time avoiding unnecessary duplication of research effort and data collection is avoided.

In order to achieve its aim, the report presents brief summaries of previous reports, studies, consent applications and documents that include information on the coastal processes shoreline change, and developments or management practices within this coastal area that have influenced or have the potential to influence these processes. The inclusion of any key data on coastal processes or shoreline change within the individual documents is identified within the summary for that document. This annotated bibliography is presented in the chronological order that the reports and documents were produced. For each of the key process areas of waves, currents, sediments, and shoreline change; the information in the individual documents is then collated to present a summary of the information and data available for that process.

An alphabetical listing of all references is provided at the rear of the report, along with the page number where the summary of the reference can be found in section 2. The appendices include the reproductions of figures and tables containing key coastal process information from the referenced reports.

2.0 Annotated Bibliography Presented in Chronological Order

Thomson P. 1870: On the sand hills, or dunes, in the neighbourhood of Dunedin. Trans. N.Z. Inst. 3: 263-269.

Describes beaches around Dunedin except Ocean Beach (as it was already well known). However, notes that the source of sand on Ocean Beach was from Clutha & Taieri Rivers, and from erosion of soft sandstone cliffs between Green Island and Forbury. Also noted that there is one point at Ocean Beach where "*the* [sand] *hills are neither wide nor high, and that an extra high tide accompanied by heavy seas was able to work a channel through to the St. Kilda flats inside* [the sand hills]."

Elliott E.L. 1958: Sandpits of the Otago coast. <u>NZ Geographer</u> 14:65-71

Discusses the effect of local wind on ocean swell along the Otago coast. Suggests that wave height is increased by the common strong southwest winds, which are an onshore wind to the predominant south and SW swells, and that more frequent north-east winds are generally offshore winds that decrease swell heights and periods.

Data presented:

1) Wind direction and strength frequencies at Taiaroa Head and Waikouaiti 1937-1945. Source NZ Met Service.

McDonald K.C. 1965: A century of civic enterprise. Dunedin City Corporation. 434 pps.

Includes extracts describing history of issues with the St. Clair and St. Kilda coast. Among these are accounts of: the sand extraction from Tahuna back dunes 1880-1883; construction of the St. Clair seawall in 1884, being destroyed 1886, re-built in 1888, destroyed again in 1889, and rebuilt again in 1913; the sea breaching the dunes and causing flooding in March 1883, June 1891, May & July 1898; the use of brushwood barriers in 1891; dune planting with marram grass & lupins since around 1901; beaches & sandhills building up in the period 1901 to at least 1911; and groynes being constructed at some time prior to 1911.

It is of interest to note that at least one report from the 1890's declared that "*a complete survey of sand movements and ocean currents was essential*" for the determining the best type of protection for the St. Clair esplanade.

Data presented:

1) Storm occurrence information (1880's & 1890's)
2) Shoreline movements (1883-1911)
3) Coastal Development information (1884 - 1913)

Hodgson W.A. 1966: Coastal processes around the Otago Peninsula. NZ Jl of Geology & Geophysics 9: 76-90

Used observations of wave conditions at Taiaroa Head, Cape Saunders, St. Clair and St. Kilda during the year from December 1963 to December 1964 to assess the influence of sea and swell waves on developing the beaches and spits in the area.

From Cape Saunders observations found that swell direction was predominately from south (57%) and SE (26%). 81% of swell periods were between 6 and 12 seconds, with highest average period at St. Clair & St. Kilda (12 sec), and lowest at Taiaroa Head (8.5 sec). Observed breaker heights were in the range 3-11 ft (0.9-3.4 m), giving calculated deep water wave heights in the range 1.5-ft (0.5-2.9m). Average wave height was found to increase from 3ft (0.9m) to 4ft (1.2 m) between summer and winter, but is unclear whether this is deepwater or breaker height.

Presents wave refraction diagrams for the Otago Peninsula area for southerly swell at 10 & 15 second periods, which show a good fit of inshore approach direction with general shoreline orientation. Uses results of this refraction to suggest that predominant wave period is between 10 and 15 degrees. Also suggests that south west gales decrease wave period (opposition to Elliott 1958), which may influence the nearshore approach direction such that the effects of refraction are reduced, resulting in increased northerly sand transport by beach drift. As a result of the nearly complete refraction, considered that it is unlikely that ocean swell could cause extensive beach drift around the Otago Peninsula, but does not provide an alternative explanation for the source of sand entering the Otago harbour. Notes that the influence of north-east sea conditions north of the harbour entrance dominants over the refracted southerly swell, resulting southward beach drift along this section of the coast.

Data presented:

1) Distribution of wave period at Taiaroa Head and wave direction at Cape Saunders, December 1963 to December 1964. Summary statistics of wave climate over this year.
2) Wave refraction plots for the Otago Peninsula area for 10 & 15 second waves from southerly directions.
3) Mean grain size for St. Clair-St. Kilda beach given as 1.94 phi (0.26 mm), which is medium sand.

Andrews P.B. 1973: Late Quaternary continental shelf sediments off Otago Peninsula, New Zealand. NZ Jl of Geology & Geophysics 16(4): 793-830

Presents results of investigations into surface sediments and benthic assemblages of continental shelf east of Otago Peninsula based on 163 samples. Although the investigations area does not include the shelf off Ocean Beach, the findings are still relevant for the patterns of sediment distribution. Findings include that sand and pebble sediments derived predominantly from Otago Schists supplied to the continental shelf largely by the Clutha River and transported north by the combined action of the Southland Current and longshore drift by southerly waves. Four drowned shoreline positions were identified, with the most landward, a drowned spit at -21 to -27 m, being interpreted as being the shoreline formed by the temporary halt in sea level rise at 8-9000 yrs B.P.

Sediment mode size was used to determine the depositional history of sediments on the shelf. Pebble and medium sand size material found as a prominent and continuous band in the mid-shelf was considered to be deposited during the early to middle phase of the post glacial sea level rise, while the temporary halt in sea level rise at 8-9000 yrs B.P. and resulting aggradation of the lower reaches of the Clutha valley resulted in the only fine sands being supplied being supplied around this period and deposited at depths around -20 to -30 m. Andrews suggested that the presence of organic skeletal debris in these middle and outer shelf areas indicate that negligible Holocene sediment reaches these areas, and the sediments found there are largely relict from earlier and lower sea level situations.

Since sea level attained approximately its present position (*c*. 6000 yrs B.P.) only very fine sand and silt is considered to being supplied, which is accumulating over the inner shelf (e.g. less that 20 m depth) and is gradually being reworked northward. Wave action was considered to selectively removes mud from shallow depths to result in clean sand in inshore areas, with the gradation to muddy sands in deeper waters of the inner shelf indicating that winnowing by wave action is progressive less effective with depth.

Data presented:

1) Maps of spatial distribution of continental shelf sediments including textural class, mean and medium grain size, sorting and skewness.

Heath R.A. 1973: Direct measurements of coastal currents around southern New Zealand. <u>NZ Jl Marine & Freshwater Research</u> 7(4): 331-367

Presents results of direct measurement of subsurface currents by current drogues at 10 coastal positions, including off the Otago Peninsula, and geomagnetic electrokinetograph measurements (GEK) of surface currents between these positions. The mean velocity from the drogue at 50 m depth off the Otago Peninsula was 0.23 m/s, in a SW direction, however it was felt that this reversal from the normal NE flow was a result of strong NE winds (14m/s) at the time of the measurement.

The conclusions of the investigations was that the fastest mean currents on the continental shelf were where the shelf is the narrowest, and that the largest component to the flow is tidal currents.

Data presented:

1) Subsurface and surface current velocities off Otago Peninsula measured on one day in April 1971.

Carter L. & Heath R.A. 1975: Role of mean circulation, tides, and waves in the transport of bottom sediment on the New Zealand continental shelf. NZ Jl Marine & Freshwater Research 9(4): 423-448

This paper determines the relative contribution of mean circulation, tidal currents, and wave induced currents to sediment transport on the continental shelf. For the Otago shelf, the findings included that the Southland current, with a surface speed of only 7-8 cm/s (from Heath 1972, (see reference list for citation)), was incapable of transporting shelf sediment on its own, hence disputes the findings of Andrews, (1973) that this was the primarily driver of shelf sediment transport. By contrast tides were found to have sufficient speed to initiate transport, being up to 51 cm/s for north flowing flood tide off Otago. The paper concluded that sediment movement on the Otago shelf was therefore initiated by tides, and to a lesser extent by storm-driver components (e.g storm waves stirring the bottom), with the mean circulation (Southland Current) playing a minor role. Hence, only minor sediment transport occurred during non-storm conditions, movement on the inner and middle shelf during events up to annual storm magnitude, and transport over most shelf depths during 25 year return period storms. Once sediment movement was initiated, the direction of transport was considered to be probably controlled by the storm-driven components associated with south-westerly storms, hence transport northward towards the shore.

Data presented:

1) Mean circulation and tidal current velocities on the Otago shelf.

Bardsley W.E. 1977: Dispersal of some heavy minerals along the Otago-Eastern Southland coast. NZ Geographer 33(2): 76-79

Used the occurrence of natural heavy mineral sand tracers in 21 sediment samples collected from a number of beaches along the Otago-Southland coast to confirm that *"sand transport along the Otago coast is that of a north-eastward moving sand stream pressed against the coast to a greater or lesser extent by wave action*".

Data presented:

1) Variations in longshore occurrence of heavy mineral distributions from Porpoise Bay, East Southland, to the Pleasant River mouth, North Otago.

Nicholson D.C. 1979: Sand beaches in southern Blueskin Bay, Otago. Unpublished M.A. thesis (Geography), University of Canterbury, 185pps.

Although the study area for this thesis is north of the Otago Peninsula, wind and wave data is presented that is relevant to Ocean Beach. Wind roses of daily wind records from the Taiaroa Head lighthouse between 1957 and 1978 are presented, which show that the most frequently occurring winds are from the north to northeast (39%), and south to south-east directions (34%). The thesis notes that these results conflict with those presented by Elliot (1958) from the same source. The distribution of wind speed showed southerly winds tend to achieve higher velocities, however it is noted that the recorded speeds at this site are likely to be higher than on the beaches due to the increased elevation.

A wave directional wave rose for offshore wave data from ship reports (NZ met service data) for grid square 44 (lat 45-49.9ºS, long 170-179.9E) is presented, which show the dominant wave approach directions being from the southwest (23%), south (23%), and northeast (16%. The thesis notes distribution is different from the daily beach observations of Hodgson (1966).

Data presented:

1) Wind roses from Taiaroa Head Lighthouse 1957-1978.
2) Wave roses from ships observations in grid square 44 (NZ met service data)

Kirk, R.M. 1979: Physical stability of sandy beaches in the Dunedin Metropolitan Area. Unpublished report to Dunedin Metropolitan Regional Planning Authority by Morris and Wilson Consulting Engineers, Christchurch. 39pps

The report presents results of an investigation on the stability of sandy beaches near Dunedin, and was commissioned "*as a first step in developing a more adequate data base for comprehensive planning*". The principles of sand beach dynamics are set out extensively in the report as a background to the general process environment. Previous studies of the Otago coast were reviewed, and historical changes at Green Island, Ocean Beach, Tomahawk Beach and Smails Beach were determined from an analysis of an 1862 survey plan showing MHWM position and aerial photographs between 1942 & 1979. The nature and effects of a variety of management activities on the beaches are also discussed.

Kirk found that 1862 MHWM position was similar to 1942 photo position for all of the beaches between Green Island and Sandfly Bay, hence concluded that none of these beaches had suffered from persistent long-term retreat and loss of the foredune. He noted that marram grass planting had *"done much ... to ensure extensive development of high, broad foredunes on most of the beaches*". The aerial photograph analysis was noted to be limited by the variety of scales, discontinuous nature of the coverage, and distortions in the images, with the error band for measurements being given as ± 5 m for Ocean Beach. A sketch plan of the changes in the dune/beach boundary from air photos in 1942, 1958 and 1970 is presented, which shows little net change in position at St. Clair (due to seawall); 20-30 m seaward growth at Moana Rua, which was considered to be due to planting and sand conservation activities; and growth along John Wilson in the 1942-1958 period, which was attributed to dune planting and filling for the development of the roadway. Kirk concluded that majority of sand transfers were on and offshore at various time scales, and therefore the beaches were essentially equilibrium features that undergo periodic fluctuations in form and volume in response to the changing incidence of swells and storms.

From field inspections and interviews, Kirk notes the presence of foredune toe erosion as a result of storms in 1977 & 1978. At Moana Rua, where the development of playing fields had encroached into the foredune crest, the dune toe erosion had resulted in partial collapse of the foredune crest, resulting in sand blowouts onto the playing fields. At attempt to combat these problems by dumping earth fill on the dune crest is noted, along with a comment that this "*achieves nothing with respect to periodic scouring of the dune face and is a less satisfactory method of dune protection that planting with marram grass*". Kirk also observed that the erosion damage occurred at the northern end of Ocean Beach in the 1977 & 1978 storms, which was attempted to be offset by "*dumping large volumes of earth and industrial rubble from the roadway to form a steep, unstable slope of extremely dubious value as protection for the roadway".* Kirk considered that the northern end of the beach was more exposed to storm wave attack, and that erosion threatened the northern 400 m of roadway due to its alignment along the crest of the foredune and the extremely steep slopes as a result of earth fill. He suggested that effective management of this problem would require re-aligning the road to landward of the active zone of foredune erosion, and that the placement of gabions along the beach/dune boundary would be desirable to prevent further scour of the dune base.

In relation to protection of Ocean Beach, Kirk concluded that "low cost responses such as filling dumping provide coastal protection which is both ineffective and leads to further loss of amenity". He recommended that a buffer zone management approach be taken at Ocean Beach, adopting the principles of sand beach dynamics as set out in the report. In addition, it was recommended that an adequate survey network be established to record changes to the shore. The network should include air-photograph coverage and beach profile surveys.

Data presented:

1) Sketch plan of the changes in the dune/beach boundary at Ocean Beach determined from aerial photographs in 1942, 1958 and 1970. (Included as Appendix A).
2) Dune erosion in coastal storms 1977 &1978
3) Information on earth and rubble dumping post 1977 & 1978 storms at Moana Rua and northern end of John Wilson Drive.

Carter R.M., Carter L., Williams J.J., Landis C.A. 1985: Modern and releict sedimentation on the South Otago Continental Shelf, New Zealand. NZ Oceanographic Institute Memoir 93. 43pps.

Describes the characteristics, origins and transport of the sediments found on the South Otago Continental shelf (Nugget Point to Karitane) based on high resolution seismic and side-scan sonar profiles, sediment sampling, photographs, and previous information. The investigations revealed four major sediment facies, with the one of particular interest for Ocean Beach coastal processes being the modern terrigenous (e.g. formed mainly silicate minerals) facies of fine grey sand on the inner shelf primarily sourced from the Schist in the Clutha and Taieri catchments since sea level stabilised some 6,500 years BP. The sediment distribution mapping presented in the paper shows that this wedge of modern sand narrows dramatically as it approaches Otago Peninsula, to be a nearshore ribbon of only 2-3 km in the vicinity of Ocean Beach. The paper notes that the cause of this marked reduction cannot be pin pointed with certainty, but is thought to be a response to local hydraulic conditions and reflect the maximum extent of modern sand transport. The paper reports that unfortunately there is no seismic coverage of this nearshore sand wedge boarding the Otago Peninsula, so the thickest of the feature cannot be determined, however the available bathymetric data suggests that it is a simple seaward tapering feature, which, based on the land geology, rests on a gently seaward dipping surface of Cenozoic sandstones and mudstones.

Seaward of the modern sand wedge is a relict terrigenous gravel facies on the middle shelf primarily consisting of quartz pebbles and granules from the Clutha catchment. These relict gravel ridges (e.g. the Saunders Ridges, south of Cape Saunders) are found at around 55 m depth and were deposited during a period of sea level standstill around 12,000 years B.P.

Data presented:

1) Map of distribution and description of sediment types across the south Otago Shelf from Nugget Point to Karitane. (Included as Appendix B).

Carter L. & Carter R.M. 1986: Holocene evolution of the nearshore sand wedge, South Otago continental shelf, New Zealand. <u>NZ Jl of Geology & Geophysics 29: 413-424</u>

Describes the structure of the inner and middle shelf sand wedge between Nugget Point and Brighton from the results of 530 km of high resolution seismic profiles and the results of previous studies. This paper addresses the questions asked in Carter *et a*l (1985) regarding the cause of the marked reduction in wedge size at Brighton.

The paper concluded that the wedge appeared to have evolved in two main stages: 1) a lower wedge in the early Holocene formed against a shoreline associated with the -27 to -24 m standstill in sea level between 9600 and 8800 years B.P., and 2) an upper more recent wedge deposited over the lower wedge since sea level stabilised at its present position around 6500 years BP. Dispersal of sediment in both wedges was across and along the shelf by under the combined influence of waves, tides and southland current, which could transport fine sands on the middle shelf at depths up to -75 m. A wide wedge extends 60km north of the Clutha to Brighton, where further transport was considered to be inhibited by localised southwest currents formed by deflection of the regional northeast-ward flow against Otago Peninsula. By contrast, model sand being transported along the innermost shelf and littoral zone, has been relatively unimpeded, and now extends at least 190 km from the Clutha River, giving an average advance rate of 29km/1000 years.

Rates of deposition for each period of wedge evolution were estimated from volumes and length of time in sea level standstill. The results indicated that deposition rates were up to 5 times greater for the early wedge deposition (e.g. 3.5×10^6 m^3/yr compared to 0.7×10^6 m^3/yr). It was considered that the different could have been due to climatic changes resulting in the formation of the nature sediment trapping lakes of Hawera, Wanaka & Wakatipu, and the breaching of Foveaux Strait.

Data presented:

1) Structure of inner shelf sand wedge

Carter L. 1986: A budget for modern Holocene Sediment on the South Otago continental shelf. <u>NZ Jl Marine & Freshwater Research</u> 20: 665-676

This paper ties together the results of previous studies on sediment supply, shelf bathymetry and sediment transport to estimate a sediment budget of the modern sands on the South Otago shelf between Nugget Point and the Otago Peninsula over the last 6,500 yrs. Inputs of modern sand and gravel were estimated to in the order of 2.15 Mt/yr, dominated by the Clutha River (pre-dams) at 1.23 Mt/yr (Mt=million tonne), with lesser quantities from the Southland shelf, Tairei River, and biogenic production (shells). Based on seismic profiles presented in Carter & Carter (1986), it was estimated that about 50% of this bedload supply is stored within a large nearshore wedge in the protected waters of Molyneux Bay, and only 1.1 Mt/yr is transported in the narrow wedge along the coast of Dunedin and the Otago Peninsula. Only a relatively small amount was considered to be stored as beach or dune deposits, the remainder being transported north-eastwards to accumulate on the Peninsula Spit and in Blueskin Bay. Another 2.33 Mt/yr of mud is supplied to the shelf, however little is retained on the shelf, being swept into the submarine canyons on the edge of the shelf to the north-east of the Otago Peninsula.

From 6 profiles drawn from combined previous information, the size of the nearshore sand wedge from Brighton to Cape Saunders was estimated to be in the order of 3-4 m thick and 1-2 km wide, giving an estimated volume of 0.11×10^9 m^3 (0.2×10^9 Mt).

Carter also discussed the question of effect of the damming of the Clutha River on the nearshore sediment budget. He noted that the Roxburgh dam was estimated to trap 0.61 Mt/yr of bedload material, hence may reduce the supply to the shelf by up to 50%, which he considered could affect nearshore sediment transport and wedge growth. However, he noted that "*it is uncertain whether the shelf-coast sedimentary regime has had sufficient time to respond to any effects of the dams*".

Data presented:

1) Sediment budget of the inner south Otago continental shelf
2) Sediment transport and storage on the nearshore sand wedge at Dunedin

Kirk, R.M. 1991: Coastal management and control of shoreline erosion, Ocean Beach – St Clair, Dunedin. Unpublished report to Constantine Coutts, Consulting Planners, Dunedin, and to Dunedin City Council. 17pps

This report was concerned with the management of the Ocean Beach Domain area, and recognised that the beach and coastal dune system constituted the primary defence for a substantial part of the Dunedin urban area against the hazards of marine erosion and inundation. Based on the findings of Kirk (179) and observations since, Kirk concluded that the Ocean Beach sand system was "*either in long-term stability of has a mildly positive sediment budget*". The beach cuts back in times of storms, but recovers during quieter periods. Planning and management concepts appropriate to Ocean Beach are presented, and a "buffer zone' approach recommended to deal with the uncertainties of long-term changes in the coastal sediment supply (e.g. effect of Clutha dams) and the effects of climate change. The report noted that ORC had installed an excellent monitoring programme, and that it should be continued, especially with re-surveying of beach profiles as soon as possible after major storms.

Comments on site specific issues are presented, a summary of which includes:

- St. Clair: Recommends that no further seawall extensions be contemplated, and that the random tipped rocks used to control "end erosion" at the northern end of the sea wall such be removed and replaced by with a properly engineered transition to the foredune system, such as a reno mattress.
- Moana Rua: Noted that the dumping of soil and other undesirable materials has continued since his 1979 report. Emphasises the issues of this practice for coastal stability, noting that only area of Ocean Beach not currently in an accretional state was this area of dumping. Recommended that soil and rubbish should be removed altogether of if possible, or at least strongly battered to prevent slumping onto the beach.

- St. Kilda: Notes damage to dune vegetation from human use and the resulting issue of wind blown sand. Recommended planting and dune conservation fencing to control human use around the surf club.
- John Wilson Drive-Lawyers Head: Noted success of ORC initiated programme of foredune growth to seaward of the slumped soil dumped off the road, with the new foredune isolating the soil material from the beach. Recommended that this improvement be continued.

Data presented:

1) Infers that random rock dumping at the northern end of the St. Calir seawall, soil dumping at Moana Rua, and foredune development at Lawyers Head has occurred since 1979.

Dunedin City Council 1992 Ocean Beach Domain Management Plan. Recreation Planning Dept, Dunedin City Council. 48pps

This plan was produced in accordance with Section 41 of the Reserves Act 1977. It includes statements about the history of the reserve, the physical features, vegetation and soils, the present use, adjoining land-use and importance of the reserve for the area. Management objectives and policies are presented. Those relevant to coastal process, erosion, and protection include:

- To maintain the sand dunes in as natural state as is practical;
- To undertake planting programmes to encourage advancement of the sand dunes;
- To adopt coastal protection techniques which utilise natural process in favour of the introduction of structures;
- To remove all non-sand material from major dune formations;
- To prohibit placement or dumping of material other than sand in foredune areas; and
- To support and assist long-term monitoring of ORC including interpreting survey results following major storms with respect to the sustainability of the foredunes.

Dyer M. J. 1994: Beach profile change at St. Clair Beach, Dunedin. Unpublished MSc thesis (Geography), University of Canterbury. 229 pps

This thesis examined the nature of changes that occur within the beach profile at St Clair, and links changes with variations in the wave and wind environment. Wind data was collected at Tomahawk Beach for a six month period from December 1993 to June 1994 using a Lambrecht Anemometer. Monthly and seasonal wind roses are presented, which were compared to long term data from Taiaroa Head presented by

Eliott (1958) and Nicolson (1979). For the collected data set, northerlies winds dominated, followed by an even distribution of west, SW, WSW, SSW, south and SSE winds. The absence of NE winds was considered to be due to local topographic influences. Wave data was obtained from collating the daily NZ Met Service marine forecasts for the Chalmers sea area for the period December 1993 to August 1994, and from daily beach observations from the headland at the eastern end of Tomahawk Beach from December 1993 to June 1994. Monthly and seasonal wave roses from both sources are presented, which were compared to data from ships observations presented by Nicolson (1979). The results showed that SW was the dominant direction from the coastal forecasts (54.5%), with mean wave heights being 1.7 m in summer and 2.4 m in winter. Southerly swells generally had higher forecast heights than northerly swells. By comparison, southerly swell strongly dominated the beach observations (90%), showing the influence of wave refraction. Mean wave heights were 1.3 m in summer and 1.6 m in winter. Breaker type was observed to be strongly linked to direction, with southerly waves generally have spilling breakers, and northerly waves generally spill-plunge breakers. The observations also indicated that extended periods of SW wind were associated with increased wave height and shorter wave periods, hence more energetic waves. Conversely, northerly winds were associated with lower wave heights and longer periods, hence a flatter lower energy wave.

Three beach profiles at St. Clair and one at St. Kilda were surveyed repeatedly over the period January to June 1993 to determine the envelope of seasonal beach change and the role of wind and waves the profile changes. Profile changes and Excursion Distance Analysis (EDA) results are presented, and correlated with the sea conditions. Movements of the MSL contour of up to 50 m in front of the seawall were recorded with corresponding volume changes of up to 80 m^3/m. Changes at St. Kilda over the same period were of a lower magnitude. In relation to the drivers of change, Dyer's findings included:

- Erosion at St Clair occurs during extended periods of strong southwest winds associated with high, short period waves and enhanced longshore currents. Sand is transported offshore and alongshore to the east and results in a low beach profile.
- Erosion at St Clair is accentuated by the sea wall.
- Accretion of the St Clair beach is associated with east to west longshore currents associated with easterly quarter swell conditions. Deposition of sand was noted as being rapid.

Data presented:

1) Wind and wave observations at Tomahawk Beach for period December 1993 to June 1994.
2) Marine forecast swell summaries for period December 1993 to August 1994

3) Beach profile changes at St. Clair and St. Kilda over multiple surveys between January and June 1994.
4) Mean sediment grain size at St. Clair from samples collected in May 1994 given as 1.75 phi (0.30 mm), which is medium sand.

Townsend, B.J. 1997: Towards effective management of the Ocean Beach sand dunes, Dunedin. Unpublished Master of Science thesis (Geography), University of Otago. 112pps

This thesis examined management of Ocean Beach during the twentieth century, with the aim of developing appropriate management and monitoring strategies for the beach.

The history of dune development for the area was examined by analysis of historical photographs, aerial photographs and written records, with stretch plans showing beach width, dune vegetation cover, and hinterland developments being presented at for each decade thru the 20th century. For each decade, beach and dune sediment volumes were estimated from the photographs for seven sections of the beach length. From this analysis, Townsend concluded that sand volumes peaked in the 1920's, before urban and sports field developments in the 1940's saw a dramatic decrease in the sand volume, which took a long time to recover and only reached a new stable state in the 1970's. Spatial differences were found between the western and eastern parts of the beach, with the western section (e.g. west of Moana Rua), losing over 1 million m^3 since 1910, while the steady development of dunes to the east of Moana Rua saw this area accumulate in the order of 600,000 m^3 over the same period.

Further analysis involved examining for relationships between the patterns in the decadal sediment budgets and 1) the southern oscillations, and 2) vegetation cover. The results indicated: 1) that due to broad time scales of data on shoreline changes there was little evidence to support the feeling that eastward transport was enhanced in El Nino conditions, and that westward transport was enhanced in La Nina conditions, and 2) dune volume lose and gains in different areas of the beach mirrored changes dune vegetation cover.

Townsend interpreted seasonal changes in beach profiles from monthly profile surveys between July 1996 to January 1997 at 8 locations along Ocean Beach, daily observations of wave conditions, and daily wind data from Musselburgh. The results showed accumulation at St. Clair, and little change further west. Vegetation cover at each of the profiles is also reported. Townsend concluded that the Dunedin City Council stated management objectives for Ocean Beach had not been achieved. He attributed this to a lack of funds for coastal zone management.

Data presented:

1) Stretch plans showing beach width, dune vegetation cover, and hinterland developments for each decade thru the 20th century.
2) Summary of wave observations at Ocean Beach and wind records from Musselburgh for period June to December 1996.
3) Summary of beach profile changes from monthly profile surveys between July 1996 to January 1997 at 8 locations.

Tonkin and Taylor Ltd 1998: Dunedin City Council coastal dune conservation investigations: Ocean Beach Domain. Report to City Consultants. 5pps

This report presents recommendations on fencing and dune planting at the dune restoration area to the east of the St Clair, and on John Wilson Drive adjacent to Lawyers Head. For St. Clair, the report notes the narrow state of the dune with an erosion scarp extending 250-300m along from the seawall resulting in undermining of dune restoration fencing. It was recommended that for the restoration area, sand trap fencing should be used along the walkway edge, the dune height reduced to provide flatter slopes, and the dunes planted. Formed beach access should be provided from the walkway, and fences should be constructed to prevent destruction of the dune vegetation by uncontrolled access. For Lawyers Head, the existed situation of dumped asphalt, rubble, and soil material is described. Recommended actions included control of run-off from the road, remove undesirable fill material from dune slope, fencing of the carpark edge and access route.

Data presented:

1) Dune restoration area established at eastern end of St. Clair seawall prior to 1998.

Allen C.: 1999: Longshore drift at St. Clair Beach and implications for the eroding seawall. Unpublished Post Graduate Diploma Report (Marine Sciences), University of Otago. 61pps

This dissertation described a series of experiments to characteristic longshore drift at St. Clair using the placement of “pea-gravel” in the swash zone under four different swell regimes: southwest, south, southeast, and northeast. The experiments, carried out over 4 individual days in Sept-October 1999 with moderate to light swell conditions, showed that sand moved southwest along Ocean Beach during swells from the northeast and southeast, and eastward during swells from the south and southwest. This eastward movement was considered to be associated with erosion of sand from below the St. Clair seawall, whereas westward movement was associated with accretion below the wall.

Wave refraction modelling for 2 m southwest, south, and southeast offshore swell directions are also presented. For Southwest swell, refraction is nearly complete, arriving at shore as southerly waves, while southeast swell is refracted less to still be oblique to the shore orientation. There appears to be divergence of energy along Ocean Beach for all 3 approach directions, but particularly for southerly swell due to the influence of White Island, with associated convergence on the St. Clair headland and Lawyers Head.

Data presented:

1) Wave data from Hodgson 91966), Nicholson (1979), and Dyer (1994), and wind data from Dyer (1994)
2) Sediment transport patterns for different swell directions of S, SW, SE, & NE.
3) Wave refraction for 2 m swell from SW, S, & SE.

Tonkin & Taylor 2000: Clutha consent programme: Coastal erosion issues. Report for Contact Energy Ltd. 95pps

The aims of this report included to assess the influence of changes in the sediment input of the Clutha River to the coastal sediment budget on shoreline movements on the East Otago coast. Data on supply of sand and gravel from the Clutha River was larger derived from Hicks et al (2000) (reference given in alphabetical references), and on storage in the sand wedge from Carter (1986). Sediment budgets were estimated for 4 scenarios of supply from the Clutha River: 461,600 m^3/yr for 1000 years ago; 854,300 m^3/yr for pre-damming (increase due to influence of gold mining activities; 42,100 m^3/yr for the present dammed situation; and 29,400 m^3/yr for 100 years in the future. The relevant conclusions from the sediment budget analysis included: 1) that losses from the coastal and nearshore systems of East Otago are small in relation to the rate of supply, hence most of the sediment is held in storage, principally the nearshore wedge; 2) even with damming of the Clutha, the supply of material to the coastal sediment budget is still above losses, hence the reduction in supply is taken up with less storage rather than net erosion of onshore or nearshore storage areas.

The data on shoreline movements presented included for 3 sites at Ocean Beach: St. Clair, Middle Beach & St. Kilda; with shorelines positions being mapped from cadastral plans (1860 & 1883) and aerial photographs in 1958, 1982, and 1997. The results of the analysis for these sites are presented in Appendix C, which show no clear temporal or spatial trend of movement within Ocean Beach. The conclusions from all 14 sites in the analysis included that there is no clear temporal trend of movement to suggest that there has been any long-term reduction in the rate of onshore deposition that could be attributed to a reduced sediment supply as a result of damming the Clutha River, and that future erosion of the Otago coast will have more to do with the effects of sea level rise than sediment trapping in the Clutha River.

Data presented:

1) Sediment budget of the inner South Otago continental shelf
2) Shoreline movements at St. Clair, Middle Beach, and St. Kilda measured from cadastral plans and aerial photographs from 1860 to 1997. (Appendix C)

DTec Consulting Ltd 2000: Dunedin beaches site inspection and recommendations. Unpublished letter report to Dunedin City Council. 6pps

Reports on site inspections on St. Clair and Middle Beach following high seas and heavy rainfall events in September 2000. Notes previous recommended erosion mitigation measures in 1998 and 1999 for east of St. Clair seawall were not undertaken, and that future erosion and further erosion and exposure of rubble had occurred in the recent events. Recommends future mitigation works in this area including planting, fencing, and importing of approx 5000 m^3 of sand over a 100 m length. At Middle Beach it was recommended that the dis-used surf club building be removed

Data presented:

1) Storm occurrence resulting in erosion in April-May 1999, September 2000.
2) Sand pushed up from lower foreshore to dune toe in May 1999 at east end of St. Clair to replace removed rubble.

Single, M.B. 2001: Coastal stability at "Middle Beach", St Clair, Dunedin. Unpublished report to Dunedin City Council by Land and Water Studies International Ltd

This report is concerned with the coastal stability of "Middle Beach", and addresses the coastal environment adjacent to the carpark on Moana Rua Road and the old surf life-saving building present on the dunes. Coastal hazards of the area are assessed and existing and future management of the dunes is discussed. Planting and fences had helped to mitigate some hazards, but it was noted that further measures were required. These included removal of rubble from within the dunes, removal of the old building at Moana Rua, provide formal access to the beach and provide information on dune management for the public.

Duffill Watts & King Ltd: 2001 St. Clair Sea Wall Study. Report to Dunedin City Council. 25 pps + appendices.

Report summarises the issues at St. Clair beach, gives the condition of each of the protection structures in the area, and the future maintenance, repair, or replacement options.

The biggest single issue is given as "*the instability of the beach and its frequent depletion of sand which results in the loss of amenity values and erosion of adjacent* *dunes*". The report notes that "*a number of man-made factors have changed the beach and the equilibrium of sand*", and includes following conclusion from the history of change at St. Clair: "*While the esplanade wall was quite justified at the time, its angle to the waves and type of construction has contributed to sand depletion."* The report goes on to suggest that *"the alignment of the wall reflects waves to the extent that longshore drift is created from west to east..... This sand cannot be replaced by the reflected waves at anything like the rate of its removal and depletion occurs at the west end and gradually progresses eastward".* It is also noted that mining of the dunes has substantially changed the dune shape, that the present height to depth ratio is not natural and does not have the stability of the original dunes.

This report found that the St. Clair sea wall was in poor condition with a high risk of extensive failure. Options for replacement included a similar type to the existing structure, or an offshore artificial reef/wave rotator which would result in significant beach replenishment. Given the high risk of failure and time required for the necessary studies in the offshore option, the report recommends that a replacement wall be constructed as soon as possible that incorporates and strengthens the existing structure.

Issues and options are also presented for dealing with the transition area between the area wall and the dunes, which covers approximately a 200 m length.. This section of the report was prepared by DTec Consulting. Issues listed include stability, appearance, access, and lack of area for passive recreation. Options includes do nothing, extension of the existing gabion revetment, extension by either geotextile sand sausages or loose rock revetment, extension of the seawall, groynes, sand renourishment, sand transfer from lower foreshore and nearshore, and dune re-contouring with associated planting and fencing. No one preferred option is identified.

Appended to the main report is a is a secondary report by ASR Consultants assessing a variety of other long-term solutions to erosion control at St. Clair Beach, including dune management, beach nourishment, groynes, detached breakwaters, wave dissipation units, and offshore submerged reefs. This report concludes that the best long-term solution would be provided by submerged reefs and possibly beach renourishment, but points out that a data collection programme involving wave and current modelling, bathymetric survey and sediment sampling is required to verify this conclusion and for design of the works.

Data presented:

1) Seawall history

Cawthron Institute 2001: Oceanographic Investigations of a proposed outfall for the Tahuna Wastewater Treatment Plant: Dunedin. Report for Beca Steven. Cawthron Report No. 693. 11pps + appendices

Presents findings of measurements of ocean currents at proposed discharge locations, 900 m & 1600 m offshore from Tahuna, and dye dilution studies in vicinity of existing discharge at Lawyers Head. Data collection involved mooring a current meter at both offshore sites for a 60 day period during both summer (Feb-Apr 2001) and winter (Jul-Sept 2001). However, due to a software problem data from 16000 m offshore was not recorded during the summer deployment. Dye studies involved both qualitative visual tracking of the dye slug, and quantitative measurements of dye concentrations.

Results of the current meter deployments showed that there was a predominantly longshore tidally reversing flow (east on flood tide & west on ebb tide) in both summer and winter, with a stronger easterly compartment indicative of the Southland Current. Current velocities were found to generally exceed 50 cm/s during winter and 40cm/sec during summer. Stronger and more pronounced SW and NE vectors in winter were considered to result from storm events during this deployment period. Vector plots for each day are presented in Appendix 1 of the Cawthron report, and the cumulative vector plots for each deployment are presented in Appendix D of this bibliography.

Results of the dye dispersion studies showed that under large onshore swell conditions, effluent from Lawyer’s Head is predominantly directed onshore, while during calmer conditions the effluent plume spread predominantly offshore and horizontally with prevailing current. Aerial photographs of the dispersion patterns are presented in Appendix 2 of the Cawthron report.

Data presented:

1) Current meter results from proposed outfall locations 900 m and 1600 m offsite from Tahuna in summer and winter 2001 (Appendix D).

DTec Consulting Ltd 2002a: Dunedin City Council Coastal Dune Conservation Programmes. Report for the Parks Department of Dunedin City Council. 217pps

This report recommends the dune conservation works programmes to be carried out over an eight year period at the 14 coastal reserves in Dunedin City, including Ocean Beach Domain. The report provides information on shoreline stability and recreational use of the beach/dune environment at each reserve and recommends works programmes for managing visitor access, provision of visitor amenities, planting, other erosion control measures, and monitoring.

For Ocean Beach information on shoreline movements was determined at 12 sites from aerial photographs in 1947, 1957, 1967, 1990, and 2000. The results of this analysis are presented in a Table in Appendix E, and confirmed the results of previous literature that the beach undergoes phases of erosion and accretion, with a general trend over the last 50 years of dune erosion from St. Clair to Middle Beach and accretion from St. Kilda to Lawyers Head. The report also notes that periodic beach profile data between 1989 and 1996 is available from ORC for 7 sites along Ocean Beach. This data shows the range of foreshore fluctuations is greatest at the St. Clair seawall, and dune slopes are the steepest to immediately east of the wall. Both foreshore and dune slopes are more stable the further east along.

Noted erosion patterns from July 2001 storm was increase in height of erosion scarp on the dune face from St. Clair to St. Kilda then a reduction again to Lawyers Head. Sea level rise impacts on shoreline position at Ocean Beach were estimated to be retreat in the order of 3-5 m over the next 50 years based on a rise of 0.16 m, which was the mid-point of the IPCC 2001 most likely scenario. Hence result would be small increase in erosion at western end and less accretion at eastern end.

Ocean Beach was classified as a high priority reserve for dune conservation works. Some for the recommended works programme tied in with the re-construction of the St. Clair seawall, including the following works to the east of the wall:

- removal of inappropriate fill material,
- placement of 200 m length of geo-textile sand sausages under the dunes,
- inputs of around 8,000 m^3 sand for beach renourishment,
- construction of elevated staircase access to the beach.

Other major works included removal of inappropriate fill material and beach re-contouring at Middle Beach, and use of sand trap fencing along dune toes, and dune face re-vegetation along the whole length of the reserve.

Suggested monitoring network for Ocean Beach to consist of:

- Ten annual photograph sites,
- eight profile sites to be re-surveyed on a two yearly basis,
- bi-annual topographic survey of the dune re-contouring area to east of St. Clair seawall and at St. Kilda surf club.

Data presented:

1) Observations of erosion patterns from storm 18-21 July 2001
2) Shoreline movements at 12 sites measured from aerial photographs from 1860 to 2000. (Appendix E)
3) Summary of observations from periodic beach profiles by ORC at 7 sites between 1989 and 1996.

Duffill Watts & King Ltd: 2002 St. Clair Sea Wall Study. Report to Dunedin City Council. 48 pps + appendices.

Repeats the information presented in Duffill Watts & King 2001, but includes budgets for different packages of protection options. All of the options include replacement of the seawall. The preferred options for dealing with erosion issues in the transition area to the east of the seawall included increasing the wall length by 50 m, use of geotextile "sand sausages" laid under the dune to provide protection against "end effects", and associated dune contouring.

Although offshore artificial reef/wave rotator are not included in any if the budget options, the report reproduces as an appendix the ASR Consultants report on long-term solutions which recommends an artificial offshore reef, and another report by the same authors on wave rotation for coastal protection.

Data presented:

1) Seawall history and extension plans.
2) Sand sausage design east of seawall.

OCEL Consultants Ltd 2002: Tahuna Ocean Outfall Constructability Study. Report to Dunedin City Council. 24 pps

This report is primarily concerned with pipeline design and constructability. Presents some information on the design wave climate, noting that there is no site specific wave data for Ocean Beach, and therefore infers design wave from ship observations on the Otago coast between 1960 and 1998, and wave refraction carried out for Waldronville.

The results from the 10,000 ship observations were that the predominant wave direction is from the south (30%), with reasonably similar frequencies of 10-16% from other directions between NE and SW. For height, 35% of the waves were observed to be 1 m, and 19% above 3m. The highest frequency of extreme wave height was from a SW direction. The full results of the ship observations are included presented in Appendix F.

The inferred wave refraction coefficients for deep water waves were 0.85 for southerly waves and 0.53 m for SW waves. The 100 year offshore design significant wave height for the outfall was estimated to be 8 m based on the maximum from the ship observations, with the corresponding maximum wave being 15.2 m. However, it is noted that there are large uncertainties with these estimates. The mean period from wave observations was given as 12 seconds.

Data presented:

1) Wave data from ships observations (Appendix F)

DTec Consulting Ltd: 2002b: St. Clair Sea Wall Study: Transition area from sea wall to sand dunes. Technical report in support of resource consent applications. Report to Duffill Watts & King 13 pps. .

Provides information on technical aspects of dune reconstruction in support of the resources consents required for the activity. Notes that the design of the dune reconstruction is a trade-off between volume, slope, and location; with location being constrained by the presence of private property behind the dune and the requirement to maintain the walkway in its current position. Used recorded and modelled dune scour at Christchurch to recommend the location and depth for placement of the geotextile sand sausages. Also includes recommendations on dune slopes, location of dune fencing, planting, and post storm mitigation following exposure of the geotextile tubes, which included renourishing the dune with sand from an external source to recover the tubes.

Data presented:

1) Beach profile changes east of sea wall 1994-2002.

Allen R.B 2002: Dune vegetation at St. Clair beach, Dunedin. Wildlands Consultants Report to Duffill Watts & King Ltd. 6pps.

Report for resource consent for dune reconstruction that describes the dune vegetation present to the east of the St. Clair seawall. . concludes that area is dominated by plant species that are not native to the Dunedin area and that the only plant of conservation importance is pingao, which is spreading reasonably vigorously in one location from planted stock.

Beca Carter Hollings & Ferner 2002: Tahuna 2006: Ocean discharge dispersion study. 2nd edition: including 1100 m outfall option. 36pps + appendices.

Presents information and data on current measurements from Cawthron (2001), hence not summarised again here, and wind climate from the Musselburgh weather station. The current data presented included the 10 & 90 percentile , and medium current values, which are not presented in Cawthron 2001, and a comparison of these with Green Island data. The conclusion of this was "*variations over time, particularly the large random fluctuations associated with climatic events and oceanic circulation, are more important than spatial variations (i.e. variations in current speed with distance offshore)*".

The wind data was used as an indicator of the climatic conditions during the current meter deployments, hence analysis is largely restricted to 2001. However, information presented included wind rose for 1997-2001 period, which is re-produced in Appendix G. Conditions during the two current meter deployments were considered to be reasonably typical, with NE, west, and SW winds most frequent.

Data presented:

1) Summary of current meter results at Tahuna, summer and winter 2001 (From Cawthron 2001)
2) Wind rose from Musselburgh weather station 1997-2001 (Appendix G)

Cawthron Institute 2002: Tahuna Wastewater Plant Upgrade: Baseline Ecological Study. Report for DCC. Cawthron Report No. 733. 20pps + appendices

Reports on survey of soft sediment contaminants and ecological communities in the vicinity of the proposed Tahuna offshore outfall, which included size analysis from 6 grab samples of the seabed sediment. The results showed that the "*soft-sediments across the entire survey area were clean sands having a rippled surface and containing very little detrital material".* Details of the sample locations and results of the grain size analysis are re-produced in Appendix H.

Data presented:

1) Sediment grain size results from 6 offshore grab samples in vicinity of proposed Tahuna wastewater outfall (Appendix H).

MWH New Zealand Ltd 2002: Tahuna Wastewater Treatment Plant Upgrade: Assessment of Effects on the Environment including Resource Consent Applications. Prepared for DCC. 132pps + appendices

The AEE and applications are for an outfall located approximately 1100 m offshore from MHWS position, approximately 900 m west of Lawyers Head.

The body of the AEE contains information on history, wind climate, currents, and sediments. Much of this information is from reports appended to the AEE (E: Beca Carter Hollings & Ferner 2002, F: Cawthron 2002), which are referenced separately in this bibliography. Additional information not included in these reports deals with the seabed sediments at Tahuna, which are described as being a band of coarse relict gravels seaward of approximately 39 m depth, landward of which sediments are dominated by modern , Clutha derived fine sands with increasing ripples, sand waves and other current features at shallower depths. A seabed profile from the *M.V. Munida* survey in 1992 is presented which shows a reef of high density material extending either to the surface or immediately below the surface between approximately 700 m to 1 km from the shore, and has an average width of 50-100 m. A copy of this profile is reproduced in Appendix I.

Suggested monitoring included annual survey of sub-tidal sediments at 10, 50, 250, 500, 1000 & 2000 m either side of the 1100 m outfall and generally parallel to the shore.

Data presented:

1) Offshore profile and sediments at Tahuna from *M.V. Munida* survey, 1992 (Appendix I)

Patterson Pitts Resource Management Ltd 2002: St. Clair wall redevelopment resource consent applications on behalf of Dunedin City Council. 83pps. C

Applications and AEE for landuse consents and coastal permits for the redevelopment of the St. Clair seawall. Apart from construction plans by Duffill Watts & King, and technical reports by DTec (2002b) and Allen (2002), it does not include any other relevant information on coastal process.

Ryder Consulting Ltd 2003 Tahuna WWTP proposed offshore outfall: Offshore sediment survey December 2002. Report for DCC. 43pps

The purpose of the survey was to provide baseline information on the sub-tidal benthic biology in the area of the proposed outfall. The survey involved sampling the seabed sediment along a transect parallel to, and 11000m offshore from the beach. Samples were taken at 10 m, 50 m, 250 m, 500 m, 1000 m, and 2000 m along the transect from the proposed outfall. The location of the sample sites is shown in Appendix J. Sediment grain size analysis of the samples was not undertaken, but the divers noted the immediate characteristics of the bed, finding that the sites were dominated by sand with rocky intermittent rocky outcrops. The results of these observations are presented in Appendix J.

Data presented:

1) Offshore sediment characteristics along a 4 km shore parallel transect centred at proposed Tahuna wastewater outfall.

Dunedin City Council 2003: Evidence presented to Coastal Permit Application for Offshore Wastewater Outfall at Tahuna.

Evidence on coastal processes and parameters was presented by on behalf of the Dunedin City Council (the applicant) by Gary Teear (wave climate), Dr. David Papps (current measurements in relation to dispersion of contaminants), and Dr. Greg Ryder (sediments in relation to ecological monitoring). However, none of these witnesses produced new information as part of their evidence, instead relying on the data presented in OCEL (2002), Cawthron (2001) & MWH 2002), and Cawthron 2002 respectively, all of which have been reviewed separately for this bibliography.

Otago Regional Council and Dunedin City Council 2003: Joint decision on applications for resource consents for St. Clair seawall redevelopment. 33pps.

Sets out summary of evidence presented at hearing, decisions made by the hearings panel and the reasons for them. Evidence on coastal processes was presented by Mr. Maurice Davis from Duffill Watts & King, but from the summary appears to be light on details of the process environment. The hearing panel also commissioned an independent review of the process information by Professor Alex Sutherland,

which concluded that *" the existing variety of protective structures is causing the level of beach sand to be lowered in excess of what would occur naturally"*.
The decision includes consideration of three following issues related to the coastal processes:

- The Esplanade wall and sand dunes: Found that majority of submissions not concerned with these aspects. Concluded that the Esplanade wall was in such a state of repair that there was a significant risk of substantial failure during a 1:10 year storm event, hence replacement was required. Also concluded that use of geotextile tubes, re-sloping and re-vegetating dunes to east of wall were appropriate actions against "end effects" erosion, but noted that these works would require ongoing maintenance, as per the dune management plan (which is DTec 2002a)
- Rock Revetment Beach St to Salt Water Pool: Based on Professor Sutherland's review, concluded that neither rock riprap or near vertical concrete wall will encourage much sand retention in the western corner of the beach, but that rock riprap will result in less scour, hence is a better solution in this area. Decision notes that this revetment at a 1:2 slope plus infill would result in a 16 m protrusion onto the existing beach.
- Wave energy dissipation structures at the western end of the beach: Panel were not convinced that the benefits of sand retention in the western corner from the proposed 20 m long rock groyne would outweigh the significant adverse effects on recreational & visual amenity and natural character. Accordingly, this part of the application was declined.

Data presented:

2) Rock Revetment encroachment on beach in western corner of St. Clair

Perry J.: 2003: Dunedin Ocean Beach Sandhills. In Proceedings of the Coastal Dune Vegetation Network 2003 Conference, Dunedin.

This report documents the history of the Ocean Beach sand dunes, covering sand removal in the 1870's, erosion and flooding in the 1880's and 1890's, and the initiation of fencing and planting efforts by the Dunedin Amenities Society from the early 1890's. Largely repeats information presented in McDonald (1965), however does note that historically "*the sandhills were always minor in the west where they were breached by a lagoon, and rose gradually to a major accumulation of sand in the east*".

Duffill, Watts & King: 2004 Ocean Beach Domain: Middle Beach Erosion Remedial works. Report to Dunedin City Council. 6 pps + appendices

This report presents three options for addressing on-going erosion issues at Middle Beach. These options are: 1) re-contouring of the existing dune, 2) re-contouring and geotextile toe protection, and 3) beach renourishment. Details of the history and process contributing to the erosion problems, and design of the proposed beach re-contouring is provided in an appended report prepared by DTec Consulting. This report notes the possible role of long established rip cells east and west of Moana Rua in contributing to localised dune retreat in the area.

The report recommended that under the current level of funding, option 1 is the most viable, but noted that it is likely to only be a 10-15 year solution, therefore also recommended that further funding should be provided for a data acquisition programme to allow more effective design of long term solutions.

Data presented:

1) Existing beach profiles at 5 locations from 2004 topographic survey and proposed re-contour design at these sites.

DTec Consulting Ltd: 2006: Assessment of Environmental Effects for Coastal Dune Restoration at Middle Beach, Dunedin. Report for Dunedin City Council. 78pps + appendices

This report was prepared as part of the resource process for removal of inappropriate material from dunes, beach re-contouring and beach renourishment at Middle Beach. Information presented included description of activities, design of dune re-contouring and beach renourishment, and potential effects of the proposed works.

Information on coastal processes included summaries from previous literature on wind and wave climate, sea levels, storm events, sand dune use & development and stability and tsunami risk. Information presented that is not reviewed in this bibliography included:

- Tonkin & Taylor (1999): Return period winds and storm surge at Taiaroa Head, and
- Berryman *et al* (2005): Tsunami risk

New information included wave statistics from the NOAA deepwater hindcast site located 57 km ESE of Ocean Beach from March 1997 to March 2005. The results are slightly different that from the ship observations reported by OCEL (2002) with the predominant deep water wave direction being from the SW (45%), 60% of waves having significant wave heights between 1 m and 2 m and only 8% above 3 m, and a mean significant wave period of 9.5 seconds. [Note: This information is not re-produced in an Appendix to this bibliography as it is superseded by information in DTec 2007.]. A one-line wave refraction was used to get the deepwater wave from each direction which would generate the maximum depth-limited breaker height with a 5 m nearshore water depth. Twenty one storm events were identified which met the criteria of depth-limited breaking waves at the 5 m contour for more than 12 hours. The highest ranked storm based on duration and tides was May 2002, followed by July 2001. The most frequent storm years were 2004 (6) and 1997 (4). [Note: This information is not re-produced in an Appendix to this bibliography as it is superseded by information in DTec 2007.]

The proposed activities included:

- Removal of an estimated 6,000 m^3 of soil from the dune cap and 1,200 m^3 of hard fill from the dune toe.
- Recontour 700 m length of dune involving reducing crest elevation by 2 m, having a front slope of 1:4, having an average crest cap width of 7 m and minimum of 4 m; all of which would require the beach/dune boundary to be relocated an average of 14 m seaward.
- Importing 5,000 to 9,000 m^3 of sand from an external source to construction the required dune profile.
- Re-vegetating the dune with appropriate plantings and controlling access by fencing.
- Importing in the order of 44,000 m^3 of sand from an external source to renourish the foreshore for the 700 m length.

[Note that the resource contour hearing for these proposed activities did not proceed due to the effects of the damaging storms in 2007]

Data presented:

1) Wave statistics and storm data from NOAA deep water hindcast site 57 km ESE of Ocean Beach (171.25E 46.0S)
2) Beach profiles at 25 m intervals generated from the Airborne Laser Survey (e.g. Lidar) in September 2004 and the proposed profile after re-contouring and re-nourishment at these sites.

DTec Consulting Ltd: 2007: Coastal Storm Events and Emergency Works, Ocean Beach 2007. Report for DCC 22pps

This report details the sequence of storm-in-series that occurred during the winter of 2007, the erosion damage which occurred, and the emergency works undertaken as a result. New background information not previously reviewed in this bibliography includes:

- 5 years of sea level recordings from Green Island (Dec 2002 to Sept 2007). Highest recorded sea level was over this period was 1.48 m above MSL on 3/1/06, which included 0.43 m of storm surge.
- Updated wave statistics and storm register from NOAA deepwater hindcast model, showing 34 events from March 1997 to September 2007. This data

is re-produced in Appendix K. The criteria for a storm was defined as being 24 hours or more with wave heights greater than 4 m. The potentially most damaging event was June 2007, with duration of 108 hours. The return period for this event was calculated as 13-17 years. Years with the most frequent storms were 1997 (6), 2007 & 2005 (5 each). 70% of storms events had a SSW deep water approach direction, being refracted to arrive at shore as southerly swell.

Reports that storms-in-series during 10 week period from mid April 2007 to end of June 2007 included 8 high energy swell events, of which 4 were had durations longer than 24 hours, and 3 occurred in conjunction with tides greater that MHWS. The return period for this sequence of events was calculated as being in the order 20-30 years. Also noted that beach exposed to more frequent high energy events in 2002, 204, and 2006, so likely to have reduced volumes and elevations prior to the 2007 events.

Reports that the erosion effects of the 2007 storm-in-series were the largest at the St. Clair sand sausages estimated to 8-12 m retreat, and along the Kettle park frontage estimated to be a maximum of 20 m. Total volume losses were estimated to 100,000 m^3 from the dunes and another 100,000 m^3 from the beach. Details of the emergency works are given, which included the placement of 12,800 m^3 of sand from Blackhead quarry at the St. Clair sand sausages, placement of 8,000 m^3 of sand from Port Otago and the construction of a 90 m long reno mattress at Moana Rua, re-shaping the exposed rubble field to act as a wave run-up trip and removing unstable clay/loess dune cap along the west Kettle Park frontage.

Data presented:

1) Wave statistics and storm data from NOAA deep water hindcast site 57 km ESE of Ocean Beach (171.25E 46.0S) for period from March 1997 to September 2007. (Appendix K).
2) Effects of storm-in-series April-June 2007
3) Emergency protection works undertaken as a result of erosion in 2007 storms-in-series

L&R New Zealand Ltd 2009: An Overview of the history of human intervention at Ocean Beach, and other factors that may have contributed to the current erosion issues. 58pps

This report forms part of the current investigations programme into long-term management options for Ocean Beach. The report provides a comprehensive overview of historical intervention impacting on the foreshore and coastal hinterland of Ocean Beach. Information was compiled from archival and published material and includes the reproduction of photographs showing the state of the beach and dunes through time from the 1870's. The report is broken into time periods, and provides records of such developments as the St. Clair salt water pool, seawall and groynes;

early sand removal for lagoon infilling; the use of plantings and brush fences for dune development at Middle Beach/St. Kilda; the construction and subsequent loss of a beach roadway from St. Clair to St. Kilda; the use of the middle beach dunes for landfill and then sports fields; and the construction of John Wilson Drive. Also reports on the damage and erosion caused by various storm events.

Data presented:

1) Shoreline Developments 1870's to 2009
2) Occurrence of storm events causing inundation (1883), damage to seawall (1886, 1889, 1891) ,or erosion (1920, 1955, 1974, 1977, 1978, 1987, 1990, 1992, 1996, 2000, 2001, 2007, 2008).

3.0 Sources of Information on Key Process Areas

3.1 Wind and Wave Data

Elliott E.L. 1958:

- Wind direction and strength frequencies at Taiaroa Head and Waikouaiti 1937-1945. Source NZ Met Service.

Hodgson W.A. 1966:

- Summary of wave observations from Taiaroa Head and Cape Saunders, December 1963 to December 1964.
- Wave refraction plots for the Otago Peninsula area for 10 & 15 second waves from southerly directions.

Nicolson D.C. 1979:

- Wind roses from Taiaroa Head Lighthouse 1957-1978.
- Wave roses from ships observations in grid square 44 (NZ met service data)

Dyer M.J. 1994:

- Wind and wave observations at Tomahawk Beach for period December 1993 to June 1994.
- Marine forecast swell summaries for period December 1993 to August 1994

Townsend B.J. 1997:

- Summary of wave observations at Ocean Beach and wind records from Musselburgh for period June to December 1996.

Allen C 1999:

- Wave data from Hodgson 91966), Nicholson (1979), and Dyer (1994), and wind data from Dyer (1994)
- Wave refraction for 2 m swell from SW, S, & SE.

OCEL 2002

- Wave observation from 10,000 ships observations in Otago coastal area 1960-1998 (Appendix F).

Beca Carter Hollings & Ferner 2002:

- Wind rose from Musselburgh weather station 1997-2001 (Appendix G)

DTec 2006:

- Wave statistics March 1997-March 2006 from NOAA deep water hindcast site 57 km ESE of Ocean Beach (171.25E 46.0S)

DTec 2007:

- Wave statistics March 1997-Sepember 2007 from NOAA deep water hindcast site 57 km ESE of Ocean Beach (171.25E 46.0S) (Appendix K)

1) Effects of storm-in-series April-June 2007

2) Emergency protection works undertaken as a result of erosion in 2007 storms-in-series

3.2 Storm Information

McDonald K.C. 1965 (and largely repeated in Perry 2003):

- Storm occurrence March 1883, June 1891, May & July 1898

Kirk R.M. 1979:

- Dune erosion in coastal storms 1977 &1978

DTec 2000:

- Series of storms in April-May 1999.
- Storms and heavy rainfall in September 2000.

DTec 2002a:

- Observations of erosion patterns from storm 18-21 July 2001

DTec 2006:

- Individual storm event statistics for events from March 1997 to March 2006 from NOAA deep water hindcast site 57 km ESE of Ocean Beach (171.25E 46.0S)

DTec 2007:

- Storm data from NOAA deep water hindcast site 57 km ESE of Ocean Beach (171.25E 46.0S) for period March 1997 to September 2007.(Appendix K).
- Effects of storm-in-series April-June 2007
- Emergency protection works undertaken as a result of erosion in 2007 storms-in-series

L&R New Zealand Ltd 2009:

- Occurrence of storm events causing inundation (1883), damage to seawall (1886, 1889, 1891) ,or erosion (1920, 1955, 1974, 1977, 1978, 1987, 1990, 1992, 1996, 2000, 2001, 2007, 2008).

3.3 Current Data

Heath R.A. 1973:

- Subsurface and surface current velocities off Otago Peninsula measured on one day in April 1971.

Carter L. & Heath R.A. 1975:

- Mean circulation and tidal current velocities on the Otago shelf.

Cawthron Institute 2001:

- 60 days of summer and winter measurements from 900 m & 1600 m offshore from Tahuna in 2001 Appendix D).

Beca Carter Hollings & Ferner 2002:

- Summary of current meter results at Tahuna, summer and winter 2001 (From Cawthron 2001)

3.4 Sediment Data

3.4.1 Nearshore and Inner continental Shelf Sediments

Andrews P.B. 1973:

- Maps of spatial distribution of continental shelf sediments off Otago Peninsula including sediment textural class, mean and medium grain size, sorting and skewness.

Carter R.M. *et al*. 1985:

- Map of distribution and description of sediment types across the south Otago Shelf from Nugget Point to Karitane. (Appendix B)

Carter L. & Carter R.M. 1986:

- Structure of inner shelf sand wedge

Carter L. 1986:

- Sediment budget of the inner south Otago continental shelf
- Sediment transport and storage on the nearshore sand wedge at Dunedin

Tonkin & Taylor 2000

- Sediment budget of the inner south Otago continental shelf
- Shoreline movements at St. Clair, Middle Beach, and St. Kilda measured from cadastral plans and aerial photographs from 1860 to 1997.

Cawthron Institute 2002

- Sediment grain size results from 6 offshore grab samples in vicinity of proposed Tahuna wastewater outfall (Appendix H).

MWH New Zealand Ltd 2002

- Offshore profile and sediments at Tahuna from *M.V. Munida* survey, 1992 (Appendix I)

Ryder Consulting Ltd:

- Offshore sediment characteristics along a 4 km shore parallel transect centred at proposed Tahuna wastewater outfall (Appendix J)

3.4.2 Beach Sediments

Hodgson W.A. 1966:

- Mean grain size for St. Clair-St. Kilda beach given as 1.96 phi (0.26 mm) which is medium sand

Bardsley W.E. 1977:

- Variations in longshore occurrence of heavy mineral distributions from Porpoise Bay, East Southland, to the Pleasant River mouth, North Otago.

Dyer M.J. 1994

- Mean sediment grain size at St. Clair from samples collected in May 1994 given as 1.75 phi (0.30 mm), which is medium sand.

Allen C 1999:

- Sediment transport patterns at St. Clair for different swell directions of S, SW, SE, & NE.

3.5 Change in Shoreline Position/Condition Information

McDonald K.C. 1965:

- Dune breaching and erosion 1883-1898, then building up 1901 to at least 1911.

Kirk R.M. 1979:

- Sketch plan of the changes in the dune/beach boundary at Ocean Beach determined from aerial photographs in 1942, 1958 and 1970. (Appendix A)

Dyer M.J. 1994:

- Beach profile changes at St. Clair and St. Kilda over multiple surveys between January and June 1994.

Townsend B.J. 1997:

- Stretch plans showing beach width, dune vegetation cover, and hinterland developments for each decade thru the 20th century.
- Summary of beach profile changes from monthly profile surveys between July 1996 to January 1997 at 8 locations.

Allen C. 1999:

- 1998: sand levels at St. Clair lowest in 70 years (quote from long-term resident)

Tonkin & Taylor 2000:

- Shoreline movements at St. Clair, Middle Beach, and St. Kilda measured from cadastral plans and aerial photographs from 1860 to 1997. (Appendix C)

DTec 2000:

- Erosion at east end of St. Clair sea wall following storms in May 1999 and September 2000 resulting in exposure of rubble for up to 200 m length.

DTec 2002a:

- Shoreline movements at 12 sites measured from aerial photographs from 1860 to 2000. (Appendix E)
- Summary of observations from periodic beach profiles by ORC at 7 sites between 1989 and 1996.

DTec 2002b:

- Beach profile changes east of sea wall 1994-2002.

Duffill Watts & King 2004:

- Existing beach profiles at 5 locations at Middle Beach from 2004 topographic survey and proposed re-contour design at these sites.

DTec 2006:

- Beach profiles at 25 m intervals generated from the Airborne Laser Survey (e.g. Lidar) in September 2004 and the proposed profile after re-contouring and re-nourishment at these sites.

DTec 2007:

- Effects of storm-in-series April-June 2007

3.6 Shoreline Development Information

McDonald K.C. 1965 (and largely repeated in Perry 2003):

- Sand extraction Tahuna 1880-1883
- St. Clair Seawall 1884-1913:
- Dune marram planting since around 1901
- Groynes constructed some time prior to 1911

Kirk R.M. 1979:

- Earth and rubble dumping post 1977 & 1978 storms at Moana Rua and northern end of John Wilson Drive.

Kirk R.M. 1991:

- Infers that random rock dumping at the northern end of the St. Calir seawall, soil dumping at Moana Rua, and foredune development at Lawyers Head has occurred since 1979.

Townsend B.J. 1997:

- Decadal stretch plans show 3 groynes at St. Clair 1906-1911, development of Tahuna Park 1940's, development of John Wilson Drive 1950's, the northeast extension of Kettle Park in the 1960's, and walkway development from St. Clair to Moana Rua in the 1970's & 1980's.

Tonkin & Taylor 1998:

- Dune restoration area had been established at eastern end of St. Clair seawall.
- Still dumping issues on John Wilson Drive adjacent to Lawyers Head.

Allen C 1999:

- Timeline of developments on dunes, including the following not previously dated: 1890 – dune restoration programme started with planting; 1894 – wooden groynes erected at St. Clair, 1950's – area near Moana Rua used as landfill with rubble, bricks, concrete dumped on dunes; 1953 – start of construction on John Wilson Drive; 1960 – dunes still being used as landfill; 1993 – dune restoration at St. Clair involving sand deposited on top of dunes.

DTec 2000:

- May 1999: Sand pushed from lower foreshore to dune toe at east end of St. Clair sea wall.
- Removal of old surf club building at Middle Beach recommended

Shingle 2001:

- Removal of old surf club building at Middle Beach recommended

Duffill Watts & King 2001:

- Extension of St. Clair seawall eastward in 1935.

Duffill Watts & King 2002:

- Plans for seawall extension and sand sausage placement to east of wall.

Otago Regional Council and Dunedin City Council 2003:

- Rock Revetment encroachment on beach in western corner of St. Clair

DTec 2007:

- Emergency protection works undertaken as a result of erosion in 2007 storms-in-series

L&R New Zealand Ltd 2009:

- St. Clair salt water pool 1884-2003
- St. Clair seawall 1879-2009
- St. Clair groynes 1903-1955
- Sand Extraction 1870's-1914
- Dune planting and fencing 1890's-1934
- Ocean Drive roadway from St. Clair to St. Kilda 1914-1919
- Kettle Park landfill and sports field development 1923-1962
- John Wilson Drive 1906-1993.

3.7 Sea Level Rise Impacts

DTec 2002:

- Retreat 3-5 m with rise of 0.16 m over next 50 years (IPCC 2001)

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Berryman K. *(et al)* 2005 Review of tsunami hazard and risk in New Zealand. Report for Ministry of Civil Defence and Emergency Management by GNS Ltd, Lower Hutt.139p.

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P23 Dunedin City Council 2003: Evidence presented to Coastal Permit Application for Offshore Wastewater Outfall at Tahuna.

P11 Dyer M. J. 1994: Beach profile change at St. Clair Beach, Dunedin. Unpublished MSc thesis (Geography), University of Canterbury. 229pps

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Disclaimer

This report has been prepared for the benefit of Dunedin City Council with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

DTec Consulting Ltd
Environmental & Coastal Consulting

Report written by:	Report Reviewed by:
....	....
Derek Todd	

5 August, 2013
new report.dot

APPENDIX A

Kirk R.M. 1979: Figure 5

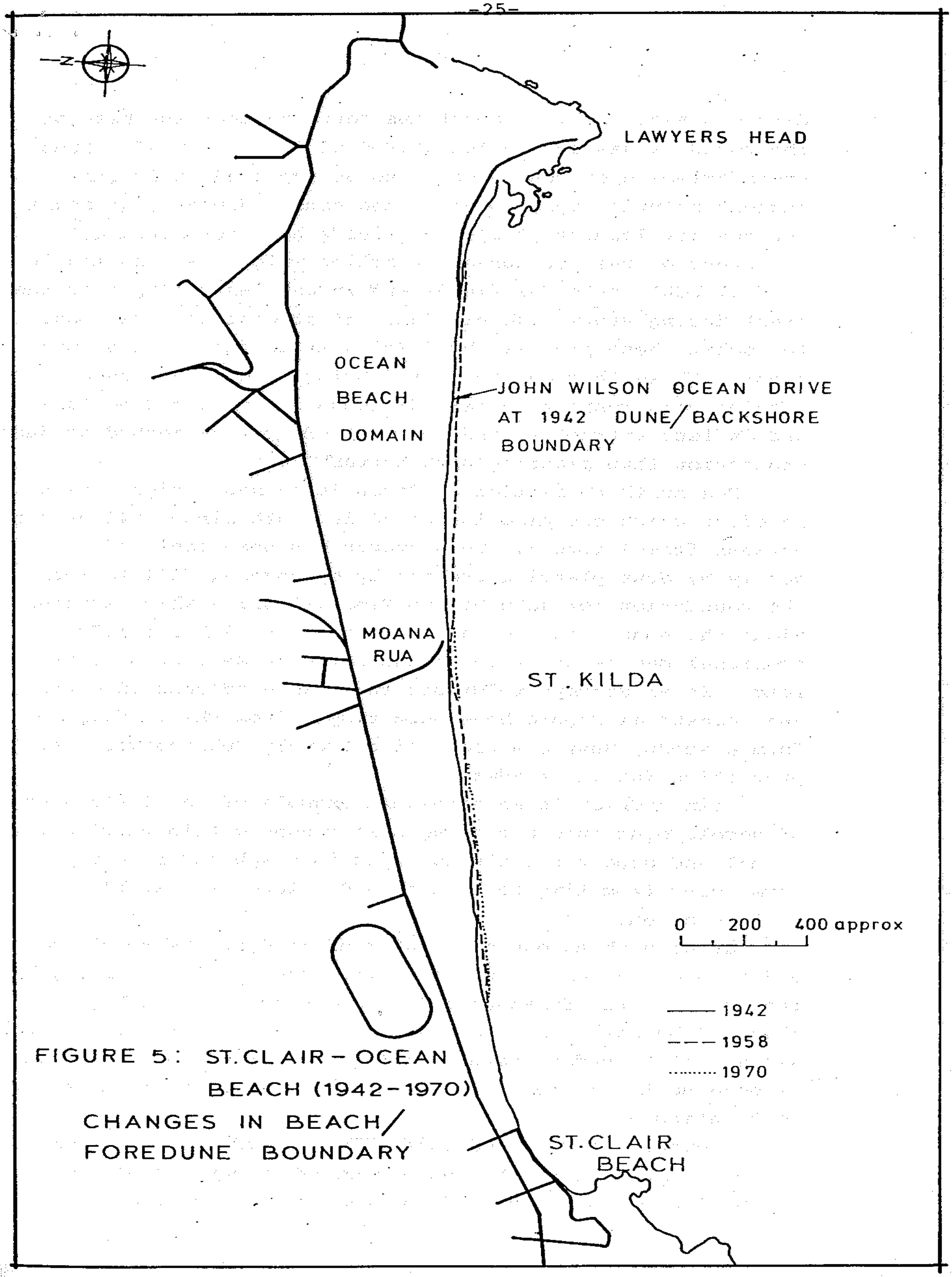


FIGURE 5: ST. CLAIR – OCEAN BEACH (1942–1970) CHANGES IN BEACH/ FOREDUNE BOUNDARY

APPENDIX B

Carter R.M *et al* 1985: Figure 4

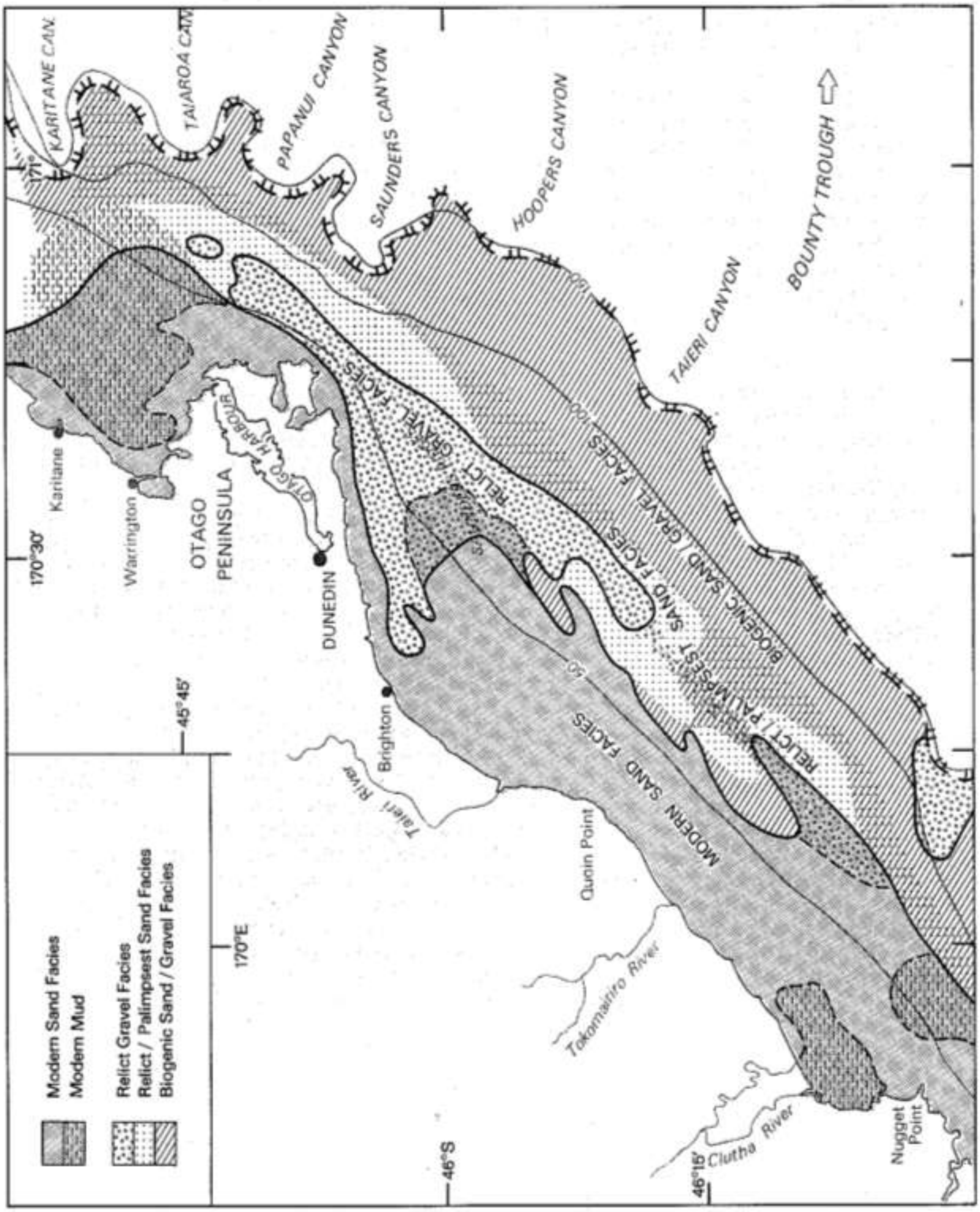


FIG. 4. Distribution of the main sediment facies on the South Otago continental shelf determined from all available sedimentary and geophysical data. Solid boundaries delimit main body of the facies, dashed boundaries denote areas where facies limits are indistinct, e.g., areas of sediment mixing.

APPENDIX C

Tonkin & Taylor 2000: Exerts from Table 1 & 2

Table 1: Comparison of shoreline change distances and rates from pre-and post-damming of the Clutha River

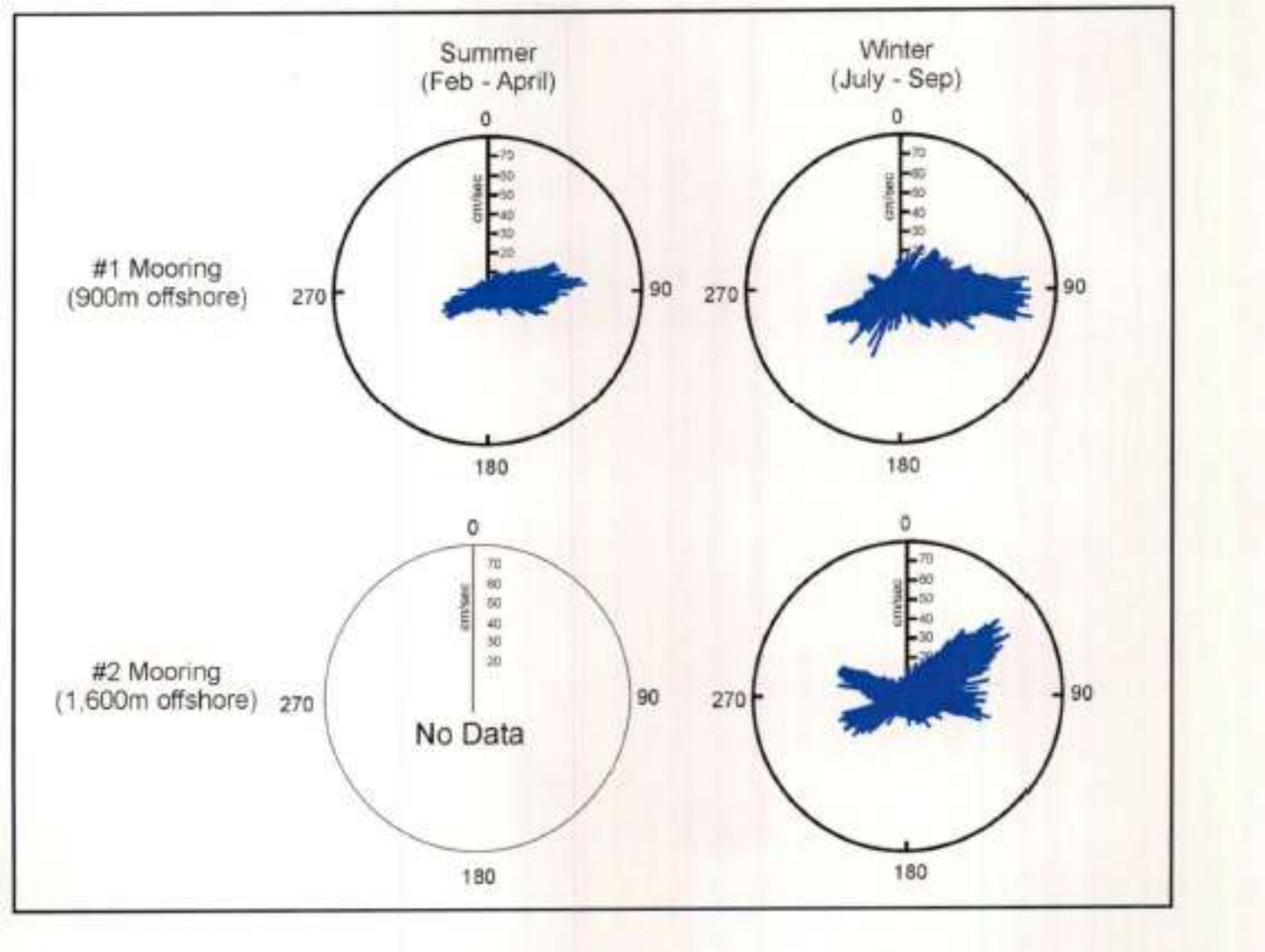
Location	**Pre-Damming**				**Post-Damming**		
	Time	Change (m)	Rate (m/yr)		Time	Change (m)	Rate (m/yr)
St. Clair	1860-1958	-74.9±8.7	-0.76±0.09		1958-1997	-0.7±13.9	-0.1±0.28
Middle Beach	1860-1958	-24.5±8.7	-0.25±0.09		1958-1997	+16.7±13.8	+0.33±0.28
St. Kilda	1883-1958	+109.0±4.3	+1.45±0.06		1958-1997	+15.8±9.8	+0.40±0.25

Table 2: Comparison of shoreline change distances and rates from two post-damming periods

Location	**Pre-Damming**				**Post-Damming**		
	Time	Change (m)	Rate (m/yr)		Time	Change (m)	Rate (m/yr)
St. Clair	1958-1982	+11.2±4.6	+0.46±0.19		1982-1997	-3.4±7.7	-0.23±0.51
Middle Beach	1958-1982	+6.6±4.7	+0.27±0.20		1982-1997	-3.6±7.6	-0.24±0.51
St. Kilda	1958-1982	+4.2±4.6	+0.18±0.19		1982-1997	+11.6±7.7	+0.77±0.51

APPENDIX D

Cawthron Institute 2001: Figure 4: Cumulative vector plots for each current meter deployment offshore from Tahuna in 2001.



APPENDIX E

DTec 2002a: Table 7.1: Shoreline movements Ocean Beach 1947-2000 determined from aerial photographs.

Table 7:1: Shoreline Movements at Ocean Beach Domain 1947-2000

Location	1947-57 (m)	1957-67 (m)	1967-90 (m)	1990-00 (m)	Total Change (m)	Rate (m/yr)
East End of Seawall	+1	+2	-7	0	-4	-0.08
Forbury Tennis courts	-1	+18	-12	+2	+7	+0.13
Forbury park stand	-2	+12	-15	-5	-10	-0.19
Moana Rua	-4	+2	-8	+1	-5	-0.09
Freyberg Tce	-7	1957-90: +6		-6	-7	-0.13
Mills Street	-6	1957-90: +10		-4	0	0.0
St. Kilda	+4	+20	0	+10	+34	+0.64
Tahuna Motor Camp	1947-67: +29		-5	+1	+25	+0.47
Tahuna stables	-	-	-9	+18	+9	+0.27
Golf Club	-	-	0	0	0	0.0
Golf Course	-6	0	+13	+1	+14	+0.26
Lawyers Head	+8	+3	-10	0	+1	+0.02

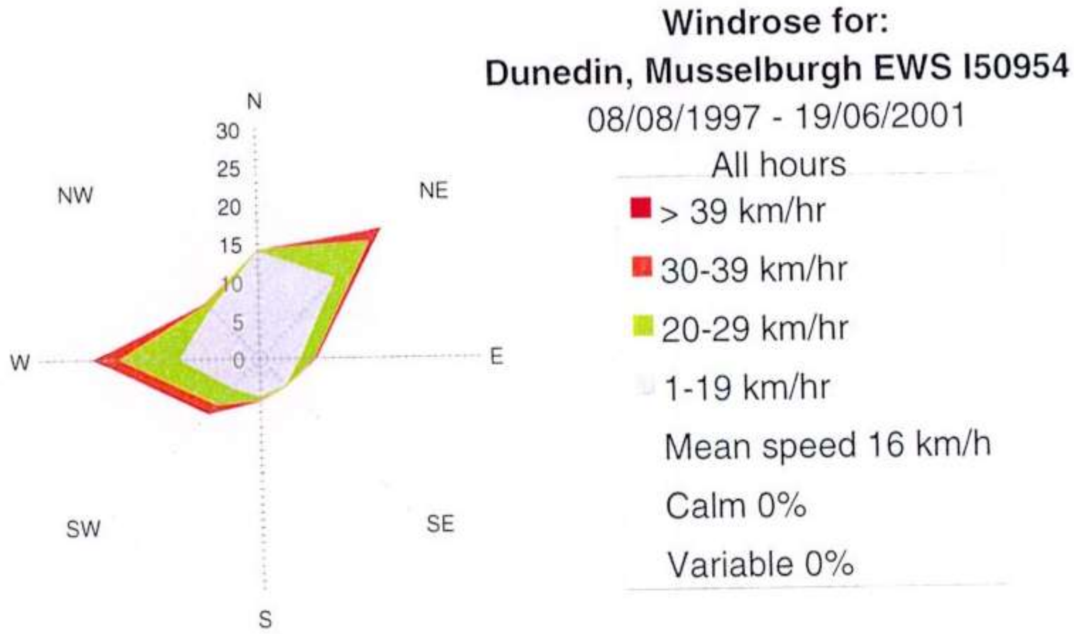
APPENDIX F

OCEL 2002: Table 1: Frequencies of wave heights and direction from ship observations in Otago coastal area 1960-1998

FREQUENCIES (PER TEN THOUSAND) FOR: Coastal Otago MONTHS: ALL HOURS: ALL NUMBER OF ANALYSED DATE: 11020									
HEIGHT (m)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8+**	**ALL-HT**
DIR									
N	34	64	15	2	0	0	0	0	115
NE	612	227	456	19	23	1	0	0	1337
E	772	144	626	20	30	1	2	0	1595
SE	647	56	526	3	69	0	1	0	1302
S	1196	436	1124	99	163	4	1	0	3023
SW	331	191	419	64	75	6	11	1	1099
W	18	54	23	13	5	0	1	2	115
NW	17	5	7	1	0	0	0	0	30
Confused	56	63	28	5	1	1	0	0	153
ALL	3684	1240	3224	224	366	13	15	3	
CALM	1230								

APPENDIX G

Beca Carter Hollings & Ferner 2002: Figure 4: Wind speed and direction at Musselburgh over period August 1997 to June 2001.



APPENDIX H

Cawthron Institute 2002: Table 1 and Appendix 2: Grain size results and location of samples for offshore sediment samples in vicinity of proposed Tahuna wastewater outfall.

Table 1 Sediment grain size analysis.

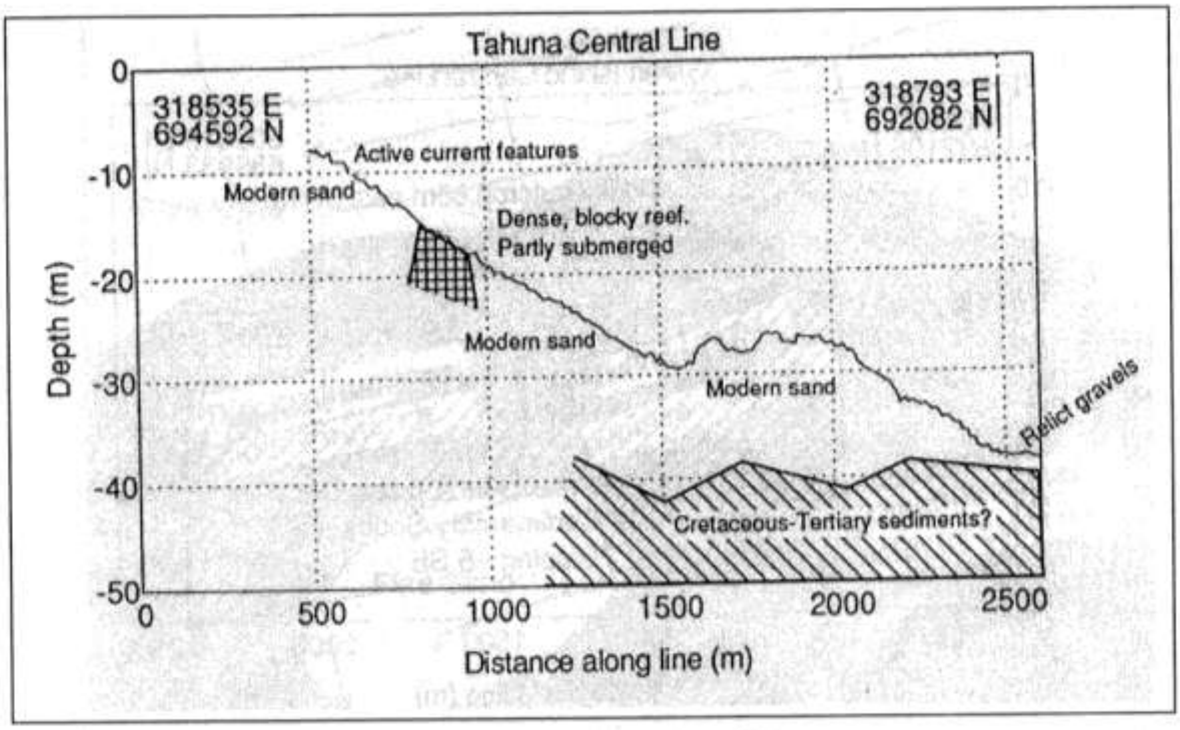
	Sediment Grain Size (% w/w dry)[1]								
	Victory			Tahuna			Akatore		
Site & replicate	Gravel	Sand	Mud	Gravel	Sand	Mud	Gravel	Sand	Mud
1a	<0.10	99.30	0.70	<0.10	99.30	0.70	<0.10	99.00	1.00
1b	<0.10	99.30	0.70	<0.10	99.60	0.40	<0.10	99.00	1.00
1c	<0.10	99.40	0.60	<0.10	99.20	0.80	<0.10	99.10	0.90
Mean[2]	0.05	99.33	0.67	0.05	99.37	0.63	0.05	99.03	0.97
St Dev[2]	0.00	0.06	0.06	0.00	0.21	0.21	0.00	0.06	0.06
2a	<0.10	99.30	0.80	0.10	98.40	0.60	<0.10	99.30	0.70
2b	<0.10	99.30	0.60	<0.10	99.90	<0.10	<0.10	99.20	0.80
2c	<0.10	99.30	0.60	0.10	99.40	0.50	<0.10	99.20	0.80
Mean[2]	0.05	99.30	0.67	0.08	99.23	0.38	0.05	99.23	0.77
St Dev[2]	0.00	0.00	0.12	0.03	0.76	0.29	0.00	0.06	0.06

Tahuna dredge samples:11/5/2002 & 10 - 14/5/2002

Site	Sample	Time	Latitude	Longitude	Depth (m)	Code
1	A	14:15	45 55.214	170 31.331	26	TahunaD1As
			45 55.384	170 31.306		TahunaD1Ae
1	B	14:30	45 55.339	170 31.338	30	TahunaD1Bs
			45 54.392	170 31.212		TahunaD1Be
1	C	14:45	45 55.488	170 31.824	32	TahunaD1Cs
			45 55.541	170 32.161		TahunaD1Ce
2	A	15:15	45 54.994	170 32.070	17	TahunaD2As
			45 54.919	170 32.398		TahunaD2Ae
2	B	15:30	45 54.909	170 32.480	18	TahunaD2Bs
			45 55.056	170 32.501		TahunaD2Be
2	C	15:45	45 55.058	170 32.434	16	TahunaD2Cs
			45 54.975	170 32.319		TahunaD2Ce

APPENDIX I

MWH New Zealand Ltd 2002: Figure 4.8.2(b): Offshore profile and sediments at Tahuna from *M.V. Munida* survey, 1992



APPENDIX J

Ryder Consulting Ltd 2003: Figure 3 and Table 3: Off-shore sampling locations and general sediment characteristics found in December 2002 survey.

Figure 3: Sampling locations around proposed Tahuna wastewater outfall.

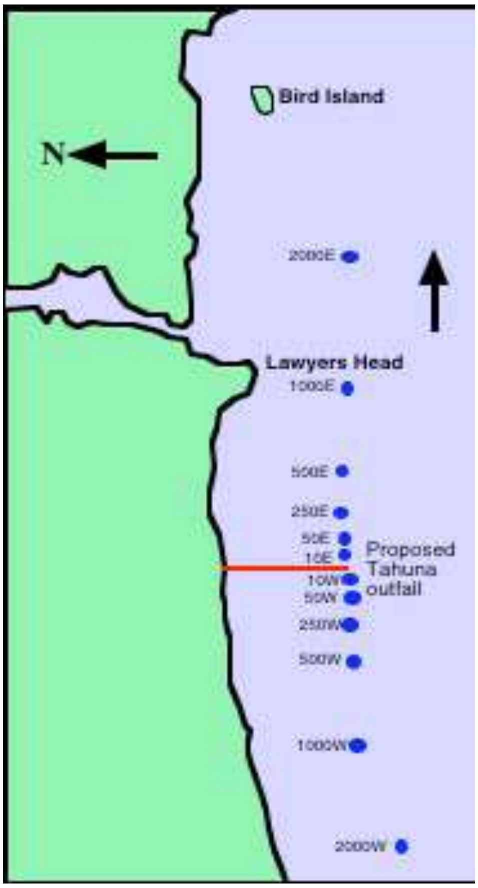


Table 3: General characteristics of sites

Location	Depth (m)	Substrate
2000E	21.0	Compact sand
1000E	20.5	Sands/Shells
500E	21.0	Mobile Sands
250E	20.5	Mobile Sands
50E	22.0	Sand/reef
10E	20.6	Sand/reef
Outfall site	21.0	Compact sand
10W	21.0	Sand/reef
50W	20.8	Sand/reef/shells
250W	19.8	Sand/reef/shells
500W	20.2	Mobile Sands
1000W	16.7	Mobile Sands
2000W	9.4	Mobile Sands

APPENDIX K

DTec 2007: Table 2 and 3: Wave statistics and storm events for Ocean Beach, March 1997, March 1997 to September 2007 from NOAA deep water hindcast model at site 57 km ESE of Ocean Beach Dunedin (171.25E 46.0S).

Table 2: Wave Statistics from Deep Water Hindcast Model March 1997-September 2007					
Significant Wave Height		**Peak Wave Period**		**Wave Approach Direction**	
Height (m)	Frequency	Period (sec)	Frequency (%)	Direction	Frequency (%)
0-1.0	7.6%	<5.0	11.0%	N	3.3%
1.01-2.0	60.1%	5.0-6.99	13.4%	NE	13.6%
2.01-3.0	24.0%	7.0-8.99	14.1%	E	10.8%
3.01-4.0	6.2%	9.0-10.99	25.0%	SE	6.5%
4.01-5.0	1.7%	11.0-12.99	24.1%	S	17.8%
>5.0	0.4%	>13.0	12.3%	SW	45.0%
Mean	1.86 m	Mean	9.5 sec	W	1.6%
Std Dev	0.77 m	Std Dev	3.0 sec	NW	1.4%
Max	6.78 m	Max	18.8 sec		

Table 3: Ranking of Storm Events, Ocean Beach March 1997- September 2007										
					Deepwater Nww3 site			5m Depth contour		
Rank	Year	Date	Duration (hrs)	Predicted High tide	Mean Hs	Mean Tp	Mean Dir	Mean Hs	Mean Dir	EPI
1	2007	22-27 Jun	108	0.58	5.68	12.92	203.40	5.11	175	132.3
2	2002	24-28 May	96	1.04	4.90	12.44	208.00	3.92	179	91.85
3	2001	19-21 Jul	72	1.09	4.99	11.47	105.67	3.99	137	78.0
4	2006	25-Apr	36	0.77	4.71	8.81	134.84	5.18	149	60.6
5	1999	26-27 Jul	24	0.83	4.50	9.00	171.67	4.95	167	38.8
6	1997	2-3 Aug	27	0.84	4.21	9.25	160.63	4.63	159	36.9
7	2004	10-12 Apr	42	0.89	4.86	12.23	215.09	3.89	182	33.2
8	1997	4-5 Sep	30	0.75	4.45	12.47	188.65	4.45	172	32.6
9	2007	12-14 Apr	42	0.82	4.93	12.16	213.50	3.94	179	32.5
10	2004	6-7 Jun	30	1.12	4.87	11.14	210.54	3.90	179	30.1
11	2007	29-31 Jul	33	0.9	5.30	9.84	97.02	3.98	135	29.1
12	1997	14-15 Sep	27	1.05	5.03	14.43	211.08	4.02	179	29.0
13	1997	20-21 Jun	24	0.96	4.56	13.71	200.00	4.10	175	25.4
14	2001	11-12 Jul	36	0.64	4.06	12.47	192.33	4.06	172	24.3
15	2000	18-19 Nov	33	0.89	4.76	12.02	211.32	3.81	179	23.7
16	2003	1-3 Jul	48	0.78	4.46	13.00	211.58	3.57	179	21.3
17	2006	16-Sep	24	0.75	4.62	14.15	223.54	4.15	175	20.8
18	2002	2-4 May	72	0.79	4.19	11.39	215.00	3.35	179	20.0
19	2006	3-Mar	30	1.1	4.40	9.33	210.14	3.52	179	17.2
20	2006	21-Jul	30	0.68	4.67	12.44	206.79	3.74	179	15.0

21	2004	24-Feb	24	0.87	5.28	9.78	226.69	3.70	182	14.5
22	2005	23-Apr	24	0.83	4.64	12.20	211.50	3.71	179	14.2
23	2002	25-27 Aug	30	0.77	4.47	10.53	207.73	3.58	179	13.4
24	1999	24-Aug	27	0.74	4.51	13.39	211.82	3.61	179	12.2
25	2004	9-11 Dec	33	0.94	4.20	10.77	214.00	3.36	179	11.2
26	1997	23-24 July	24	1.01	4.33	12.12	217.36	3.46	179	11.2
27	2007	16-17 May	33	1.06	4.41	13.29	217.00	3.31	177	10.8
28	1998	20-21 Aug	30	0.9	4.24	10.63	209.43	3.39	179	10.7
29	2004	18-19 Sep	24	0.84	4.33	11.97	209.50	3.47	179	9.4
30	1999	28-29 July	33	0.9	4.10	12.51	101.04	3.28	137	8.2
31	2000	13-Aug	24	0.75	4.85	12.43	219.50	3.40	182	7.1
32	2007	6-9-Jun	54	0.74	4.54	12.54	218.40	3.18	182	7.1
33	1997	13-16 May	66	0.68	4.50	13.59	219.00	3.15	182	6.7
34	2003	4- 6 Oct	24	0.89	4.13	11.39	208.97	3.31	179	6.5