Shoreline Monitoring in Tory Channel and Queen Charlotte Sound

Summary report
November 2013 – November 2016

Report prepared for the Marlborough District Council

by

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Executive Summary

The introduction of fast ferries in the mid-1990s resulted in very significant effects in Kura Te Au/Tory Channel and Tōtaranui/Queen Charlotte Sound resulting in coastal change (both erosion and accretion), and concern for public safety from high energy waves. A bylaw for navigational safety purposes in December 2000 had the effect of slowing fast ferry speeds.

The shoreline erosion monitoring program was established in 1997, specifically to examine the effects on beach and shoreline morphology of the fast ferries. Professional surveyors have regularly measured 21 shoreline profiles in Tory Channel and Queen Charlotte Sound.

Over the last 20 years, the monitoring program has reported the effects of the fast ferries and conventional vessels where possible, and determined the natural variability of beach profiles along the ferry route. Data have also been collected from control sites in the outer part of Queen Charlotte Sound, off the Wellington – Picton ferry route. The survey data have been analyzed at approximately three-yearly intervals and reported to Council.

A purpose of this report is to present the last three years of monitoring for each site within the context of the long-term data set. The results overall show relatively little change over this period. This is a continuation of a slow return that has been happening, to pre-fast ferry conditions. The return to a pre-fast ferry equilibrium state, started to occur immediately after the bylaw was brought in, although in some locations 'relict' fast ferry sediment deposits remain. Sediment transport processes are now largely influenced by waves from conventional ferry traffic and natural drivers of processes, such as storms.

The report's other purpose is to present a review of the programme, and to provide recommendations for its future, the outcome of which depends primarily on whether its purpose remains the same as it was when the program was established or if it changes.

The ongoing monitoring has been effective in demonstrating the effects of fast ferry operation on beaches. Measurements of wake characteristics showed that the fast ferries generated sufficient energy to transport sediment in both alongshore and cross-shore directions. It has also demonstrated the importance of sediment supply, and how fast ferries contributed to increased sediment availability along the route. It has also been shown that the beach profiles in the outer Queen Charlotte Sound, not affected by regular large vessel traffic, are generally very stable.

It is recommended that if the purpose of the monitoring program remains as it was when it was established, that is to determine the impacts of vessel-wakes, then the monitoring program could be suspended. This is on the basis that it could be resumed should there be a need based on changes in vessel operation, such as the introduction of large conventional vessels which may have different wave effects to existing vessels. The accurate survey of positions and heights to the Picton datum undertaken in 2013, enables the reestablishment of benchmarks should they be lost

If the purpose of the monitoring program is to fulfil obligations to monitor the state of the environment, then the value of continuing to monitor sites that already have a 20 year record far outweighs a possibly more appropriate set of locations that might be more representative. In this case, the monitoring program should continue, perhaps at a reduced frequency, and the number of sites could be reduced by up to a third based on the present understanding of shoreline dynamics after 20 years and the fact that some locations are not representative of significant sections of shoreline.

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Introduction

The monitoring program was established specifically to examine the effects on beach and shoreline morphology of fast ferries which were introduced to the Wellington to Picton route in the mid-1990s. Experimental work involving the measurement of wakes was also undertaken in the first few years of the program, and together the monitoring and experimental work was generally effective in determining the morphological effects of the fast ferries. Much of this early work culminated in the development of the Navigation Bylaw 2000 which came into force on 10 December 2000. The bylaw has been replaced by the Navigation (Vessel Speed) Bylaw 2009 which continued the same approach as the Navigation Bylaw 2000 with respect to large vessel speed regulation.

The choice of profiles that comprised the monitoring program was determined based on a number of factors that were relevant at the time, all of which related to the objective of the monitoring program. Some profile locations were used because there was already data collected since 1995. Other locations were included at the request of elected Councilors. The remaining locations on the ferry route were selected based on them being representative of sections of shoreline where access was relatively simple. The sites in the outer Queen Charlotte Sound were selected essentially as ‘Control’ sites to gain some understanding of natural variability where vessel generated wakes were infrequent.

The monitoring continued after the fast ferries ceased operation, and beyond the implementation of the management strategy enforced through the Navigation Bylaw 2000. This may have been due to the possibility of legal challenges to the Bylaw, or the possibility of fast ferries returning, or new classes of vessels entering service which may have had different wake characteristics to those that operated in the past or continued to operate. A good example of a situation like this is reported by Parnell et al. (2008)[1], where high powered ‘conventional’ ferries were introduced that produced wakes with characteristics similar to those generated by fast ferries. However, it could be argued that the introduction of such vessels can be managed through the Navigation Bylaws.

It is also possible that the continuation of the monitoring program was in response to the requirements under the Resource Management Act (1991) for Councils to monitor the environment. A major problem with coastal monitoring is that long-term monitoring is expensive but required for useful conclusions to be made. It is therefore very tempting (and normally a very good practice) to continue adding to already established data sets. However, it is certain that the choice of monitored sites would have been very different if the purpose of the program was not specifically related to vessel wakes.

The value of the monitoring program has been increased by an accurate survey of positions and heights to the Picton Datum undertaken in 2013. This enables the reestablishment of benchmarks should they be lost (something that is certain if regular monitoring is discontinued).

[1] Parnell KE et al. (2008) Far-field vessel wakes in Tallinn Bay. Estonian Journal of Engineering, 14 (4). pp. 273-302

A review of the effectiveness of the monitoring is one of the purposes of this report. Comments are also made on the future shape of the monitoring in terms of frequency and configuration. In this respect, the objectives are to:

- Provide an overview of the effectiveness of the monitoring in detecting effects on beach profiles over the duration of the monitoring programme.
- Evaluate the continued fitness-for-purpose of the monitoring and provide suggestions for either: reducing the monitoring; refining the existing monitoring in terms of sites and frequency of monitoring; increasing the monitoring in terms of sites and frequency.
- Summarise the effects of ship-wakes on shoreline dynamics at each site over the entire duration of the monitoring programme.
- Provide commentary on the utility of the monitoring design for understanding the effects of sea-level rise.

The other purpose is to report on the last three years of monitoring data at all sites in the context of the long-term monitoring record, and to update the commentary on the data set, including the most recent benchmark information. This continues the series of approximately triennial summary

Profile locations and methods

The location of the 21 profiles is shown in Figure 1, and their positions are detailed in Table 1. Most profiles were first surveyed under this contract in April 1997. A small number of profiles were established using the lines and levels of profiles established by Prof Robert Kirk of Canterbury University in 1995, operating as consultant to NZ Rail Ltd. Where data prior to 1997 exist, the EDA plots and the volume data and plots incorporate the earlier data.

In 2013 Aysons undertook a GPS static/semi-static survey to rationalize all of the cross section locations into one vertical datum and obtain an accurate position for each cross section. The process was reported in the November 2013 survey report. This enables the re-establishment of cross sections should all profile marks be lost (Table 1). The data detailing profile locations as received from Aysons have been modified to include the reduced level of the point reported on the profile line (RL interpolated). This was done using linear interpolation from the profile data. These data will be required to reestablish the height of any profile markers if all the markers on the profile are lost, along with the location.

Current survey pegs and their reduced levels are listed in Table 2. The constants required for translation between the pre-2013 and the current reduced levels are also listed.

A visual impression of the profiles can be obtained from the photographs in Section 4 and in Appendix 2.

Table 1: Profile positions

Surveyors: Ayson &Partners Ltd
Contract: 8400 MDC - Tory Channel and QCS Beach Cross
November 2013
Coordinate System: NZTM
Coordinate Origin: BEOE Dieffenbach Point 5434876.50mN 1696066.06mE
Level Datum: Chart Datum (Picton) - GPS Heights adjusted via NZVD09
Level Origin: BQFK Elaine Cairn RL 2.771m
Note: figures shown in the 'Distance' column below give the location of the coordinated point with respect to each cross section's established 'chainage'. The magnetic bearing is that of the cross section alignment as per measured via compass.
The approximate grid bearing is calculated from the measured magnetic bearing + 20° as per a comparison of magnetic/grid for a known observed line in Picton.

Cross Section #	mN	mE	Distance (m)	Magnetic Bearing °	Approximate Grid Bearing°	RL Interpolated (m)
1	5428756.53	1684319.62	0.00	17	37	2.55
2	5432466.78	1686820.63	6.49	283	303	1.01
3	5436189.10	1700041.44	6.43	286	306	1.17
4	5434146.79	1699370.31	7.59	94	114	1.22
5	5431416.52	1687914.38	4.51	334	354	0.59
6	5433415.02	1701873.99	8.81	115	135	0.97
7	5433403.76	1701862.14	11.78	137	157	1.00
8	5430177.23	1685171.06	6.69	232	252	0.69
9	5437351.49	1707964.33	0.00	142	162	2.35
10	5435152.78	1707854.53	3.89	293	313	0.99
11	5446832.48	1706622.88	6.92	306	326	1.28
12	5445251.51	1708422.43	9.39	278	298	0.65
13	5432856.47	1696550.86	10.51	17	37	1.06
14	5433814.62	1698838.71	5.05	154	174	0.96
15	5432856.97	1699938.15	13.20	293	313	0.27
16	5433246.86	1700817.21	11.94	5	25	1.14
17	5433301.53	1700773.40	4.35	53	73	0.65
18	5434306.14	1695188.44	7.14	274	294	1.11
19	5433867.59	1692508.91	7.74	312	332	0.75
20	5440212.84	1705942.69	8.95	331	351	0.83
21	5442717.22	1703576.61	7.10	300	320	0.77

Table 2: Survey benchmark reduced levels

Pr	Name	Peg	Dist. (m)	Pre 2012 RL	2013 RL	Convert 2012 RL to 2013 RL	Notes
1	NEWPicton Foreshore	C	0.0	2.55	2.55	0	C" hole in grey stone (now alluminium tappet)
1	Picton Foreshore	Wall	6.9	2.44	2.44	0	Top of Wall
2	The Snout at Picton Point	IT	-1.0	3.30	3.35	0.05	
2	The Snout at Picton Point	W	0.0	2.95	3.00	0.05	
3	Double Bay	W	-1.5	2.72	2.78	0.06	
3	Double Bay	IT	0.0	1.98	2.04	0.06	
4	Ngaionui Bay (C Thomas)	IT (flush)	-2.5	2.39	2.43	0.04	
4	Ngaionui Bay (C Thomas)	W	-2.0	2.69	2.72	0.03	
5	Blackmore's at Waikawa	Nail	0.0	1.90	2.11	0.21	In round post
6	Moioio Island 2	W	-2.0	1.74	2.18	0.44	
6	Moioio Island 2	0IS A	0.0	1.41	1.85	0.44	
7	Moioio Island 1	W	-2.0	1.70	2.18	0.48	
7	Moioio Island 1	IT	0.0	1.34	1.81	0.47	
8	Bob's Bay	IT	-2.7		3.16		New Nov 2015
8	Bob's Bay	W	-2.0	2.96	3.57	0.61	
9	Te Awaiti	W	-6.0	2.01	3.00	0.99	
9	Te Awaiti	IT	0.0	1.13	2.12	0.99	
10	Tipi Bay	W	-2.5	2.19	2.79	0.60	
10	Tipi Bay	New IT	-1.5	1.56	2.16	0.60	
11	Long Island	W	0.0	2.84	2.86	0.02	
11	Long Island	IT	-2.5	2.14	2.17	0.03	
12	Clark Point	IT	-1.4		2.13		New Nov 2013
12	Clark Point	OISA	2.3	2.03	1.40	-0.63	
13	Slip Beach	IT	-0.5	1.74	2.54	0.80	
13	Slip Beach	W	-0.1	2.00	2.82	0.82	
14	Ngaionui Point	W	-2.0	2.39	2.46	0.07	
14	Ngaionui Point	IT	0.0	1.87	1.95	0.08	

15	Te Weka Bay	IT	0.0	1.50	1.79	0.29	
16	McMillan's Bay	W	-2.0	2.91	3.45	0.54	
16	McMillan's Bay	IT	0.0	1.42	1.98	0.56	
17	McMillan's Side	IT	-2.0	2.94	3.40	0.46	Use this one for calc.
17	McMillan's Side	W	0.0	1.79	2.27	0.49	Labelled as 'old'
18	Dieffenbach West	W	-0.2	2.57	2.58	0.01	
18	Dieffenbach West	OIS A	0.0	2.52	2.55	0.03	
19	Curious Monkey	W	-1.0	3.68	3.68	0.00	Apparently gone.
19	Curious Monkey	IT	-0.6		3.68	0.00	New Nov 2016
19	Curious Monkey	OIS A	0.0	2.52	2.51	-0.01	Use this one for calc.
20	Patten's Passage	IT	-1.1	3.49	3.53	0.04	
20	Patten's Passage	W	0.0		2.35	0.04	Noted 'New Level Nov 2016'
20	Patten's Passage	W	0.0	2.64	2.68	0.04	
21	Blumine Island	W	-0.2	2.66	2.67	0.01	
21	Blumine Island	IS New	-5.5	4.81	4.80	-0.01	

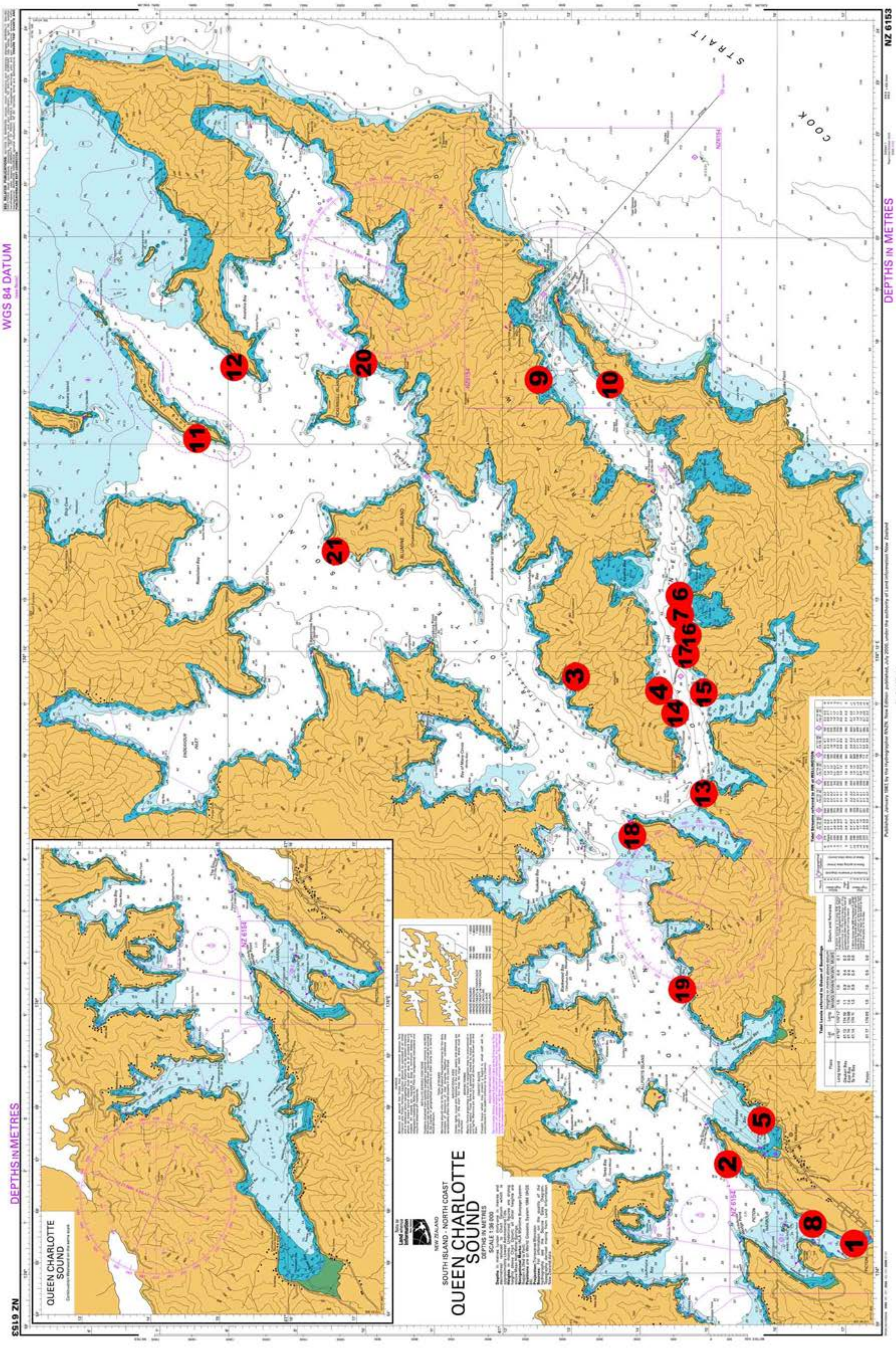


Figure 1: Profile locations

Vessel operations affecting the profile sites

Vessels carrying passengers and freight between Wellington and Picton, have operated the Tory Channel/Queen Charlotte Sound route for many years. In late 1994, fast ferries started using the route alongside the conventional ferries. Until 2000, various fast ferries operated over the summer months, after which an almost continuous service ran until April 2005. However, in December 2000 the MDC enacted a bylaw that had the effect of slowing fast ferries to 18 knots while in the Sounds. Fast ferries have not operated on the Wellington – Picton route since early 2005. Figure 2 shows the time periods over which various vessels have operated. Other vessels, both large and small, also use the route.

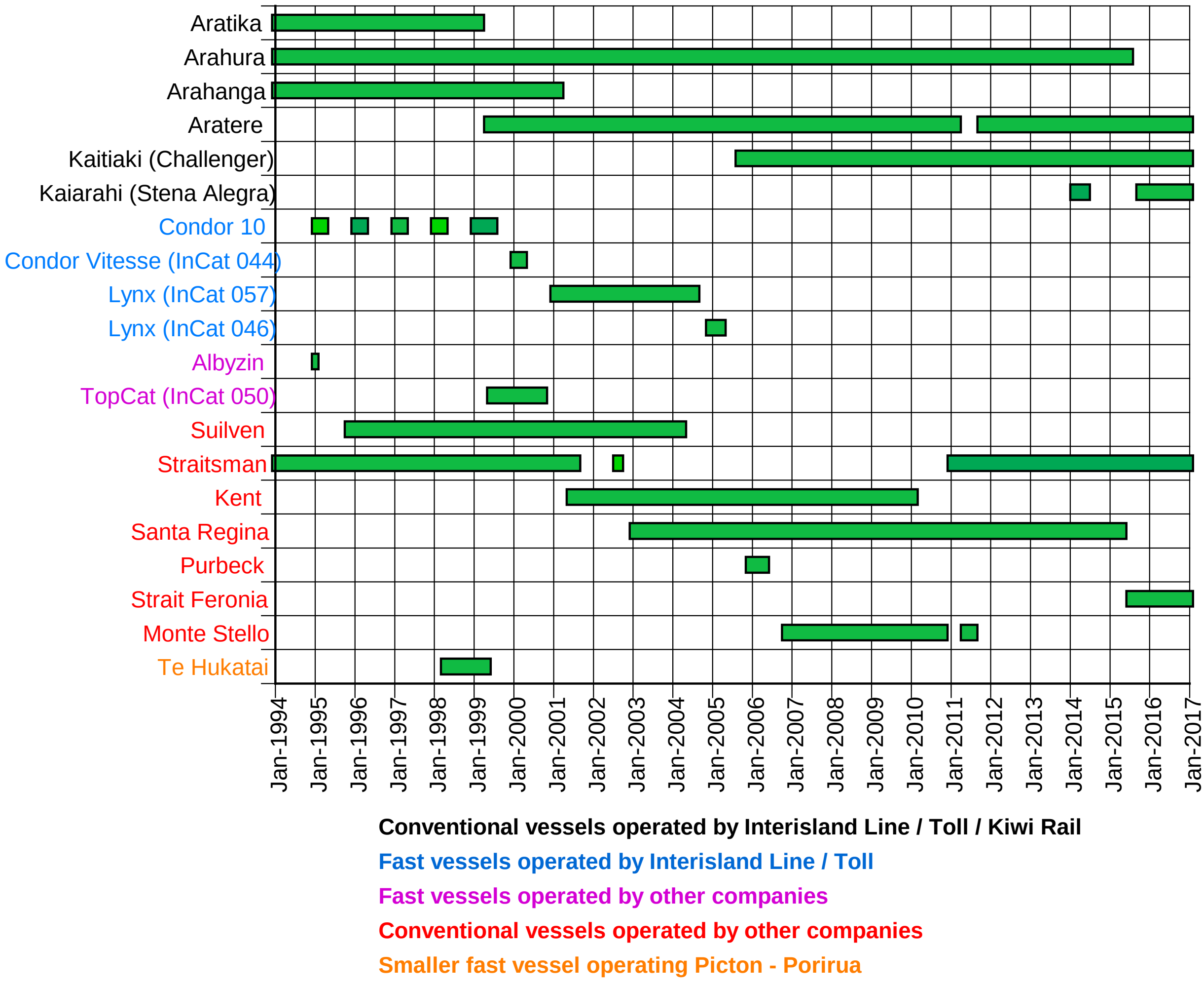


Figure 2: Vessels using the Tory Channel/Queen Charlotte Sound route on regular inter-island services. Notes: 1) The 'Straitsman' that commenced operation in December 2010 is a different vessel operating under the same name. 2) The Monte Stello was operated by the Interisland Line between April and September 2011.

Profile analyses

In this section, data are presented for each profile, along with an interpretation of the changes that have occurred. Each profile analysis is accompanied by three pages of figures. The first page has photographs taken November 2016, of the profile site taken from about 20 meters each side looking back towards the profile line. At the bottom of the first page is a diagram of profile lines at the start of the monitoring programme in April 1997, the end of the first contract (November 1999), the end of the second contract period (April 2002), the end of the third contract (May 2006), the end of the fourth contract (April 2009), the end of the fifth contract (May 2012) and in November 2016. The second page comprises a ‘spaghetti’ plot showing the 33 surveys of the profiles (April 1997, November 1997, April 1998, November 1998, April 1999, November 1999, April/May 2000, November 2000, June 2001, November 2001, April 2002, November 2002, April 2003, November 2003, April 2004, November 2004, April 2005, November 2005, May 2006, November 2006, April 2007, November 2007, April 2008, November 2008, April 2009, November 2009, November 2010, April 2011, November 2011, May 2012, November 2013, November 2015 and November 2016) in the upper section, and in the lower section, a different view of the same data commonly known as an ‘Excursion Distance Analysis’. The final page shows beach volume data (m^3 per linear meter of beach) presented as a graph and a table.

The limits for the volume calculations are determined as shown in Figure 3 and Table 3. The upper beach limit was a point on the upper beach landward of any profile change (if possible) or at the upper limit of the profile measurement. Because changes at the lower beach can indicate erosion, a measurement based on elevation is appropriate. This was taken at profile closure depth if this was evident, or at a point which was reached on most surveys. In order to maintain continuity with previous surveys, the lower beach limit was maintained after the datum shift undertaken in 2013, which is why the lower limits are different from those reported in previous reports, and appear ‘irregular’. The profile covered is, however, identical. On the odd occasion when a profile survey did not reach the chosen lower limit, a value was estimated based on linear extrapolation or on values measured before and after a missing data point.

Table 3: Volume calculation limits

Prof.	Name	Upper beach limit (m)	Lower beach limit (m)
1	Picton Foreshore	6.87	-0.50
2	The Snout at Picton Point	0.00	-0.95
3	Double Bay	-1.50	-0.94
4	Ngaionui Bay (C Thomas)	-2.00	-0.21
5	Blackmore's at Waikawa	2.30	-0.54
6	Moioio Island 2	-2.00	-1.06
7	Moioio Island 1	0.00	-1.02
8	Bob's Bay	0.00	-0.39
9	Te Awaiti	0.30	-0.51
10	Tipi Bay	0.00	-0.65
11	Long Island	0.00	-0.72
12	Clark Point	0.00	-0.88
13	Slip Beach	-1.00	-0.44
14	Ngaionui Point	-2.00	-0.67
15	Te Weka Bay	2.00	-1.21
16	McMillan's Bay	0.00	-0.20
17	McMillan's Side	-2.00	-0.28
18	Dieffenbach West	0.00	-0.47
19	Curious Monkey	0.00	-0.50
20	Patten's Passage	0.00	-0.46
21	Blumine Island	0.00	-0.50

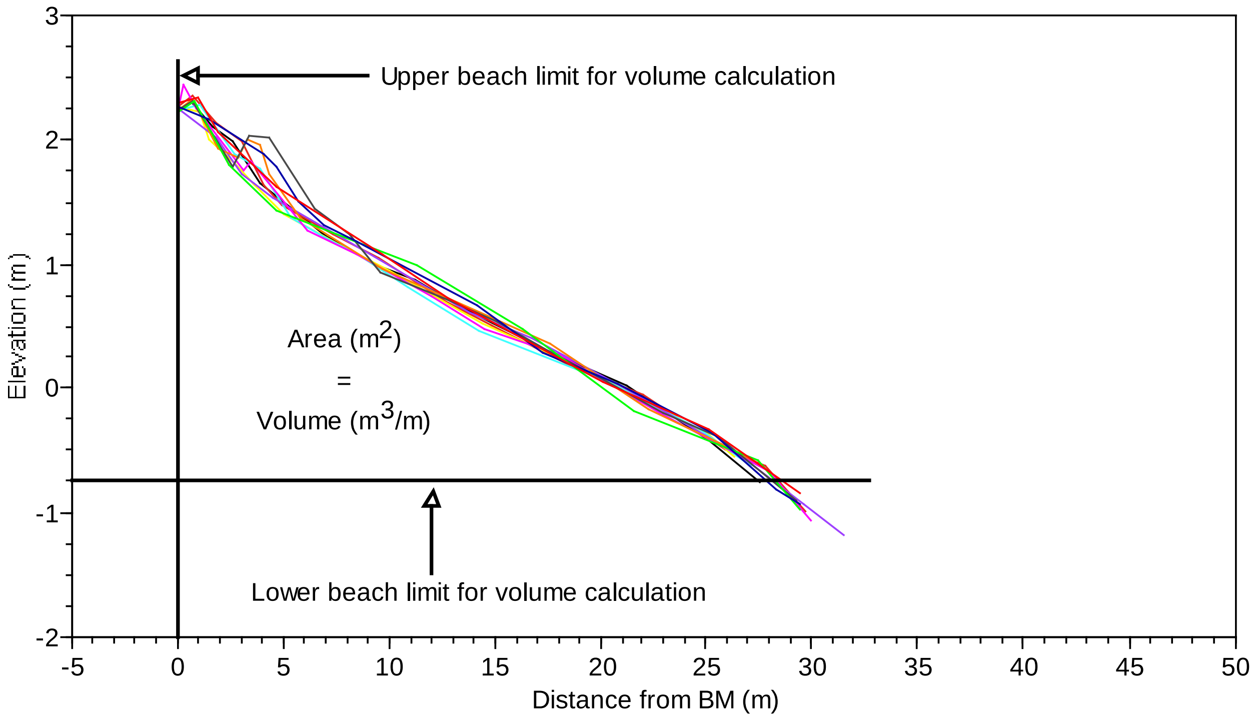


Figure 3: Volume calculation methodology

The ‘spaghetti’ plots of profiles are useful for establishing envelopes of change of the beach shape, but interpretations of changes that have occurred are difficult, due to the clutter of lines that are present. As the data set grows, any useful interpretation based on these plots becomes almost impossible. Excursion distance plots use exactly the same data plotted as a time series, and makes interpretation of beach changes easier. Excursion distance analysis is a method by which three dimensional data sets (distance, height and time) can be illustrated as plots with time on the independent axis. It can be undertaken with either distance or height on the vertical axis, although having distance on the vertical axis is more useful for most purposes. Excursion distances are calculated by determining a set of height values for which calculations will be made. These values are normally equally spaced and in the following figures, are shown in the box on the right hand side of the graph. These numbers are in units of metres above or below the datum (in this case the zero level established by Aysons in the GPS survey in 2013, stated as being Chart Datum Picton). Using linear interpolation, the horizontal distance from the datum is calculated for each of the height values, and these are plotted as a time series with time on the horizontal axis. For each survey this provides a “point contour map” of the profile, and when plotted as a time series, an indication of how levels change through time. The graphs provide a lot of information. If two lines converge, the beach is getting steeper at those contour heights. If two lines diverge, the beach is getting flatter. If the lines trend seaward (increasing values on the distance axis), the beach is accreting. If the lines trend landward, the beach is eroding. Figure 4 attempts to show the methodology of Excursion Distance Analysis.

The terms ‘erosion’ and ‘accretion’ correctly refer to the landward and seaward migration of the entire beach profile. However, they are commonly used to reference changes within the beach profile. In this report, the common usage is generally applied. Where there is actual erosion or accretion, the context is made clear in the description.

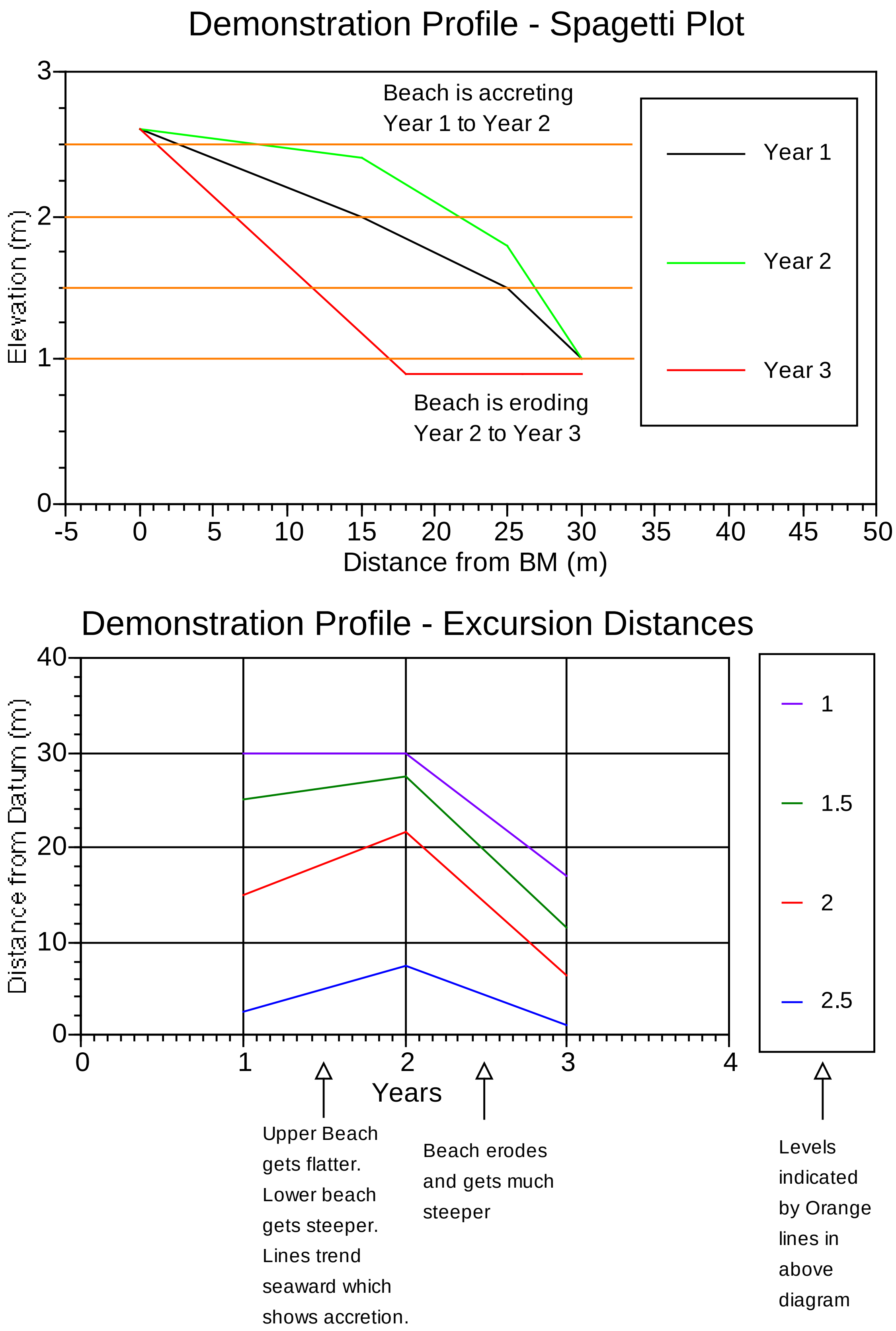


Figure 4 : Excursion Distance Analysis Demonstration

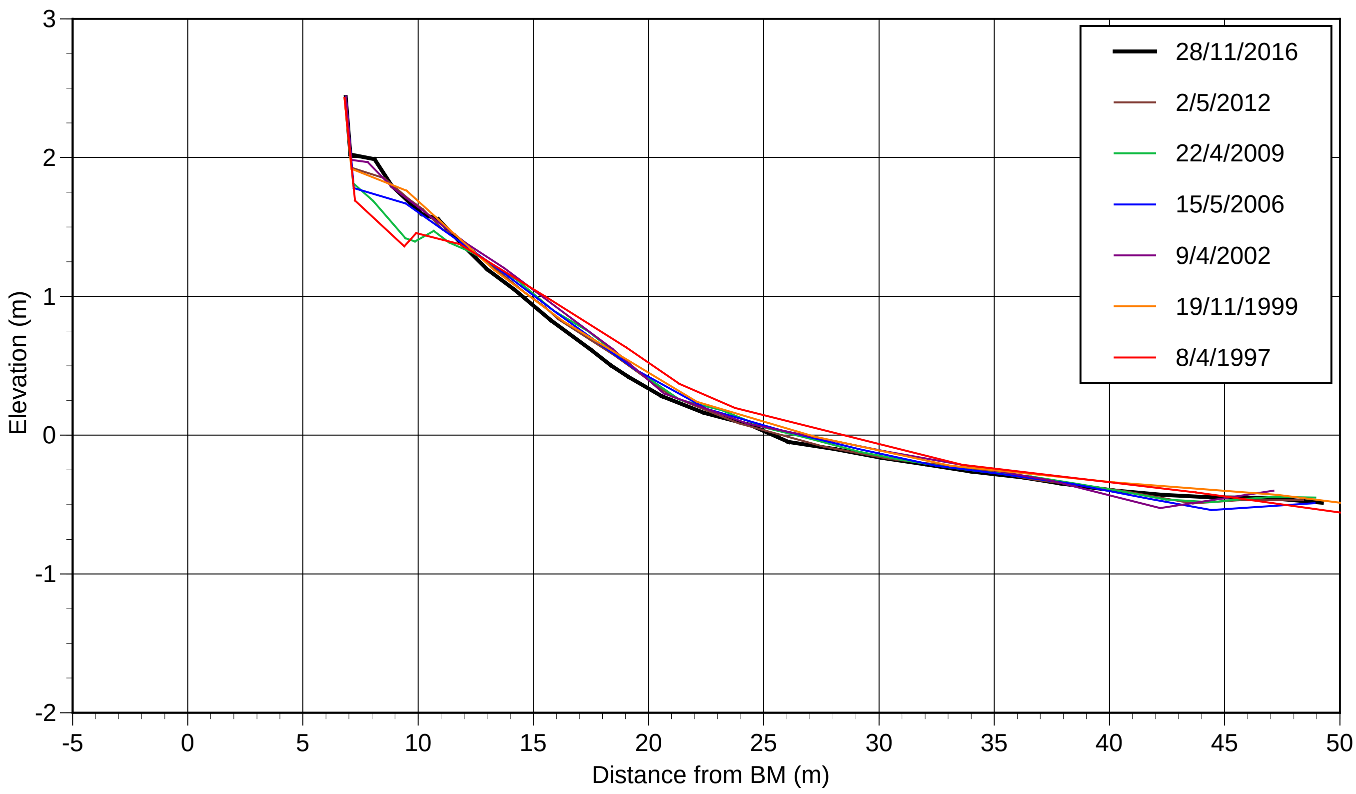
Profile 1 – Picton Foreshore

The Picton Foreshore underwent extensive modification with the improvement of the landward side of the retaining wall in late 1997. Sediments on the beach comprise both natural marine sediments and river sand deposited on the beach periodically over the past 20 years as part of a beach nourishment program.

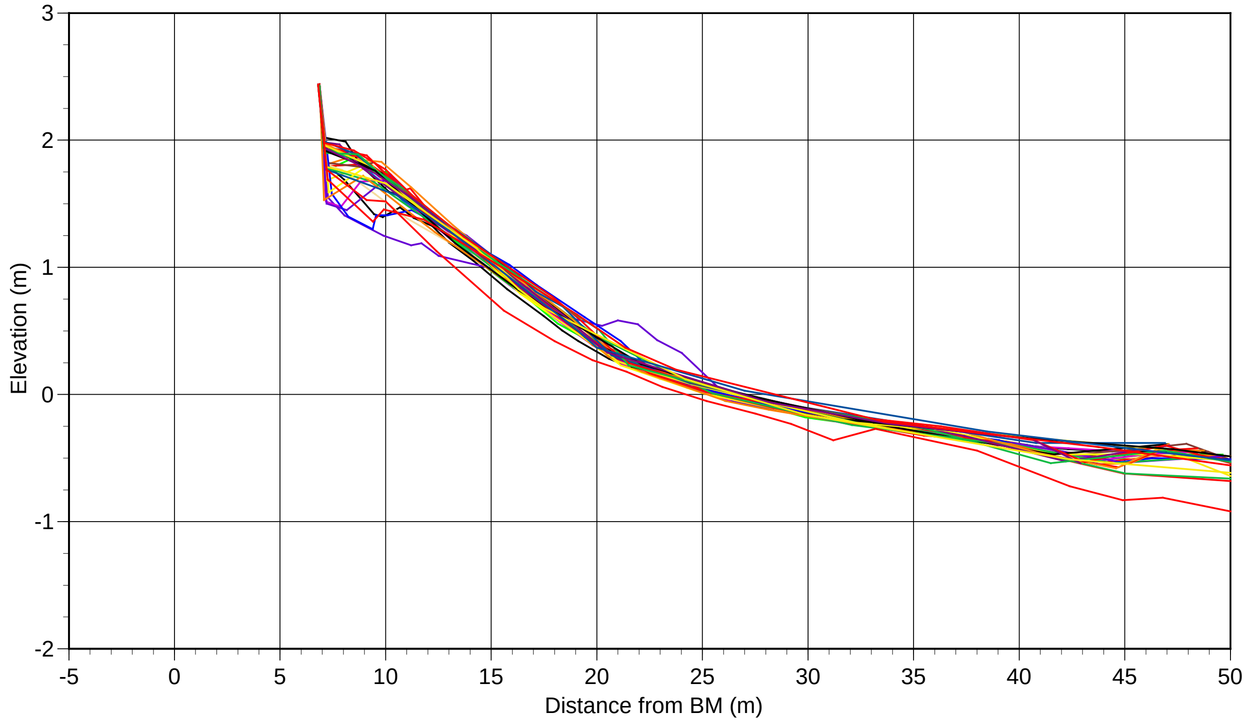
There is nothing obvious in the record with respect to when the nourishment has taken place. This could be because the timing of the surveys have not coincided with the time immediately before or immediately after the nourishment, or the frequency has been insufficient to capture the nourishment-related variability. What is clear, is that the rate of renourishment is clearly appropriate for the location as the beach has been relatively stable.

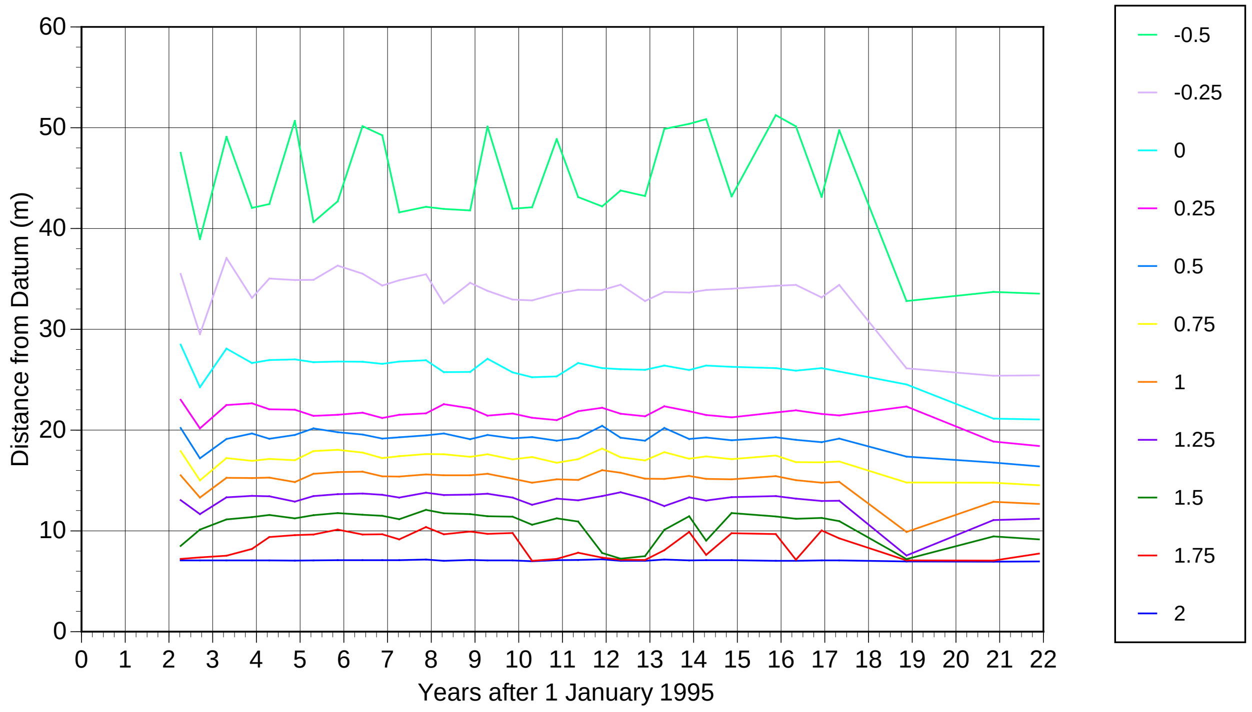
The level of the upper beach adjacent to the wall has varied by up to ~0.75m, and the middle beach by up to ~0.25m. The beach is currently at a high level on the upper beach, and a relatively low level across the mid-beach. The most recent period with a low upper beach was in 2013. As there was no survey in 2014, it is not known when recovery occurred.

Beach volume has maintained a relatively narrow range since April 1998, between 29.1m^3/m and 32.9m^3/m. There has been no apparent change in sediment characteristics. It is not known if the need for nourishment is the result of the presence of the seawall, or if wake waves in the inner harbour are having an adverse effect on beach stability.



Profile 1: Picton Foreshore





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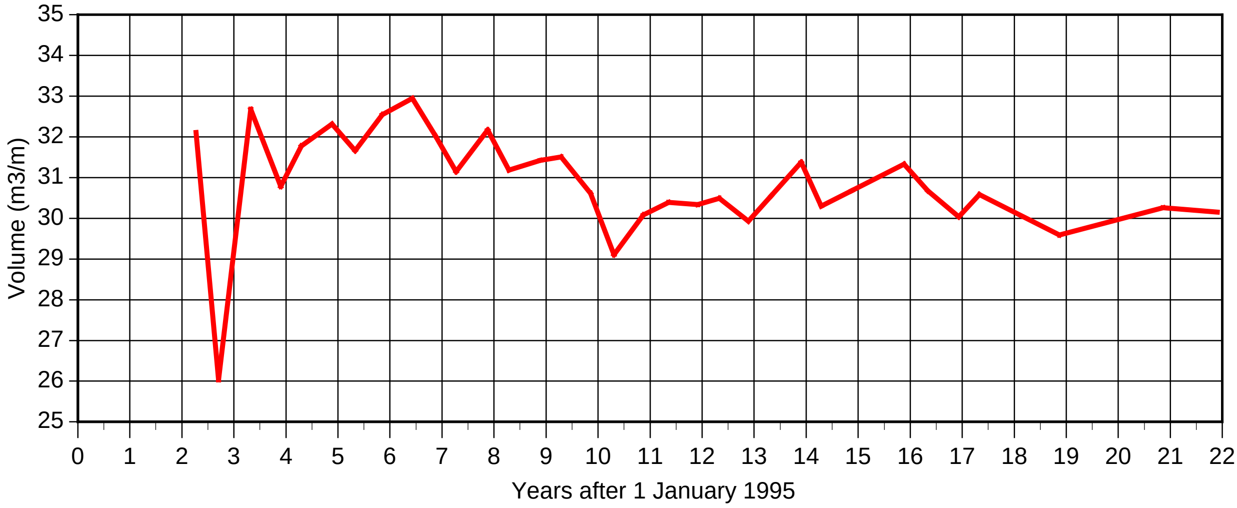
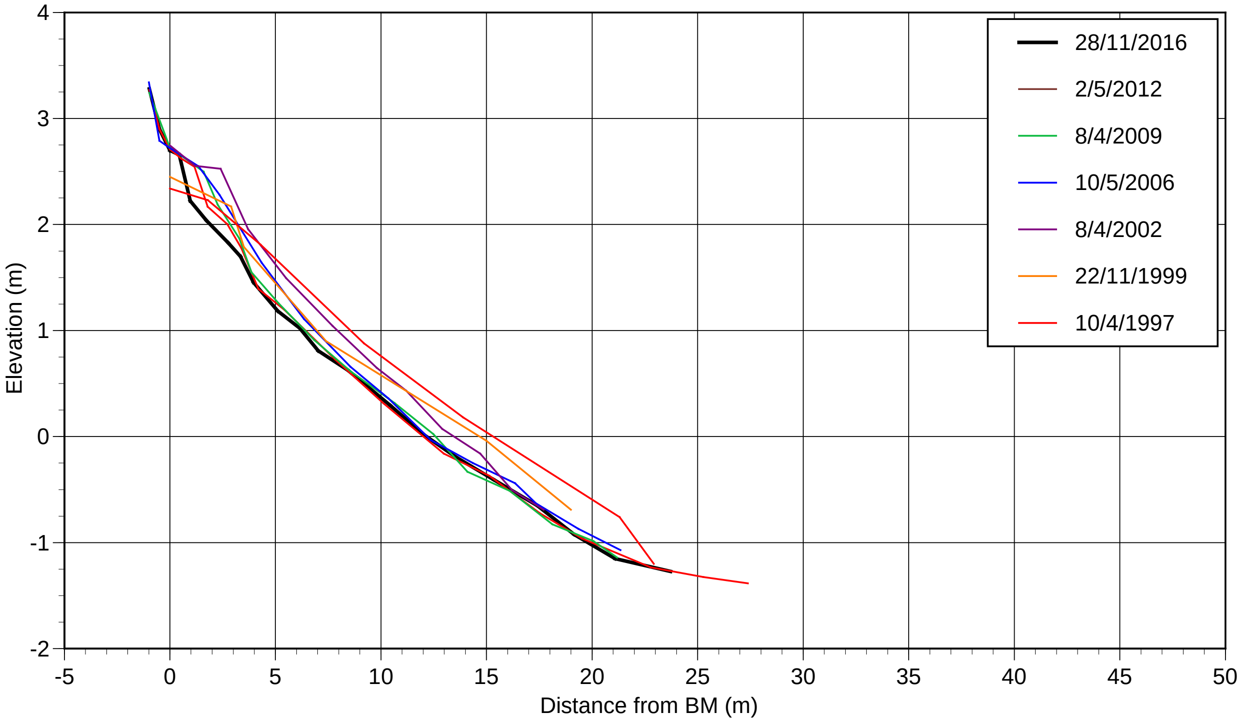


Date	Years after 1/1/95	Volume (m^3/m)
8-Apr-97	2.27	32.1
15-Sep-97	2.71	26.0
27-Apr-98	3.32	32.7
26-Nov-98	3.90	30.8
19-Apr-99	4.30	31.8
19-Nov-99	4.88	32.3
1-May-00	5.33	31.7
8-Nov-00	5.85	32.5
5-Jun-01	6.43	32.9
15-Nov-01	6.87	32.0
9-Apr-02	7.27	31.1
18-Nov-02	7.88	32.2
14-Apr-03	8.29	31.2
21-Nov-03	8.89	31.4
20-Apr-04	9.29	31.5
9-Nov-04	9.86	30.6
26-Apr-05	10.31	29.1
15-Nov-05	10.87	30.1
15-May-06	11.36	30.4
06-Dec-06	11.91	30.3
14-May-07	12.33	30.5
22-Nov-07	12.89	29.9
04-Apr-08	13.33	30.6
01-Dec-08	13.90	31.4
22-Apr-09	14.29	30.3
16-Nov-09	14.87	30.7
03-Dec-10	15.88	31.3
05-May-11	16.34	30.7
08-Dec-11	16.93	30.0
02-May-12	17.33	30.6
14-Nov-13	18.87	29.6
10-Nov-15	20.86	30.3
26-Nov-16	21.90	30.2

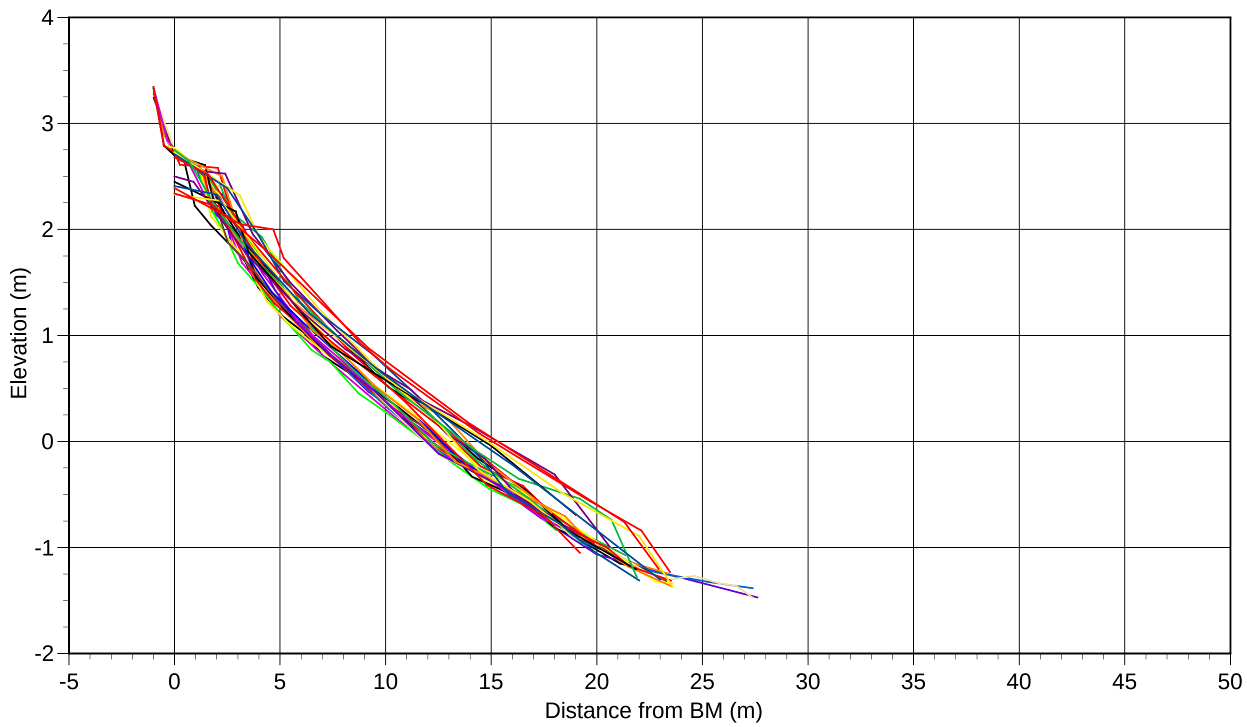
Profile 1: Picton Foreshore

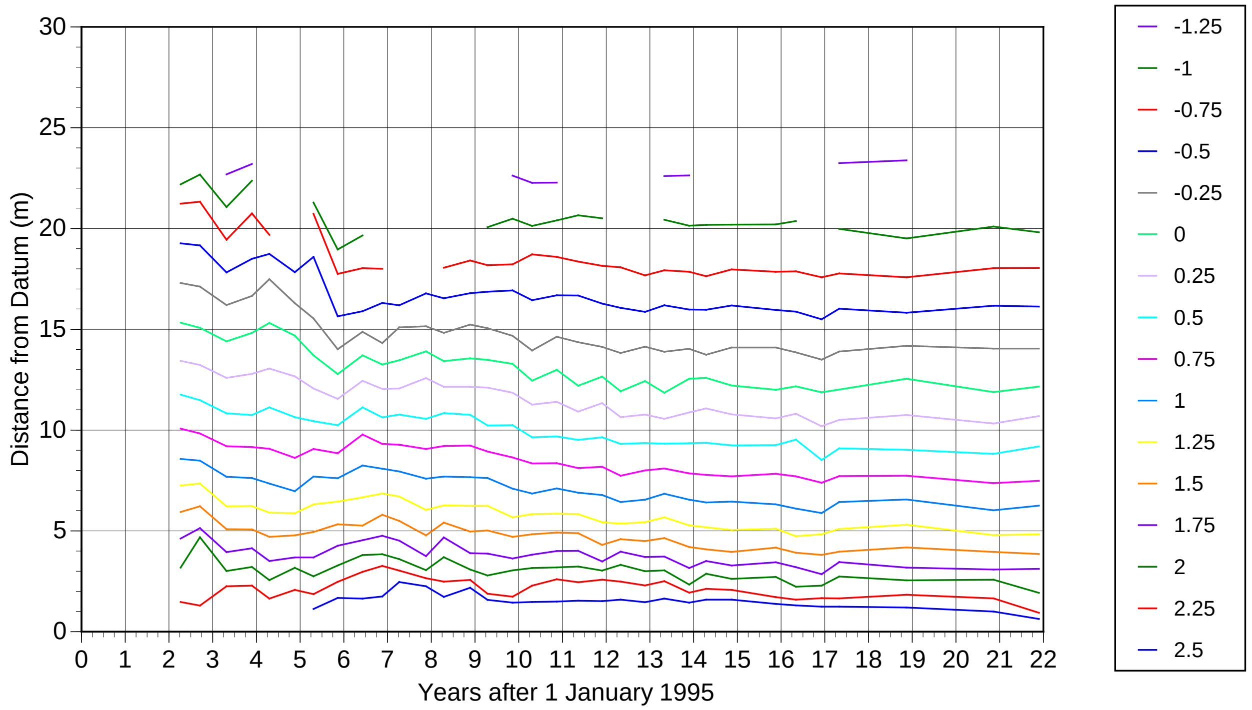
Profile 2 – The Snout at Picton Point

Since April 1997, the profile landward of about -1m CD has retreated and significantly steepened on the upper beach. The extent of retreat has been in the order of 2-3m horizontally. This is seen particularly by the downward trend and convergence of lines on the EDA plots. The major cause is probably the slow migration of the deep water channel in a shoreward direction. Beach volumes have followed an almost linear trend of loss over the same period, with the loss of over $7m^3/m$. A significant loss of volume between December 2010 and December 2011, was reversed through to November 2013, when the loss trend returned. There have been no apparent changes to sediment composition. The reason for the channel migration is not clear, although the site does receive considerable and regular wake energy.



Profile 2: The Snout at Picton Point





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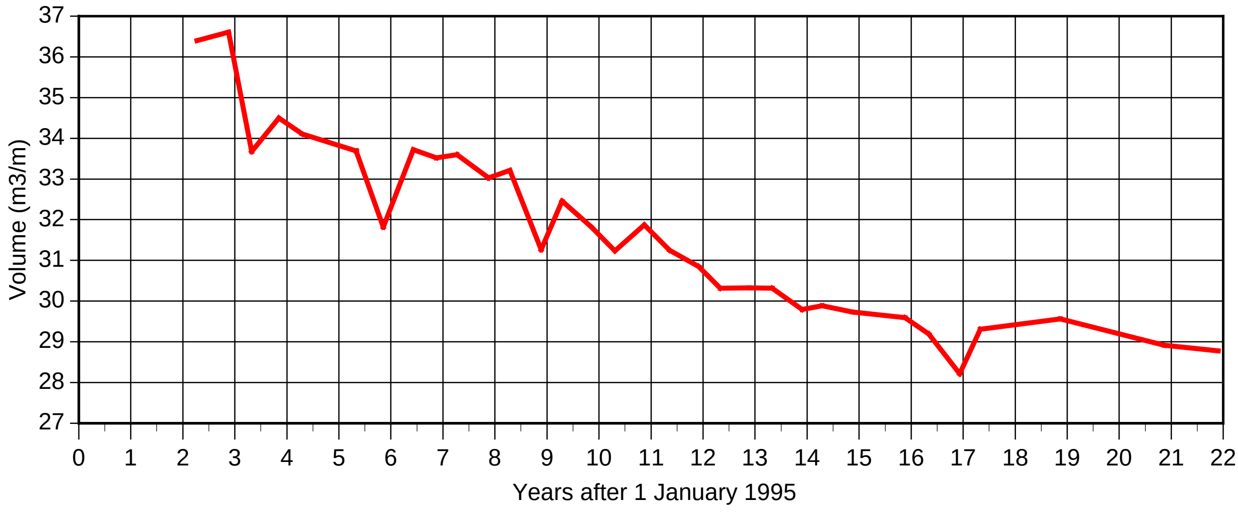
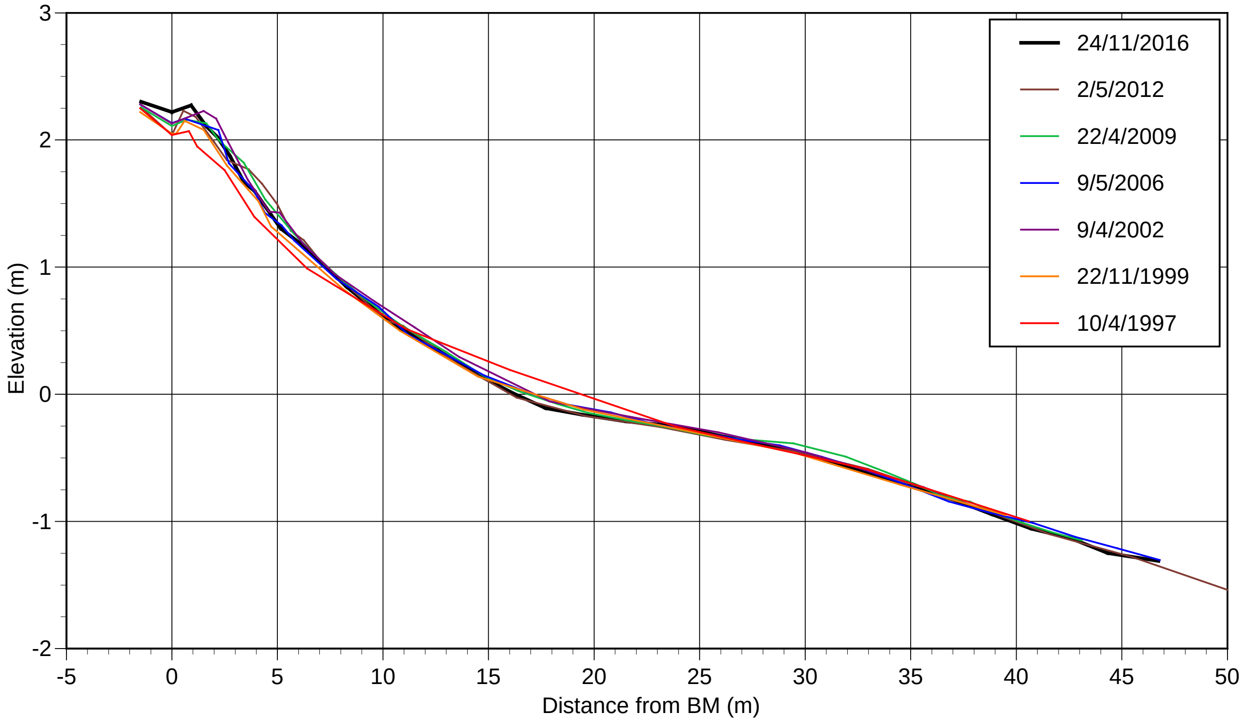


Date	Years after 1/1/95	Volume (m^3/m)
10-Apr-97	2.28	36.4
18-Nov-97	2.88	36.6
27-Apr-98	3.32	33.7
5-Nov-98	3.84	34.5
19-Apr-99	4.30	34.1
1-May-00	5.33	33.7
1-May-00	5.33	33.7
9-Nov-00	5.86	31.8
5-Jun-01	6.43	33.7
15-Nov-01	6.87	33.5
8-Apr-02	7.27	33.6
19-Nov-02	7.88	33.0
14-Apr-03	8.29	33.2
19-Nov-03	8.89	31.3
20-Apr-04	9.29	32.5
9-Nov-04	9.86	31.8
26-Apr-05	10.31	31.2
15-Nov-05	10.87	31.9
01-Dec-06	11.91	30.9
14-May-07	12.33	30.3
20-Nov-07	12.89	30.3
06-May-08	13.33	30.3
26-Nov-08	13.90	29.8
08-Apr-09	14.29	29.9
16-Nov-09	14.87	29.7
03-Dec-10	15.88	29.6
29-Apr-11	16.34	29.2
08-Dec-11	16.93	28.2
02-May-12	17.33	29.3
14-Nov-13	18.87	29.6
10-Nov-15	20.86	28.9
26-Nov-16	21.90	28.8

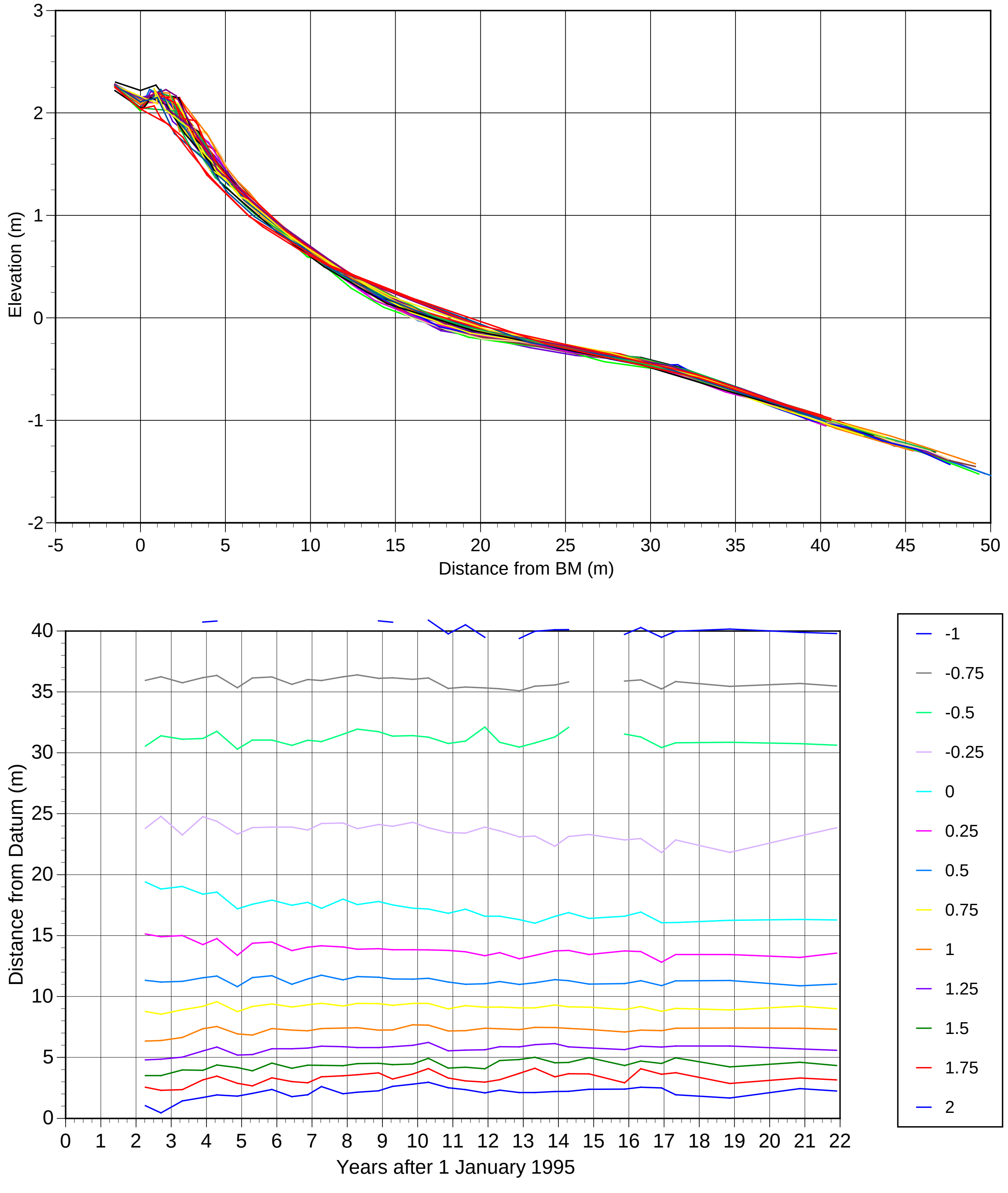
Profile 2: The Snout at Picton Point

Profile 3 – Double Bay

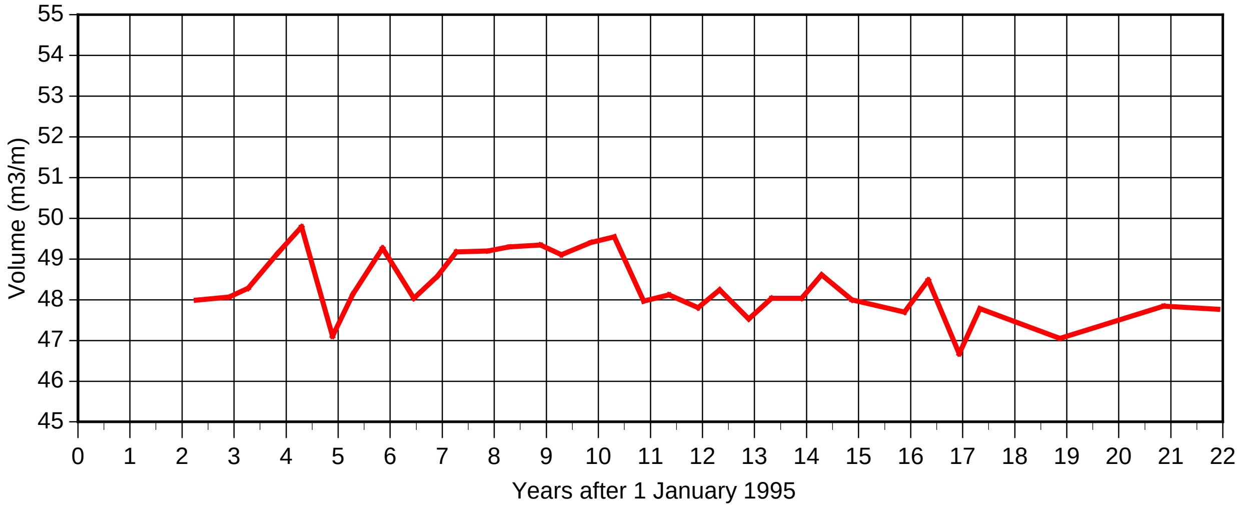
The Double Bay beach profile has changed within a very narrow range over the nearly 20 years since 1997. The most recent profile data shows a relatively high level on the upper beach and a low level on the mid-beach. Beach volume at the last survey is almost identical to that in 1997. Ho being only 0.2m^3/m different to April 1997. There has been a minor steeping of the upper beach with the construction of a berm over the earlier years of the survey and a minor lowering of the mid-beach surface. The profiles clearly reach closure depth at about -0.1m. Sediment characteristics have not changed significantly.



Profile 3: Double Bay



Profile 3: Double Bay

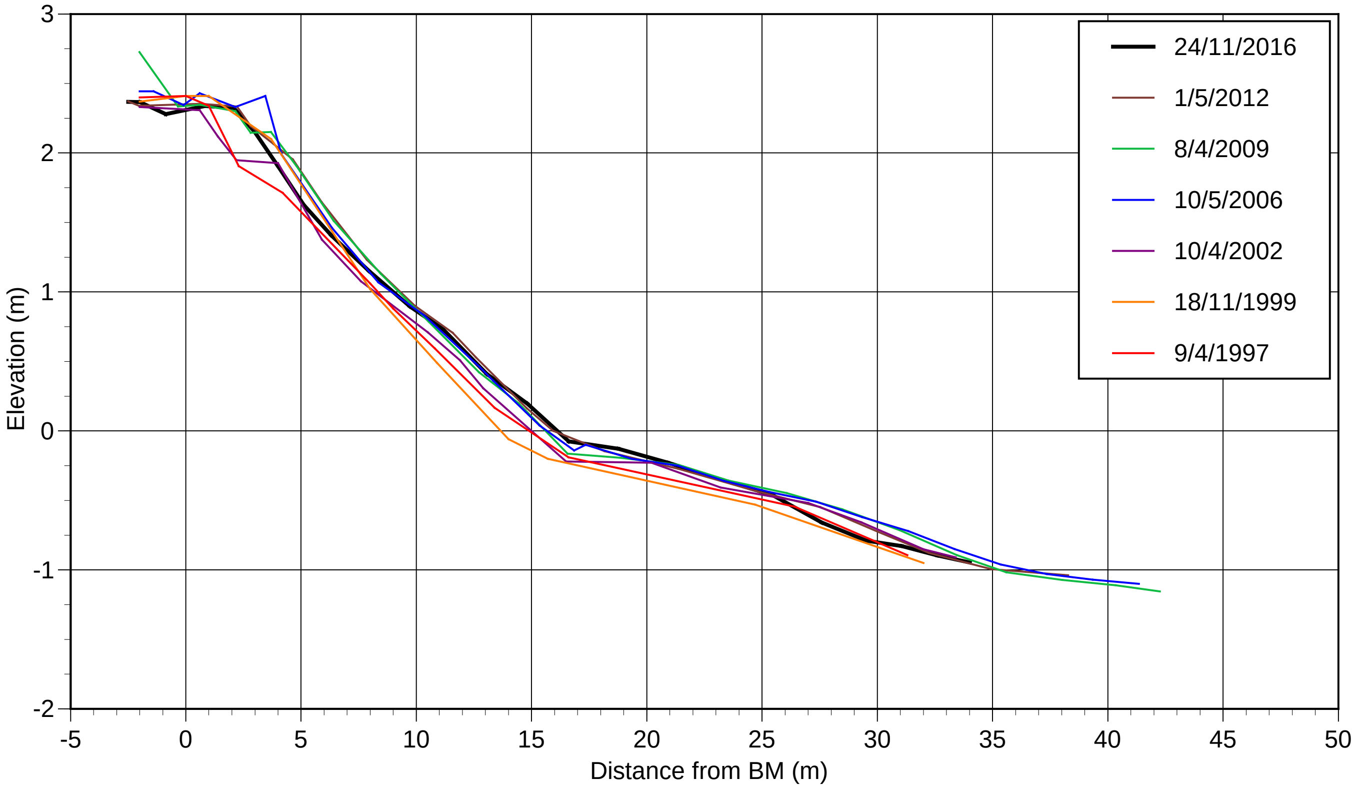


Date	Years after 1/1/95	Volume (m^3/m)
10-Apr-97	2.28	48.0
26-Nov-97	2.90	48.1
8-Apr-98	3.27	48.3
2-Nov-98	3.84	49.1
19-Apr-99	4.30	49.8
22-Nov-99	4.89	47.1
13-Apr-00	5.28	48.1
9-Nov-00	5.86	49.3
15-Jun-01	6.46	48.0
26-Nov-01	6.90	48.6
9-Apr-02	7.27	49.2
18-Nov-02	7.88	49.2
14-Apr-03	8.29	49.3
19-Nov-03	8.89	49.3
16-Apr-04	9.29	49.1
7-Dec-04	9.86	49.4
22-Apr-05	10.31	49.5
14-Nov-05	10.87	48.0
9-May-06	11.36	48.1
20-Nov-06	11.91	47.8
30-Apr-07	12.33	48.2
20-Nov-07	12.89	47.5
06-May-08	13.33	48.0
12-Nov-08	13.90	48.0
22-Apr-09	14.29	48.6
16-Nov-09	14.87	48.0
03-Dec-10	15.88	47.7
29-Apr-11	16.34	48.5
07-Dec-11	16.93	46.7
02-May-12	17.33	47.8
14-Nov-13	18.87	47.1
10-Nov-15	20.86	47.8
26-Nov-16	21.90	47.8

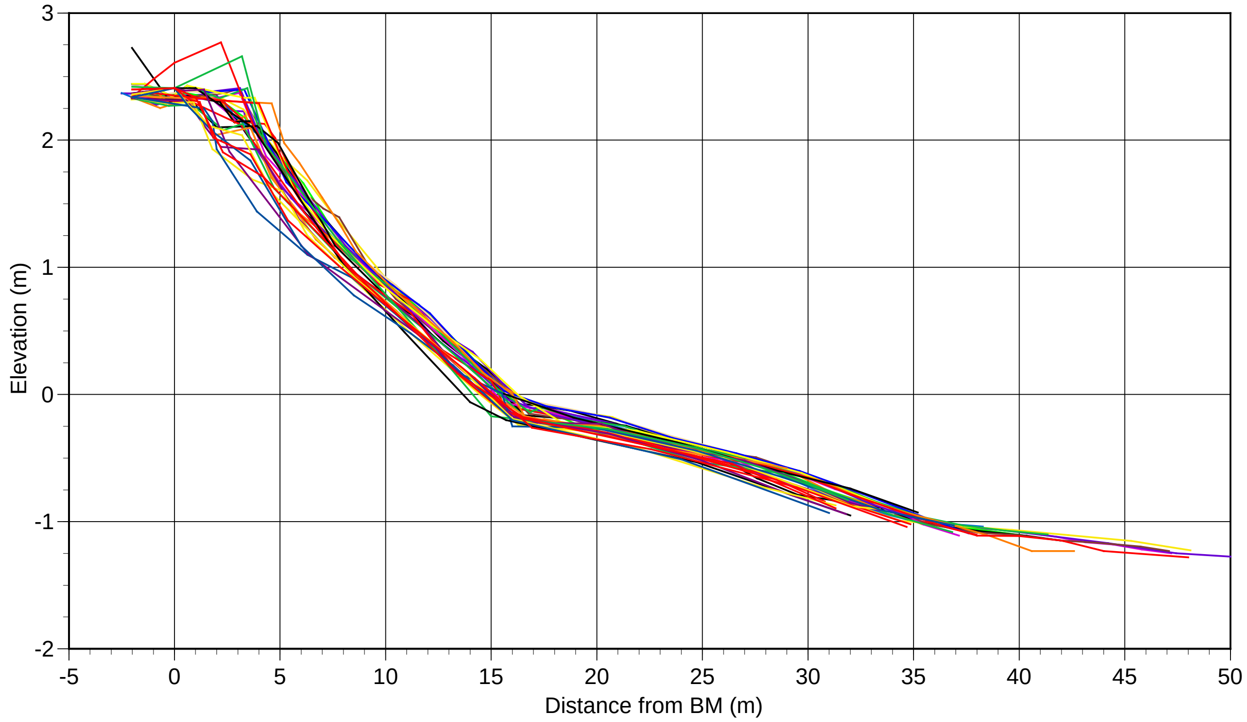
Profile 3: Double Bay

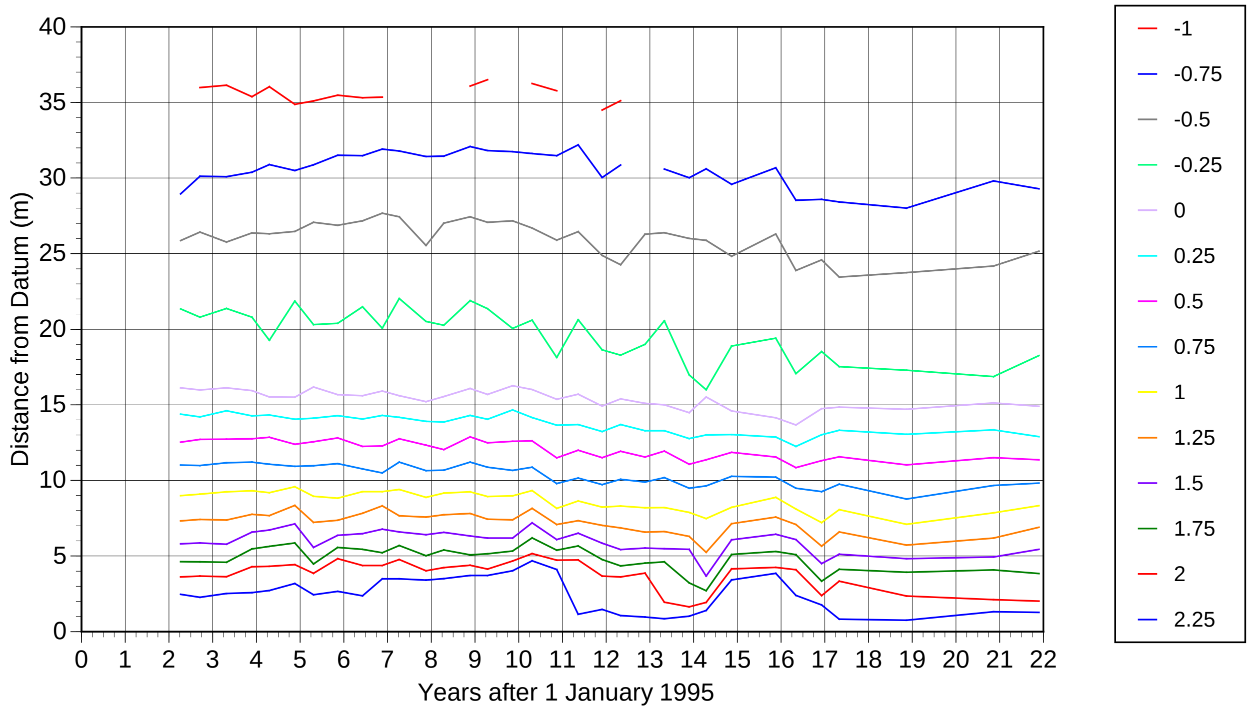
Profile 4 – Ngaionui Bay

The Ngaionui Bay site is complicated by human modifications to move sediment from the top of the beach which was covering the launching rails and potentially causing water to pond. The most significant removal of sediment was in 2000-2001.The nature of any works and their frequency since 2001 is not known, but between 2001 and 2006 the beach sediment that was removed or reprofiled, returned or was replaced . The interpretation is also complicated by the presence of a landslide at the western end of the beach, with sediment redistribution within the compartment. It was very clear in the early years of the monitoring program that fast ferry operation contributed to significant beach accretion (see the high berm evident on two early surveys on the 'spaghetti' plot), and that wakes and natural waves, coinciding with an increased sediment supply from the slip, contributed to beach building during the time that the fast ferries were operating. This site was the subject of much media and political attention during those years. Since 2006, beach volume has varied little within a 1.5m^3/m range.

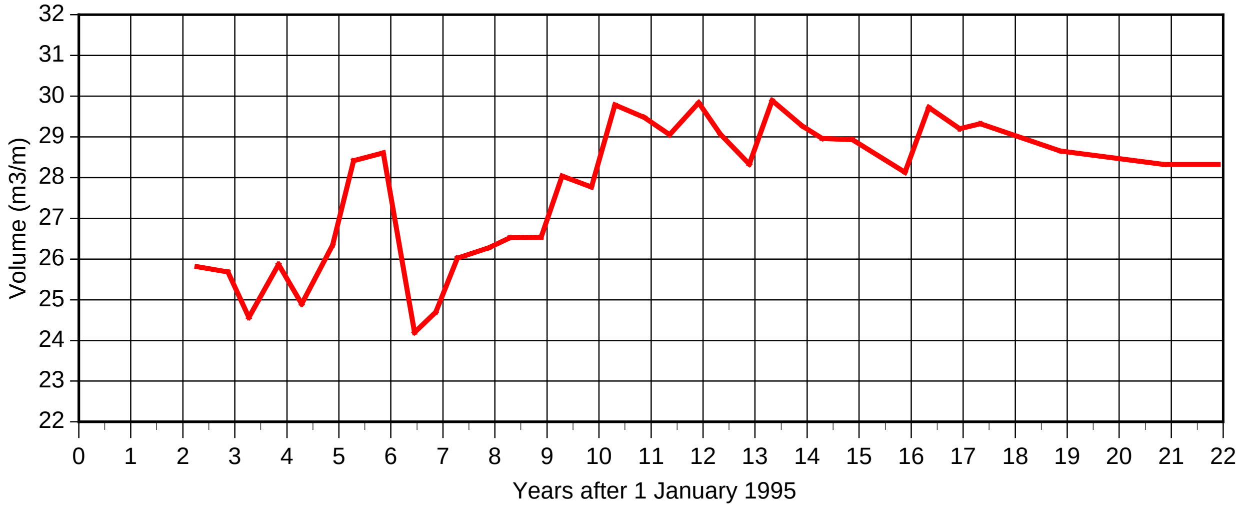


Profile 4: Ngaionui Bay





Profile 4: Ngaionui Bay

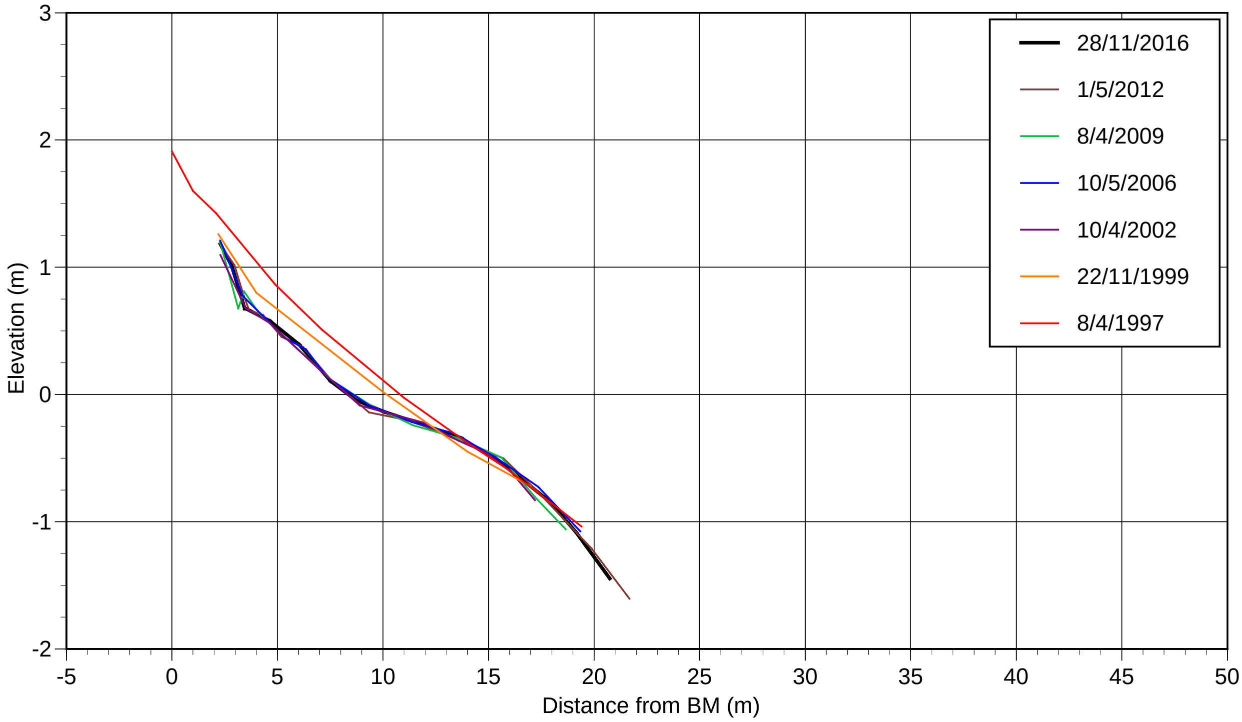


Date	Years after 1/1/95	Volume (m^3/m)
9-Apr-97	2.27	25.8
14-Nov-97	2.87	25.7
9-Apr-98	3.27	24.6
4-Nov-98	3.84	25.9
14-Apr-99	4.29	24.9
18-Nov-99	4.88	26.3
13-Apr-00	5.28	28.4
9-Nov-00	5.86	28.6
15-Jun-01	6.46	24.2
12-Nov-01	6.86	24.7
10-Apr-02	7.28	26.0
15-Nov-02	7.88	26.3
15-Apr-03	8.29	26.5
20-Nov-03	8.89	26.5
15-Apr-04	9.29	28.0
8-Nov-04	9.86	27.8
20-Apr-05	10.31	29.8
11-Nov-05	10.87	29.5
10-May-06	11.36	29.1
01-Dec-06	11.91	29.8
01-May-07	12.33	29.1
21-Nov-07	12.89	28.3
02-May-08	13.33	29.9
26-Nov-08	13.90	29.3
08-Apr-09	14.29	29.0
13-Nov-09	14.87	28.9
16-Nov-10	15.88	28.1
02-May-11	16.34	29.7
07-Dec-11	16.93	29.2
01-May-12	17.33	29.3
14-Nov-13	18.87	28.7
10-Nov-15	20.86	28.3
26-Nov-16	21.90	28.3

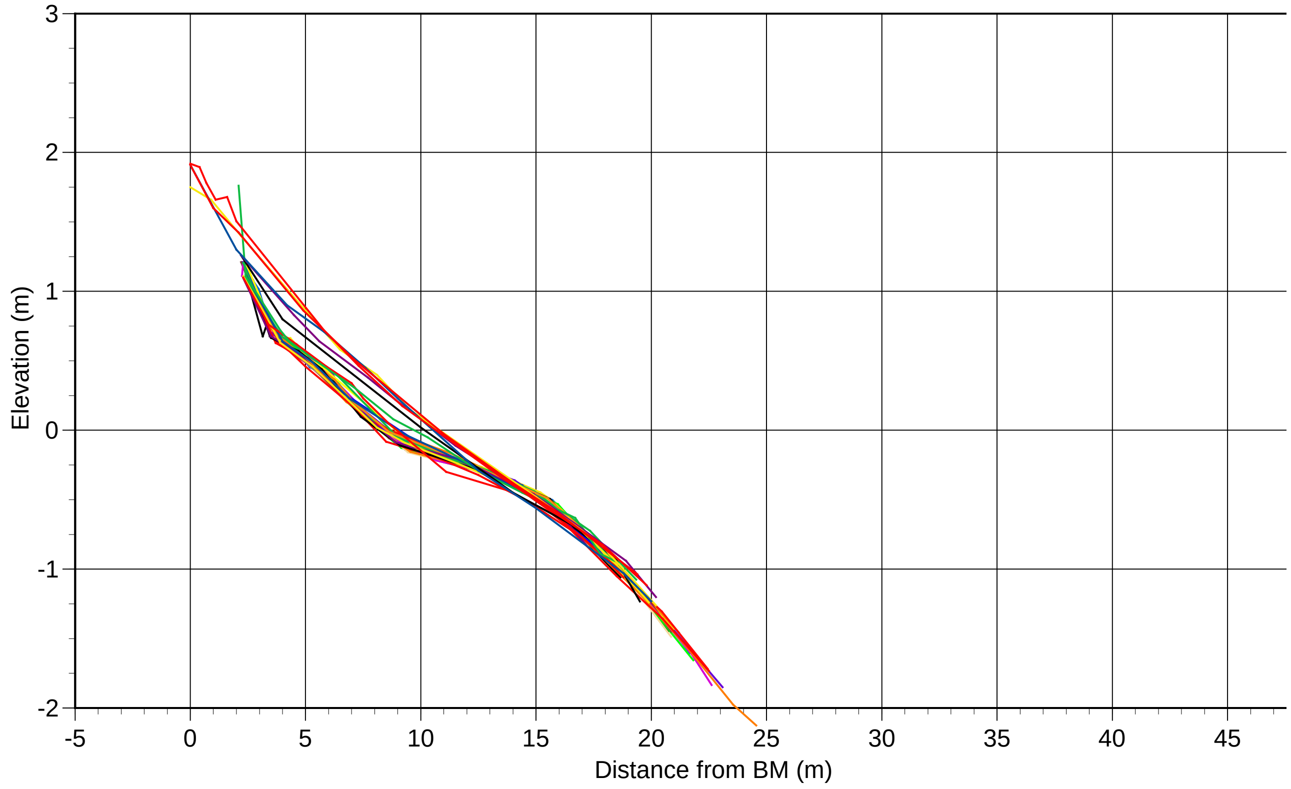
Profile 4: Ngaionui Bay

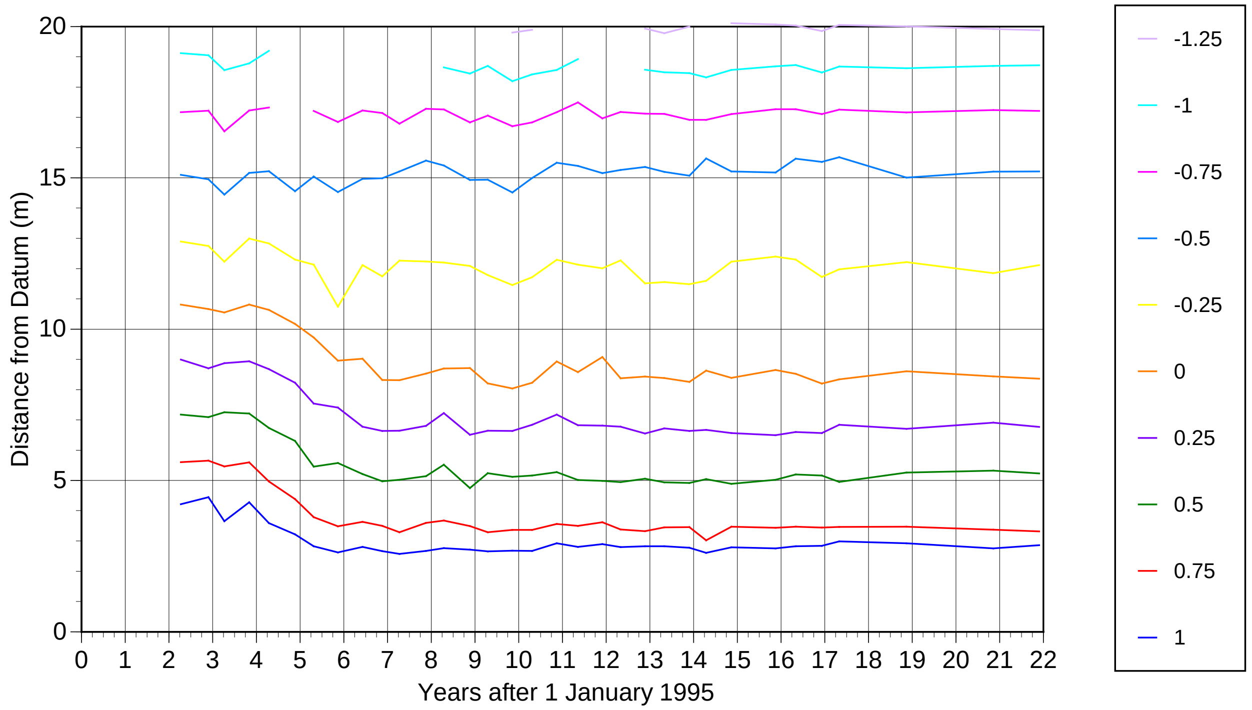
Profile 5 – Blackmore's at Waikawa

Between April 1999 and November 1999, sand on the small beach started to disappear. By November 2001, the beach had been stripped to bedrock, and it has remained essentially devoid of sediment since that time. Further loss of sediment is therefore not possible. There is almost no doubt that this change was the result of fast ferry operation. There has been no recovery since the fast ferries slowed down in December 2000, probably because the wave energy in this location, including the energy contributed by conventional ferry operation, is insufficient to entrain sediment that was transported into deeper water. Minor changes in profile and volumes recorded since that time are likely to be the result of slightly different survey alignments, and possibly minor changes in sediments on the lower profile.

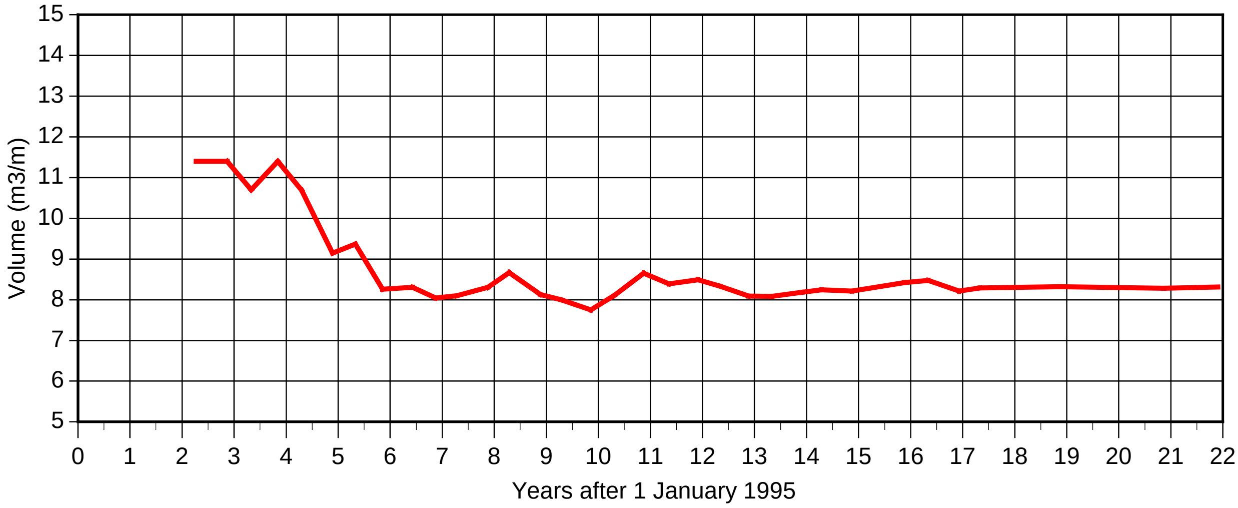


Profile 5: Blackmore's at Waikawa





Profile 5: Blackmore’s at Waikawa



Date	Years after 1/1/95	Volume (m^3/m)
8-Apr-97	2.27	11.4
14-Nov-97	2.87	11.4
29-Apr-98	3.33	10.7
4-Nov-98	3.84	11.4
19-Apr-99	4.30	10.7
22-Nov-99	4.89	9.1
1-May-00	5.33	9.4
9-Nov-00	5.86	8.3
5-Jun-01	6.43	8.3
15-Nov-01	6.87	8.0
10-Apr-02	7.28	8.1
18-Nov-02	7.88	8.3
16-Apr-03	8.29	8.7
19-Nov-03	8.89	8.1
20-Apr-04	9.29	8.0
9-Nov-04	9.86	7.7
20-Apr-05	10.31	8.1
14-Nov-05	10.87	8.7
10-May-06	11.36	8.4
21-Nov-06	11.91	8.5
14-May-07	12.33	8.3
21-Nov-07	12.89	8.1
04-Apr-08	13.33	8.1
12-Nov-08	13.90	8.2
08-Apr-09	14.29	8.2
16-Nov-09	14.87	8.2
03-Dec-10	15.88	8.4
02-May-11	16.34	8.5
07-Dec-11	16.93	8.2
01-May-12	17.33	8.3
14-Nov-13	18.87	8.3
10-Nov-15	20.86	8.3
26-Nov-16	21.90	8.3

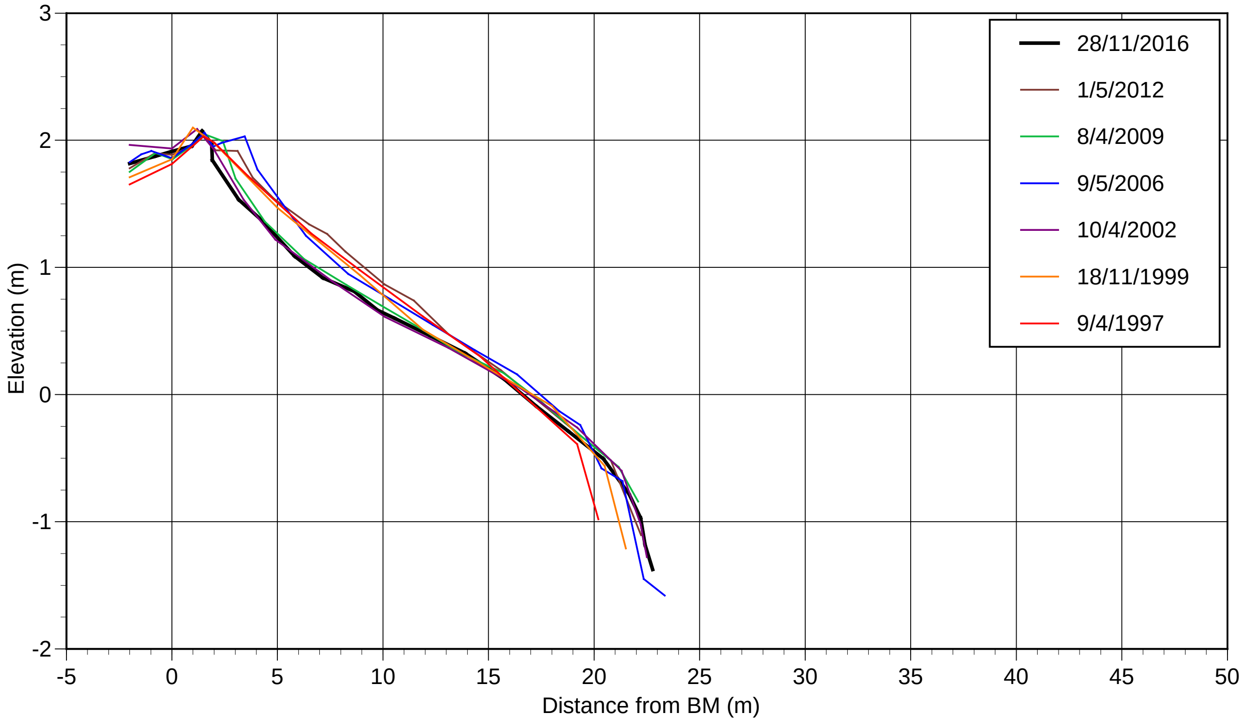
Profile 5: Blackmore's at Waikawa

Profile 6 – Moioio Island 2

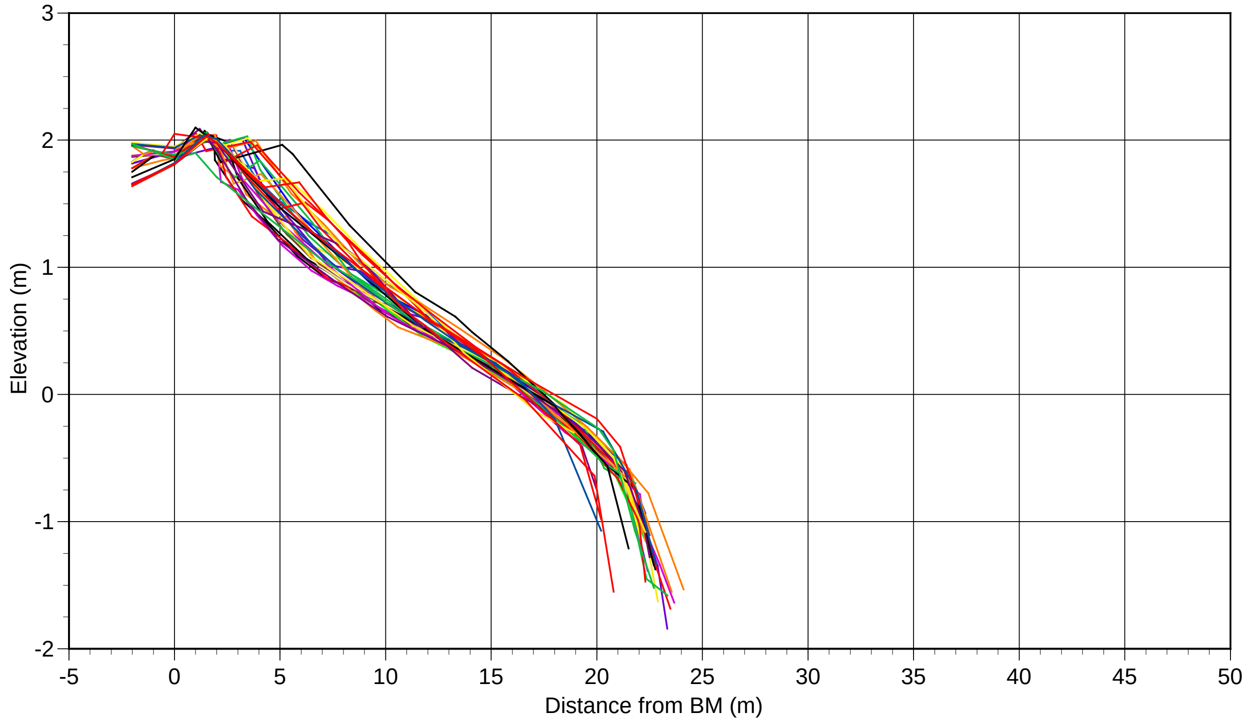
Moioio Island 2 is at the eastern end of the beach on the island, near the slip that was of considerable concern to Te Ati Awa at the time the fast ferries were operating. This profile has a record going back to November 1995 and until 1999 the beach profile demonstrated seasonality, with a build-up of a berm on the upper beach over the winter months and its removal over the summer months, after which time, seasonal patterns have not been evident. The beach experienced significant accretion up to 2005, with a significant reversal for a period between November 2000 and April 2002 (coinciding with the slowing of the fast ferries possibly affecting sediment mobility from the slip source). Between 2005 and 2009 the beach eroded, particularly on the upper and middle sections. Between 2009 and 2011 the beach accreted. The trend reversed again about 2011 and erosion of the upper beach has occurred since that time. The upper and middle beach is currently at a low level, although the height of the upper berm has been maintained. In general, the lower beach has extended into the adjacent channel.

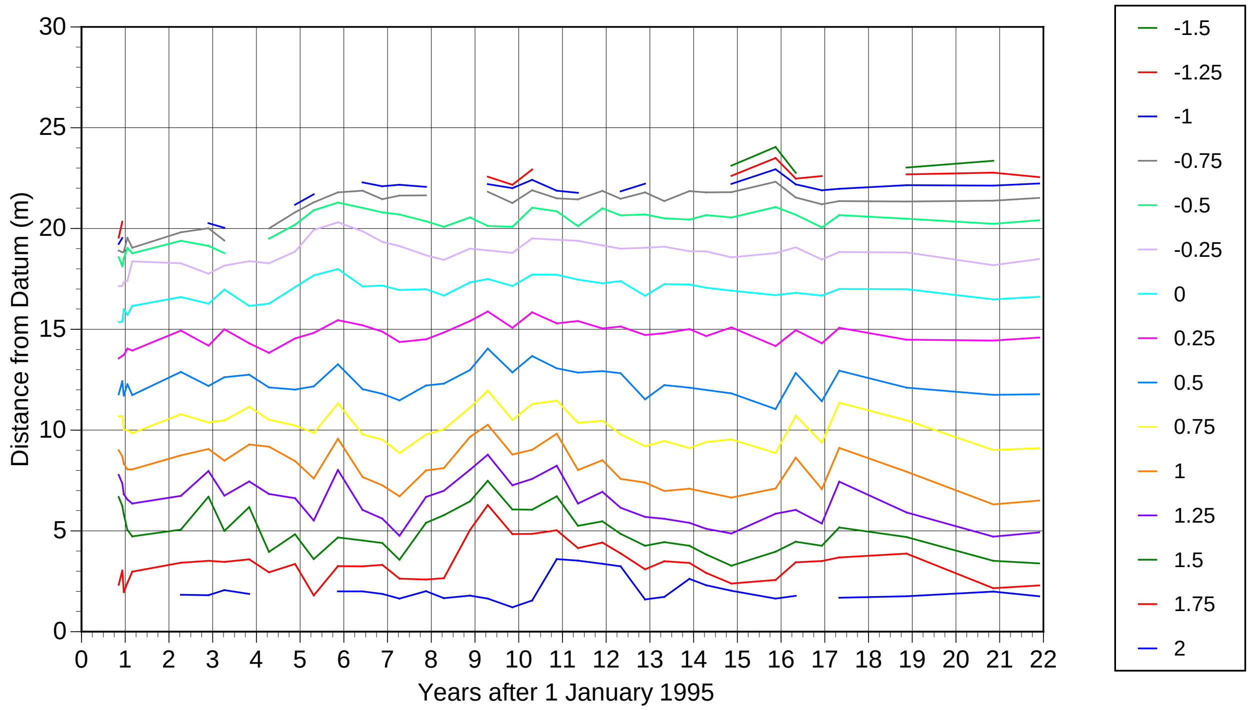
The most significant effect on this profile has almost certainly been the adjacent slip. Major fluctuations in beach shape and volume, and indeed the general accretion, are almost certainly related to sediment supply from periods of activity and inactivity of the slip. It is almost certain that higher energy waves associated with fast ferry operation resulted in more frequent activity on the slip. There has probably been little movement on the slip in the last 3 years. The beach volume has been highly variable, again associated with the state of the slip.

In recent years, the surficial sediment has been considerably finer than in earlier years, particularly as compared to when the slip was active during fast ferry operation.

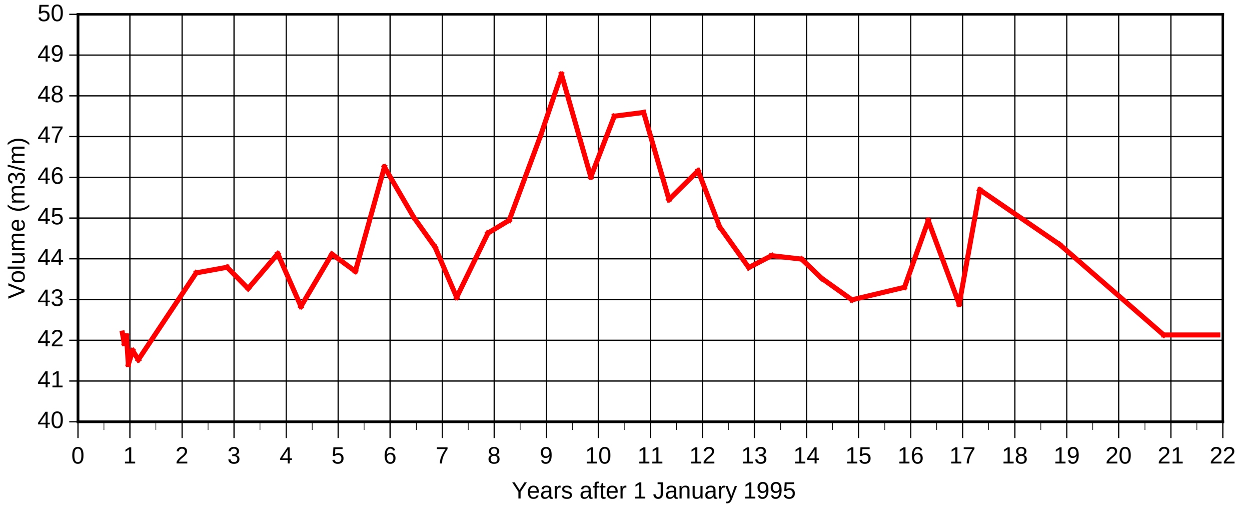


Profile 6: Moioio Island 2





Profile 6: Moioio Island 2



Date	Years after 1/1/95	Volume (m^3/m)	Date	Years after 1/1/95	Volume (m^3/m)
8-Nov-95	0.85	42.2	15-Apr-04	9.29	48.5
21-Nov-95	0.89	41.9	9-Nov-04	9.86	46.0
6-Dec-95	0.93	42.1	20-Apr-05	10.31	47.5
20-Dec-95	0.97	41.4	11-Nov-05	10.87	47.6
19-Jan-96	1.05	41.8	9-May-06	11.36	45.5
29-Feb-96	1.16	41.5	21-Nov-06	11.91	46.2
9-Apr-97	2.27	43.7	01-May-07	12.33	44.8
14-Nov-97	2.87	43.8	21-Nov-07	12.89	43.8
9-Apr-98	3.27	43.3	02-May-08	13.33	44.1
4-Nov-98	3.84	44.1	26-Nov-08	13.90	44.0
13-Apr-99	4.28	42.8	08-Apr-09	14.29	43.5
18-Nov-99	4.88	44.1	13-Nov-09	14.87	43.0
1-May-00	5.33	43.7	16-Nov-10	15.88	43.3
22-Nov-00	5.89	46.3	02-May-11	16.34	44.9
15-Jun-01	6.46	45.0	07-Dec-11	16.93	42.9
12-Nov-01	6.86	44.3	01-May-12	17.33	45.7
10-Apr-02	7.28	43.1	14-Nov-13	18.87	44.4
15-Nov-02	7.88	44.6	10-Nov-15	20.86	42.1
15-Apr-03	8.29	44.9	26-Nov-16	21.90	42.1
20-Nov-03	8.89	47.0			

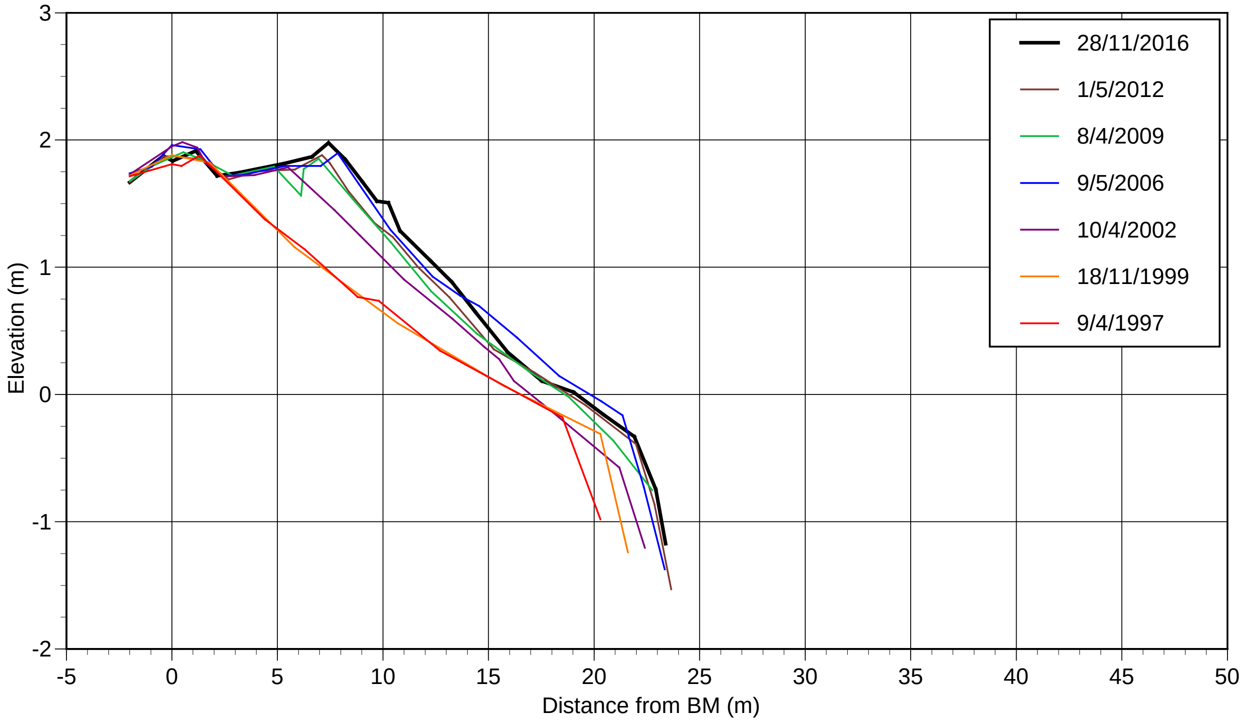
Profile 6: Moioio Island 2

Profile 7 – Moioio Island 1

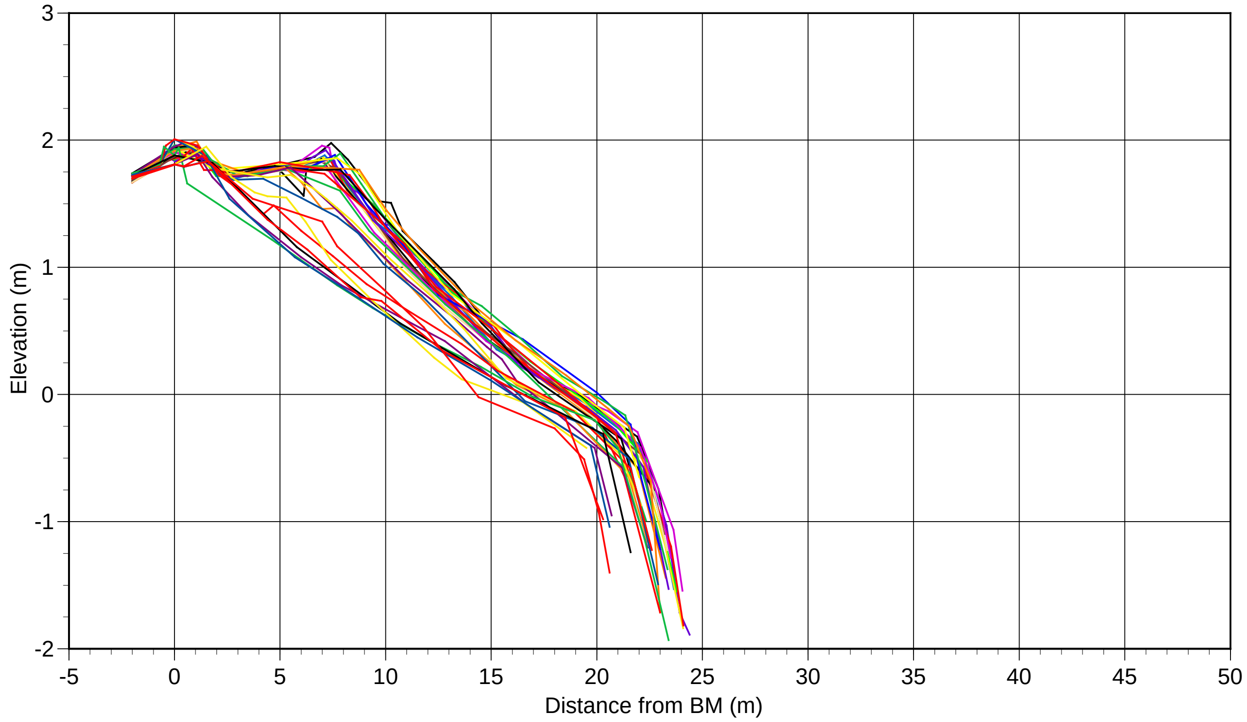
The Moioio Island 1 profile is to the west of Profile 6. There was remarkable seasonality up to the winter of 1999, with the growth of a berm over winter and its loss over summer. Up until the end of 2000, the upper beach was generally stable, with seasonality, and with the lower beach accreting into the channel. Behaviour of the profile during this time is highly likely to be linked to fast ferry operation, particularly with respect to sediment supply (from the slip adjacent to Profile 6) and processes existing hat were able to move sediment. Up to 2006, like Profile 6, the whole profile accreted rapidly with very substantial volume increases. There was substantial accretion of the upper beach between May 2000 and May 2006, with a major increase in volume, particularly between May 2000 and April 2001. Like Profile 6, there was a reversal in 2006, with a year of significant erosion, although the substantial berm remained. Since 2007 the profile has been relatively stable, with minor accretion. In 2016, the profile is in the most accreted condition of the survey period over most of the profile. This profile is almost certainly reacting principally to sediment supply.

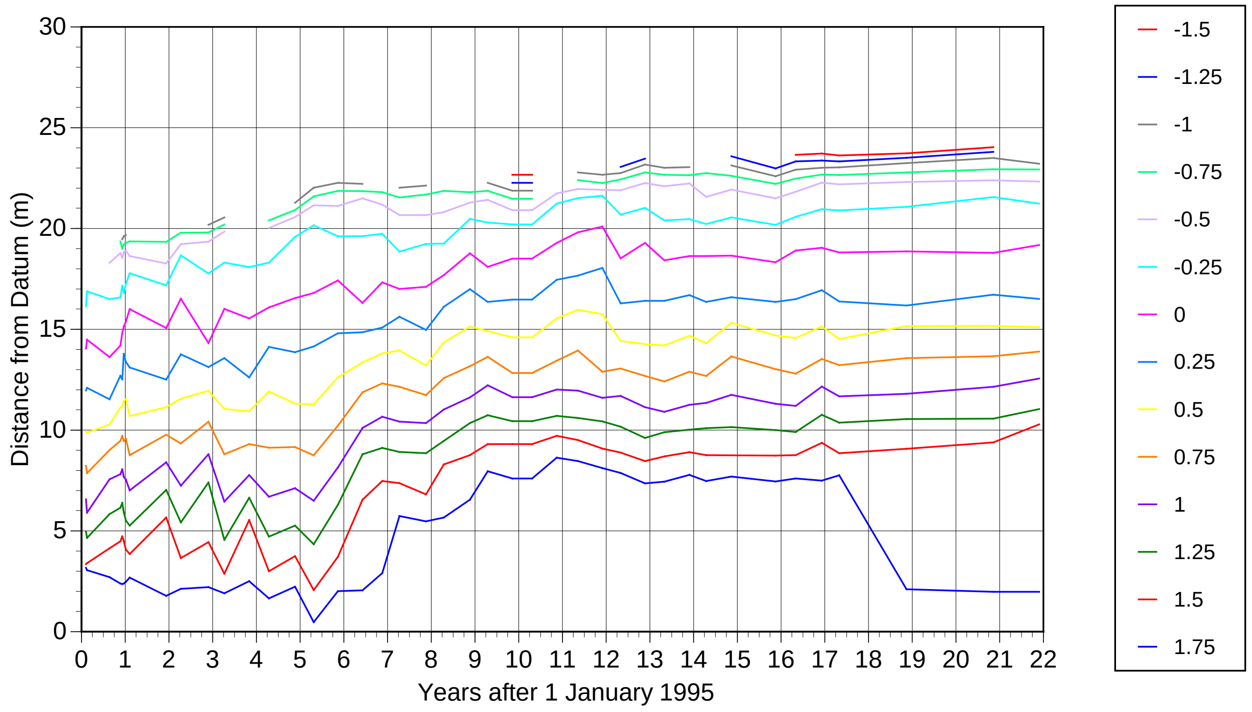
There is little doubt that the beach changes taking place on this profile are related in part to ferry operation (evidenced by the very strong seasonal signal when fast ferries were operating seasonally), but they are affected significantly by changes to sediment supply. For example, the accretion event observed on Profile 6 between April 2003 and April 2004 is reflected on Profile 7 between November 2004 and April 2005.

Over the period of surveys, the high tide berm has grown seaward by about 7m, and has become vegetated. Beach volume increased (with seasonal reversals) from 1995 through to 2006, and has been stable since then.

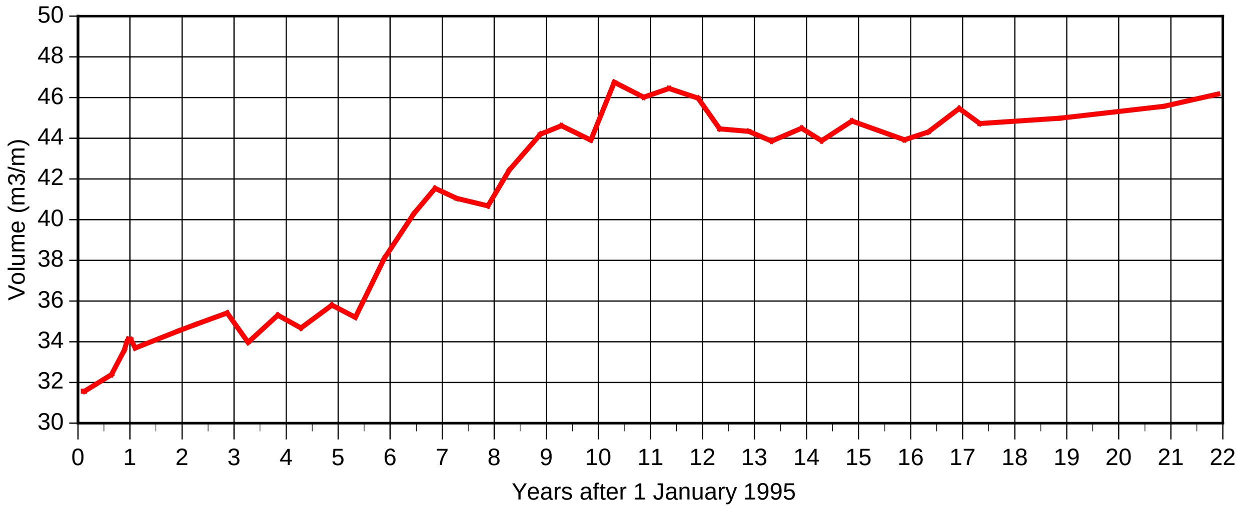


Profile 7: Moioio Island 1





Profile 7: Moioio Island 1



Date	Years after 1/1/95	Volume (m^3/m)	Date	Years after 1/1/95	Volume (m^3/m)
1977		38.3	15-Nov-02	7.88	40.7
8-Feb-95	0.10	31.6	15-Apr-03	8.29	42.4
17-Feb-95	0.13	31.6	20-Nov-03	8.89	44.2
22-Aug-95	0.64	32.4	16-Apr-04	9.29	44.6
22-Nov-95	0.89	33.6	9-Nov-04	9.86	43.9
8-Dec-95	0.94	34.0	20-Apr-05	10.31	46.8
20-Dec-95	0.97	34.1	11-Nov-05	10.87	46.0
7-Jan-96	1.02	34.1	9-May-06	11.36	46.4
8-Feb-96	1.10	33.7	21-Nov-06	11.91	46.0
9-Dec-96	1.94	34.5	01-May-07	12.33	44.5
9-Apr-97	2.27	34.9	21-Nov-07	12.89	44.3
14-Nov-97	2.87	35.4	02-May-08	13.33	43.9
9-Apr-98	3.27	34.0	26-Nov-08	13.90	44.5
4-Nov-98	3.84	35.3	08-Apr-09	14.29	43.9
13-Apr-99	4.28	34.7	13-Nov-09	14.87	44.8
18-Nov-99	4.88	35.8	16-Nov-10	15.88	43.9
1-May-00	5.33	35.2	02-May-11	16.34	44.3
22-Nov-00	5.89	38.1	07-Dec-11	16.93	45.5
15-Jun-01	6.46	40.3	01-May-12	17.33	44.7
12-Nov-01	6.86	41.5	14-Nov-13	18.87	45.0
10-Apr-02	7.28	41.0	10-Nov-15	20.86	45.6
			26-Nov-16	21.90	46.2

Profile 7: Moioio Island 1

Profile 8 – Bob's Bay

Bob's Bay has demonstrated an almost linear erosion trend since 1995 across the whole beach profile down to the change in slope (and probable closure depth) at about –0.7m. Most of the beach has lowered in level by about 1.2m. Volume data shows a volume change of the monitored profile from 38.2m^3/m in 1995 to 14.0 m^3/m in 2016. Because the profile line clearly encompasses the sweep zone, the 63% volume loss accurately reflects the total loss of sediment. This erosion is very significant within the context of beaches in this study. The beach slope has stayed relatively constant.

The location of this profile is at the northern end of the beach, adjacent to a headland of significance to Te Ati Awa (which is why the profile line was established in this location in 1995 by Professor Kirk).

An investigation into the shoreline erosion in Bob's Bay was undertaken By Opus International Consultants Ltd in 2013 (Ward, 2013)[2] which showed that the erosion was more significant in the northern section of the bay (the location of this profile site). The cause of the erosion remains uncertain, although it is suggested that vessel wakes may play a role. In a 2015 report (Ward and Edwards 2015)[3], Opus suggested that beach nourishment was the most appropriate option to mitigate the erosion, with more intrusive engineered options being required on the headland adjacent to the monitored sight which is of significant to Te Ati Awa.

At the time of the 2015 report, Ward and Edwards (2015) noted that the beach level had risen since July 2013 and that the urgency to undertake works had reduced. The profile measurement in November 2016, however, showed that the long-term rate of retreat had resumed.

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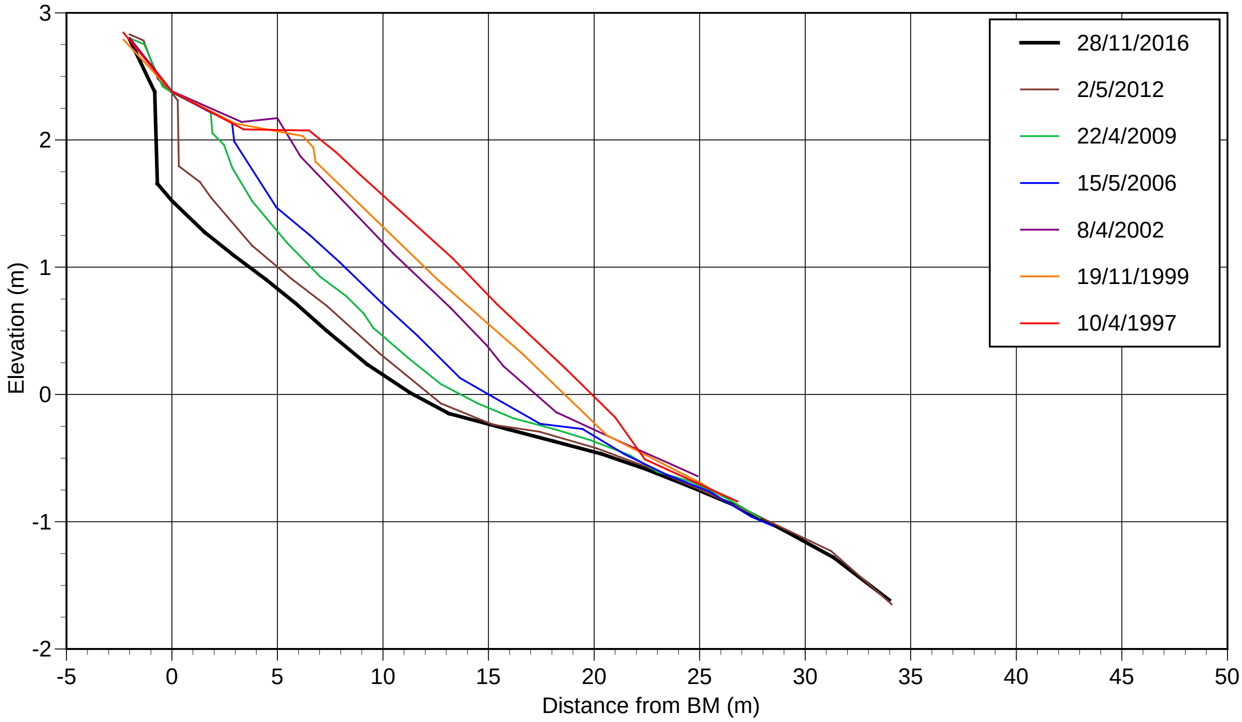
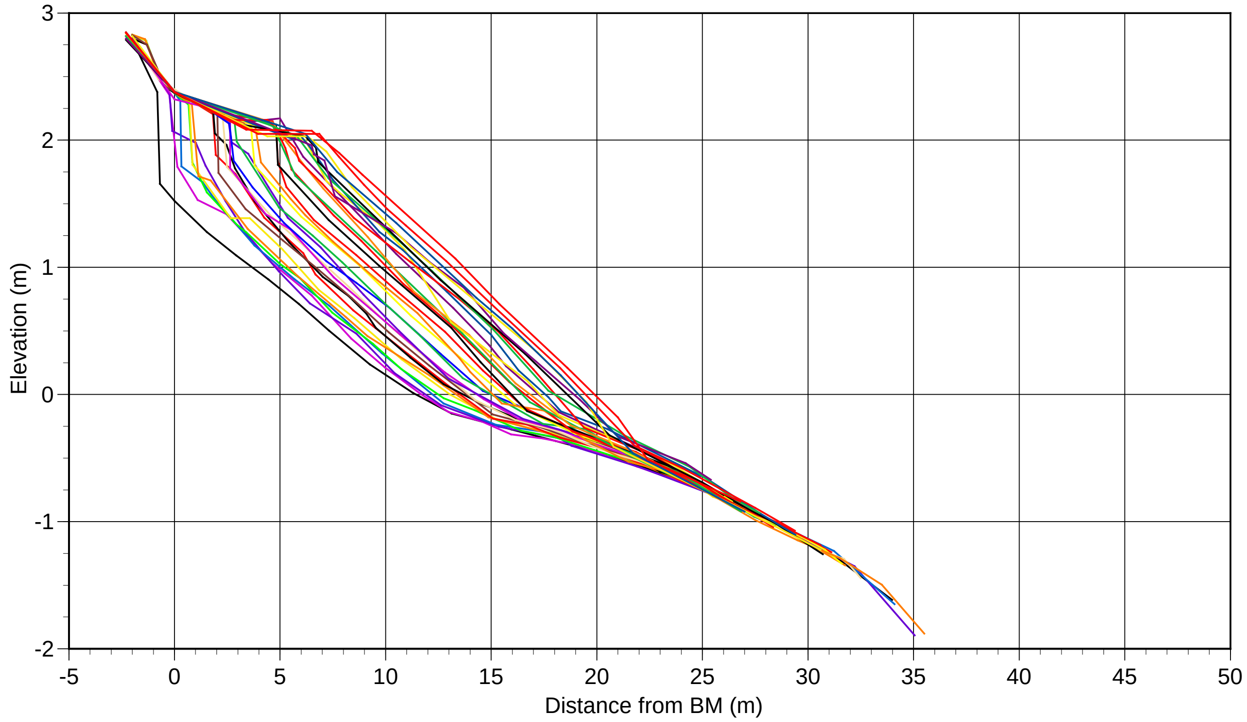
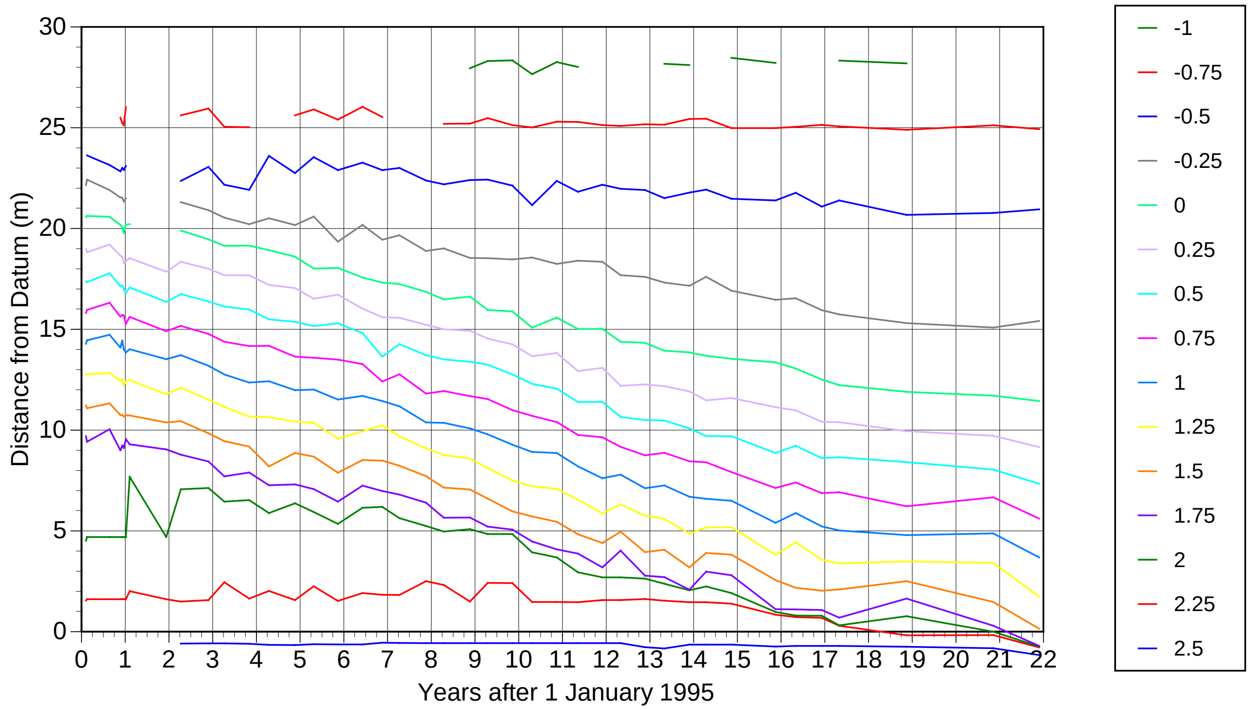
[2] Ward H (2013) Bob's Bay Erosion Assessment. Prepared for Marlborough District Council, Opus International Consultants. Reference 3-53099.00 August 2013

[3] Ward H and Edwards S (2015) Bob's Bay Erosion Options Assessment. Prepared for Marlborough District Council, Opus International Consultants. Reference 3-53148.00 April 2015

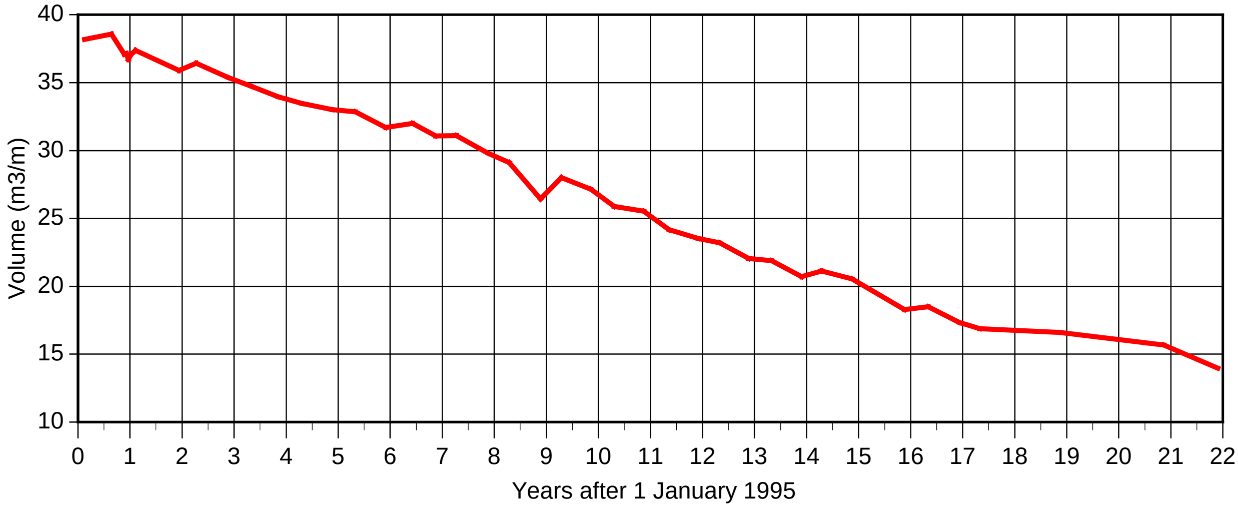


Profile 8: Bobs Bay





Profile 8: Bobs Bay



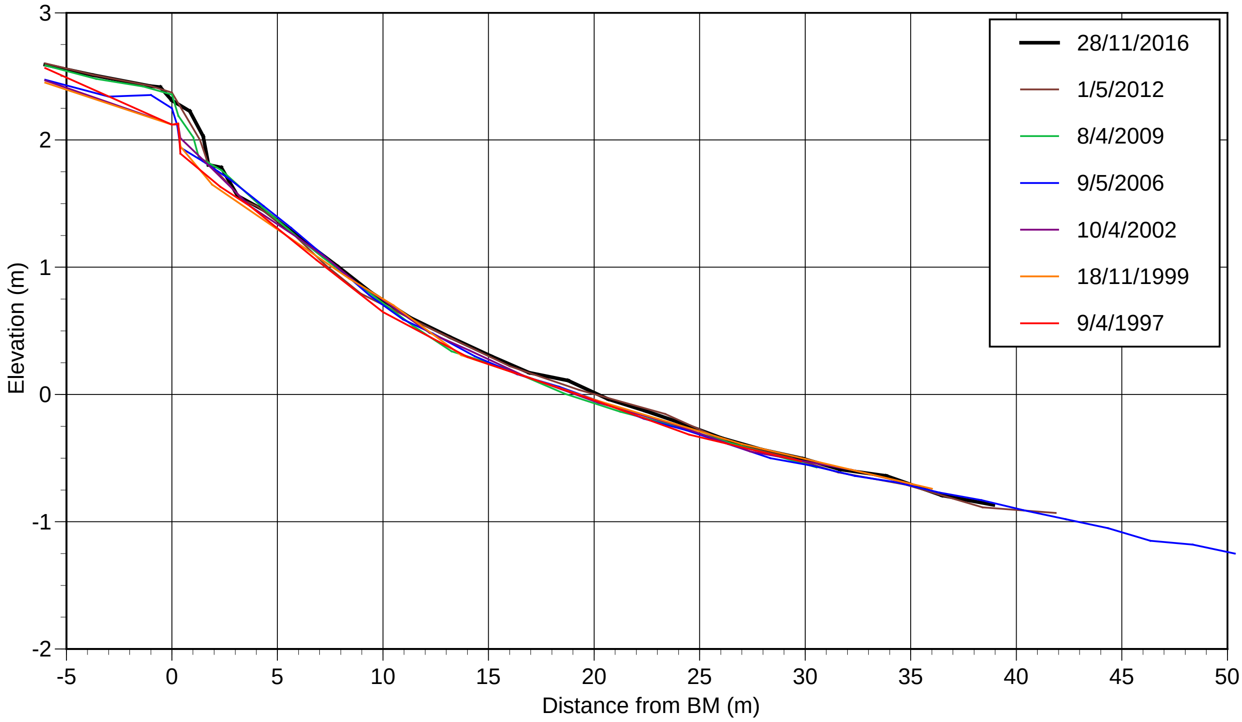
Date	Years after 1/1/95	Volume (m^3/m)	Date	Years after 1/1/95	Volume (m^3/m)
17-Feb-95	0.13	38.2	19-Nov-03	8.89	26.4
22-Aug-95	0.64	38.6	20-Apr-04	9.29	28.0
21-Nov-95	0.89	37.1	9-Nov-04	9.86	27.1
7-Dec-95	0.93	37.1	26-Apr-05	10.31	25.9
20-Dec-95	0.97	36.7	15-Nov-05	10.87	25.5
7-Jan-96	1.02	37.0	15-May-06	11.36	24.2
10-Feb-96	1.11	37.4	01-Dec-06	11.91	23.5
10-Dec-96	1.94	35.9	14-May-07	12.33	23.2
10-Apr-97	2.28	36.4	22-Nov-07	12.89	22.1
18-Nov-97	2.88	35.4	06-May-08	13.33	21.9
27-Apr-98	3.32	34.7	26-Nov-08	13.90	20.7
5-Nov-98	3.84	34.0	22-Apr-09	14.29	21.1
19-Apr-99	4.30	33.5	16-Nov-09	14.87	20.5
19-Nov-99	4.88	33.0	03-Dec-10	15.88	18.3
1-May-00	5.33	32.8	29-Apr-11	16.34	18.5
29-Nov-00	5.91	31.7	06-Dec-11	16.93	17.3
5-Jun-01	6.43	32.0	02-May-12	17.33	16.9
15-Nov-01	6.87	31.1	14-Nov-13	18.87	16.6
8-Apr-02	7.27	31.1	10-Nov-15	20.86	15.7
19-Nov-02	7.88	29.8	26-Nov-16	21.90	14.0
14-Apr-03	8.29	29.1			

Profile 8: Bobs Bay

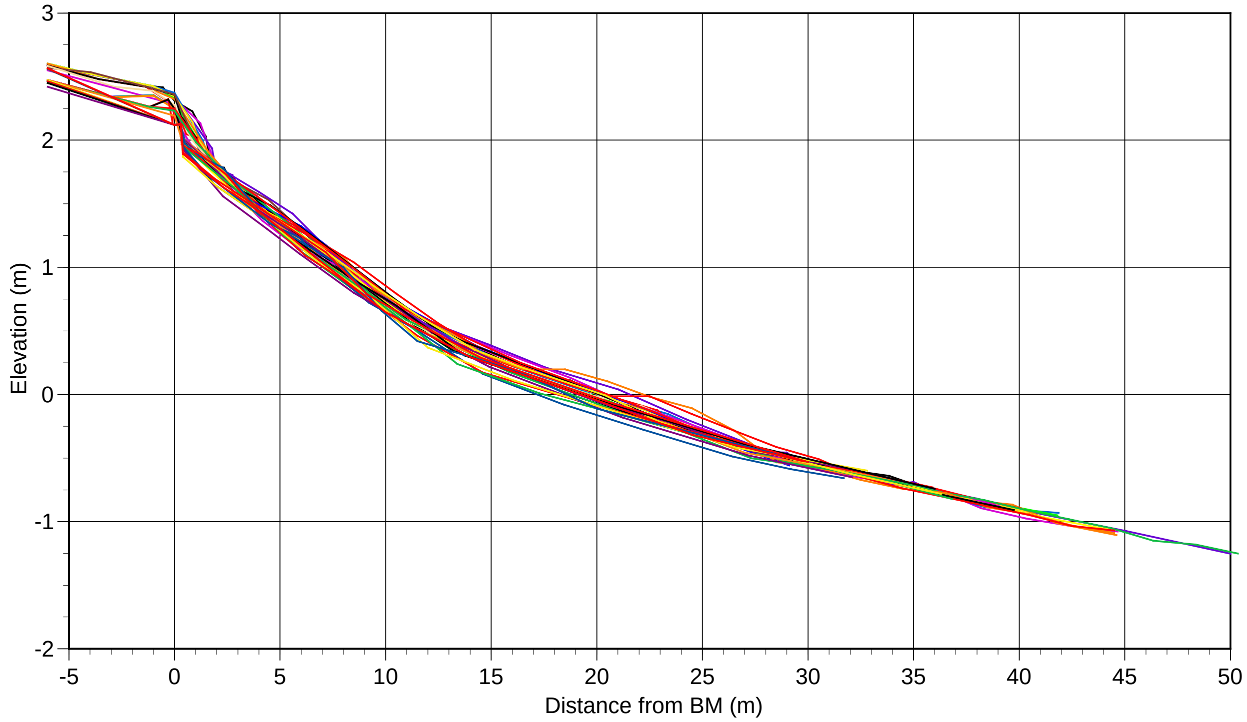
Profile 9 – Te Awaiti Bay

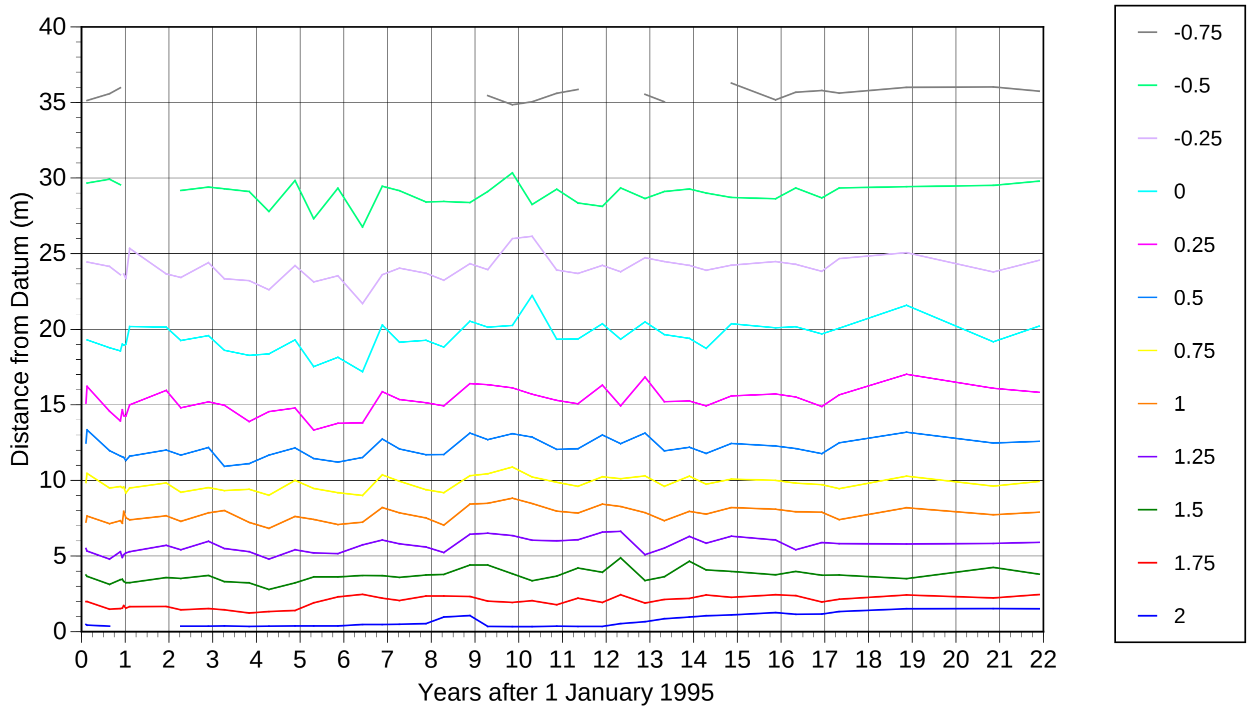
Despite frequent changes in surficial sediments (more common up to 2003), with the deposition and removal of a small quantity of fine sediment, the beach profile has changed little with respect to overall shape, but with minor (~1m) accretion across the middle and upper beach. Apparent changes on the upper beach in the profile is the result of different survey pole placement rather than real change. Beach volumes were relatively stable up until 2001, but then increased significantly, coinciding with the slowing of the fast ferries. Volumes peaked in 2004, and have remained constant since, albeit with considerable variability (~2m^3/m).

Photographs indicate that the sediment deposited at the top of the beach may have an aeolian origin.

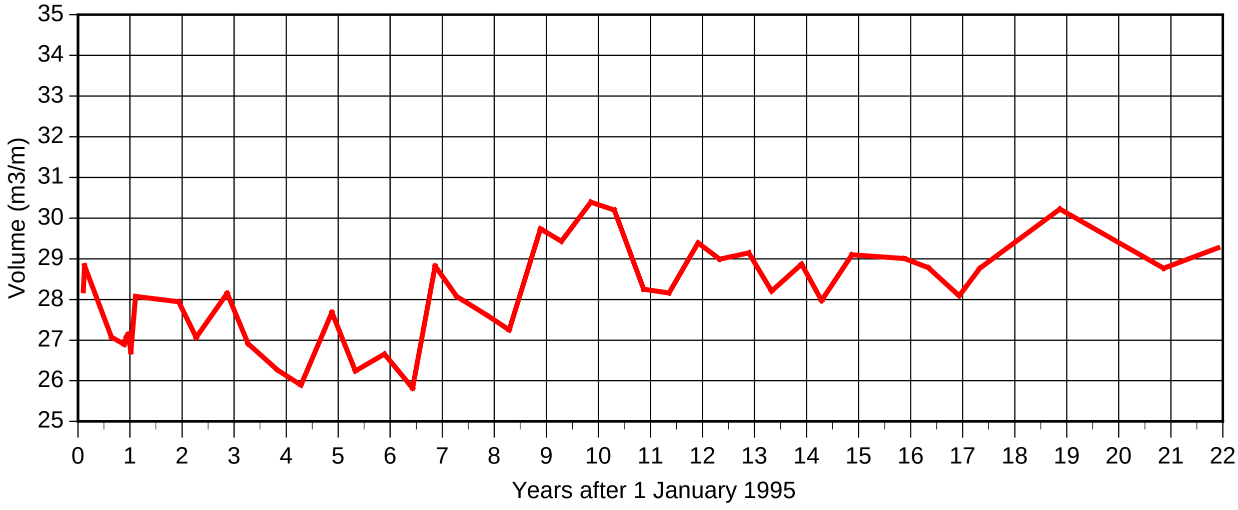


Profile 9: Te Awaiti Bay





Profile 9: Te Awaiti Bay

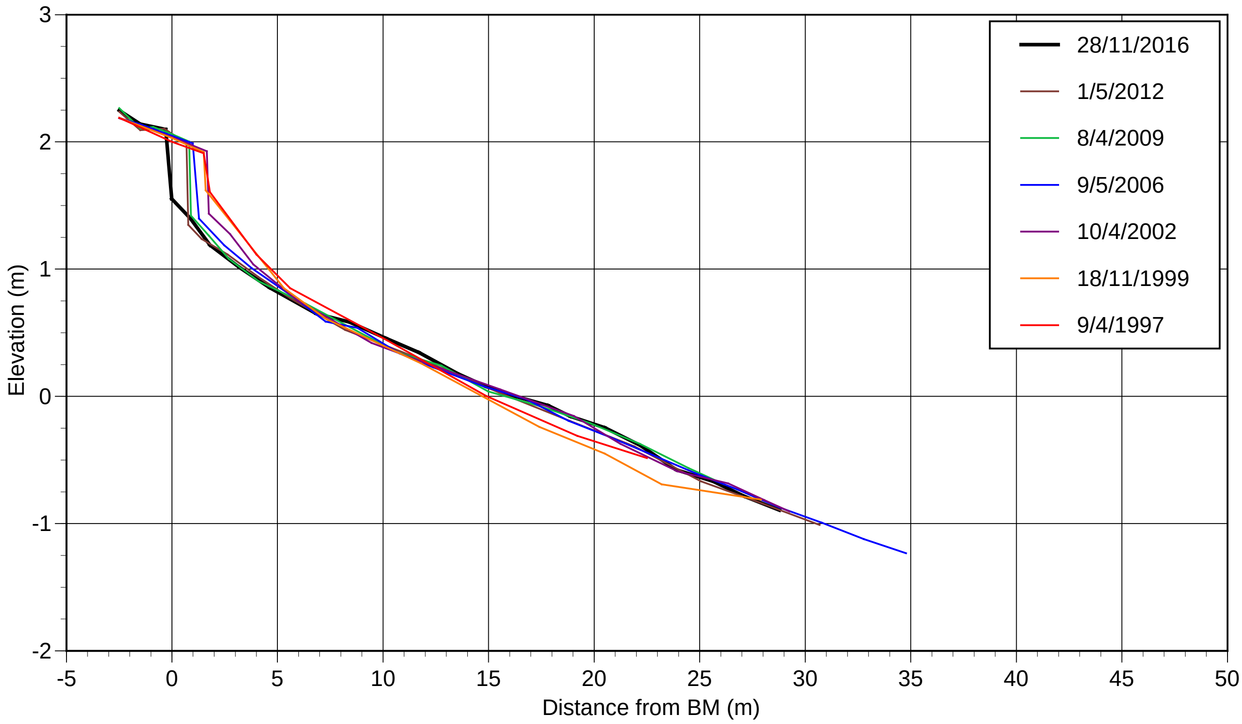


Date	Years after 1/1/95	Volume (m^3/m)	Date	Years after 1/1/95	Volume (m^3/m)
8-Feb-95	0.10	28.2	15-Apr-03	8.29	27.3
17-Feb-95	0.13	28.8	20-Nov-03	8.89	29.7
23-Aug-95	0.64	27.1	16-Apr-04	9.29	29.4
22-Nov-95	0.89	26.9	9-Nov-04	9.86	30.4
7-Dec-95	0.93	27.1	22-Apr-05	10.31	30.2
20-Dec-95	0.97	27.1	14-Nov-05	10.87	28.2
7-Jan-96	1.02	26.7	9-May-06	11.36	28.2
9-Feb-96	1.11	28.1	9-May-06	11.36	28.2
9-Dec-96	1.94	27.9	21-Nov-06	11.91	29.4
9-Apr-97	2.27	27.1	01-May-07	12.33	29.0
14-Nov-97	2.87	28.1	21-Nov-07	12.89	29.1
9-Apr-98	3.27	26.9	02-May-08	13.33	28.2
2-Nov-98	3.84	26.3	26-Nov-08	13.90	28.9
13-Apr-99	4.28	25.9	13-Nov-09	14.87	29.1
18-Nov-99	4.88	27.7	16-Nov-10	15.88	29.0
1-May-00	5.33	26.2	02-May-11	16.34	28.8
22-Nov-00	5.89	26.7	07-Dec-11	16.93	28.1
6-Jun-01	6.43	25.8	01-May-12	17.33	28.8
12-Nov-01	6.86	28.8	14-Nov-13	18.87	30.2
10-Apr-02	7.28	28.1	10-Nov-15	20.86	28.8
15-Nov-02	7.88	27.6	26-Nov-16	21.90	29.3

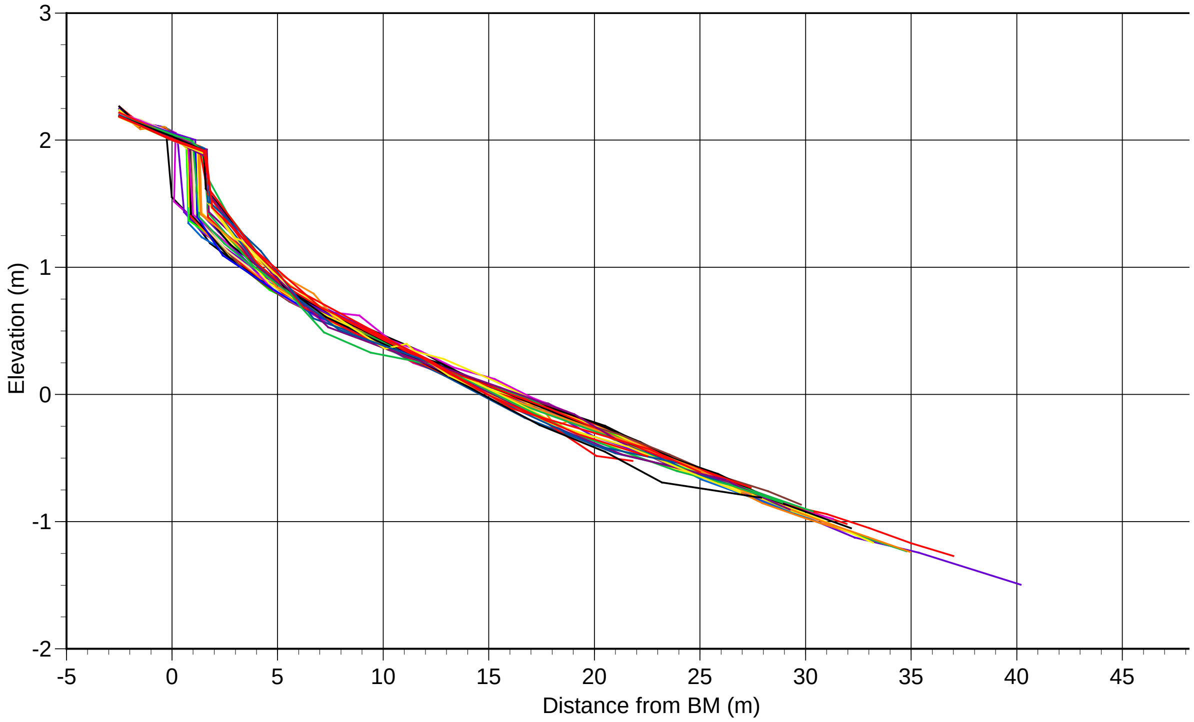
Profile 9: Te Awaiti Bay

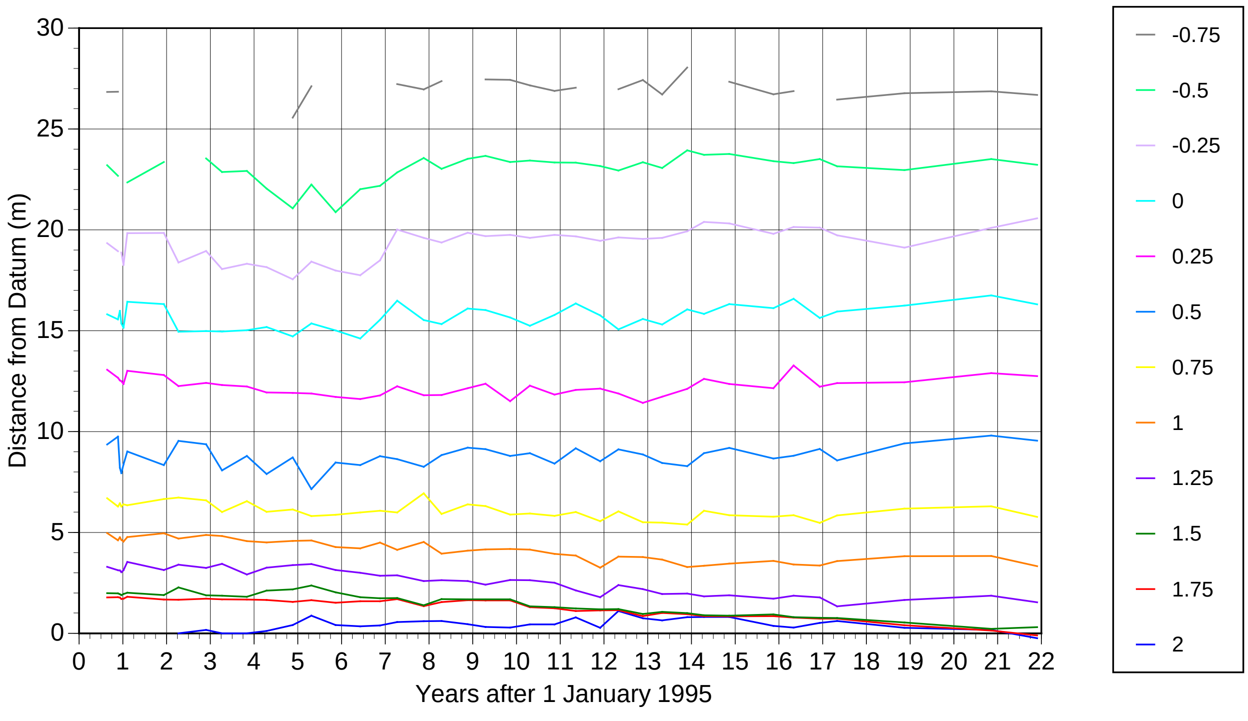
Profile 10 – Tipi Bay

Tipi Bay beach is backed by reworked sediments associated with an old whaling station. There has been some retreat of the upper beach scarp (approximately 2m) and a corresponding increase in the level of the middle to lower beach, but the changes have generally been minor. Because of the relatively coarse nature of the sediments, the placement of the survey staff can have significant impact on the apparent appearance of the profile line. Beach volumes declined over the period of fast ferry operation, before recovering and remaining relatively stable since.

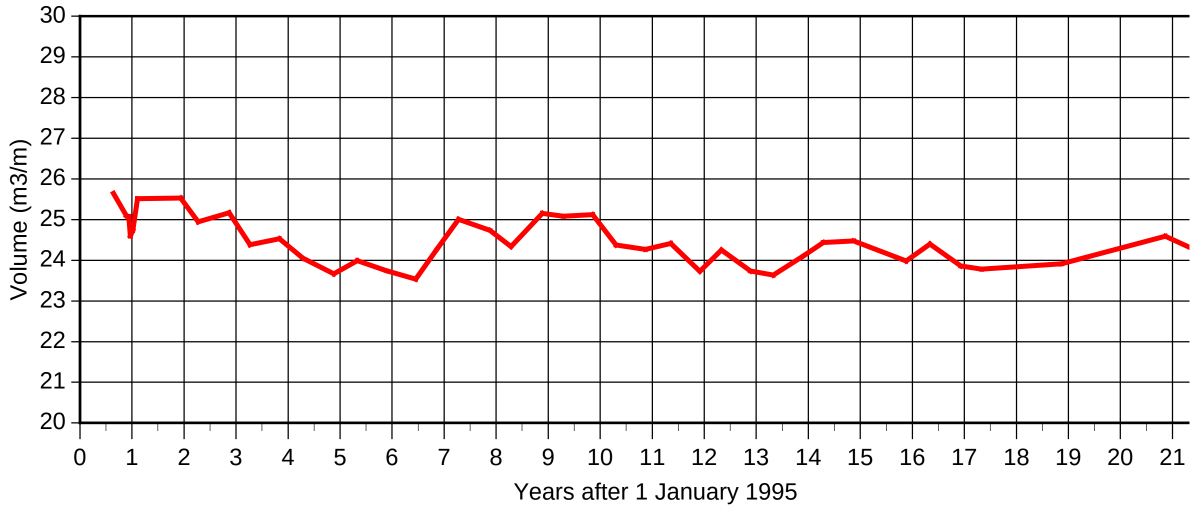


Profile 10: Tipi Bay





Profile 10: Tipi Bay

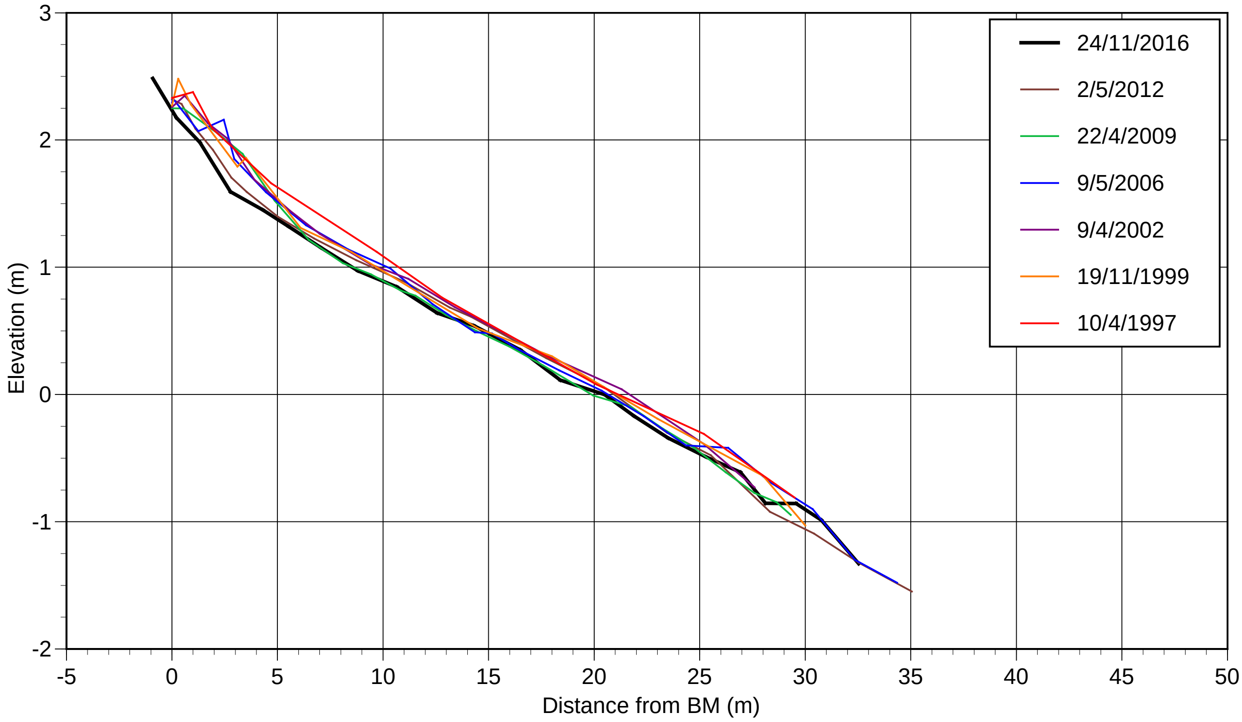


Date	Years after 1/1/95	Volume (m^3/m)	Date	Years after 1/1/95	Volume (m^3/m)
23-Aug-95	0.64	25.6	20-Nov-03	8.89	25.1
22-Nov-95	0.89	25.1	16-Apr-04	9.29	25.1
8-Dec-95	0.94	25.1	9-Nov-04	9.86	25.1
20-Dec-95	0.97	24.6	22-Apr-05	10.31	24.4
7-Jan-96	1.02	24.7	14-Nov-05	10.87	24.3
9-Feb-96	1.11	25.5	9-May-06	11.36	24.4
9-Dec-96	1.94	25.5	21-Nov-06	11.91	23.7
9-Apr-97	2.27	24.9	01-May-07	12.33	24.3
14-Nov-97	2.87	25.2	21-Nov-07	12.89	23.7
9-Apr-98	3.27	24.4	02-May-08	13.33	23.6
2-Nov-98	3.84	24.5	26-Nov-08	13.90	24.1
13-Apr-99	4.28	24.0	08-Apr-09	14.29	24.4
18-Nov-99	4.88	23.7	13-Nov-09	14.87	24.5
1-May-00	5.33	24.0	16-Nov-10	15.88	24.0
22-Nov-00	5.89	23.7	02-May-11	16.34	24.4
15-Jun-01	6.46	23.5	07-Dec-11	16.93	23.9
12-Nov-01	6.86	24.3	01-May-12	17.33	23.8
10-Apr-02	7.28	25.0	14-Nov-13	18.87	23.9
15-Nov-02	7.88	24.7	10-Nov-15	20.86	24.6
15-Apr-03	8.29	24.3	26-Nov-16	21.90	24.0

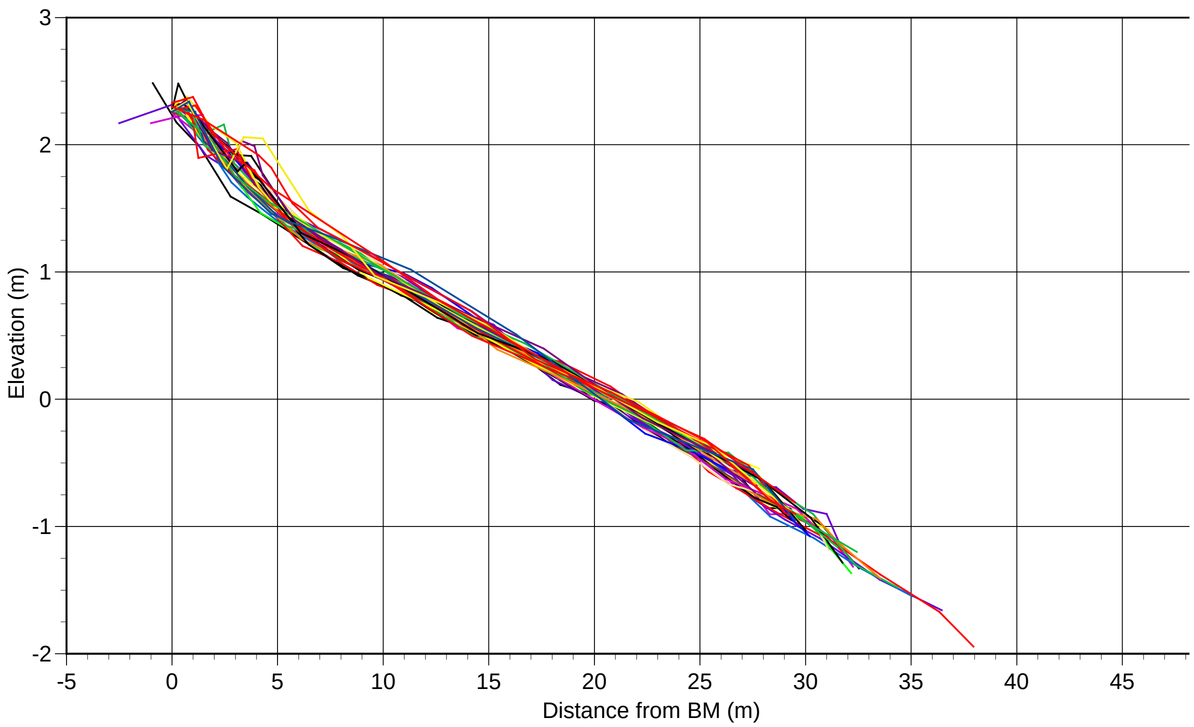
Profile 10: Tipi Bay

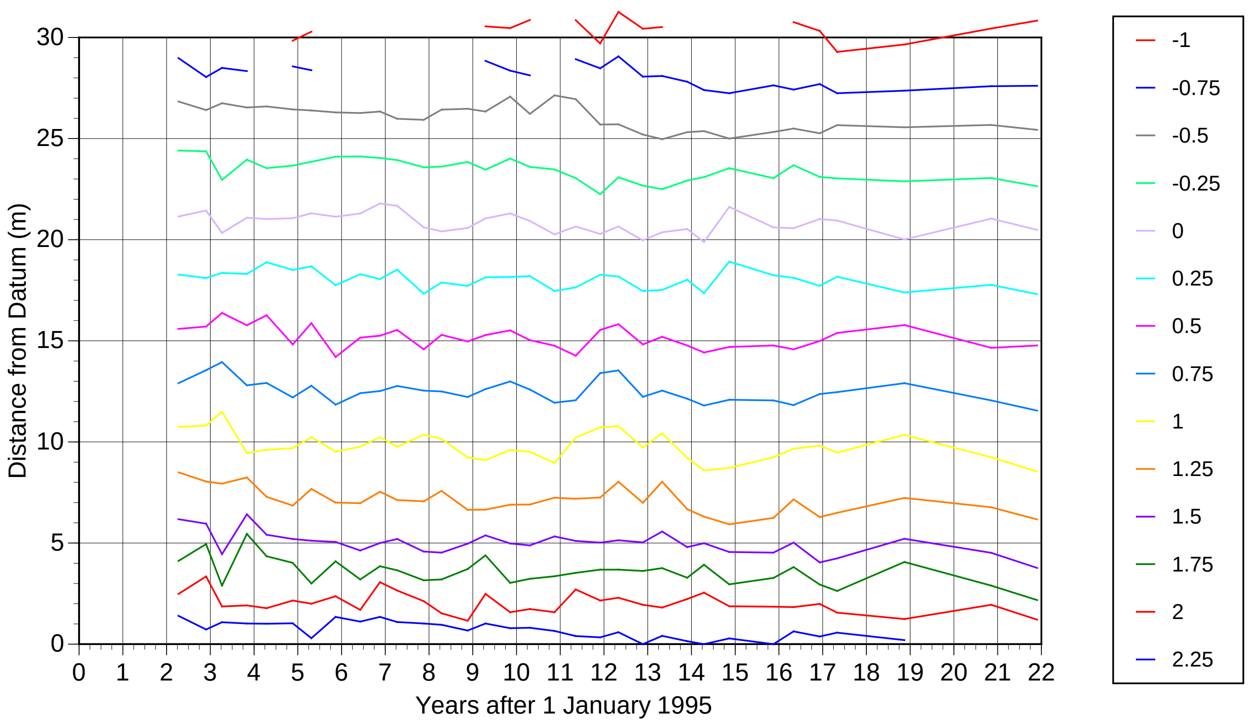
Profile 11 – Long Island

The Long Island profile is relatively exposed to storm events that cause waves to propagate through the northern entrance to Queen Charlotte Sound. There is considerable variability in the level of the upper beach, with the build-up and removal of a berm, although this has been less evident since about 2000. The level of the middle and lower beach also shows some variability, but with no obvious seasonal trends. There has been a slow trend of profile lowering since 1995 (~0.25m), and the profile is currently in its most depleted state. There has been an overall decrease in sediment volume since 1997, with considerable variability.

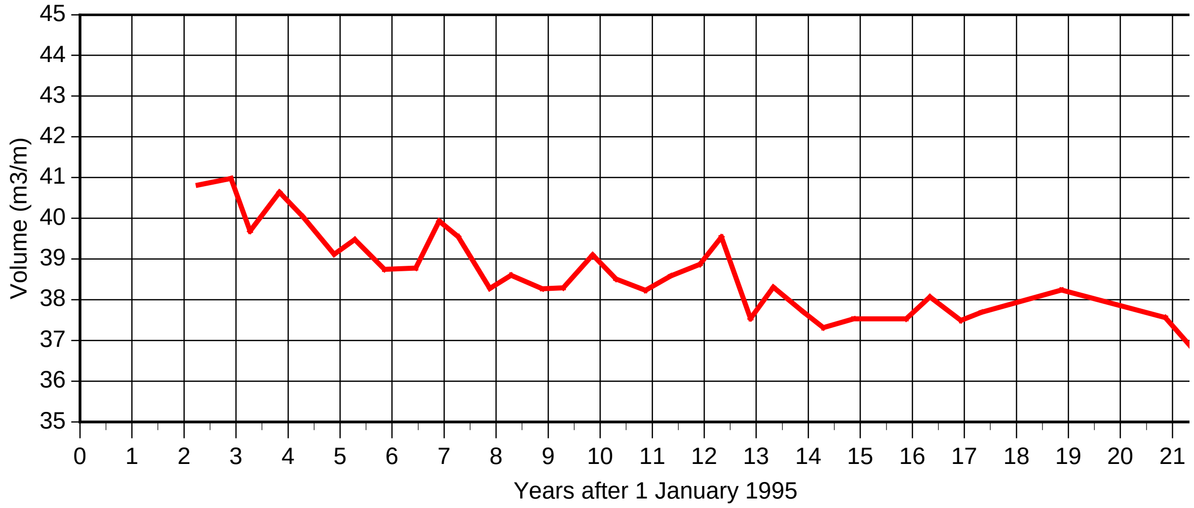


Profile 11: Long Island





Profile 11: Long Island

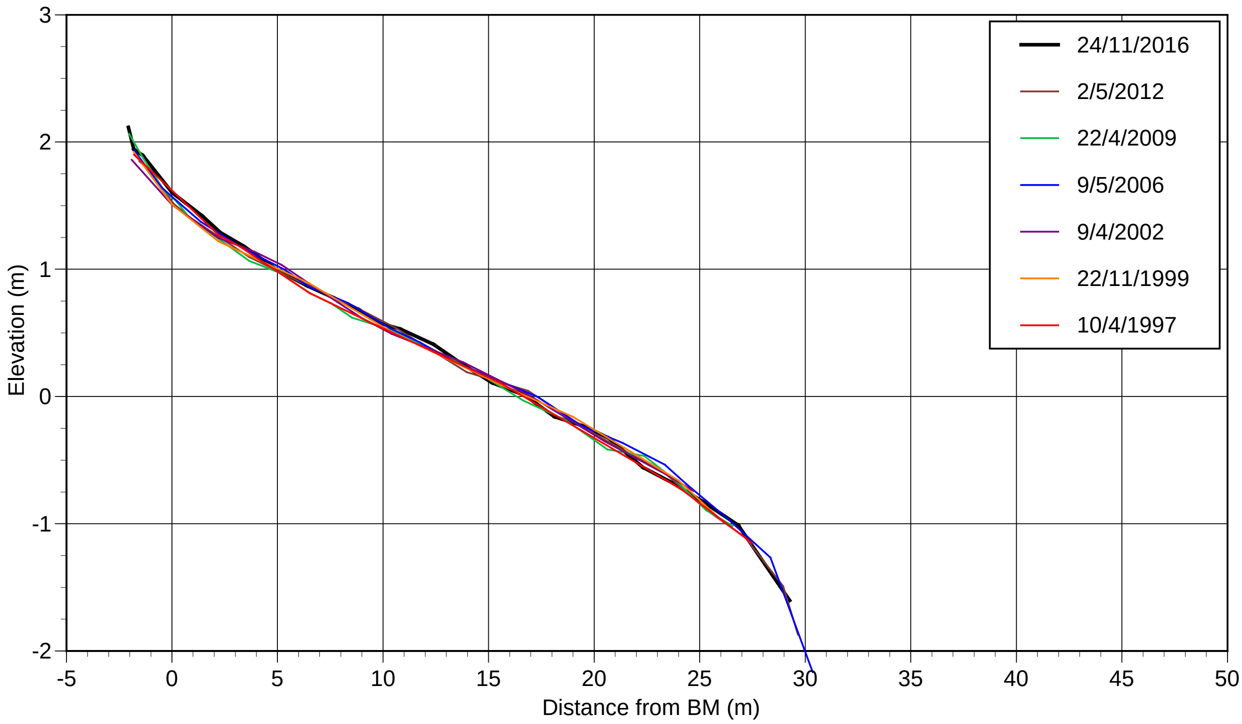


Date	Years after 1/1/95	Volume (m^3/m)
10-Apr-97	2.28	40.8
26-Nov-97	2.90	41.0
8-Apr-98	3.27	39.7
2-Nov-98	3.84	40.6
14-Apr-99	4.29	40.0
19-Nov-99	4.88	39.1
13-Apr-00	5.28	39.5
9-Nov-00	5.86	38.7
15-Jun-01	6.46	38.8
26-Nov-01	6.90	39.9
9-Apr-02	7.27	39.5
18-Nov-02	7.88	38.3
14-Apr-03	8.29	38.6
19-Nov-03	8.89	38.3
16-Apr-04	9.29	38.3
7-Dec-04	9.86	39.1
22-Apr-05	10.31	38.5
14-Nov-05	10.87	38.2
9-May-06	11.36	38.6
21-Nov-06	11.91	38.9
30-Apr-07	12.33	39.5
20-Nov-07	12.89	37.5
06-May-08	13.33	38.3
12-Nov-08	13.90	37.7
22-Apr-09	14.29	37.3
26-Nov-09	14.87	37.5
03-Dec-10	15.88	37.5
29-Apr-11	16.34	38.1
06-Dec-11	16.93	37.5
02-May-12	17.33	37.7
14-Nov-13	18.87	38.2
10-Nov-15	20.86	37.6
26-Nov-16	21.90	36.1

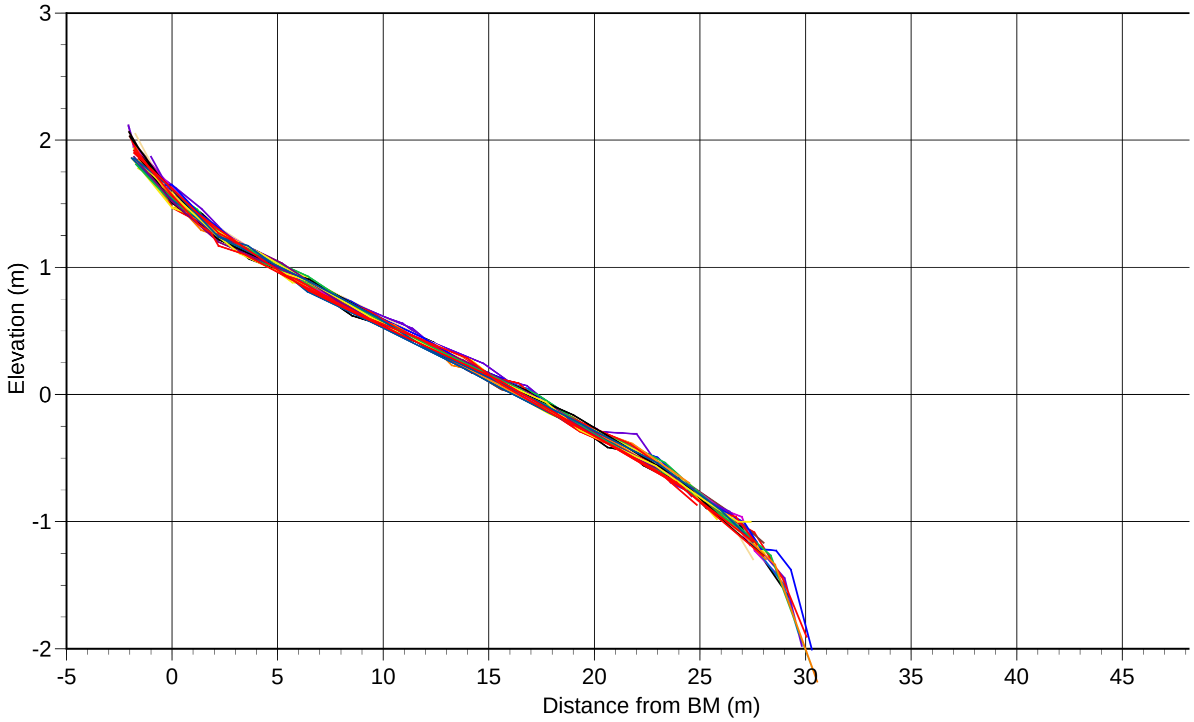
Profile 11: Long Island

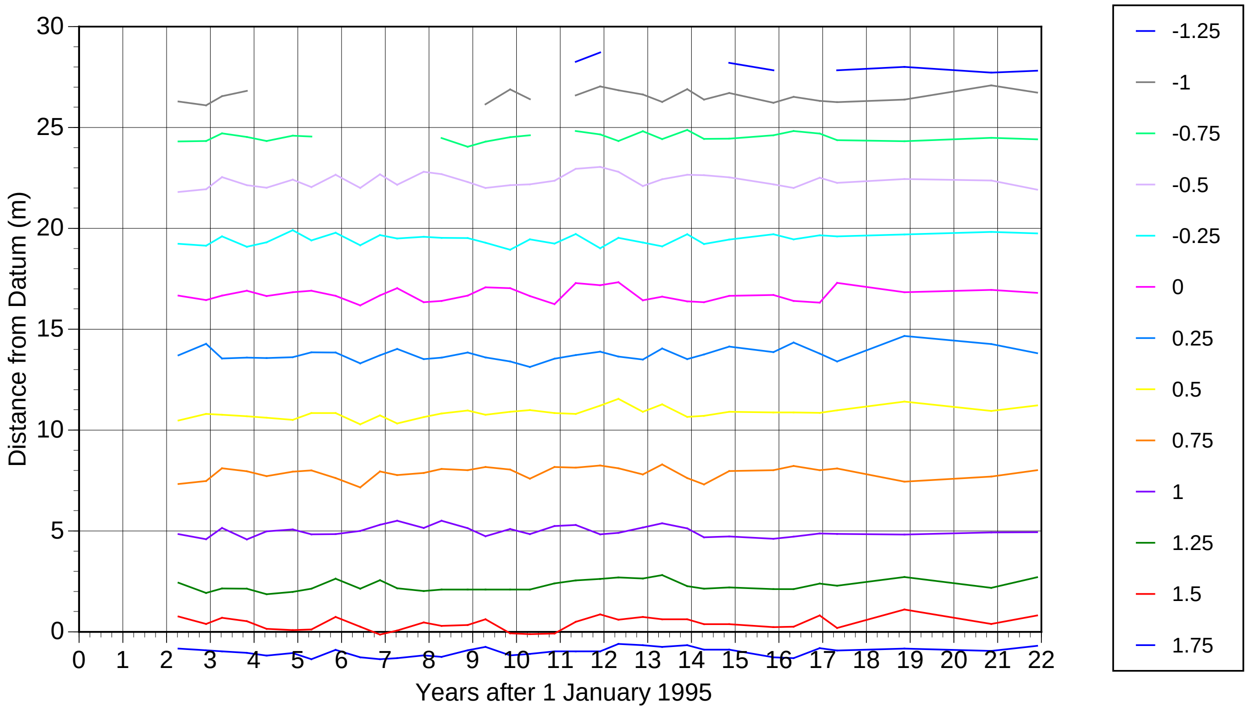
Profile 12 – Clark Point

This profile, with a similar aspect to Profile 11 (Long Island), has shown no significant change in level, volume or sediment characteristics since 1997.

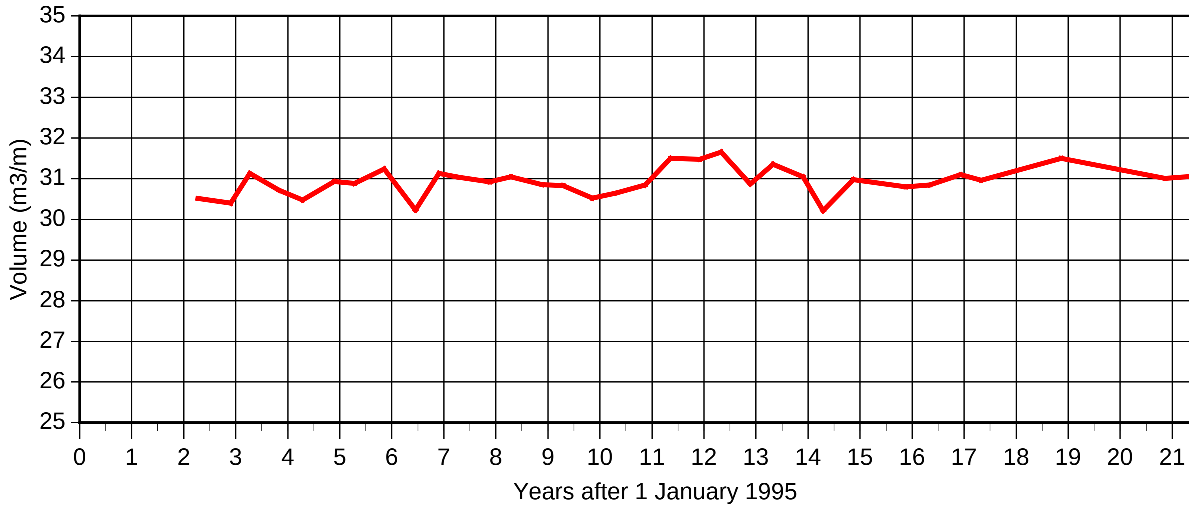


Profile 12: Clark Point





Profile 12: Clark Point



Date	Years after 1/1/95	Volume (m^3/m)
10-Apr-97	2.28	30.5
26-Nov-97	2.90	30.4
8-Apr-98	3.27	31.1
2-Nov-98	3.84	30.7
14-Apr-99	4.29	30.5
22-Nov-99	4.89	30.9
13-Apr-00	5.28	30.9
9-Nov-00	5.86	31.2
15-Jun-01	6.46	30.2
26-Nov-01	6.90	31.1
9-Apr-02	7.27	31.0
18-Nov-02	7.88	30.9
14-Apr-03	8.29	31.0
19-Nov-03	8.89	30.9
16-Apr-04	9.29	30.8
7-Dec-04	9.86	30.5
22-Apr-05	10.31	30.6
14-Nov-05	10.87	30.8
9-May-06	11.36	31.5
21-Nov-06	11.91	31.5
30-Apr-07	12.33	31.7
20-Nov-07	12.89	30.9
06-May-08	13.33	31.4
12-Nov-08	13.90	31.0
22-Apr-09	14.29	30.2
26-Nov-09	14.87	31.0
03-Dec-10	15.88	30.8
29-Apr-11	16.34	30.8
06-Dec-11	16.93	31.1
02-May-12	17.33	31.0
14-Nov-13	18.87	31.5
10-Nov-15	20.86	31.0
26-Nov-16	21.90	31.1

Profile 12: Clark Point

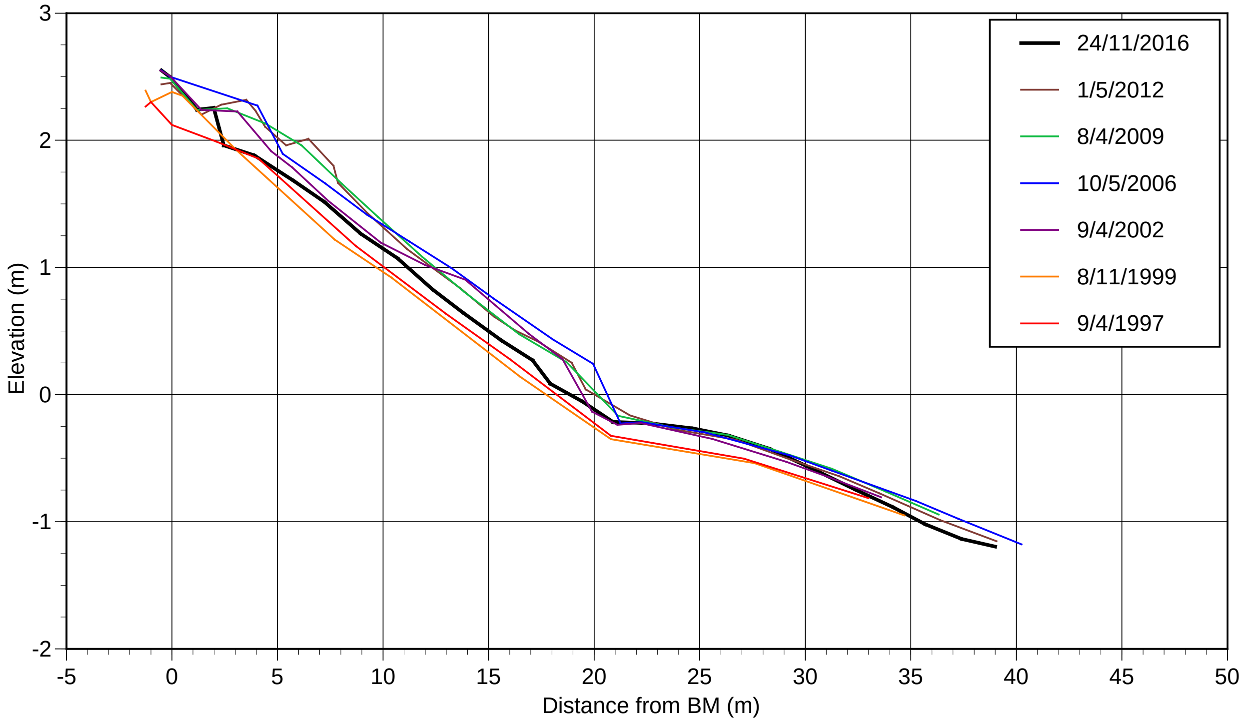
Profile 13 – Slip Beach

Slip Beach demonstrated considerable variability between 1995 and April 1998 when it reached its lowest level. Up until the end of 2000, there was variability but in the context of accretion. Between 2000 and 2006 there was less variability, but with continued accretion. Since 2006 the beach has been relatively stable from year to year, but with very significant seasonality, with accretion over the summer and sediment loss over the winter (with occasional years when seasonality is less evident). The apparent absence of seasonality in recent years (see the EDA plots) is due to survey timing and frequency, and it is highly likely that seasonal variability is still occurring. Overall, the beach is currently in an accreted state compared to 1997, but well within the long-term change envelope.

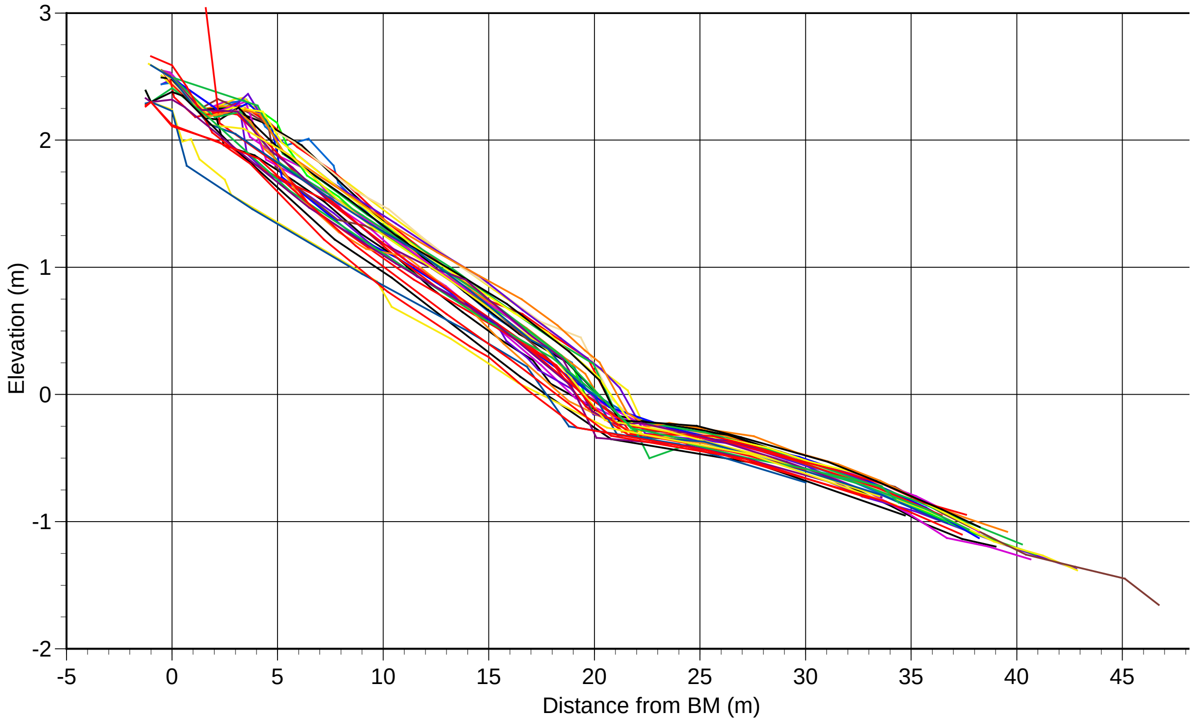
The photographs indicate that the dominant sediment type is sand with some small cobbles and pebbles.

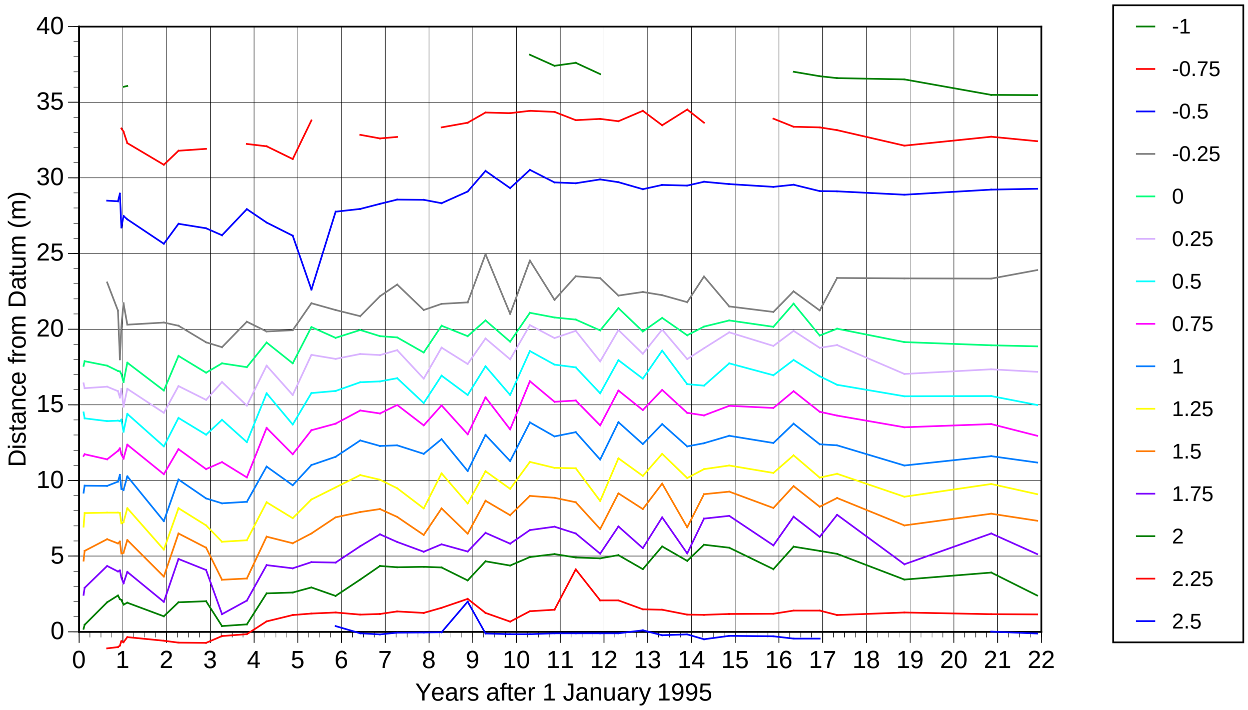
It was earlier believed that the variability in the profile was to a significant extent related to fast ferry operation. However, similar variability in levels and volumes has continued since fast ferry operation ceased. Slip beach has a long fetch into Queen Charlotte Sound to the north, and natural waves may be substantial. However, wave measurements at this site have showed substantial wake events (both fast and conventional) affect this beach that continue for unusually long periods of time.

Because of its unusual exposure, extreme seasonality, unusual wakes and, for the area, fine sediments, this location continues to be of particular interest, although apart from seasonality there is no obvious explanation for the changes observed.

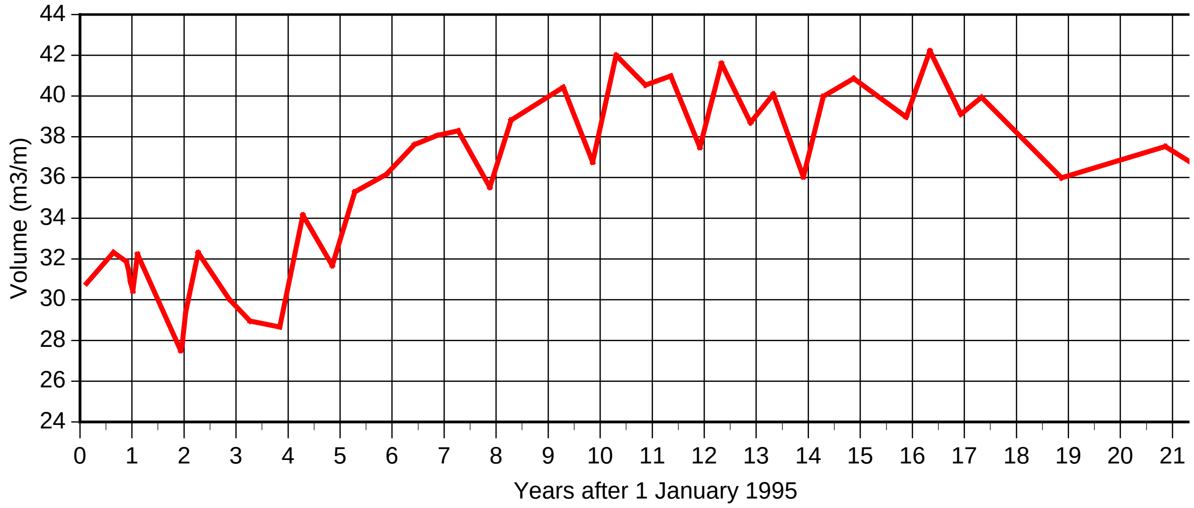


Profile 13: Slip Beach





Profile 13: Slip Beach



Date	Years after 1/1/95	Volume (m^3/m)	Date	Years after 1/1/95	Volume (m^3/m)
17-Feb-95	0.13	30.8	15-Nov-02	7.88	35.5
22-Aug-95	0.64	32.3	15-Apr-03	8.29	38.8
21-Nov-95	0.89	31.9	20-Nov-03	8.89	No data
7-Dec-95	0.93	31.5	15-Apr-04	9.29	40.4
20-Dec-95	0.97	30.9	8-Nov-04	9.86	36.8
7-Jan-96	1.02	30.4	20-Apr-05	10.31	42.0
9-Feb-96	1.11	32.2	11-Nov-05	10.87	40.5
9-Dec-96	1.94	27.5	10-May-06	11.36	41.0
19-Dec-96	1.97	27.8	01-Dec-06	11.91	37.5
13-Jan-97	2.03	29.4	01-May-07	12.33	41.6
9-Apr-97	2.27	32.3	20-Nov-07	12.89	38.7
14-Nov-97	2.87	30.0	02-May-08	13.33	40.1
8-Apr-98	3.27	29.0	12-Nov-08	13.90	36.0
4-Nov-98	3.84	28.7	08-Apr-09	14.29	40.0
14-Apr-99	4.29	34.2	13-Nov-09	14.87	40.9
8-Nov-99	4.85	31.7	16-Nov-10	15.88	39.0
13-Apr-00	5.28	35.3	02-May-11	16.34	42.2
22-Nov-00	5.89	36.2	07-Dec-11	16.93	39.1
6-Jun-01	6.43	37.6	01-May-12	17.33	39.9
12-Nov-01	6.86	38.1	14-Nov-13	18.87	36.0
9-Apr-02	7.27	38.3	10-Nov-15	20.86	37.5
			26-Nov-16	21.90	35.9

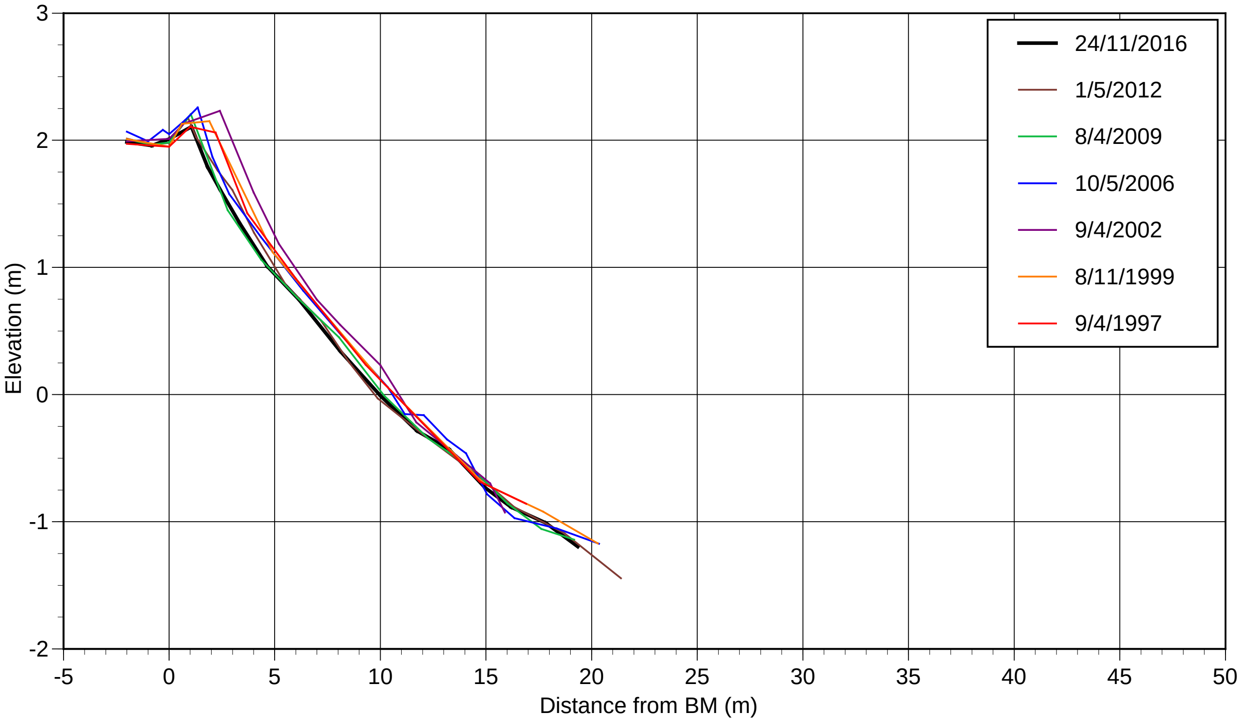
Profile 13: Slip Beach

Profile 14 – Ngaionui Point

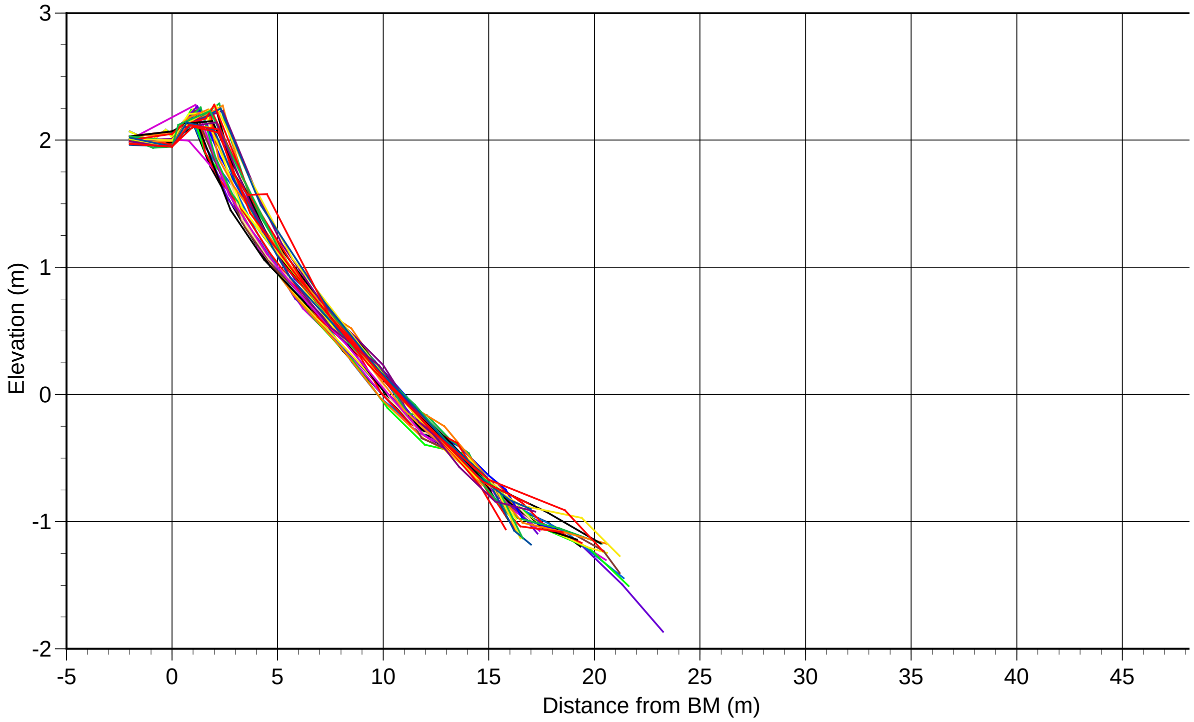
Given its proximity to the sailing line of vessels in Tory Channel, the beach at Ngaionui Point probably changed significantly when the fast ferry first started operation, with accretion and berm building. There was a slow trend towards accretion up until about April 2002, and a trend of erosion since that time, reflecting the slow return to pre-fast ferry conditions. The beach is now lower than at the start of surveys, although the first survey did not coincide with the commencement of fast ferry operation, and it is quite possible that there had already been rapid berm building.

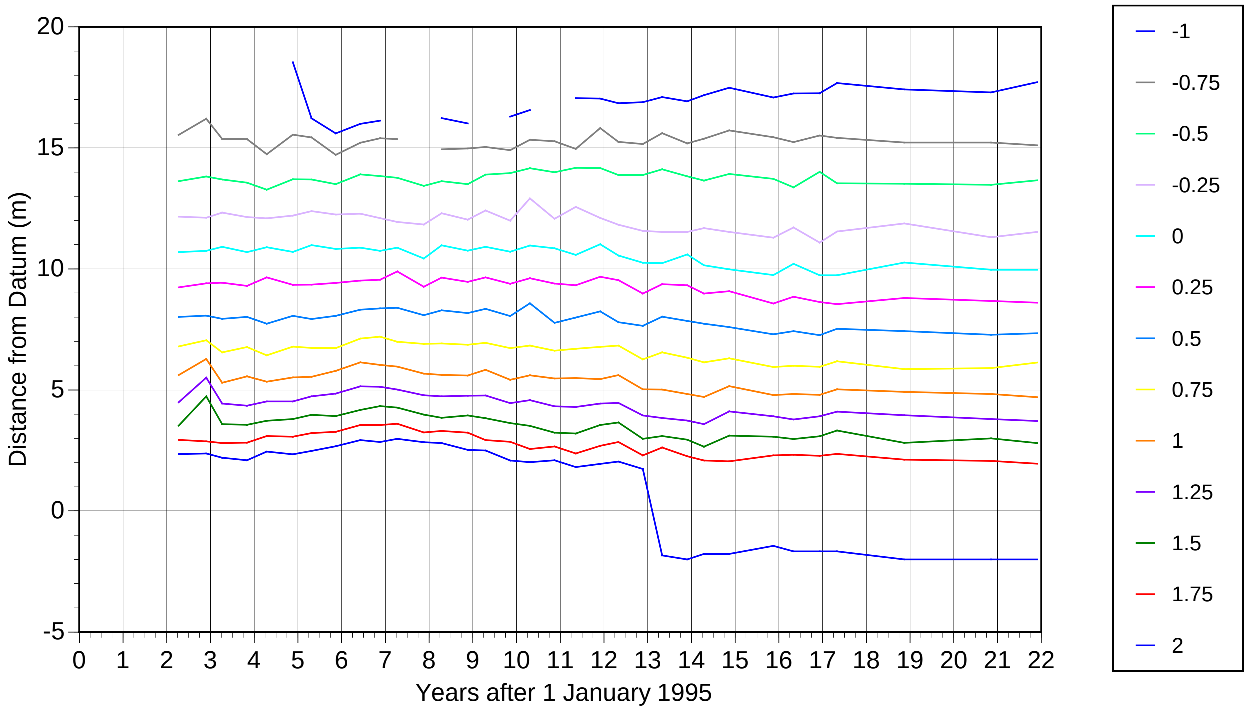
Apparent changes at the very lower beach are probably the result of different survey placement. There have been no significant changes in sediments.

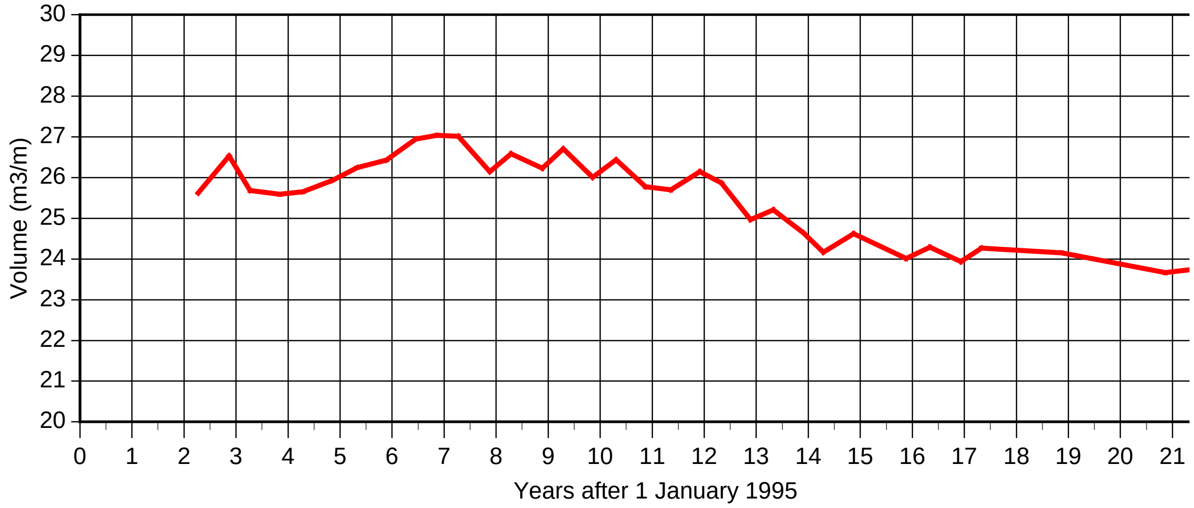


Profile 14: Ngaionui Point





Profile 14: Ngaionui Point



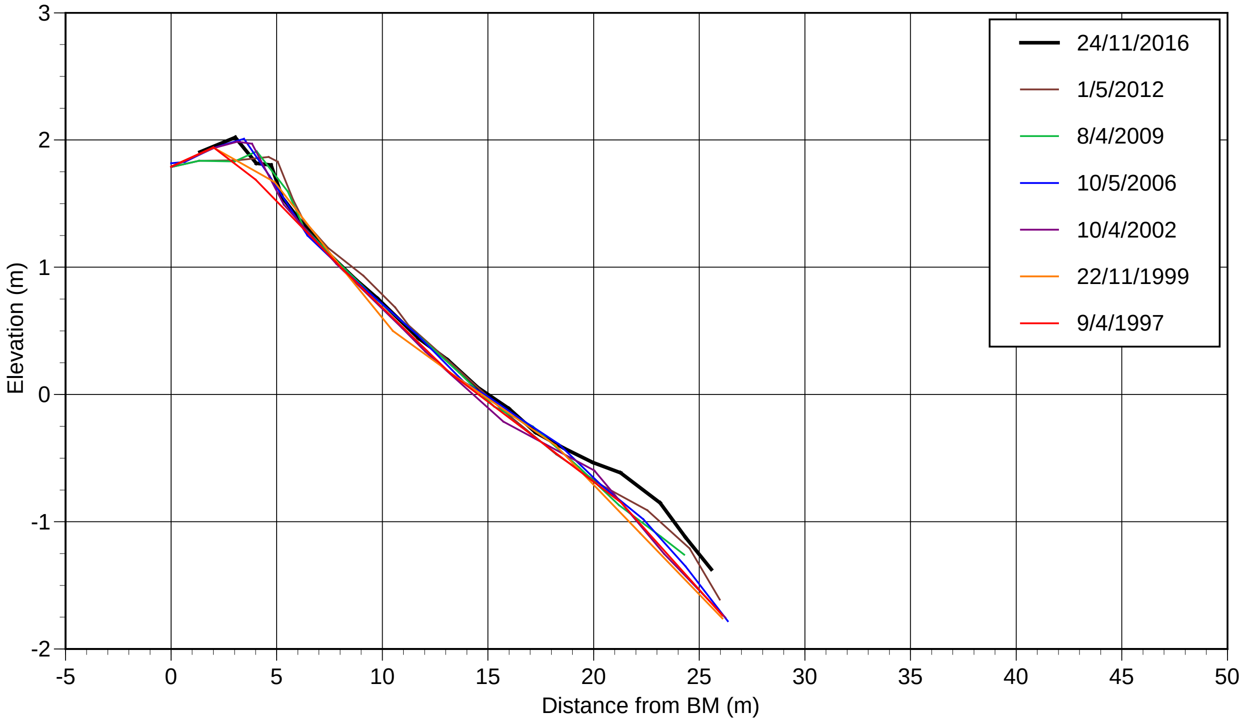
Date	Years after 1/1/95	Volume (m^3/m)
9-Apr-97	2.27	25.6
14-Nov-97	2.87	26.5
9-Apr-98	3.27	25.7
4-Nov-98	3.84	25.6
14-Apr-99	4.29	25.7
8-Nov-99	4.85	25.9
1-May-00	5.33	26.2
22-Nov-00	5.89	26.4
15-Jun-01	6.46	26.9
12-Nov-01	6.86	27.0
9-Apr-02	7.27	27.0
15-Nov-02	7.88	26.1
15-Apr-03	8.29	26.6
20-Nov-03	8.89	26.2
15-Apr-04	9.29	26.7
8-Nov-04	9.86	26.0
20-Apr-05	10.31	26.4
11-Nov-05	10.87	25.8
10-May-06	11.36	25.7
01-Dec-06	11.91	26.1
01-May-07	12.33	25.8
21-Nov-07	12.89	24.9
02-May-08	13.33	25.2
26-Nov-08	13.90	24.6
08-Apr-09	14.29	24.1
13-Nov-09	14.87	24.6
16-Nov-10	15.88	24.0
02-May-11	16.34	24.3
07-Dec-11	16.93	23.9
01-May-12	17.33	24.3
14-Nov-13	18.87	24.2
10-Nov-15	20.86	23.7
26-Nov-16	21.90	23.8

Profile 14: Ngaionui Point

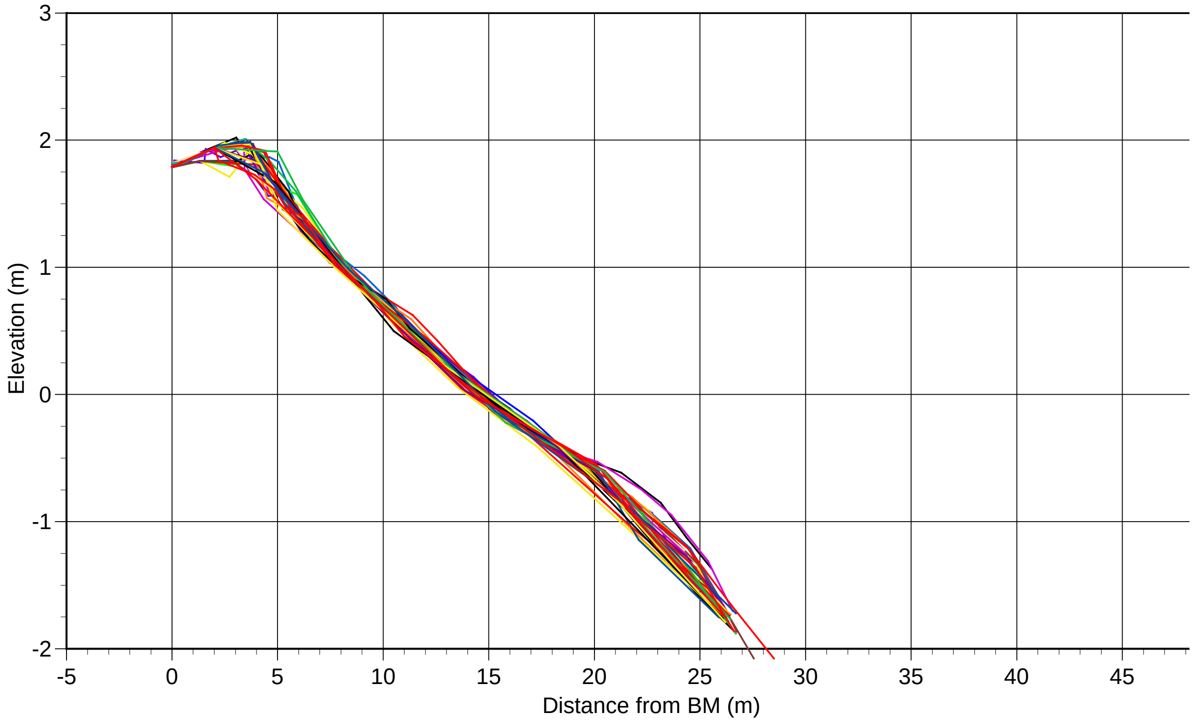
Profile 15 – Te Weka Bay

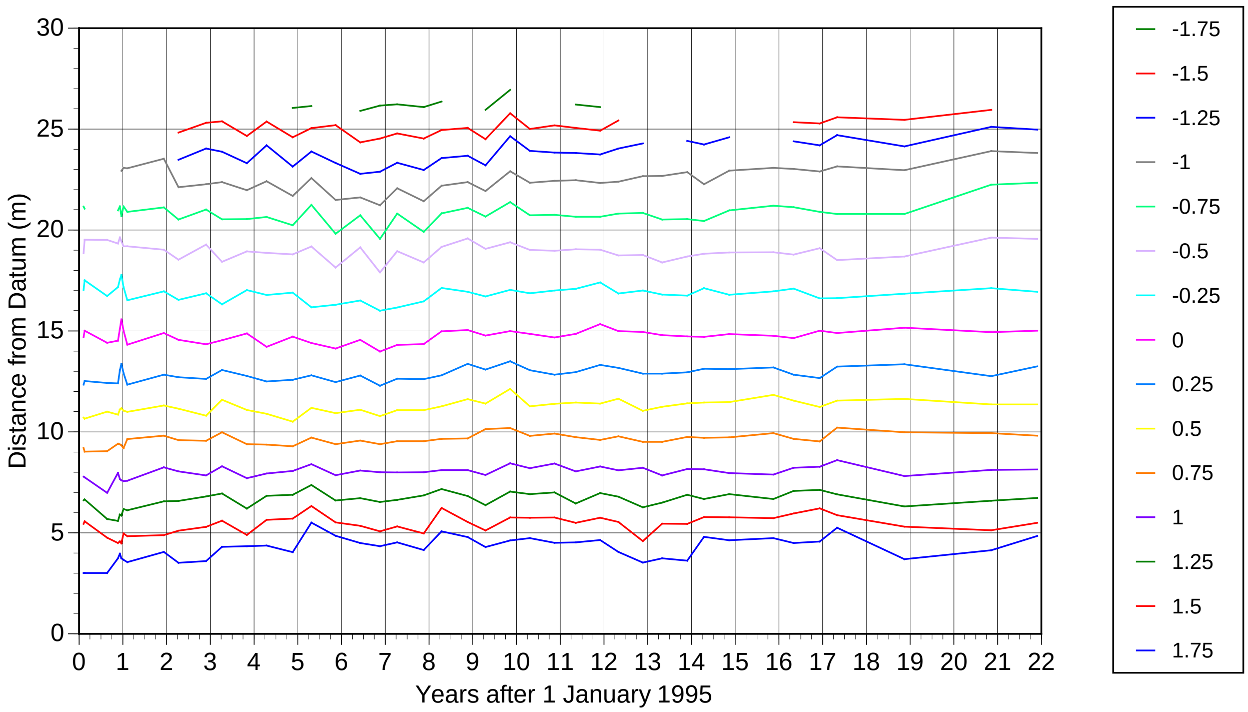
Te Weka Bay was the site of much of the ‘dramatic’ news fottage of fast ferry wakes. The fast ferries caused the development of an upper beach berm which has remained generally intact since that time. The middle beach has built a little seawards. In the last 3 years, there has been significant sediment deposited on the lower profile, although a similar feature was evident in about 2005. The source of this sediment is not known. With considerable variability, sediment volume has increased slowly. However, the deposition on the lower profile over the last 3 years has resulted in a substantial increase in sediment volume over that period.

There have been no significant changes in sediment characteristics.

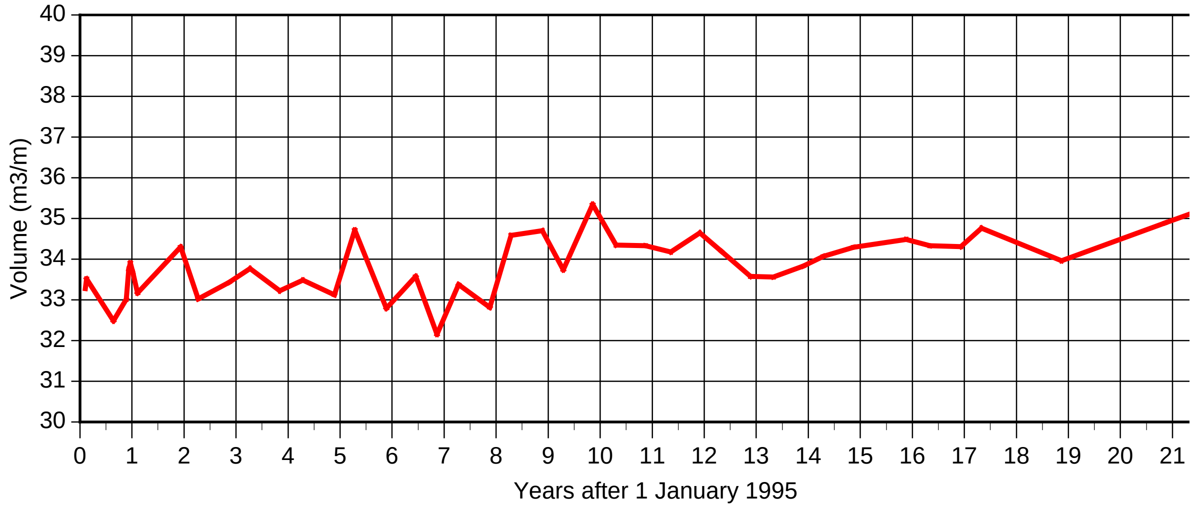


Profile 15: Te Weka Bay





Profile 15: Te Weka Bay



Date	Years after 1/1/95	Volume (m^3/m)	Date	Years after 1/1/95	Volume (m^3/m)
8-Feb-95	0.10	33.3	15-Apr-03	8.29	34.6
17-Feb-95	0.13	33.5	20-Nov-03	8.89	34.7
22-Aug-95	0.64	32.5	15-Apr-04	9.29	33.7
21-Nov-95	0.89	33.0	8-Nov-04	9.86	35.3
8-Dec-95	0.94	33.8	20-Apr-05	10.31	34.3
20-Dec-95	0.97	33.9	11-Nov-05	10.87	34.3
7-Jan-96	1.02	33.7	10-May-06	11.36	34.2
9-Feb-96	1.11	33.2	21-Nov-06	11.91	34.6
9-Dec-96	1.94	34.3	01-May-07	12.33	34.2
9-Apr-97	2.27	33.0	21-Nov-07	12.89	33.6
14-Nov-97	2.87	33.4	02-May-08	13.33	33.6
9-Apr-98	3.27	33.8	26-Nov-08	13.90	33.8
4-Nov-98	3.84	33.2	08-Apr-09	14.29	34.1
14-Apr-99	4.29	33.5	13-Nov-09	14.87	34.3
22-Nov-99	4.89	33.1	16-Nov-10	15.88	34.5
13-Apr-00	5.28	34.7	02-May-11	16.34	34.3
22-Nov-00	5.89	32.8	07-Dec-11	16.93	34.3
15-Jun-01	6.46	33.6	01-May-12	17.33	34.8
12-Nov-01	6.86	32.2	14-Nov-13	18.87	34.0
10-Apr-02	7.28	33.4	10-Nov-15	20.86	34.9
15-Nov-02	7.88	32.8	26-Nov-16	21.90	35.4

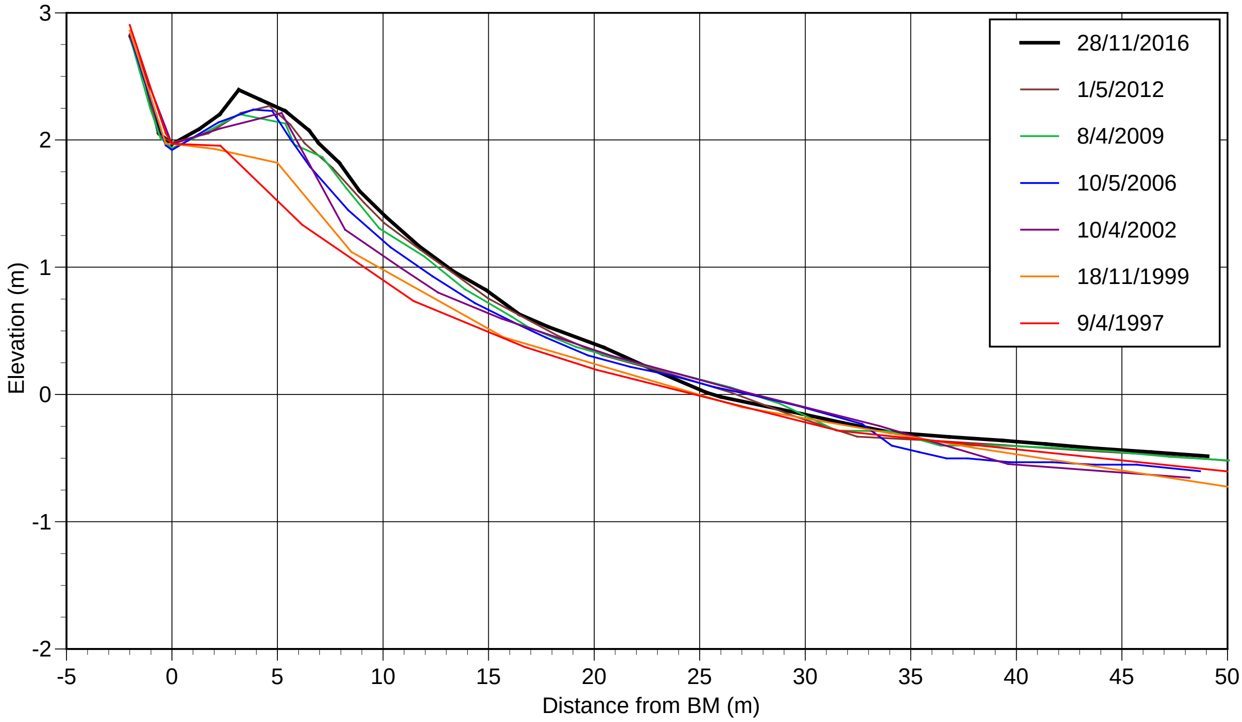
Profile 15: Te Weka Bay

Profile 16 – McMillan's Bay

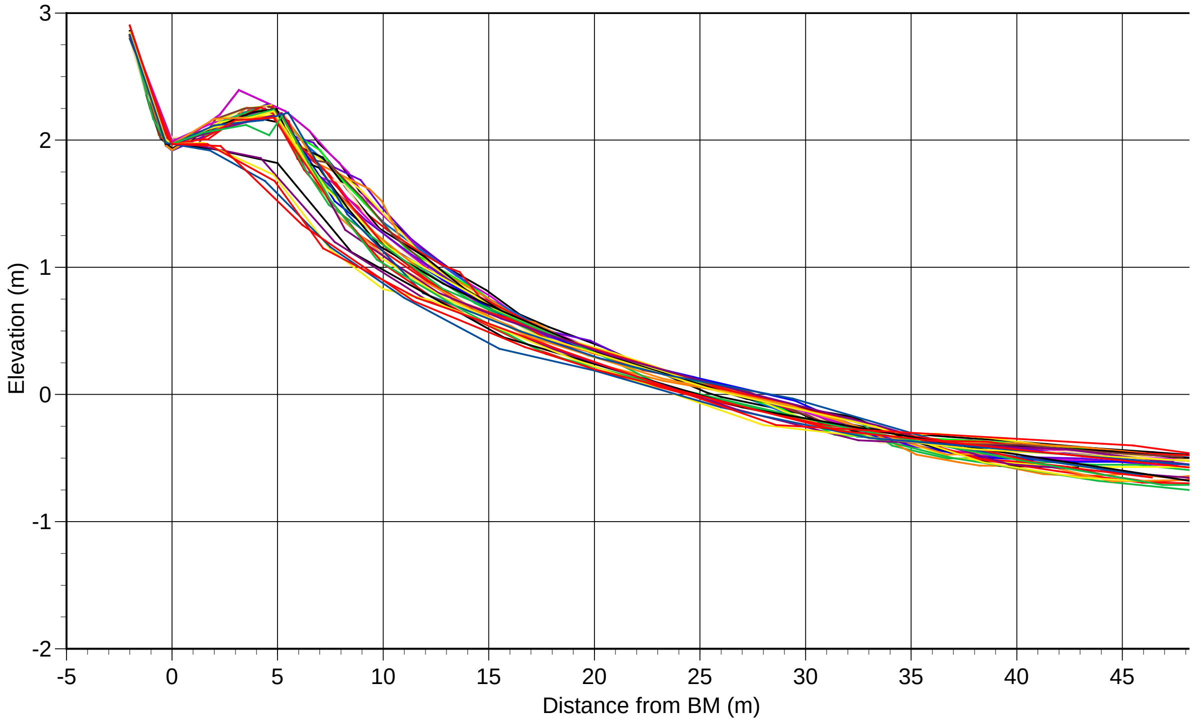
Up until November 1999 there had been a gradual accretion of the upper McMillan's Bay profile. The accretion was mainly comprised of gravels that were moving along the beach from the direction of Arrowsmith Point, although there had been some rise in the middle beach level, due to deposition of sand. Between November 1999 and May 2000 a major increase in the height of the upper beach berm occurred, with a very large deposit of gravel, again coming from the direction of Arrowsmith Point. This deposit has remained almost unchanged in shape, but slowly growing, since that time. The upper to middle beach has continued to build with the deposition of sand. The lower beach has been relatively stable, apparent changes probably being the result of minor differences in survey line. The volume of the profile increased rapidly between 1998 and 2001, and has increased at a lower rate since that time.

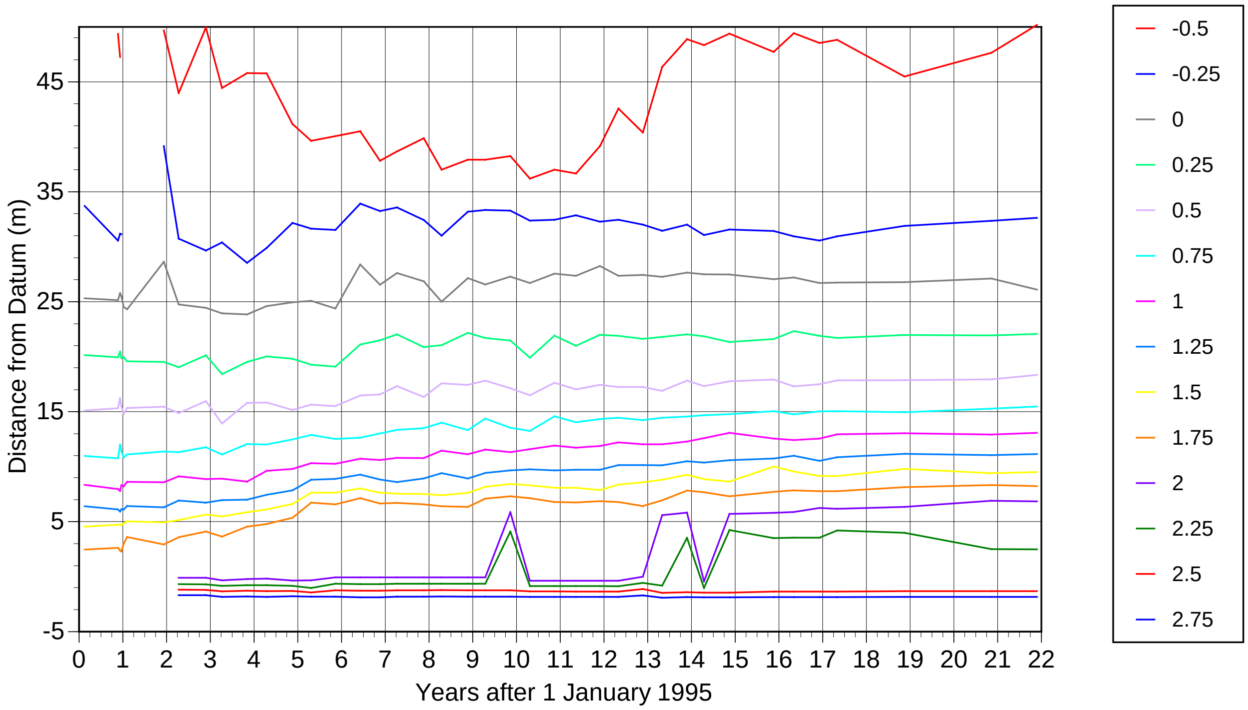
This profile line is clearly being influenced by longshore transport of gravels from west to east. It may also be that there is transport of sand either onshore or alongshore. It is most likely that the mechanism of accretion is the result of ferry generated wake waves. The rate of accretion dropped markedly about the time the fast ferry operation ceased, probably the result of a reduced ability of the waves to transport sediment.

McMillan's Bay is quite unusual in the context of the Tory Channel, being wide and with a relatively small slope. It has a wide 'surf' zone, unlike almost all other shorelines in the area.

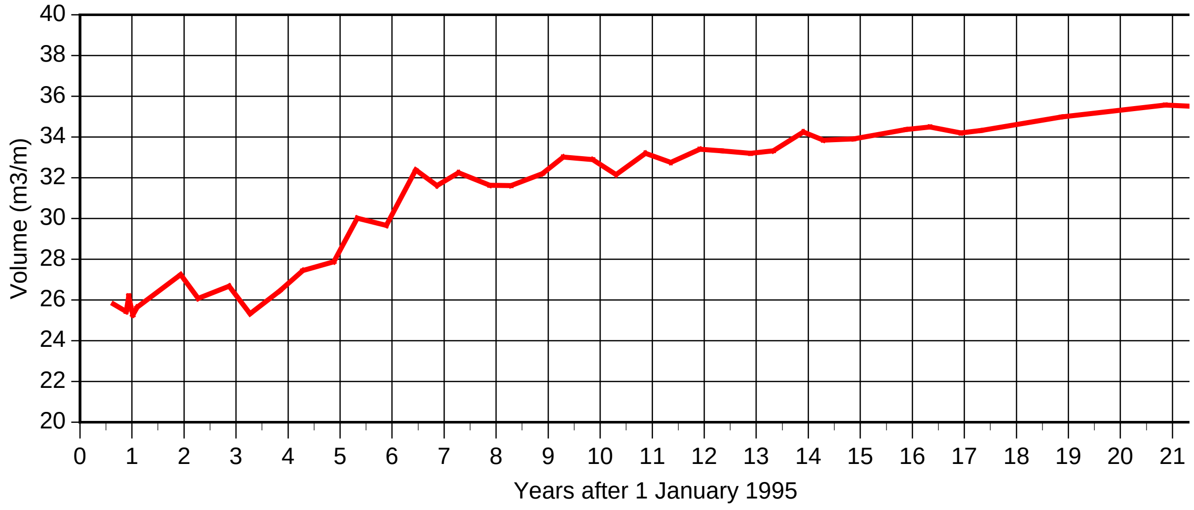


Profile 16: McMillan's Bay





Profile 16: McMillan's Bay



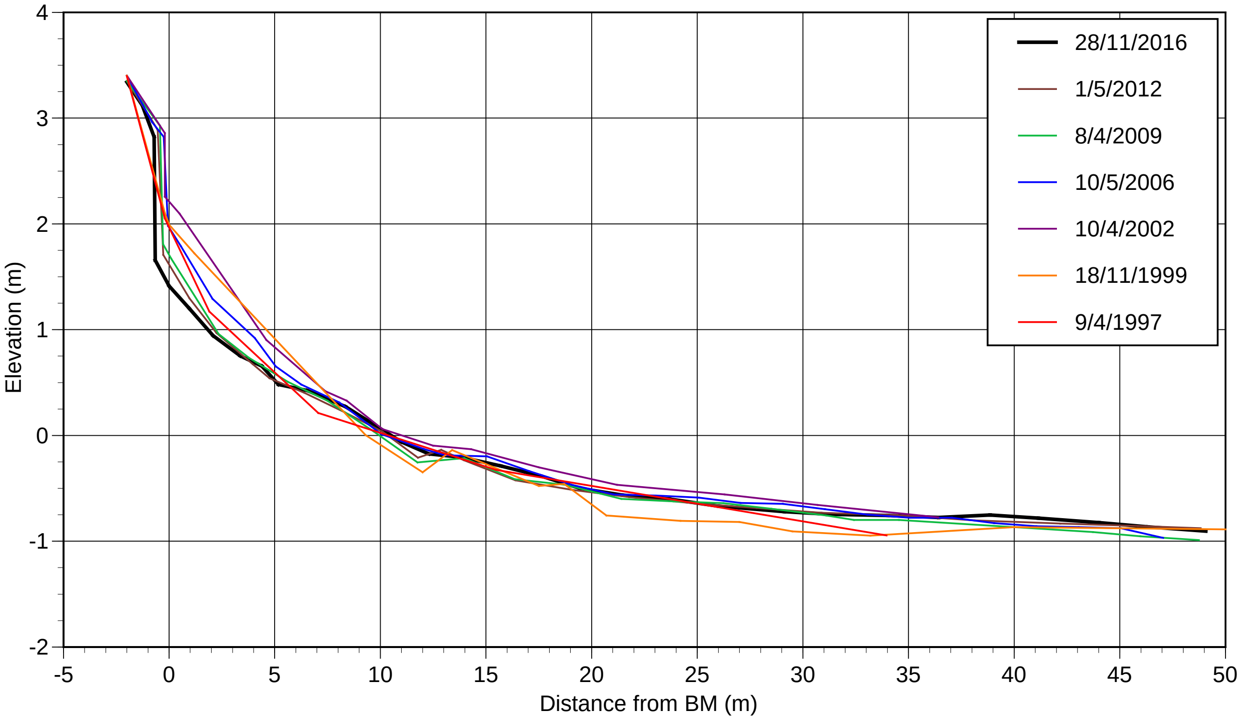
Date	Years after 1/1/95	Volume (m^3/m)	Date	Years after 1/1/95	Volume (m^3/m)
22-Aug-95	0.64	25.8	20-Nov-03	8.89	32.2
21-Nov-95	0.89	25.4	15-Apr-04	9.29	33.0
8-Dec-95	0.94	26.2	8-Nov-04	9.86	32.9
21-Dec-95	0.97	25.7	20-Apr-05	10.31	32.2
7-Jan-96	1.02	25.3	11-Nov-05	10.87	33.2
8-Feb-96	1.10	25.6	10-May-06	11.36	32.8
9-Dec-96	1.94	27.2	21-Nov-06	11.91	33.4
9-Apr-97	2.27	26.1	01-May-07	12.33	33.3
14-Nov-97	2.87	26.7	21-Nov-07	12.89	33.2
9-Apr-98	3.27	25.3	02-May-08	13.33	33.3
4-Nov-98	3.84	26.4	26-Nov-08	13.90	34.3
14-Apr-99	4.29	27.4	08-Apr-09	14.29	33.8
18-Nov-99	4.88	27.9	13-Nov-09	14.87	33.9
1-May-00	5.33	30.0	16-Nov-10	15.88	34.4
22-Nov-00	5.89	29.7	02-May-11	16.34	34.5
15-Jun-01	6.46	32.4	07-Dec-11	16.93	34.2
12-Nov-01	6.86	31.6	01-May-12	17.33	34.3
10-Apr-02	7.28	32.2	14-Nov-13	18.87	35.0
15-Nov-02	7.88	31.6	10-Nov-15	20.86	35.6
15-Apr-03	8.29	31.6	26-Nov-16	21.90	35.5

Profile 17 – McMillan's Side

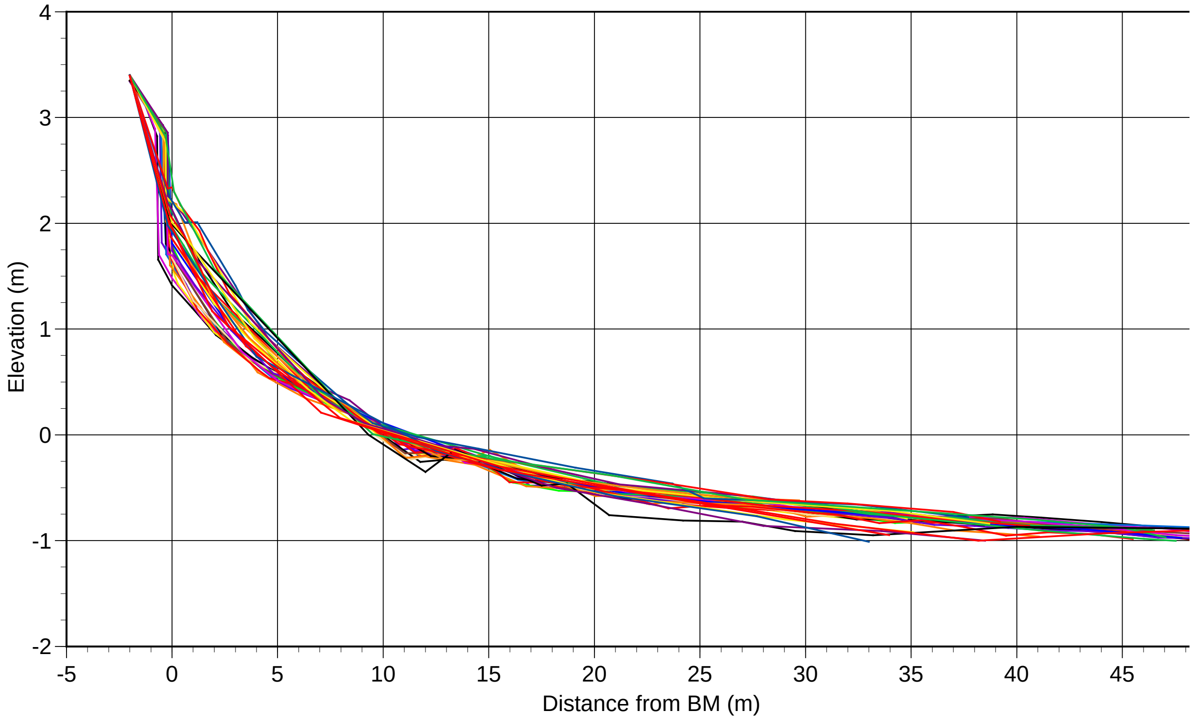
Between November 1999 and May 2000, at the same time as there was a major increase in the volume of the berm on Profile 16, there was a very significant deposition of sediment on the lower profile on Profile 17. Up until this time, the profile had been generally stable, with some accumulation on the upper beach, and perhaps some minor adjustments elsewhere on the profile line.

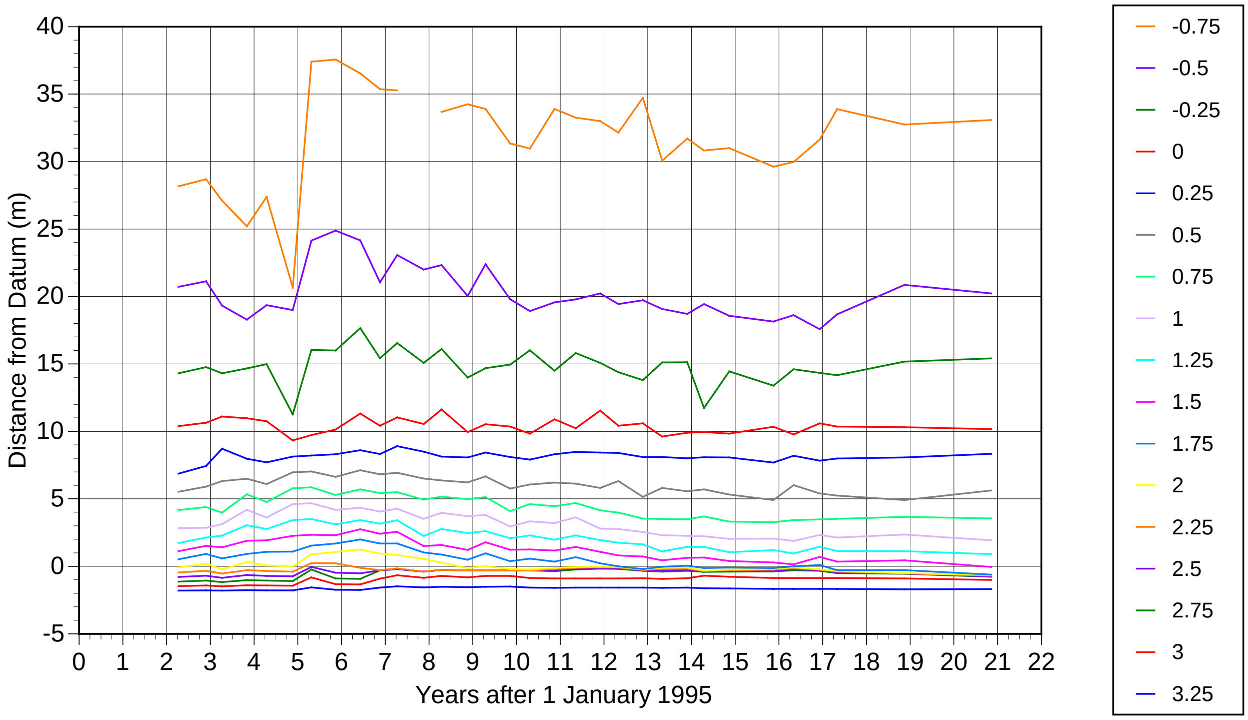
Beach volumes increased until 2001, with most of the accumulation on the lower profile. Since that time volumes have decreased, with most loss coming from the mid to upper beach. The upper beach scarp has increased in height with the removal of sediment at the base, but has moved landward by only a small amount.

The reason for the major deposition between November 1999 and May 2000, reflected also on Profile 16, is unknown. However, there must have been a significant increase in sediment supply, perhaps a slip in the vicinity of Arrowsmith Point. After fast ferry operation ceased in 2000, there was a change from sediment accumulation to sediment loss, which has continued through to the present. The change from accumulation to loss occurred at the same time as a change from sediment accumulation to stability on Profile 16. Changes in this profile reflected changes in vessel operations in the fast ferry years, but there also appears to be a sediment supply control.

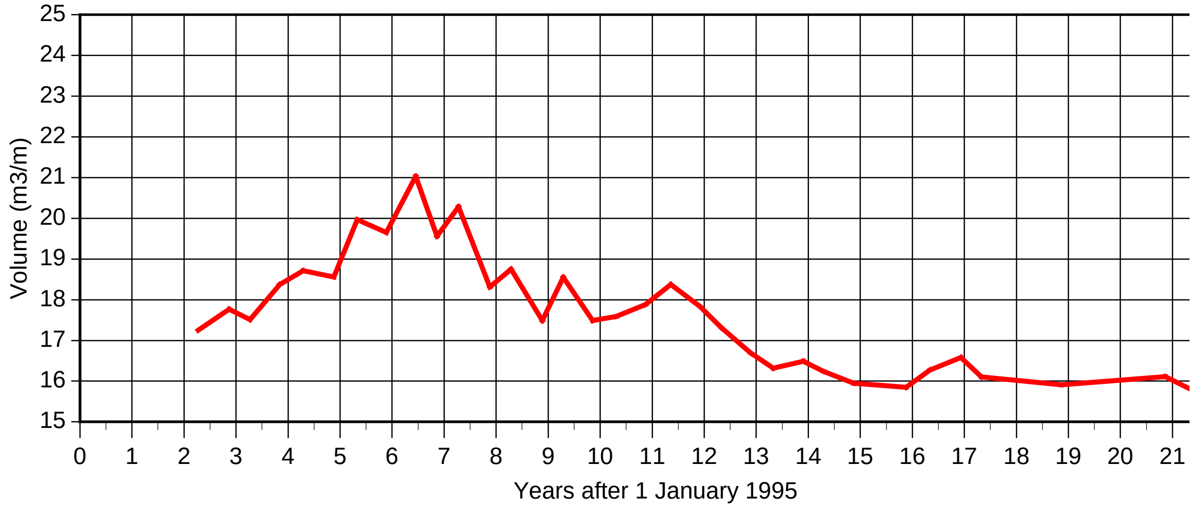


Profile 17: McMillan's Side





Profile 17: McMillan's Side



Date	Years after 1/1/95	Volume (m^3/m)
9-Apr-97	2.27	17.3
14-Nov-97	2.87	17.8
9-Apr-98	3.27	17.5
4-Nov-98	3.84	18.4
14-Apr-99	4.29	18.7
18-Nov-99	4.88	18.6
1-May-00	5.33	20.0
22-Nov-00	5.89	19.6
15-Jun-01	6.46	21.0
12-Nov-01	6.86	19.6
10-Apr-02	7.28	20.3
15-Nov-02	7.88	18.3
15-Apr-03	8.29	18.8
20-Nov-03	8.89	17.5
15-Apr-04	9.29	18.6
8-Nov-04	9.86	17.5
20-Apr-05	10.31	17.6
11-Nov-05	10.87	17.9
10-May-06	11.36	18.4
21-Nov-06	11.91	17.8
01-May-07	12.33	17.3
21-Nov-07	12.89	16.7
02-May-08	13.33	16.3
26-Nov-08	13.90	16.5
08-Apr-09	14.29	16.2
13-Nov-09	14.87	15.9
16-Nov-10	15.88	15.9
02-May-11	16.34	16.3
07-Dec-11	16.93	16.6
01-May-12	17.33	16.1
14-Nov-13	18.87	15.9
10-Nov-15	20.86	16.1
26-Nov-16	21.90	15.5

Profile 17: McMillan’s Side

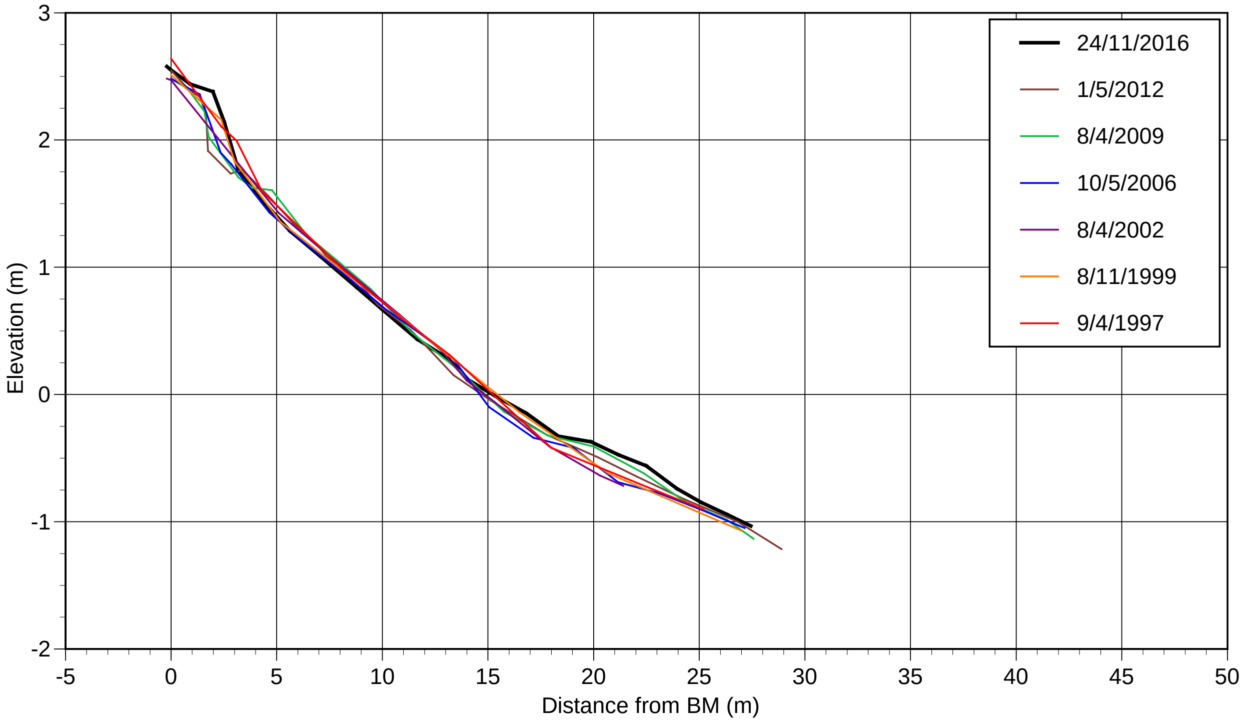
Profile 18 – Dieffenbach West

During 2000 a small cottage was built at the northern end of this beach, and in 2003 a boatshed was built and a minimal wooden seawall constructed adjacent to the profile line. The seawall, which had virtually gone by 2012, was replaced with a rock structure between May 2012 and November 2013.

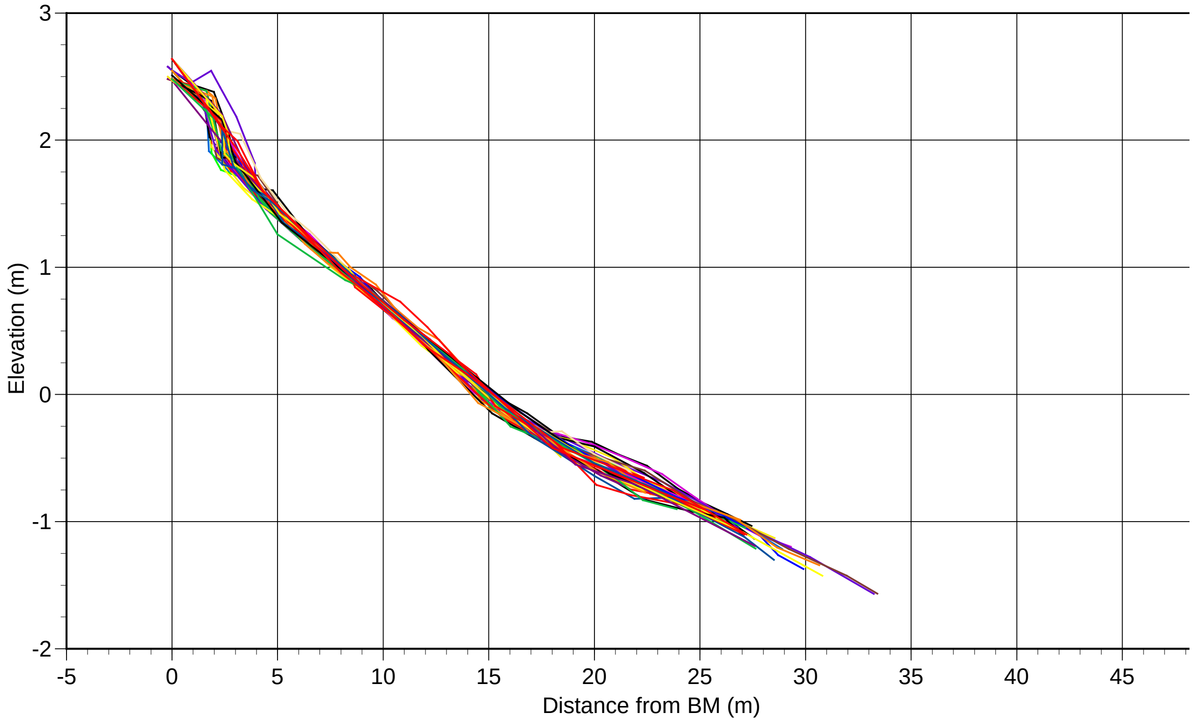
There had been no significant change in the profile shape or in sediment volume up until the time that the rock seawall was built. The upper beach scarp had retreated by about 50cm. Levels on the lower beach had increased a little. The seawall is clearly reflected in the profiles, and it is almost certain that it has resulted in a loss of sediment across the middle beach and an increase of sediment on the lower beach profile. However, overall, the changes have been relatively minor.

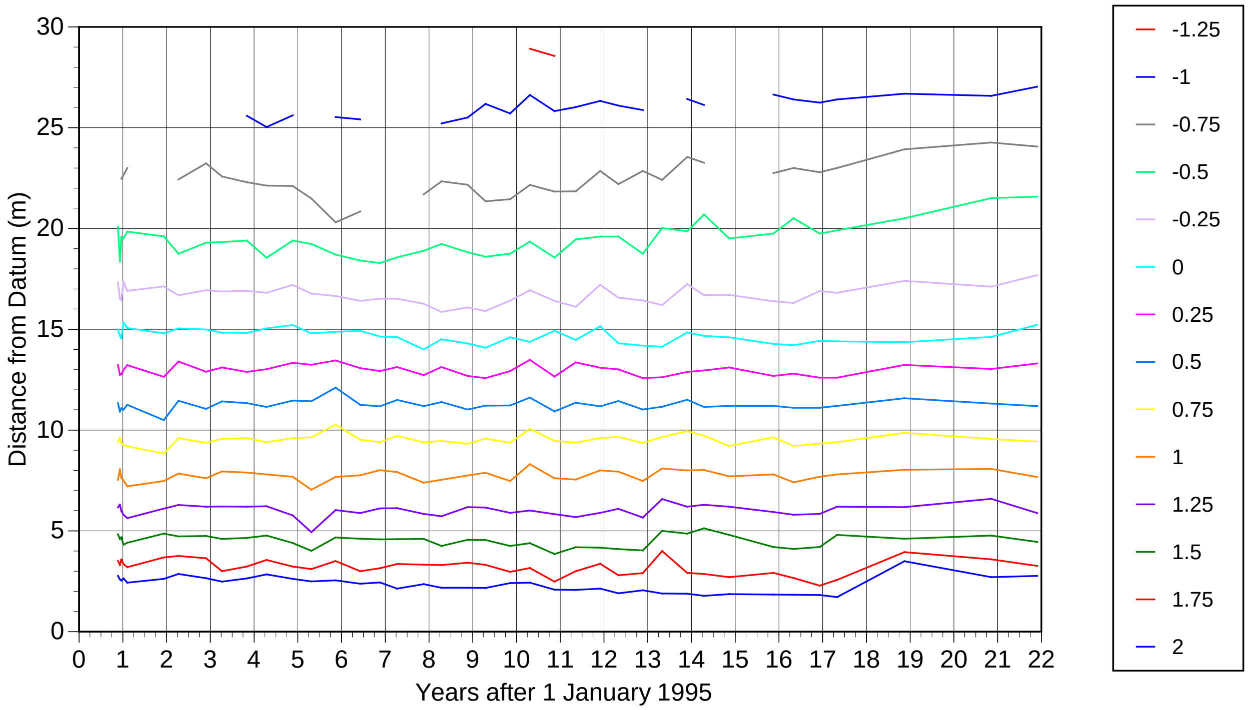
Volumes have been stable. The increase between May 2012 and November 2013 (successive surveys) simply reflects the placement of rock on the profile line.

A thin covering of sand is frequently present over the coarser beach sediment.

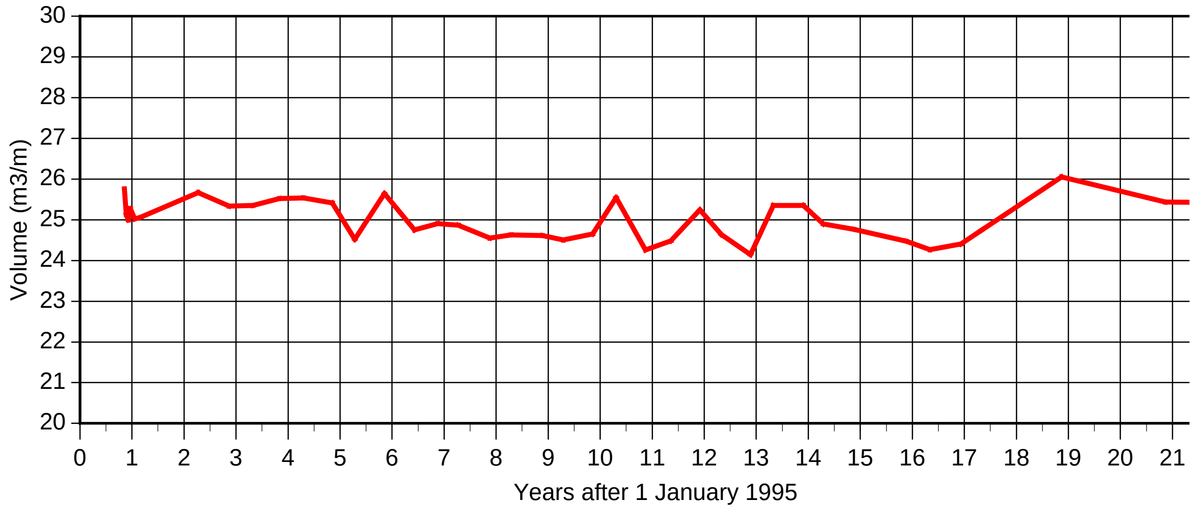


Profile 18: Dieffenbach West





Profile 18: Dieffenbach West



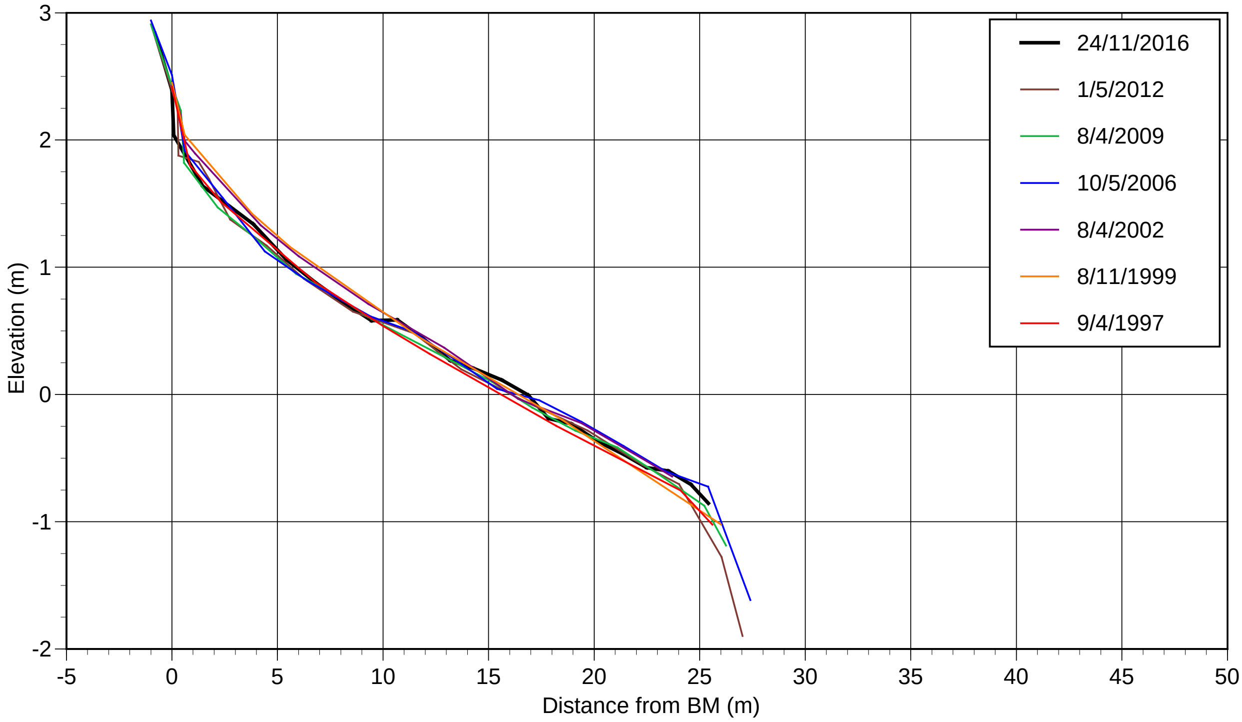
Date	Years after 1/1/95	Volume (m^3/m)	Date	Years after 1/1/95	Volume (m^3/m)
8-Nov-95	0.85	25.8	20-Nov-03	8.89	24.6
21-Nov-95	0.89	25.1	15-Apr-04	9.29	24.5
7-Dec-95	0.93	25.0	8-Nov-04	9.86	24.6
20-Dec-95	0.97	25.3	22-Apr-05	10.31	25.5
19-Jan-96	1.05	25.0	14-Nov-05	10.87	24.3
29-Feb-96	1.16	25.1	10-May-06	11.36	24.5
9-Apr-97	2.27	25.7	20-Nov-06	11.91	25.2
14-Nov-97	2.87	25.3	14-May-07	12.33	24.6
27-Apr-98	3.32	25.4	20-Nov-07	12.89	24.1
2-Nov-98	3.84	25.5	02-May-08	13.33	25.4
19-Apr-99	4.30	25.5	12-Nov-08	13.90	25.4
8-Nov-99	4.85	25.4	08-Apr-09	14.29	24.9
13-Apr-00	5.28	24.5	16-Nov-09	14.87	24.8
9-Nov-00	5.86	25.6	16-Nov-10	15.88	24.5
5-Jun-01	6.43	24.7	29-Apr-11	16.34	24.3
15-Nov-01	6.87	24.9	06-Dec-11	16.93	24.4
8-Apr-02	7.27	24.9	01-May-12	17.33	24.7
15-Nov-02	7.88	24.6	14-Nov-13	18.87	26.1
14-Apr-03	8.29	24.6	10-Nov-15	20.86	25.4
			26-Nov-16	21.90	25.4

Profile 18: Dieffenbach West

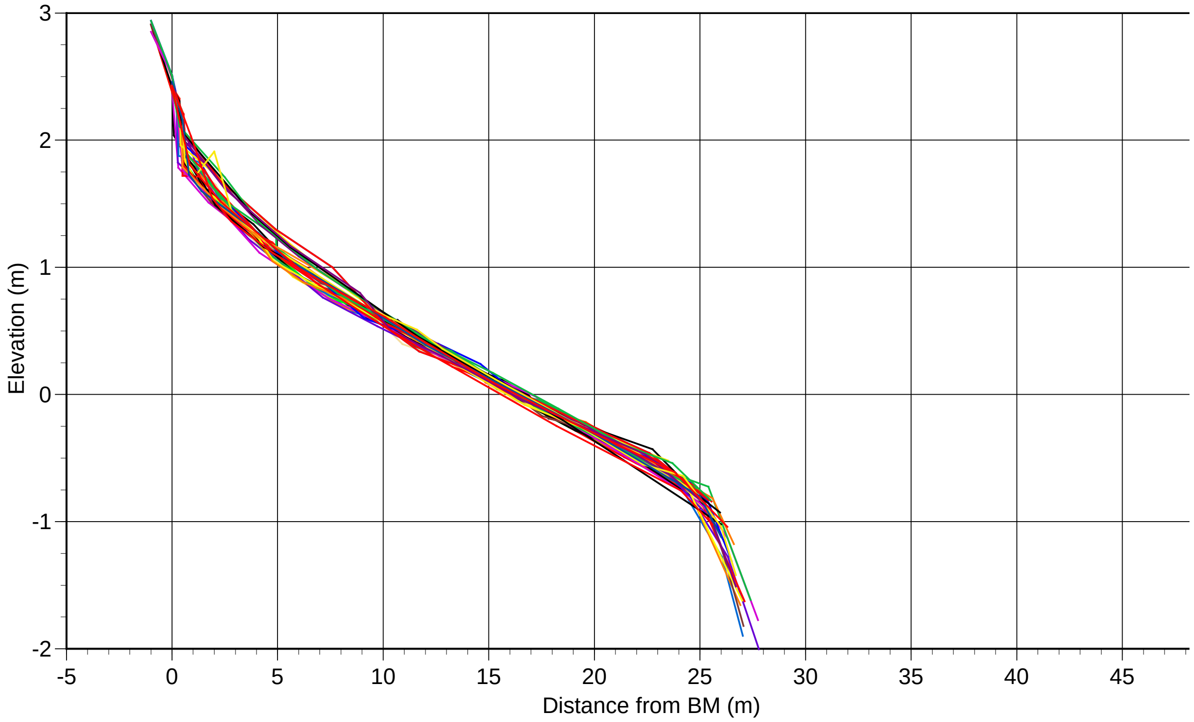
Profile 19 – Curious Monkey

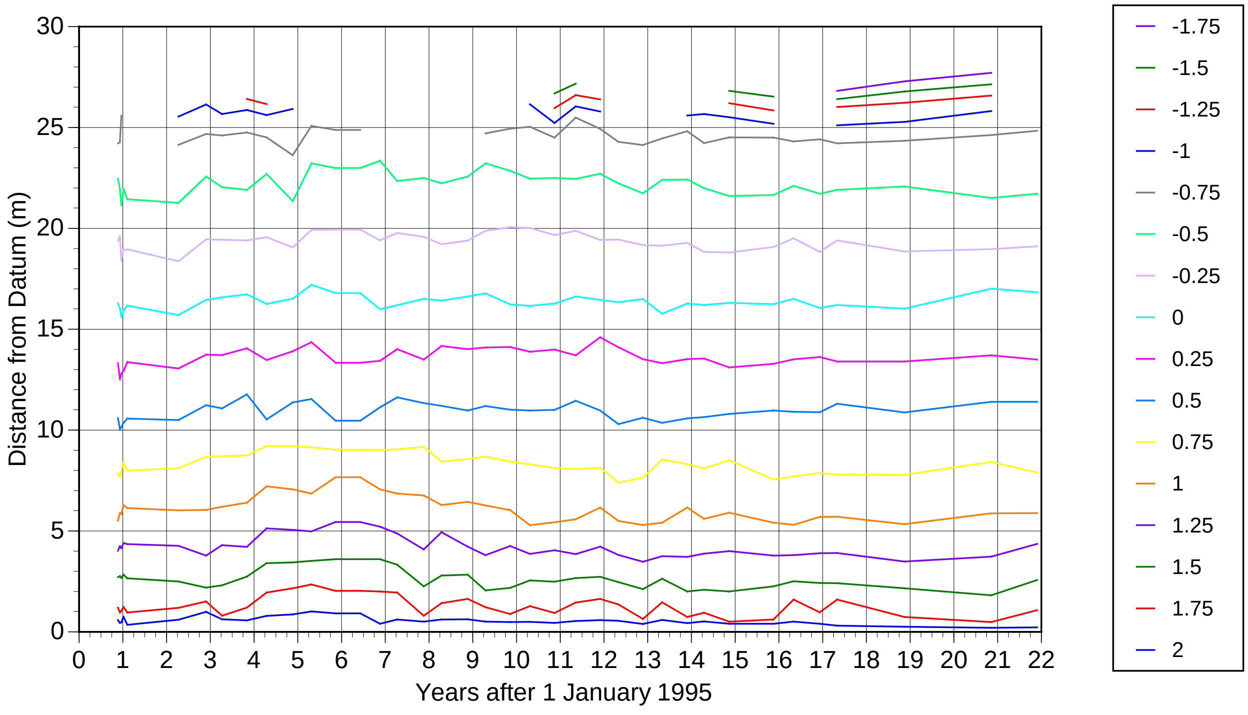
There was slow accretion over the period of fast ferry operation through to the end of 2000, and slow erosion following the end of fast ferry operations through to 2007. Since 2007 the beach has been very stable. ,

There have been no notable changes in sediment characteristics.

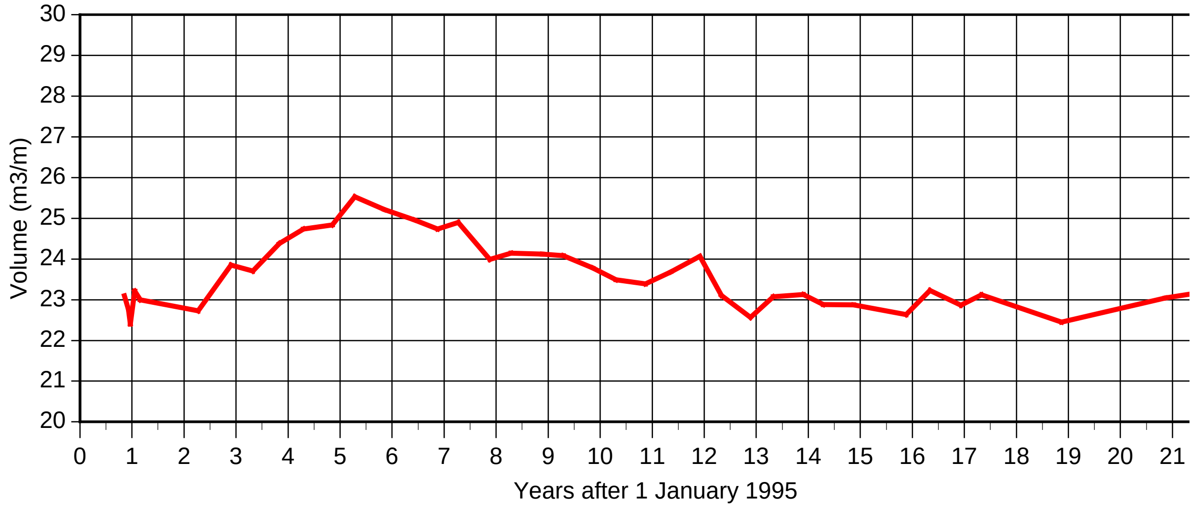


Profile 19: Curious Monkey





Profile 19: Curious Monkey

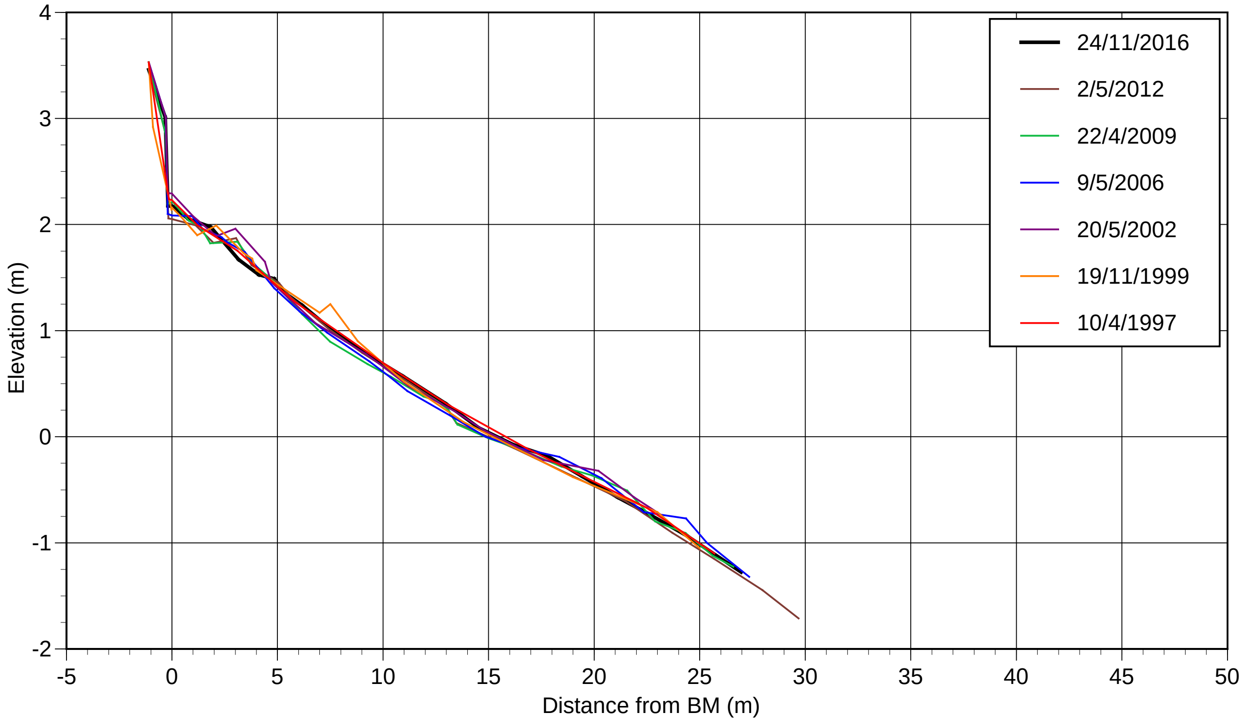


Date	Years after 1/1/95	Volume (m^3/m)	Date	Years after 1/1/95	Volume (m^3/m)
8-Nov-95	0.85	23.1	15-Apr-04	9.29	23.8
7-Dec-95	0.93	22.8	8-Nov-04	9.86	23.5
20-Dec-95	0.97	22.4	20-Apr-05	10.31	23.4
19-Jan-96	1.05	23.2	14-Nov-05	10.87	23.7
29-Feb-96	1.16	23.0	10-May-06	11.36	24.1
9-Apr-97	2.27	22.7	01-Dec-06	11.91	23.1
26-Nov-97	2.90	23.8	14-May-07	12.33	22.6
27-Apr-98	3.32	23.7	20-Nov-07	12.89	23.1
2-Nov-98	3.84	24.4	02-May-08	13.33	23.1
19-Apr-99	4.30	24.7	12-Nov-08	13.90	22.9
8-Nov-99	4.85	24.8	08-Apr-09	14.29	22.9
13-Apr-00	5.28	25.5	16-Nov-09	14.87	22.6
9-Nov-00	5.86	25.2	16-Nov-10	15.88	23.2
5-Jun-01	6.43	25.0	29-Apr-11	16.34	22.9
15-Nov-01	6.87	24.7	06-Dec-11	16.93	23.1
8-Apr-02	7.27	24.9	01-May-12	17.33	22.5
15-Nov-02	7.88	24.0	14-Nov-13	18.87	23.0
14-Apr-03	8.29	24.1	10-Nov-15	20.86	23.3
20-Nov-03	8.89	24.1	26-Nov-16	21.90	23.8

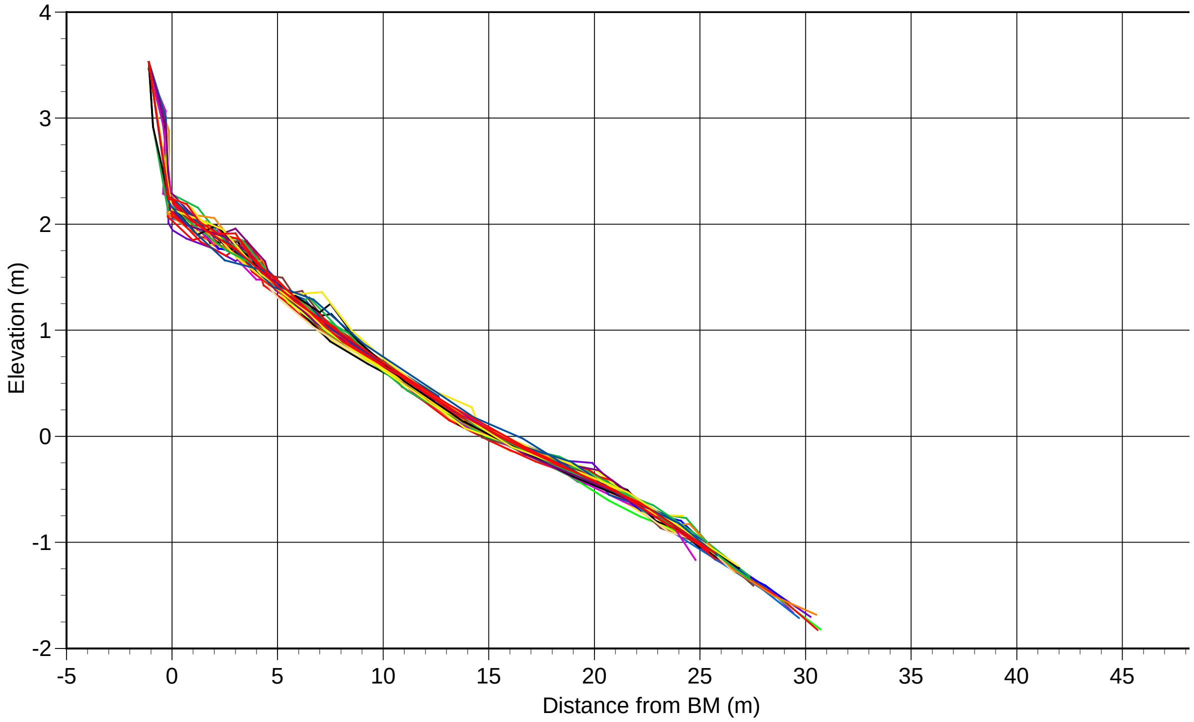
Profile 20 – Patten's Passage

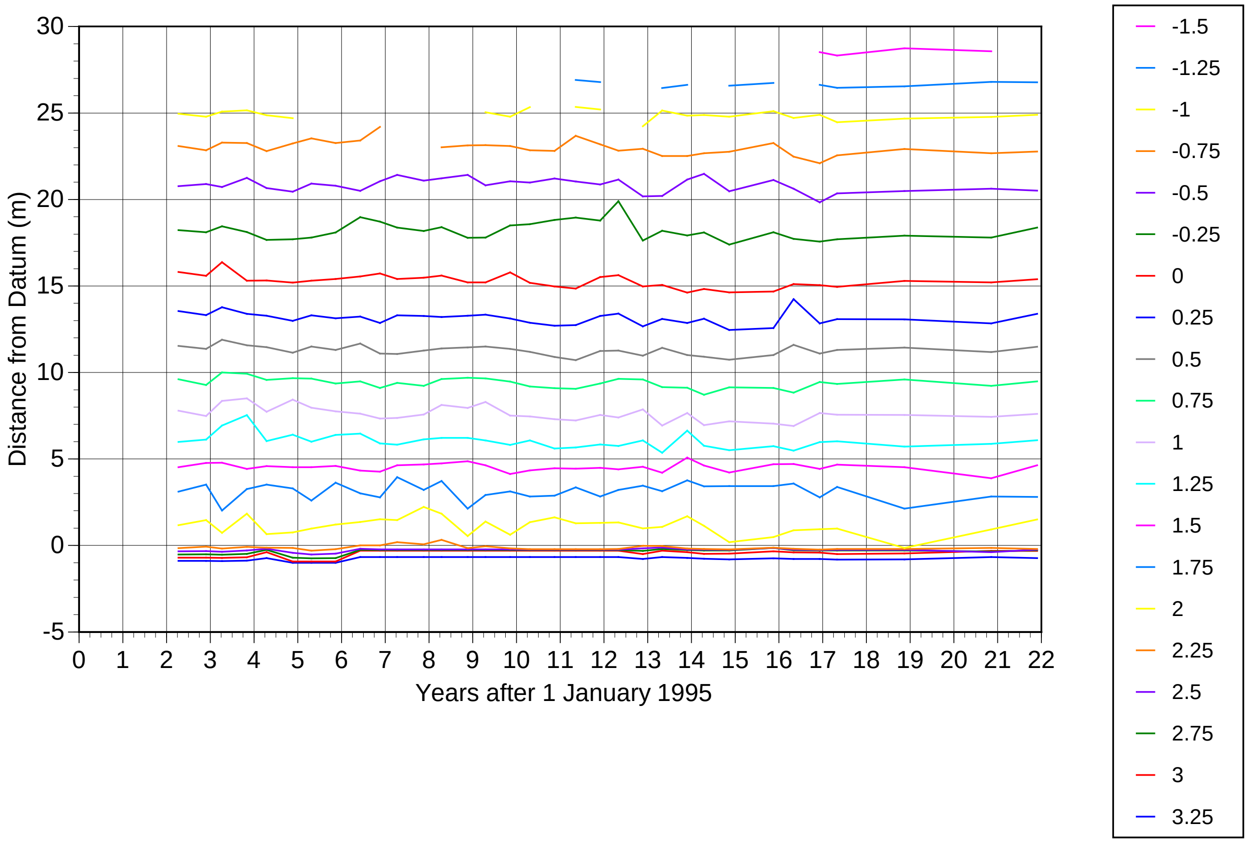
There has been some variability on the upper and middle beach, but overall the profile is very stable. Small berms build and are removed on the upper beach, with no particular seasonal pattern. Sediments are gravels and sands, and there is frequent banding, but no significant trends in sediment cover are obvious.

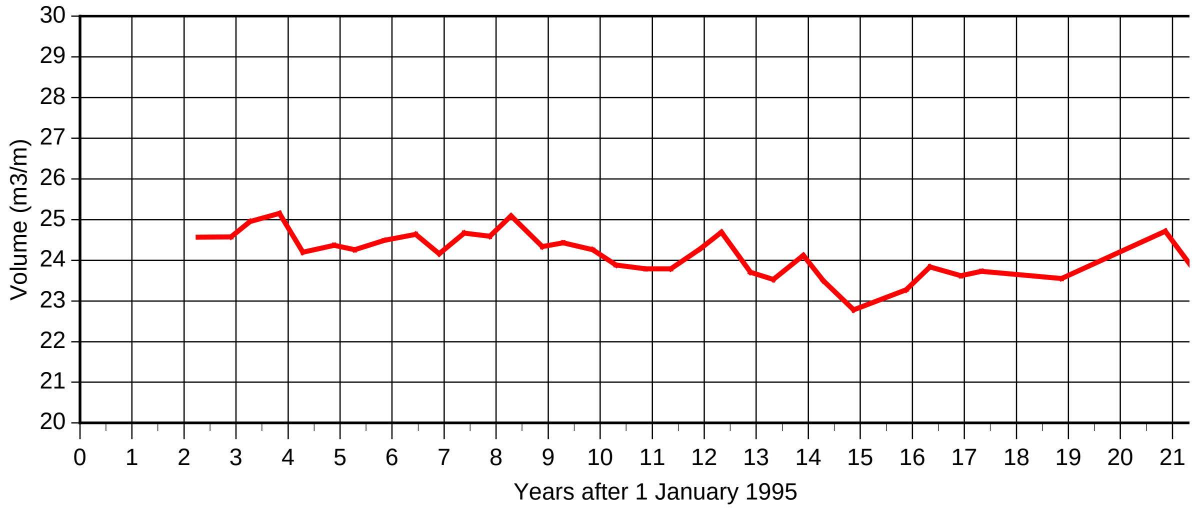


Profile 20: Patten's Passage





Profile 20: Patten's Passage

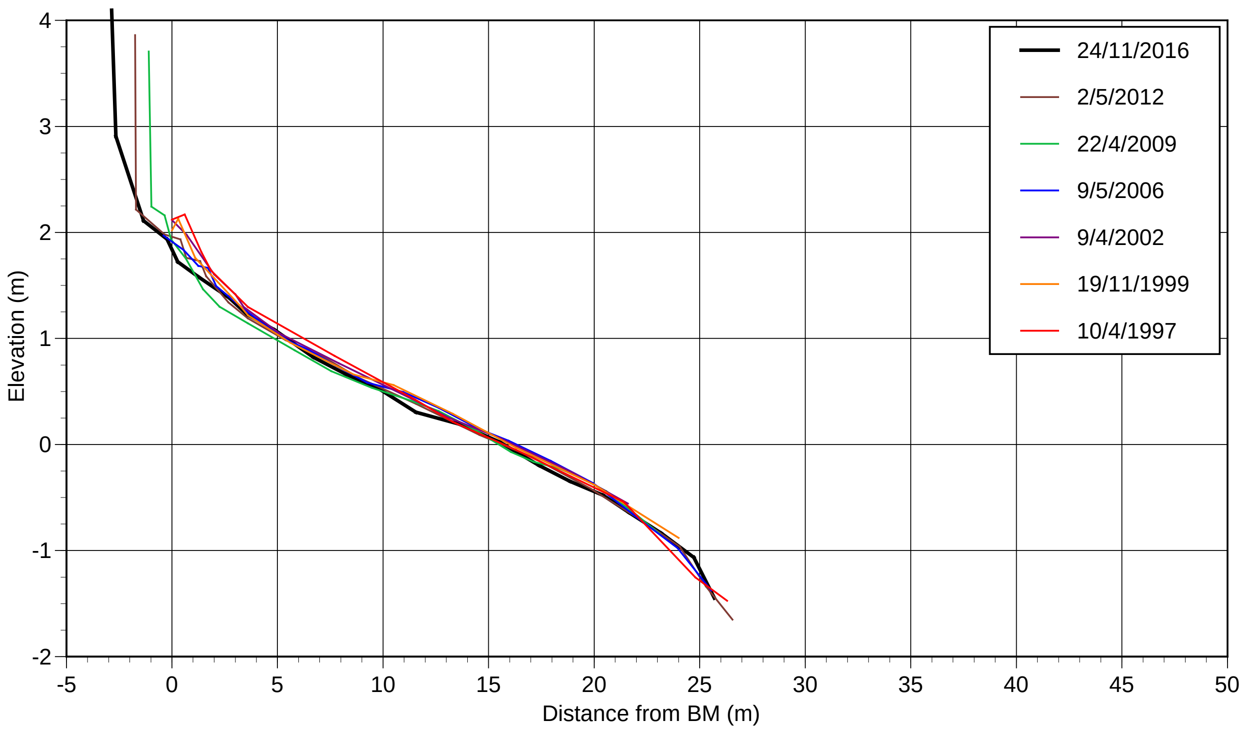


Date	Years after 1/1/95	Volume (m^3/m)
10-Apr-97	2.28	24.6
26-Nov-97	2.90	24.6
8-Apr-98	3.27	25.0
2-Nov-98	3.84	25.2
14-Apr-99	4.29	24.2
19-Nov-99	4.88	24.4
13-Apr-00	5.28	24.3
9-Nov-00	5.86	24.5
15-Jun-01	6.46	24.6
26-Nov-01	6.90	24.2
20-May-02	7.39	24.7
18-Nov-02	7.88	24.6
14-Apr-03	8.29	25.1
19-Nov-03	8.89	24.3
16-Apr-04	9.29	24.4
7-Dec-04	9.86	24.3
22-Apr-05	10.31	23.9
14-Nov-05	10.87	23.8
9-May-06	11.36	23.8
20-Nov-06	11.91	24.3
30-Apr-07	12.33	24.7
20-Nov-07	12.89	23.7
06-May-08	13.33	23.5
12-Nov-08	13.90	24.1
22-Apr-09	14.29	23.5
26-Nov-09	14.87	22.8
03-Dec-10	15.88	23.3
29-Apr-11	16.34	23.8
06-Dec-11	16.93	23.6
02-May-12	17.33	23.7
14-Nov-13	18.87	23.6
10-Nov-15	20.86	24.7
26-Nov-16	21.90	22.9

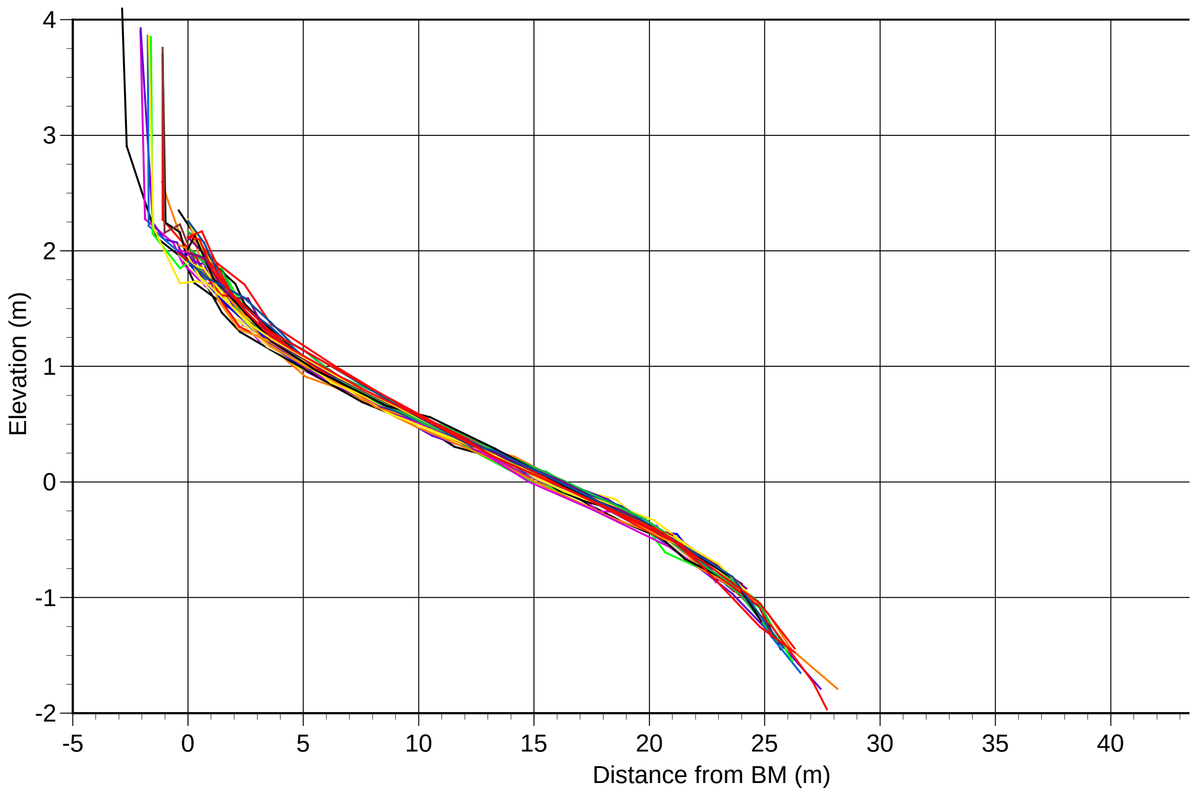
Profile 20: Patten's Passage

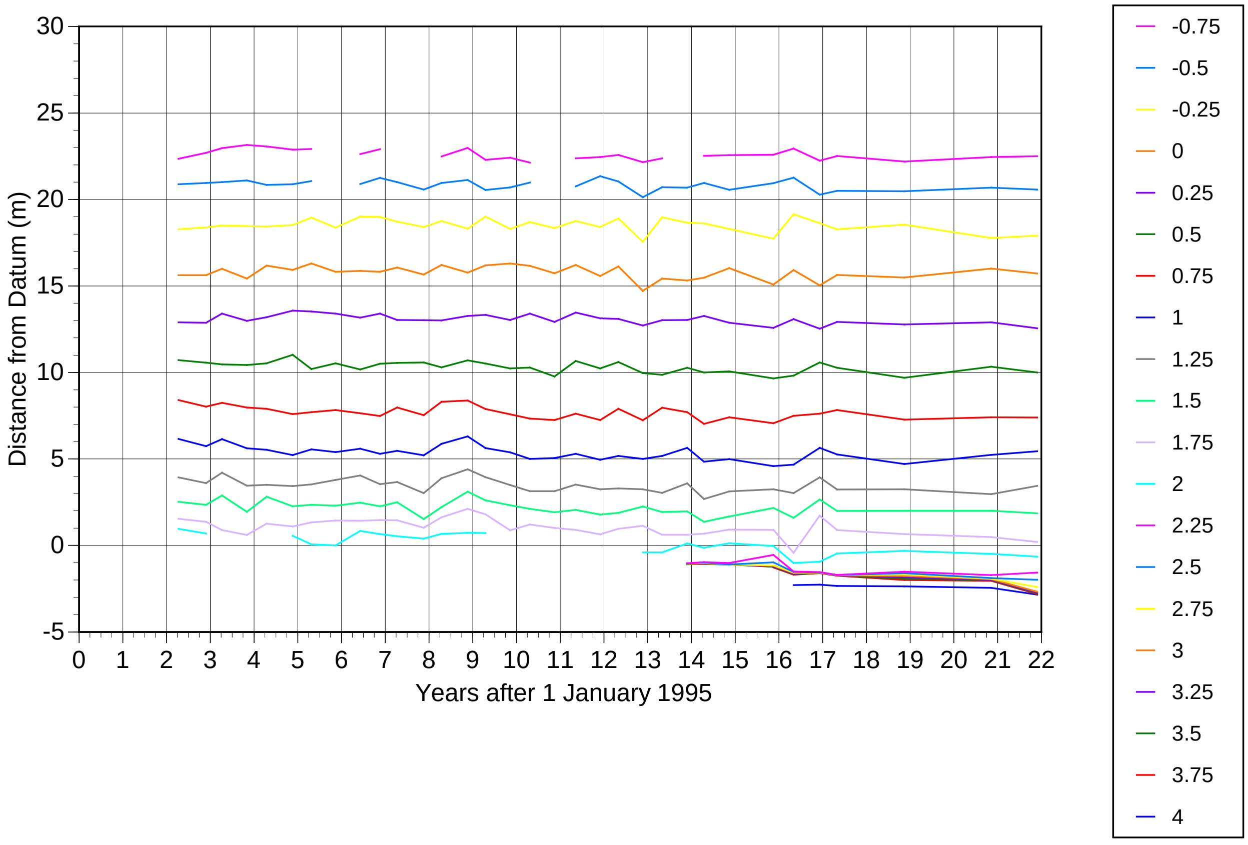
Profile 21 – Blumine Island

Blumine Island has a similar aspect to the Patten's Passage profile. Up until 2003 changes were generally minor, with no seasonality shown. Since 2003, there has been a slow erosion trend, with stability over the past 5 years. Significant erosion at the beach scarp at the top of the beach was reported by the surveyors in 2009, and the profile line was extended landward to encompass this. The beach scarp continues to retreat but there has been little change to the active beach profile as a result.

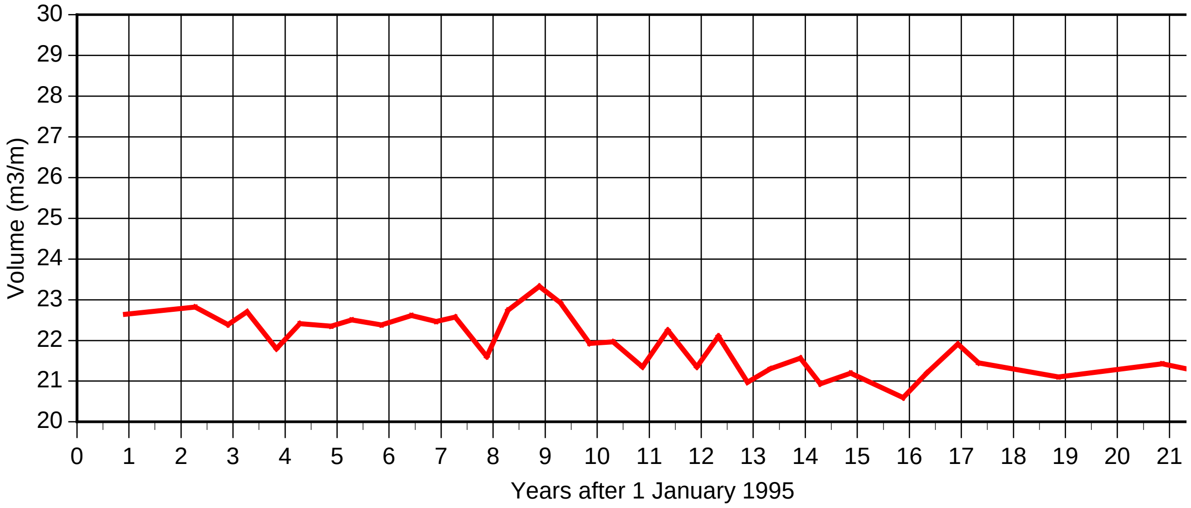


Profile 21: Blumine Island





Profile 21: Blumine Island



Date	Years after 1/1/95	Volume (m^3/m)
7-Dec-95	0.93	22.6
10-Apr-97	2.28	22.8
26-Nov-97	2.90	22.4
8-Apr-98	3.27	22.7
2-Nov-98	3.84	21.8
14-Apr-99	4.29	22.4
19-Nov-99	4.88	22.4
13-Apr-00	5.28	22.5
9-Nov-00	5.86	22.4
5-Jun-01	6.43	22.6
26-Nov-01	6.90	22.5
9-Apr-02	7.27	22.6
18-Nov-02	7.88	21.6
14-Apr-03	8.29	22.7
19-Nov-03	8.89	23.3
16-Apr-04	9.29	22.9
7-Dec-04	9.86	21.9
22-Apr-05	10.31	22.0
14-Nov-05	10.87	21.4
9-May-06	11.36	22.2
21-Nov-06	11.91	21.4
30-Apr-07	12.33	22.1
22-Nov-07	12.89	21.0
06-May-08	13.33	21.3
12-Nov-08	13.90	21.6
22-Apr-09	14.29	20.9
26-Nov-09	14.87	21.2
03-Dec-10	15.88	20.6
29-Apr-11	16.34	21.2
06-Dec-11	16.93	21.9
02-May-12	17.33	21.4
14-Nov-13	18.87	21.1
10-Nov-15	20.86	21.4
26-Nov-16	21.90	21.2

Profile 21: Blumine Island

Summary of beach changes and shoreline dynamics, and the effects of vessel wakes on shoreline dynamics over the duration of the monitoring program

As has been the case in previous summary reports, this summary is divided into three sections, comprising those sites that are conceivably influenced by vessels travelling in Tory Channel and Inner Queen Charlotte Sound (on the ferry sailing route), those sites in the outer Queen Charlotte Sound, and the Picton foreshore site, which is possibly influenced by vessels moving within the port area.

a) Picton foreshore

The beach is relatively stable, but it is known that periodic beach nourishment has occurred over the past 20 years, since improvement works along the foreshore in 1997. The stability indicates that the rate of renourishment is appropriate with respect to the processes operating.

b) Sites in outer Queen Charlotte Sound

There are five profiles located at sites in the outer Queen Charlotte Sound: Double Bay, Long Island, Clark Point, Patten's Passage and Blumine Island. The sites in outer Queen Charlotte Sound are not influenced by ferry traffic, although some are on the sailing line of larger vessels using the Port of Picton and Shakespeare Bay. All five sites have remained generally stable over the survey period since April 1997. Long Island has demonstrated a trend of slow erosion since surveys began. Clark Point has been very stable. Double Bay has had periods of accretion and erosion, but the current volume is nearly identical to 1997. At Patten's Passage, there has been a trend of slow, but minor, erosion. There has been very minor loss of sediment on the beach at Blumine Island, however the scarp at the back of the beach has retreated.

c) Sites in Tory Channel and inner Queen Charlotte Sound

Many of the sites on the ferry route have exhibited change. However, trends or seasonality consistency between sites is not generally apparent. Sites seem to be primarily influenced by local factors, particularly with respect to sediment supply.

Three sites have demonstrated consistent and significant erosion. Blackmore's at Waikawa has been stripped to bedrock, and therefore no further erosion is likely. This was almost certainly the result of fast ferry operation as the sediment removal occurred during the period they were operating. There is not sufficient wave energy at this site to return sediment and it is almost certain that the change is permanent. Bob's Bay is located on the ferry route, but at a position where ferries are likely to be operating relatively slowly as they arrive in, or leave, Picton. There has been a consistent erosion trend across the whole profile. The particular circumstances that lead to erosion at this site are not understood, although the high number of boats of all types passing this point may be a factor.

Tipi Bay has had shown retreat of the scarp at the top of the beach into disturbed sediments associated with an old whaling station. Beach volume has not changed significantly.

Te Awaiti (across the entire profile) and Te Weka Bay (particularly at the top of the beach with the development of a berm during fast ferry operation), both of which were significantly affected by fast ferry wakes, have shown minor accretion. Apparent accretion at Dieffenbach West on the inner Queen Charlotte Sound is the result of a rock revetment being built at the top of the beach. It has resulted in surprisingly little change on the middle section of the profile.

The Curious Monkey site showed a change from minor accretion to minor erosion coinciding with fast ferry operation ceasing, although overall changes are small, and there has been very little change since 2007. Ngaionui Point, a site very close to the vessel travel line, particularly on the Wellington to Picton journey, shows a change from accretion to erosion in 2002. The erosion trend eased in 2009, perhaps indicating a return to pre-fast ferry conditions.

Up to 2002, The Snout at Picton Point had accretion at the top of the profile and significant erosion at the bottom, and therefore a steepening of the beach profile. After 2002 there has been consistent erosion. Overall, a significant amount of sediment has been lost. The deep water channel is clearly cutting into the shoreline at this point. The reason may be related to vessel traffic, or may be entirely natural.

Ngaionui Bay had a berm build during the period of fast ferry operation, followed by rapid sediment loss due to human intervention, and another period of slow accretion through to 2005. Since that time there has been stability or very minor erosion.

Slip Beach had a trend of beach building through to 2005 and relative stability since that time. However there has been considerable variability between surveys. Slip Beach demonstrates the most variability of any of the profiles where, at least during the period of multiple surveys each year, there appears to be a distinct seasonal pattern.

McMillan's Bay and McMillan's Side, were relatively stable with a small amount of accretion until an event in 1999/2000 when a large amount of sediment accumulated on both profiles. Significant rates of accretion continued until the beginning of 2001, after which time the rate has reduced on the McMillan's Bay profile and erosion has been evident on the McMillan's Side profile (with the rate reducing in recent years). It is probable that the patterns relate to a mass movement event towards Arrowsmith Point, and significant sediment transport capability due primarily to fast ferry operation, although there is no direct evidence for this.

Moioio Island is an unusual case, being a beach adjacent to a major landslip, and being towards the back of the island, not directly facing the vessel track. Seasonality was evident when the fast ferries were operating seasonally. Both profiles show that the beach is extending into the deep water channel over time (a process that takes a lot of sediment), and generally accreting. Moioio Island 1 has accreted through to the present day, albeit relatively slowly in recent years. Moioio Island 2 reached its maximum accreted extent in 2006, and has cut back to its pre-fast ferry shape on the upper beach. These profiles are almost certainly influenced by changes in ferry operations, being almost completely sheltered from natural wind generated waves. However, the sediment supply from the landslide (which may be affected by vessel wakes) is likely to dominate the beach behaviour.

At the time of the summary report in 2002 it was concluded that with the exception of Bob’s Bay near Picton, the beaches on the ferry route were accreting (or were stable) as opposed to eroding, although it was equally clear that local circumstances (particularly sediment supply) play a very significant role. It is now clear that on some profiles a change from accretion to relative stability, or accretion to erosion occurred at about, or soon after the time fast ferry operation was restricted to 18 knots in December 2000. Over the last six years, the erosion has slowed or ceased, perhaps indicating a return to pre-fast ferry morphologies. Although a definitive conclusion may never be possible, the results support the understanding that the fast ferry wakes resulted in rapid sediment buildup at the top of the beach on most beaches along the ferry route. However, it is now clear that under the current vessel operational regimes, either stability (with the newly inherited morphology remaining) or a return to pre fast ferry morphology is occurring or has occurred. This conclusion was first reached in 2009 and has been reinforced by surveys since that time.

Only a small number of profiles (those established by Professor Robert Kirk) were surveyed at around the time of commencement of fast ferry operation. This has always been a limitation of the monitoring program. However, the building of berms and increased sediment transport and supply caused by the fast ferries is well established. The long-term effects of fast ferries on beach morphology has been minimal, with beaches either remaining relict or returning to their pre-fast ferry equilibrium, which may not necessarily be their natural state. Consequently, all profiles on the ferry route, with the exception of Bob’s Bay and possibly The Snout at Picton Point, are generally in equilibrium with the energy and wake characteristics of the vessels that are currently operating. The fact that fast ferries did indeed change beach profiles was reinforced by distinct seasonality exhibited by many profiles during the time that ferries were operating seasonally. With the exception of Slip Beach, which continued to change seasonally, other profiles do not have a regular seasonal pattern. The determination of seasonality in recent years has become impossible due to the infrequent and irregular surveys. However, sufficient data has been collected to support this conclusion.

The importance of sediment supply from adjacent slope instability as a driver for beach change has also been demonstrated at a number of sites (Moioio Island 1 and 2, Ngaionui Bay, McMillan’s Bay and McMillan’s Side). Slope instability in these cases (almost certain for Moioio Island) may be related to vessel operation.

The effectiveness of the program in determining the causes of beach profile change

The monitoring program was established specifically to investigate the effects of fast ferry operation on the morphology of beaches in Tory Channel and Queen Charlotte Sound. Despite most profiles only having data available from January 1997, in the third season operation of the fast ferries, it has been effective in demonstrating the effects of fast ferry operation on beaches. It has also demonstrated the importance of sediment supply, and in conjunction with other reports written at the time by Parnell and others, demonstrated how fast ferries contributed to increased sediment availability along the route. Measurements of wake characteristics also demonstrated that the fast ferries generated sufficient energy to transport sediment in both alongshore and cross-shore directions. Where sufficient sediment was available, berms built and other features (such as the depositional features adjacent to the Moioio Island Slip and the depositional features in McMillan's Bay) grew. The monitoring program has also demonstrated that the beaches are generally in equilibrium with the energy and wake characteristics of other vessels using the Wellington-Picton route. This is not surprising given the length of time that the conventional ferries have been operating. It has also been shown that the beach profiles in the outer Queen Charlotte Sound, not affected by regular large vessel traffic, are generally very stable.

With respect to the original intent of the monitoring program, it has been successful. With respect to other factors that have caused beach change, the program has only been partially successful. There has been no investigative work relating to factors other than fast ferry (and during the measurement period, other vessel) operation. Several 'mysteries' remain. The cause of the continued, almost linear erosion of the Bob's Bay profile has never been conclusively determined, although Ward (2013) suggested that vessel wakes may play a part. The cause of the landward movement of the entire profile at The Snout is also not known. Why some beaches change seasonally (most notably, Slip Beach) while others do not, has not been further investigated.

The continued fitness-for-purpose of the monitoring program and recommendations for its future operation

It was noted in the introduction that the primary purpose of the monitoring program was to determine the effects of fast ferry operation on the morphology of beaches in Tory Channel and Queen Charlotte Sound, but that the program has had value with respect to other vessel operation, and with respect to the general duty imposed by the Resource Management Act (1991) to monitor the environment.

With respect to vessel wakes, with the current vessels operating the route, an equilibrium state exists with respect to morphology and drivers of coastal processes. Unless new classes of vessels commence operation, and it is thought possible that the characteristics of the wakes cannot be reasonably managed by the Navigation Bylaw, the monitoring program has little more to offer by way of understanding. It is very important however, that should any vessels with significantly different characteristics to those currently or previously operating be proposed, that the measurement of the profiles be made prior to them commencing operations. The accurate survey of positions and heights undertaken in 2013, enabling the reestablishment of benchmarks should they be lost (something that is certain if regular monitoring is discontinued), is therefore very important.

It is therefore recommended that if the purpose of the monitoring program remains as it was when it was established, to determine the impacts of vessel-wakes, then the monitoring program could be suspended, provided that there is an understanding that it could be resumed (with some extra cost to reestablish lost survey benchmarks) should there be a need based on changes in vessel operation..

If the purpose of the monitoring program is to fulfil obligations to monitor the environment, then the value of continuing to monitor sites that already have a 20 year record far outweighs a possibly more appropriate set of locations that might be more representative. In this case, the monitoring program should continue, perhaps at a reduced frequency (and recognizing the need for occasional replacement of benchmarks should they be lost, a risk that increases with decreased frequency of visiting the sites). In this case, the number of sites could be reduced based on the present understanding. Some of these suggestions have been made in previous reports.

The following sites provide little value with respect to the above possible purposes of the monitoring program
:
Profile 1: Picton Foreshore (however, see below)
Profile 5: Blackmore’s at Waikawa
Profiles 6 and 7: Moioio Island (it would be more appropriate to monitor the adjacent slip if needed)
Profile 10: Tipi Bay
Profile 12: Clark Point
Profile 17: McMillan’s Side
Profile 20: Patten’s Passage

Profile 1 (Picton Foreshore) is periodically nourished with imported sand. It may be that continued monitoring of this site remains of value in order to assist in the determination of renourishment frequency and quantity.

There is no good reason to increase the number of sites monitored in Tory Channel, or in the sections of Queen Charlotte Sound that are currently monitored. A decision to commence monitoring in the outer sections of Queen Charlotte Sound, the Grove Arm, or in other Sounds in the District would need to be made in the light of the established obligations under the Resource Management Act (1991). Because of the considerable cost and the need for a long data record before the data would yield significant conclusions, and with the knowledge that the Sounds are typically relatively low energy with relatively coarse sediments, this approach cannot be recommend that this be considered at this time. The most likely changes to beaches in the Marlborough Sounds over the next 50-100 years and beyond are going to be caused by eustatic sea-level rise, or isostatic changes in sea-level primarily causes by earthquakes. This is discussed in the next section. A related secondary variable is a change to sediment supply, likely caused by sea-level factors or land use change.

The utility of the monitoring design for understanding the effects of sea-level rise

There has been considerable research attempting to understand the effects of sea level rise on coastal systems with improved understandings and models being produced (e.g. Dean and Houston (2016)[4]). The over-reliance on the Bruun rule remains, particularly for coastal management applications, despite its basic assumptions and utility being essentially disproved (Cooper and Pilkey, 2004)[5]. Most of the effort has been on wave dominated sandy beaches.

Gravel beach response to sea level rise has been barely mentioned in the literature, and even then, it is often in the context of the Bruun rule, where the rule is applied to predict change in systems for which even Bruun never intended the rule to be used (Cooper and Pilkey, 2004). Gravel, and mixed sand-gravel beaches in situations like the Marlborough Sounds have essentially received no attention with respect to sea level rise effects.

Conceptually, the situation is quite simple. In areas where there is accommodation space, landward movement of the sediments by overwash processes (particularly where there is a berm) might be expected. Where there is little or no accommodation space, a hard shoreline is likely to develop, with present beach sediments moving down the profile to be deposited in deeper water. However, sediment supply is likely to be a significant factor, the effects of which will be highly localized.

Determining the effects of sea level rise on the beach profiles at the time scales of interest from the monitored profiles will be very difficult, particularly with no good theoretical framework on which to base interpretations. However, the choice of sites is probably as good as any with respect to capturing change. The first step in developing an understanding of the effects of sea-level rise would be to re-examine the data with respect to the tide gauge records appropriately analyzed to extract sea-level trends to recognize changes that might be attributed to the sea level rise. However, the prospect of understanding the effects of sea-level rise is probably not significant enough to warrant the retention of the monitoring program for that purpose alone.

On 14 November 2016 a magnitude 7.8 earthquake centred approximately 60km south-west of Kaikoura could have caused both horizontal and vertical movement. Preliminary data suggested that there was minimal (if any) deformation in the monitored area. Had there been significant vertical movement, it is quite likely that this would have been reflected in the profile data, with either movement of berms inland (caused by overwash) if there had been subsidence, or new features forming further down the profile if the surface had been elevated. There is no evidence from the profile data set that would support a conclusion that there was isostatic sea-level change caused by the earthquake.

[4] Dean RG and Houston JR (2016) Determining shoreline response to sea level rise, *Coastal Engineering,* 114, 1-8
[5] Cooper JAG and Pilkey OH (2004) Sea-level rise and shoreline retreat: time to abandon the Bruun Rule, *Global and Planetary Change,* 43, 157-171

Summary and recommendations

The beach monitoring programme has been underway for over 19 years, and has been through a range of vessel operation changes, the most significant being the commencement and subsequent abandonment of fast ferry services. Beach monitoring requires a long term commitment to provide value. The value of the monitoring programme comes in understanding how beaches of the region function, both in response to vessel wakes and in response to natural events.

Changes caused by the introduction of the fast ferries were never fully captured due to the monitoring commencing after the vessels started operation, although it is assumed that they caused rapid accretion particularly on gravel beaches. It is now possible to conclude that their removal has resulted in a slow reversal of this trend, and possibly a return to pre-fast ferry conditions. In some cases, relict morphology from the period of fast ferry operation remains. It is clear that beaches on the ferry route are in equilibrium with the energy conditions imposed by the conventional ferry traffic, and that wakes created by ships that are currently operating do not create adverse effects on beach morphology or coastal processes and dynamics. That is not to suggest that the beaches are necessarily in the ‘natural’ state that existed prior to the introduction of large vessel traffic on the route.

The monitoring program would show changes should the speed limit (or associated wakes restricted by the bylaw) were lifted, and vessels travelled at a higher speed. Equally, if a class of vessels were introduced that changed wave characteristics and energy, the monitoring program would almost certainly demonstrate the effects on beach morphology. While the bylaw is in effect, changes to the beaches caused by vessel traffic are highly unlikely.

Profiles in the outer Queen Charlotte Sound, off the ferry route, were established to provide an element of control, and in response to the possibility of significant boat traffic using port facilities in Shakespeare Bay, using the northern entrance to Queen Charlotte Sound. These profiles have been generally stable.

The monitoring program was established for a particular purpose, and unless there are proposed changes to the Navigation Bylaw or there is a new class of vessel with different wake characteristics introduced, the value of the monitoring program for its originally intended purpose is limited. However, there may be value in maintaining the monitoring program in some form to fulfil obligations to monitor the environment, due to the long duration of the data record. The ability to reestablish profile lines, possible since the GPS survey in 2013, means that reactivation of the monitoring program at any time is achievable.

Some sites remain of particular interest. Bob’s Bay continues to erode and that has been the subject of some investigation by Opus International Consultants Ltd. Similarly, the cause of the long-term trend of erosion at the Snout may be of interest. Changes at other sites of particular interest, such as Moioio Island which is of cultural significance to Te Ati Awa, could be investigated in alternative ways, such as examining the causes and rates of landslip movement.

In summary, now that it is possible to recommence monitoring should the need arise, relating to either vessel wake changes or concerns relating to sea-level rise or other climate-change related causes, it would be reasonable to discontinue, or significantly reduce the frequency of monitoring. If monitoring is to continue, in response to a requirement to monitor the environment, several sites, could be abandoned without unreasonably affecting the outcome.

Appendix 1 – History of monitoring

In an agreement between Marlborough District Council and Auckland UniServices Limited, dated 25 January 1997, Auckland UniServices Ltd, was engaged to establish and report on a shoreline monitoring programme in Tory Channel and Queen Charlotte Sound. Initially, the programme was for three years, involving six sets of surveys. Progress reports were provided every six months (following a survey of shoreline profiles), concluding with a final report in December 1999.

The programme was then extended through to April 2002 with a further five surveys, concluding with a final report following the April 2002 survey. A contract for a further two surveys (November 2002 and April 2003) was negotiated in late 2002.

In November 2003 a new contract was negotiated with James Cook University, Australia for the analysis of surveys in November 2003, April 2004, November 2004, April 2005, November 2005 and April 2006, concluding with a summary report, following Dr Kevin Parnell's move to that University. In February 2007, an extension to the contract provided for the analysis of surveys undertaken in November 2006, April 2007, November 2007, April 2008, November 2008 and April 2009, followed by a summary report. A further extension for the analysis of surveys in November 2009, November 2010, April 2011, November 2011 and April 2012 was agreed in November 2009 and reported in August 2012.

A further contract with James Cook University was entered into on 12 June 2014 for further services, under which brief reports were provided for surveys in November 2013 and November 2015, all data were adjusted based on a GPS survey undertaken by Aysons and Partners (Aysons), to reduce all data to a common datum (further discussed below), and all data and images forming the complete dataset were transferred to MDC. The contract was terminated when Dr Kevin Parnell left the University. A replacement contract was agreed between MDC and Dr Kevin Parnell on 29 March 2017.

Appendix 2 – Profile photographs 2013, 2015, 2016

Profile 1 – Picton Foreshore

November 2013

November 2015

November 2016

Profile 2 – The Snout at Picton Point

November 2013

November 2015

November 2016

Profile 3 – Double Bay


November 2013


November 2015


November 2016

Profile 4 – Ngaionui Bay


November 2013


November 2015


November 2016

Profile 5 – Blackmore’s at Waikawa

November 2013

November 2015

November 2016

Profile 6 – Moioio Island 2


November 2013


November 2015


November 2016

Profile 7 – Moioio Island 1


November 2013


November 2015


November 2016

Profile 8 – Bob's Bay


November 2013


November 2015


November 2016

Profile 9 – Te Awaiti Bay


November 2013


November 2015


November 2016

Profile 10 – Tipi Bay

November 2013

November 2015

November 2016

Profile 11 – Long Island


November 2013


November 2015


November 2016

Profile 12 – Clark Point


November 2013


November 2015


November 2016

Profile 13 – Slip Beach


November 2013


November 2015


November 2016

Profile 14 – Ngaionui Point


November 2013


November 2015


November 2016

Profile 15 – Te Weka Bay


November 2013


November 2015


November 2016

Profile 16 – McMillan's Bay


November 2013


November 2015


November 2016

Profile 17 – McMillan's Side


November 2013


November 2015


November 2016

Profile 18 – Dieffenbach West

November 2013

November 2015

November 2016

Profile 19 – Curious Monkey


November 2013


November 2015


November 2016

Profile 20 – Patten's Passage

November 2013

November 2015

November 2016

Profile 21 – Blumine Island


November 2013


November 2015


November 2016