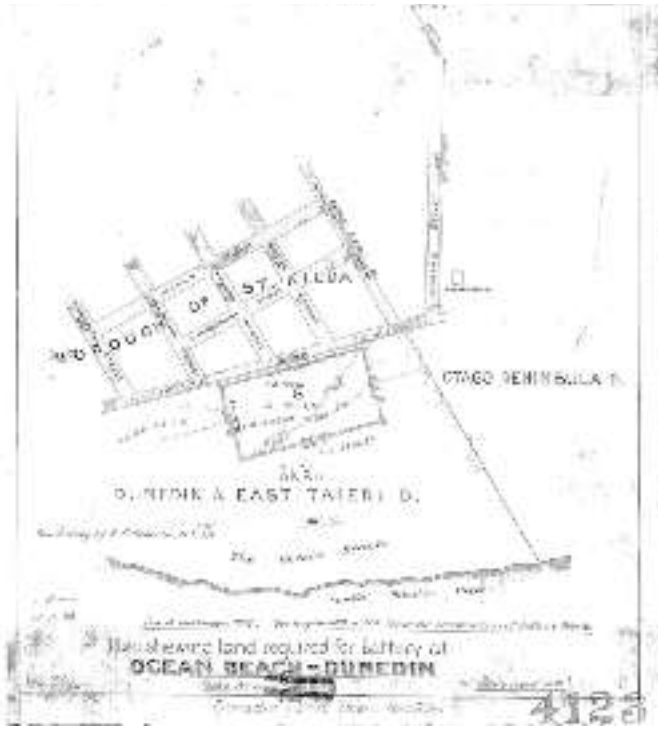
Ocean Beach Restoration Project: Historical shoreline positions



Prepared for

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Executive Summary

The purpose of this report is to:

> Present the findings of a GIS analysis of shoreline positions from historical surveys and aerial photographs.
>
> Analyse the changes in relation to long term trends and specific process events and human activities.
>
> Discuss the findings in relation to possible future beach management options.

The report addresses the plan shape change of the shoreline for the whole length of the beach between the St Clair headland and Lawyer Head. The assessment is made from plotting information from historical surveys and aerial photographs onto a geo-referenced base photograph. The information ranges from surveys of sections of the shore at various dates from 1888 through to 1952, and aerial photographs at various dates from1942 through to 2007.

The shoreline position at Ocean Beach has moved seaward since the 1880s. The dunes have become stable, in that they now form a single line along the backshore, and are fully vegetated except for the seaward face and embryo (newly formed or forming) dunes. The beach position moves landward and seaward by about 10 to 15 m in response to storms and periods of swell respectively. There can also be slight changes to the orientation of the beach in response to the direction of wave approach.

The shoreline position appears to have a seaward limit, at about the position of the 1957 High Water line in the western half of the beach, and the 1990 line in the eastern half of the beach.

Infilling and levelling of the beach hinterland prevents landward migration of dune sands, and effectively holds the landward limit of the dune position. Dynamic dune processes whereby sand is released from the dune to the beach in times of storm, and new dunes form, grow and become vegetated during long periods of quiescent wave energy and abundant sand supply, are limited in across-shore extent due to the relatively high, steep face of the main dune. Dune development seaward is limited by the episodic occurrence of high-energy wave events.

Hazards to beach users arise due to the steepness and instability of the eroded dune face during and after storms, and potential loss of hinterland resource due to retreat of the dune during storms. However there is also likely to be less landward retreat of the dune as a response to storm wave attack because the high steep dunes provide a larger volume of sand to be released to the beach per metre of horizontal retreat. A significant result of storm erosion of the dunes is that it disrupts access to the beach from the hinterland at the eastern end of the St Clair seawall, at Moana Rua Road and at St Kilda.

It is unlikely that the line of the dunes or beach could be artificially ‘encouraged’ to move seaward without construction of some feature offshore that provides for development of a tombolo or artificial headlands for a new curvature to the embayment.

It would be possible to create a dynamic dune buffer, of a lower elevation than at present along the beach between the Marae and Kettle Park by providing a more gradual slope to the hinterland. However, there would need to be provision of a width of land to allow for potential landward retreat of the dune toe in response to storms, to at least the position of the 1942 dune toe. This is a position about 30 m landward of the 2007 dune toe position, and may require sacrifice of existing hinterland resource use.

It appears that the beach position is relatively stable as long as there is a supply of sand to the nearshore. This sand can come from offshore, from the dunes or move from the beach to the nearshore and back. Beach sands can also be blown onshore to form new dunes as part of the recovery of the beach after storms.

1 Introduction

1.1 Background

This report is part of a series covering the investigations stage of the Dunedin City Council Ocean Beach Restoration Project. The purpose of this report is to:

Present the findings of a GIS analysis of shoreline positions from historical surveys and aerial photographs.

Analyse the changes in relation to long term trends and specific process events and human activities.

Discuss the findings in relation to possible future beach management options.

Todd (2010) presents an assessment of changes to the topography of Ocean Beach from survey information for the period from 1989 to 2009. These surveys include beach profile, 3-dimensional beach topography and aerial photographs. This report addresses the plan shape change of the shoreline for the whole length of the beach between the St Clair headland and Lawyer Head. The assessment is made from plotting information from historical surveys and aerial photographs onto a geo-referenced base photograph. The information ranges from surveys of sections of the shore at various dates from 1888 through to 1952, and aerial photographs at various dates from1942 through to 2007.

Mapping of past shorelines will identify the gross changes of the shoreline position, in particular the high tide mark and the position of low water. The effects of human modifications to the shore such as the St. Clair seawall, Middle Beach landfill and sports field development activities, and the construction of John Wilson Drive will also be able to be seen.

Any temporal trends in plan shape development will be important in considering the location, extent, design and likely success of different beach management options. The historical shoreline maps will also provide an opportunity for calibration of modelling of future shoreline positions.

1.2 Report Structure

The following section of this report presents the sources of data used to prepare the GIS maps, and provides a brief description of the method of analysis using ArcGIS. Sources of error are also described. Section 3 presents the findings of the examination of historical plans, while Section 4 presents the findings of the examination of aerial photographs. An interpretation of the historical shoreline change from 1888 to 2007 is presented in Section 5

2 Analysis Methods and Sources of Data

2.1 Historical Plans and Drawings

Staff from Dunedin City Council (DCC) sourced historical plans and drawings showing the shoreline along Ocean Beach from Council archives. The material was scanned into a high definition digital form (TIF) for analysis. Table 1 lists the available material, including the date of survey the digital file name and where possible, a Drawing or Plan number.

Table 1 File name and reference drawing number for hand-drawn survey maps used in GIS analysis.

Year	Digital File Name	Reference Number
1988	0010ADEC.010	4123
1894	0010ADEC.014	8907
1906	0010ADEC.012	1335
1914	0010ADEC.00B and 0010ADEC.00C	N/A
1952	0010ADEC.011	12069

It was expected that the historical survey data would also include maps based on early surveys. However there appears to be no 'Black Map' series for Dunedin. No early street maps showing an accurate shoreline feature were provided for analysis.

2.2 Aerial Photographs

Vertical aerial photographs showing Ocean Beach were obtained from New Zealand Aerial Mapping (NZAM). The temporal coverage was from 1942 to 2007, with an image approximately every 10 years. The dates of the photographs are listed in Table 2.

Table 2 File name and reference drawing number for hand-drawn survey maps used in GIS analysis.

Photograph Date	Coverage of shore	Geo-referenced
Oct 1942	Full	Yes
Mar 1947	Strips	To 1942 image
Mar 1957	Strips	To 1942 image
Feb 1967	Strips	To 1942 image
Apr 1978	Strips	To 1942 image
Feb 1985	Full	To 1942 image
Feb 1990	Strips	To 1942 image
Oct 1996	Full	To 1942 image
Mar 2000	Full	To 1942 image
Mar 2007	Full	Yes

2.3 Geo-referencing and Digitising Shoreline Features

The 1942 and 2007 photographs were used as base images, and were obtained as ortho-corrected images. This means that distortions in the photograph due mainly to the radial distance from the centre of the image are corrected to surveyed ground positions using the

New Zealand Map Grid. Each of the aerial photographs and shoreline surveys (Drawings) were geo-referenced to a base photograph using the ENVI image processing program and ArcGIS. This involves identifying reference points with identical position between photos or Drawings, such as roads and landmarks. The program adjusts the image so that the reference points overlay one another for the different images, in effect, correcting distortions in the image. Where the photographs included a number of images of the beach in a series of strips, each photographic strip was individually geo-referenced and the strips for each year combined into a mosaic and then trimmed to create a continuous image of the beach.

The Drawings were geo-referenced to the 2007 photograph. The shorelines on each Drawing were digitised and overlain onto the base-photo. Where the Lines of High Water or Low water were distinguished, these were plotted as Lines of Mean High or Low Water. Where the shoreline only was noted, this was assumed to represent the seaward line of the dunes, or close to the Line of Mean High Water.

The aerial photographs were initially geo-referenced to the 1942 photograph. Lines representing the wetted line (usually a mid-tide position on the beach) and the line of the seaward toe of the dunes were identified and digitised from the aerial photographs. The position of the wetted line was corrected relative to a mid-tide position by determining the state of the tide at the time of the photograph. These lines were overlain onto the 2007 aerial photograph as a base-photo so that the changes in shoreline position could be seen in relation to the position of the modern shore.

A geo-referenced baseline, landward of the shore, was digitised onto the base-photo. The line was segmented along the backshore to construct a sub-parallel line so that distances from the baseline to the beach features could be measured for each year. Distance to the dune position and wetted line position were measured at 50 m intervals along the baseline. Beach width for each photograph for different positions along the shore was calculated, and change between photographs was determined from these measurements.

2.4 Sources of Error

While the digitised lines give a good impression of trends change of the beach in plan view over time, there are errors associated with the analysis technique.

With regard to the aerial photographs, the position of the seaward base of the dune was approximated to the vegetation line, as the dune toe itself is not visible from the photographs. While this is generally a good approximation, there are instances where the behaviour of the vegetation line does not reflect the change in the base of the dune. The resulting error in position of the base of the dune may be in the order of 1 to 10 metres.

The position of the wetted line is usually easily identified from the photographs, but because the sandy beach is low gradient, small increments in water elevation due to the state of the tide, storm surge or wave set-up and run-up can move this position across the shore for some

distance relative to a still water tidal position. The resulting error in plan position relative to the tidal level could be in the order of 5 to 25 metres.

Errors can also arise in geo-referencing of some of the drawings. Drawings with little in the way of roads and landmarks have fewer points to geo-reference to, and so the quality of the overlay may be reduced. Any error in geo-referencing the drawings will be carried into the GIS analysis of the position of the shoreline feature. The magnitude of this type of error is unknown, but is minimised by judicious assessment of the Drawings and resulting geo-referenced image. The 1883 image shown in Figure 1 was not used for the analysis, as the geo-referenced image could not be reconciled with the features of the base photo.

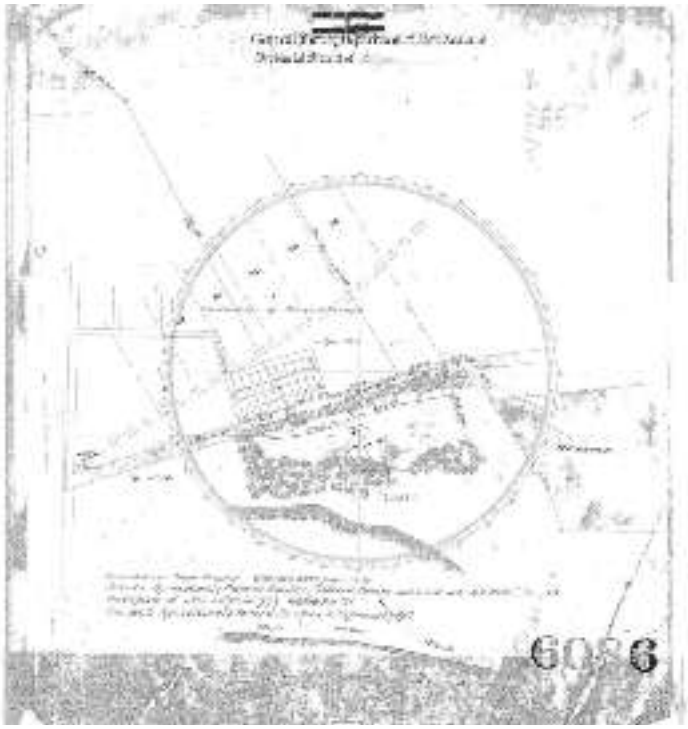

Figure 1 Area of shore at eastern end of Ocean Beach (near Musselburgh), surveyed in 1883, and showing the Mean High Water Mark and a line of Extreme Flood Tides.

3 Shoreline Change From Historical Plans and Drawings

Figures 2, 3 and 4 show the overlay of High Water and Low Water positions for the historical Plans and Drawings. The first Drawing showing the complete shoreline length is from a 1952 survey. The 1888 survey shows only the central section of the beach, while the 1894 and 1914 lines cover the western end of the beach, and the 1906 lines cover the eastern end of the beach.

From the 1888 Drawing, the marked line delineates between "The Ocean Beach" and "South Pacific Ocean". Therefore the 1888 shoreline depicted in Figures 2, 3 and 4 probably represents the landward limit of the active beach. The High Water Lines for 1894 and 1906 are denoted as such on the Drawings, but are likely to represent the seaward edge of the vegetated dunes. For all of these dates, the land landward of the High Water Line is likely to be dunes, vegetated or partially vegetated in grasses, and with different degrees of stability.

Anecdotal information indicates that ocean tides would flow inland towards Musselburgh (at the eastern end of the beach) to nearly reach Victoria Road / District Road. The 1894 Drawing also shows a line edging the dune area that may indicate the limit of extreme high water levels. This line approaches Victoria road in the vicinity of St Kilda, in the central section of the beach.

By 1914, the backshore and dune area along the western end of the beach appears more stable, with the sand hills planted in lupin. The 1952 Drawing gives no indication of the type of backshore. The High Water Line is also denoted as the Borough Boundary, while the Low Water Line appears to be drawn sub-parallel to the Mean High Water Mark.

The 1894 shoreline is the most seaward of those mapped, and is indicative of an embayment that is relatively full of sediment. It is likely that the sediment budget of Ocean Beach at this time reflects a surplus in supply of sand from offshore. However it is also likely that the dunes were partially vegetated, mobile and possibly deteriorating as buffers to storm wave incidence due to human activities and urbanisation of the hinterland.

In 1906, the beach at the eastern end of the beach is indicated by the line of High Water situated at the base of the slopes of Lawyers Head and the Lower Tomahawk Road, and a line of Low Water in a similar but slightly landward position to where it is today. This is indicative of mobile dunes and sand hills along the eastern part of the beach.

The 1914 lines of High and Low water show a narrower beach than in 1894, but the line of the beach is irregular in plan-view. This probably indicates low partially vegetated and mobile dunes on the upper foreshore. These are possibly embryo dunes, similar to those that form at the eastern end of the beach after prolonged periods of swell conditions. The irregular width of beach between the High and Low Water lines possibly represents the condition of the beach relative to recent storm and swell conditions. This type of shape can indicate onshore movement of bars in the nearshore, partially welded onto the beach, while allowing cell

circulation of nearshore currents across low sections of the bars. It shows the beach in recovery after a storm.

The 1952 shoreline is much more uniform in plan-view, and is similar in form and position to the shoreline of the 2007 base photo. The distance between the High and Low Water lines is fairly even. The distance between the St Clair seawall and the line of High Water indicates that the beach is probably well nourished with sand at the time of the survey for the Drawing, with more sand at the western end of the beach at that time than is shown in the 2007 base photo.

4 Shoreline Change From Aerial Photographs

Figures 5 and 6 show the Wetted line and line of the seaward toe of the dunes, respectively, as interpreted from aerial photographs between 1942 and 2007. The Wetted line is likely to be equivalent to the line of High Water depicted in the surveyed Drawings, while the toe of the dunes can be considered to be the landward limit of the effect of wave action, or equivalently, the seaward limit of dune growth.

4.1 Changes to the position of the toe of the dune

It can be seen from Figure 5, that the horizontal excursion of the toe of the dunes has covered a narrow width of the shore between 1942 and 2007. There has effectively been no change in position of the backshore limit of wave action at St Clair due to the presence of the seawall. The widest excursion of the dunes has occurred along the eastern end of the beach, adjacent to John Wilson Ocean Drive.

Overall, the dunes appear to have prograded seaward between 1942 and 1990, with local excursions landward at the point where John Wilson Ocean Drive reaches the shoreline and at Moana Rua Road. The landward retreat of the dune toe is greatest in 1957, occurring along the western section of the beach to John Wilson Ocean Drive, and at the extreme eastern end of the beach.

Table 3 shows the mean change in dune toe position between each of the sequential aerial photographs, for sections of Ocean Beach. The dunes appear to have built seawards between 1942 and 1985, except for retreat of the dunes in Area 6 (along John Wilson Ocean Drive). Between 1985 and 1990 there was retreat of the western section of the beach and accretion or near- stability for the rest of the beach, including the extreme eastern end. . Between 1990 and 1996 there was general retreat of the dune toe by an average of between 5 and 10 m. However by 2000, the dune toe had built seaward again to be in a similar position to 1990 except in the Moana Rua to Kettle Park section of the beach. There has been slight retreat of the dune toe between 2000 and 2007 except for the section of Kettle Park to St Kilda. The overall across shore excursion since 1942 is in the order of 6 to 30 m from west to east along the shore.

Table 3 Changes in position of the dune toe between aerial photographs. Area 1 = St Clair seawall. Area 2 = Seawall to the Marae. Area 3 = The Marae to Moana Rua. Area 4 = Moana Rua to Kettle Park. Area 5 = Kettle Park to St Kilda. Area 6 = St Kilda to Lawyers Head

	1942-47	1947-57	1957-67	1967-78	1978-85	1985-90	1990-96	1996-00	2000-07
Area 1	3.43	-6.27	7.48	-4.53	2.67	-6.93	2.23	5.10	2.88
sd	2.92	2.13	4.88	2.61	3.99	4.23	3.53	4.92	4.12
Area 2	6.94	-11.36	12.50	-3.64	14.84	-18.70	1.28	5.34	0.32
sd	6.70	2.56	3.37	3.76	1.97	1.14	2.63	3.42	2.14
Area 3	9.92	-1.38	6.87	-1.82	10.45	-5.53	-7.87	6.57	-3.05
sd	4.09	1.94	4.25	3.74	3.81	5.36	4.04	3.08	3.90
Area 4	3.34	4.58	10.46	2.74	9.88	0.54	-15.16	4.70	-2.66
sd	1.76	3.95	7.09	5.69	2.88	3.98	3.55	0.98	2.94
Area 5	1.15	6.24	15.86	3.74	8.18	-2.61	-5.10	3.95	-3.64
sd	2.61	9.92	10.77	4.98	5.03	4.69	5.93	3.03	3.62
Area 6	4.46	24.44	-0.47	10.49	-4.77	8.37	-7.97	2.59	2.80
sd	2.27	14.05	7.52	7.29	7.89	6.98	5.11	3.42	3.05
Area 7	-2.22	13.89	3.57	16.13	-18.21	18.91	-9.72	4.54	2.35
sd	5.80	16.31	13.81	5.87	4.93	6.86	3.77	2.27	1.97

4.2 Changes to position of the wetted line

Figure 6 shows the change in position of the Wetted line on the beach. The most landward position of the Wetted line was in 1942, with the most seaward being 1957 for the western end of the beach, and 1990 for the eastern end of the beach. The 'swing' of progradation and erosion of each end of the beach around a centre axis in the vicinity of Kettle Park is indicative of the beach showing different responses to different predominant wave directions.

Table 4 shows the mean change in position of the Wetted line. The most seaward mean position of this line was in 1947. The position was on average, about 43 m seaward of the 1942 position .The most landward mean position of this line (since 1942) was in 1996, with the position on average about 16 m seaward from the 1942 position. There was a narrow excursion across the beach of the position of the Wetted line over the aerial photographs, with the position generally being about 30 to 40 m from the 1942 position.

The area of the beach that has the most variable position of the Wetted line is the area from the St Clair seawall to about 100 m east of the end of the wall, about the position of the remnant wooden groyne. The Wetted line position ranges from in line with the seawall to at least 49 m seaward.

Table 4 Changes in position of the Wetted line between aerial photographs. Area definitions as per Table 3.

	1942-47	1947-57	1957-67	1967-78	1978-85	1985-90	1990-96	1996-00	2000-07
Area 1	56.53	-6.83	-5.00	-13.50	2.90	-24.97	3.30	-15.73	16.00
sd	2.49	6.07	6.32	0.98	3.51	1.72	1.48	1.10	1.06
Area 2	46.80	6.08	-15.76	-5.96	1.08	-19.62	-1.04	-7.50	22.38
sd	3.54	2.24	2.72	7.30	6.05	3.12	4.48	11.67	2.61
Area 3	50.21	-0.81	-12.95	-3.33	-1.82	-10.04	-9.65	3.71	7.78
sd	5.02	2.94	7.11	7.43	4.27	7.80	6.09	4.50	9.17
Area 4	39.14	-6.52	0.90	11.60	-15.18	3.28	-22.00	12.46	3.96
sd	6.90	7.84	7.47	5.64	7.17	8.02	9.89	5.98	6.01
Area 5	39.58	-6.94	4.28	0.04	7.31	-7.53	-14.05	9.66	0.90
sd	6.63	4.91	4.62	3.68	5.38	10.80	8.47	4.73	7.49
Area 6	38.81	-1.04	9.17	-5.59	12.90	-4.71	-20.56	7.59	15.63
sd	6.21	5.38	5.58	8.05	8.62	6.02	3.19	4.94	8.34
Area 7	32.29	-18.57	28.72	4.01	5.34	0.66	-33.09	24.78	17.97
sd	5.34	11.24	8.21	7.44	5.06	4.07	7.45	6.08	3.77

5 An Interpretation of Shoreline Change From 1888 to 2007

There are two main aspects to the shoreline change for Ocean Beach since the 1880s. The first is the destabilisation and subsequent reforming of the dunes and sand hills prior to about 1914. The second is the development of the 'straight-line' contemporary shore between the St Clair seawall and the eastern end of John Wilson Ocean Drive.

There are probably three phases to the attainment and maintenance of the 'straight-line' shore. The first is the construction of the St Clair seawall, shifting the stable backshore eastwards along the beach by about 500 m. This does not appear to have had a major effect on the plan-view development of the shoreline, except that it has limited the formation of dunes to act as a buffer against wave attack (this function being replaced by the seawall), and as storage of sand to be returned to the nearshore during storms. This has resulted in episodic exposure of the rock and cobble platform beneath the thin veneer of sand at the western end of Ocean Beach.

The second and third phases are the changes to the backshore with the construction of John Wilson Ocean Drive and infilling and levelling of Kettle Park sports fields. These works effectively stabilised the backshore, preventing dune formation in times of abundant sand supply to the beach, but also limiting sand loss from the backshore during storms. The 'softer' edge of John Wilson Ocean Drive has allowed dune development seaward of the road, but the dunes are higher and are trimmed on the seaward edge, maintaining the plan position to within a few metres since 1967, except for the erosion of about 15 m (landward retreat of the dune scarp) eastward of Tahuna during large storms between 1976 and 1978. However the dune had recovered by 1985.

The dune toe from the Marae to St Kilda moved seaward between 1942 and 1957, but has remained relatively stable in position since the 1967 aerial photograph, with excursion of the dune toe by plus or minus about 10 m. The main difference to this section of the shore has been the form of the dunes, with the seaward edge of the dunes becoming higher and steeper as the backshore was stabilised and levelled.

Overall, the movement of the dune toe is progradation in the order of 10s of metres since the 1880s, with fluctuations due to storms and storm recovery of 10 to 15 m since the late 1950s.

Specific hotspots can be identified from the aerial photographs. These are mainly associated with access points to the beach. There is apparent evidence of deterioration and subsequent repair of the dune at the beach access points at Moana Rua and on John Wilson Ocean Drive at St Kilda.

The beach area seaward of the dunes has undergone minor changes since the 1880s, with the main change being from a wide flat beach in 1894 to a narrower beach but with the High Water line located more seaward in 1957. There is very little change to the position of the High Water and Wetted lines of the beach evident in the aerial photographs since 1967. However it is known that the beach responds rapidly to storm erosion, and subsequently

recovers during swell periods, such that the position of High Water is not fixed in pace, but is dynamic within a narrow width of shore.

The aerial photographs also show that the beach response to changes in the wave environment includes re-orientation of the shore to face the incoming waves. This is evident as a slight east/west swing of the line of the beach, pivoting around a position about 150 m east of Moana Rua Road. It is also evident that there is formation of offshore bars during storms, and subsequent migration onshore of sand during swell periods. The onshore migration of sand can retain the bar form, but also can come ashore in 200 to 300 m long sections as the bars break down in response to cell circulation systems in the nearshore.

The line of the beach appears to be held in position by the artificial material in dunes (soil, rubble etc.), by planting and dune management immediately east of the St Clair seawall and in the vicinity of beach access points, and by the hinterland developments (Kettle Park, John Wilson Ocean Drive). This has resulted in a steep high dune face that presents a potential hazard to beach users after storm erosion, and inhibits but does not preclude embryo dune development at the base of the scarp.

6 Conclusions and Recommendations

The shoreline position at Ocean Beach has moved seaward since the 1880s. This involves progradation of the dune toe and the lines of High and Low water. The dunes have become stable, in that they now form a single line along the backshore, and are fully vegetated except for the seaward face and embryo dunes. The beach position moves seaward and landward by about 10 to 15 m in response to storms and periods of swell. There can also be slight changes to the orientation of the beach in response to the direction of wave approach.

The shoreline position appears to have a seaward limit, at about the position of the 1957 High Water line in the western half of the beach, and the 1990 line in the eastern half of the beach. The position is a function of the distance between the fixed points of St Clair and Lawyers Head, the amount of sand delivered to the beach from offshore, and the characteristics of the wave environment (mainly wave energy, and direction of approach).

Infilling and levelling of hinterland prevents landward migration of dune sands, and effectively holds the landward limit of the dune position. Dynamic dune processes whereby sand is released from the dune to the beach in times of storm, and new dunes form, grow and become vegetated during long periods of quiescent wave energy and abundant sand supply, are limited in across-shore extent due to the relatively high, steep face of the main dune. Dune development seaward is limited by the episodic occurrence of high-energy wave events.

There is potential for hazards to beach users due to the steepness and instability of the eroded dune face during and after storms, and potential loss of hinterland resource due to retreat of the dune during storms. However there is also likely to be less landward retreat of the dune as

a response to storm wave attack because the high steep dunes provide a larger volume of sand to be released to the beach per metre of horizontal retreat. A significant result of storm erosion of the dunes is that it disrupts access to the beach from the hinterland at the eastern end of the St Clair seawall, at Moana Rua Road and at St Kilda.

As there appears to be a seaward limit to the extent of the beach, it is unlikely that the line of the dunes or beach could be artificially 'encouraged' to move seaward without construction of some feature offshore that provides for development of a tombolo or artificial headlands for a new curvature to the embayment.

It would be possible to create a dynamic dune buffer, of a lower elevation than at present along the beach between the Marae and Kettle Park by providing a more gradual slope to the hinterland. However, there would need to be provision of a width of land to allow for potential landward retreat of the dune toe in response to storms, to at least the position of the 1942 dune toe. This is a position about 30 m landward of the 2007 dune toe position. This would provide space for the dune to grow during periods of swell waves, and for the dunes to release sand to the beach during storms. The provision of horizontal space for movement of the dunes may require sacrifice of existing hinterland resource use.

It appears that the beach position is relatively stable as long as there is a supply of sand to the nearshore. This sand can come from offshore, from the dunes or move from the beach to the nearshore and back. Beach sands can also be blown onshore to form new dunes as part of the recovery of the beach after storms.

As part of the management of this beach, it is important to understand that the beach is dynamic, and that the sand on the beach and in the dunes moves from one place on beach to another in response to changes in the wave environment. During storms, this movement is usually offshore via the formation of bars. During periods of lower wave energy, these bars will migrate back onshore and eventually the sand can resupply the dunes.

It is also important to understand that changes in orientation of the shoreline may result in periods when there will be no sand or only a thin veneer of sand in front of the St Clair seawall. This is a historical feature of the way this beach responds to storms, and the sand does return to the western end of the beach once the wave conditions change.

7 References

Todd, D. 2010 Ocean Beach Restoration Project: Topographical survey results. Unpublished report to Dunedin City Council, DTec Consulting Ltd.

7.1 Captions for attached figures

Figure 2 Historical lines of High Water, 1888 to 1952

Figure 3 Historical lines of Low Water, 1888 to 1952

Figure 4 Historical lines of High and Low Water, 1888 to 1952

Figure 5 Wetted line identified form aerial photographs, 1942 to 2007

Figure 6 Line of the dune toe identified from aerial photographs, 1942 to 2007