Coastal Hazard Assessment
Koitiata and Castlecliff Beaches:
Rangitikei & Wanganui Districts

horizons
regional council

June 2014

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June 2014
ISBN: 978-1-927250-75-4
Report No: 2014/EXT/1379

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EXECUTIVE SUMMARY

The shorelines at Castlecliff and Koitiata have been assessed for coastal hazards. For each of the beaches a comprehensive CEHZ (Coastal Erosion Hazard Zone) and CIHZ (Coastal Inundation Hazard Zone) assessment was undertaken.

It has been shown that there will be no increase in either Coastal Inundation or Erosion Risk to properties at Castlecliff over the 100 year planning timeframe considered under this investigation. The mapping of the hazard zones shows that the landward extent of these hazard zones is located within the dunes behind the beach at Castlecliff.

The investigation has shown that over the 100 year planning timeframe a number of properties at Koitiata will be at risk from coastal erosion. However, this potential risk is driven by the migration of the mouth of the Turakina River. It is assumed that this risk could be managed through the use of river training works, such as groynes, to control the alignment of the river mouth, as is done at Waikawa.

It has also been shown that there is an inundation risk to properties at the western, seaward, side of Koitiata. The number of properties subject to this risk will increase over the 100 year planning timeframe. This inundation is largely due to the effects of wave run-up and the depths of flooding will not be great. The potential inundation risk at Koitiata should be taken into account when making future planning and building consent decisions.

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COASTAL HAZARDS ASSESSMENT

KOITIATA AND CASTLECLIFF BEACHES

1. Introduction

A progressive review of the information available on coastal hazards by Horizons Regional Council (HRC) has identified the need for an assessment of the nature and scale of coastal hazards along the coastline bounded by Koitiata and Castlecliff Beaches. Specific discrete assessments are required for the following beaches respectively in the Rangitikei (RaDC) and Wanganui (WDC) Districts:

- Koitiata,
- Castlecliff.

The Mowhanau Beach is not included in this study, as WDC have carried out recent specialist investigations on coastal erosion risks there and the inundation risk relates to river flooding.

The purpose of this assessment is to identify the coastal hazards to which the identified areas are subject, in order that the respective councils can then make informed decisions as to how to manage existing and new activities and development in these areas.

1.1 Scope of Work

Task 1. To identify an ‘area sensitive to coastal hazards’ along the full shoreline at the two nominated beaches.

Task 2. To investigate and identify in detail the nature and scale of coastal hazards that exist using the following criteria:

- a. Design waves and storm surge wave run-up (SWRU) in a 1% AEP storm (note care is to be taken in any wave model that the extreme waves are not damped out due to model limitations);
- b. Storm surge in a 1% AEP storm including:
  - i. Barometric setup;
  - ii. Wind setup;
  - iii. Wave setup
  - iv. Sea level rise of 0.31 metres to 2064 and 0.95 m to 2114, being the most recent estimate from the Ministry for the Environment Guidelines 2008; and
  - v. Any other physical processes.
- c. Erosion hazards to be based on:
  - i. Short-term fluctuations in shoreline position (ST);
  - ii. The shoreline response to storm erosion (SE);
  - iii. Long term response to storm erosion (LT);
  - iv. Dune stability factor (DS);
  - v. The magnitude of shoreline retreat from sea level; and

    vi. Any other physical processes (e.g. river mouth migration).
d. Appropriate freeboard and safety margins; and
e. Scenarios are to be modelled for:
    i. The existing (2014) situation;
    ii. Inclusion of global warming impacts to the year 2064 including an agreed provision for wave intensification; and
    iii. Inclusion of global warming impacts to the year 2114 including an agreed provision for wave intensification.

1.2 Deliverables

A report outlining or including:

1. The investigations undertaken and the calculations, findings and conclusions reached to meet Task 2 as defined in the scope;
2. The analysis of the options investigated, the findings and conclusions reached in evaluating the coastal hazard risk to meet Task 1 as defined in the scope;
3. That the requirements described in Task 2, of the scope, have been satisfied;
4. Plans and maps, as appropriate, that are in a form compatible with the GIS systems of HRC [ESRI's ArcGIS], RaDC and WDC, and that map and plan information includes NZTM and NZMG projections and comes with completed metadata files.

River flooding inundation is not considered in this investigation as the flood risk from the Turakina River has been modelled previously.

Tsunami risks are not included in this investigation as they have previously been studied by GNS Science.

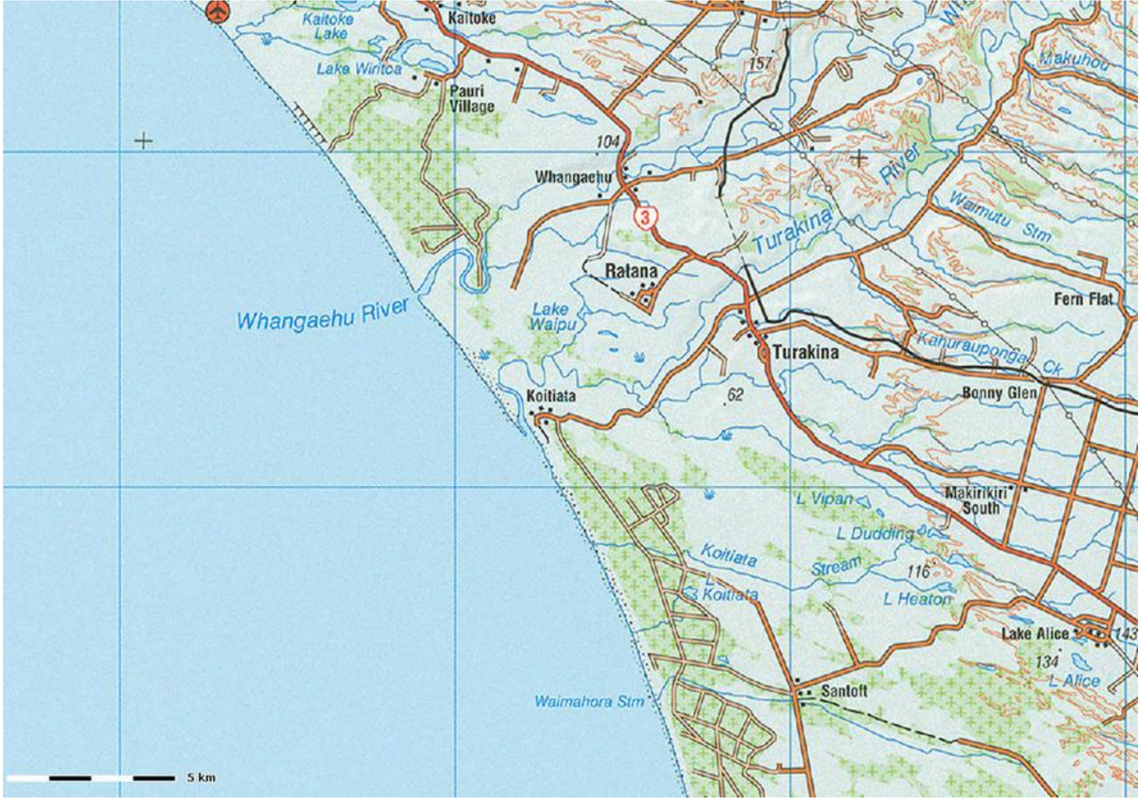
2. Site Description

Koitiata and Castlecliff are located on the west coast of the North Island.

2.1 Koitiata Beach

The settlement of Koitiata is located at the mouth of the Turakina River, approximately 7 km west of Turakina, refer Figure 2.1.

Figure 2.1 - Location of Koitiata Beach

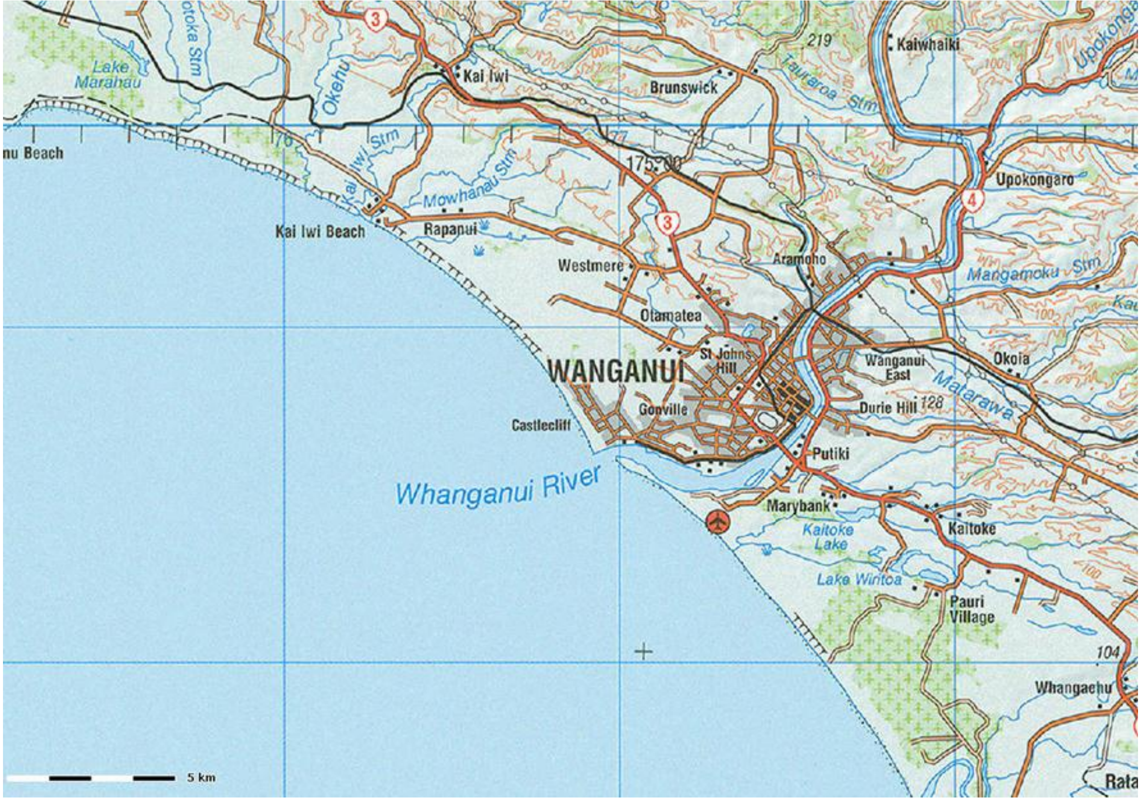


The settlement is located along approximately 450 m of the coast, and extends approximately 500 m inland. There is a general fall in elevations through the settlement towards the coast.

2.2 Castlecliff Beach

Castlecliff beach is found to the north of the Whanganui River mouth and to the west of Wanganui itself, refer Figure 2.2.

Figure 2.1 - Location of Castlecliff Beach



Properties at Castlecliff are generally found approximately 200 m landward of the fore dunes at Castlecliff beach. The surf lifesaving club and beach car park are located approximately 1 km north of the mouth of the Wanganui River and are sited on the beach front.

3. Historic Shoreline Change

3.1 Koitiata Beach

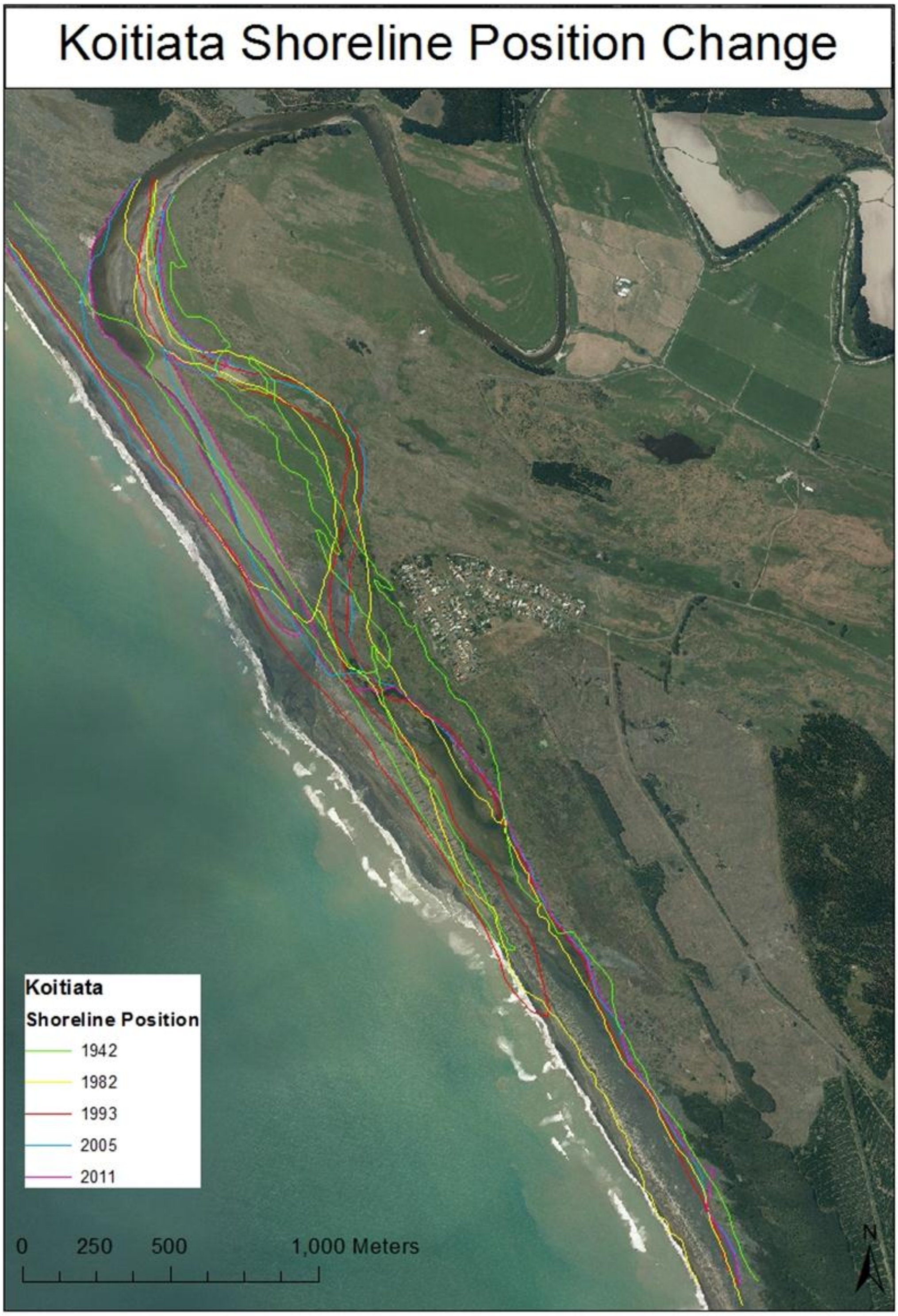
In 1983 the coastline at Koitiata was mapped by the Photogrammetric Branch of the Department of Lands and Survey. The toe of the foredune was mapped from aerial suveys that were flown in 1942 and 1982. A copy of the map can be seen in Appendix A.

The map produced in 1983 was analysed, along with aerial photographs taken in 2005 and 2011, to determine the historic coastal erosion trend at Koitiata.

The map and aerial photographs were geo-referenced and analysed using standard ARCGIS software. The estimated relative accuracy between images using this technique is +/- 2.5m.

Since the 1983 map plotted the location of the toe of the foredune, this was digitised from the aerial photographs so that a common shoreline feature could be mapped over time. This feature was chosen, rather than the swash line as the swash line is overly influenced by the most recent high tides. Figure 3.1, overleaf, shows these lines overmarked on the 2011 aerial photograph of Koitiata.

Figure 3.1 - Koitiata Shoreline Position Change



As Figure 3.1 shows, the main influence on the shoreline position at Koitiata is the Turakina River. Over time the mouth of the river has migrated along the shoreline. This is in keeping with classical theory whereby the outlet of the Turakina River migrates southwards due to the longshore drift associated with the tides. At various times, often associated with high flows, the river will blow out the sand bar at the upstream end of the beach. This accounts for the various river mouth positions seen at Koitiata over the recorded years.

It is noted that there has been very little change in the position of the toe of the foredunes external to the influence of the Turakina inlet, both to the north and to the south of Koitiata, between 1942 and 2011. It is hence reasonable to assume that there are no significant trends of either erosion or accretion at this location.

It is further noted that the position of the river channel immediately to the north of Koitiata has changed significantly. In the earlier surveys (1942-82) the river channel follows a meander that comes relatively close to the northern side of Koitiata. In more recent years the channel in this reach has straightened towards the channel that is currently seen. It is likely that in future the river channel is likely to continue to migrate in this reach and potentially come back close to Koitiata. This channel migration is something that should continue to be monitored.

3.2 Castlecliff Beach

To determine the historic coastal erosion trend at Castlecliff beach, aerial photographs from 1942, 2005 and 2011 were geo-referenced and analysed.

The historic aerial photographs were geo-referenced and digitised using ARCGIS software. The estimated relative accuracy between images for this methodology is +/- 2.5 m.

In each photograph the seaward line of vegetation was digitised as it represents a common shoreline feature. This feature was chosen because it forms a sharp discontinuity in contrast in the photographs. Figure 3.2, overleaf, shows these lines over marked on the 2011 aerial image of Castlecliff Beach.

Figure 3.2 - Castlecliff Shoreline Position Change

Analysis of the shoreline changes at Castlecliff Beach was undertaken at 52 cross-sections, spaced at 50 m intervals along the beach. The locations of these cross-sections can be seen below in Figure 3.3. The cross sections were number 1-52, with cross-section 1 closest to the North Mole and 52 at the northern end of the beach.

As, shown in Figure 3.2 the shoreline at Castlecliff is accreting (building out). Table 3.1 overleaf, summarises the shoreline changes observed at the cross-sections shown in Figure 3.3, cross-sections 18-29 have been discounted from the analysis as the shoreline at these locations is fixed by the car park.

Table 3.1 - Castlecliff Shoreline Position Analysis

	Accretion			
	1942-2005		**2005-2011**	
Cross-Section	**Total (m)**	**Average (m/yr)**	**Total (m)**	**Average (m/yr)**
1	76.05	1.21	4.20	0.70
2	77.97	1.24	4.48	0.75
3	79.89	1.27	4.75	0.79
4	92.40	1.47	10.61	1.77
5	126.32	2.01	-10.12	-1.69
6	138.69	2.20	-8.94	-1.49
7	145.57	2.31	-1.00	-0.17
8	146.90	2.33	5.71	0.95
9	139.05	2.21	7.57	1.26
10	131.19	2.08	9.44	1.57
11	121.44	1.93	9.54	1.59
12	111.21	1.77	9.27	1.55
13	109.12	1.73	9.10	1.52
14	107.25	1.70	8.72	1.45
15	105.37	1.67	8.25	1.38
16	102.82	1.63	7.21	1.20
17	100.38	1.59	6.05	1.01
30	90.12	1.43	19.61	3.27
31	100.53	1.60	13.62	2.27
32	108.58	1.72	9.79	1.63
33	100.03	1.59	9.18	1.53
34	99.67	1.58	8.57	1.43
35	105.37	1.67	7.96	1.33
36	111.57	1.77	7.22	1.20
37	113.39	1.80	6.89	1.15
38	114.09	1.81	6.62	1.10
39	114.71	1.82	6.43	1.07
40	114.20	1.81	6.41	1.07
41	108.77	1.73	6.78	1.13
42	103.26	1.64	7.24	1.21
43	98.08	1.56	7.52	1.25
44	92.87	1.47	8.27	1.38
45	88.53	1.41	9.01	1.50
46	85.04	1.35	9.25	1.54
47	82.74	1.31	9.33	1.56
48	81.58	1.29	10.16	1.69
49	80.53	1.28	10.99	1.83
50	79.70	1.27	11.82	1.97
51	78.87	1.25	12.65	2.11
52	78.04	1.24	13.50	2.25
average	***103.55***	***1.64***	***7.59***	***1.27***

As the table shows, there has been a significant amount of accretion since 1942. This accretion has been occurring at an average rate of approximately 1.6 m/yr in the period between 1942 and 2011.

It is noticed that the average rate of accretion over the latest period of record, 2005-2011, is slightly lower at approximately 1.3 m/yr.

4. Coastal Erosion Hazard Zone Assessment

4.1 Methodology

To maintain a consistent approach to the assessment of coastal erosion hazards in the Horizons Region the methodology used in the Waikawa to Waitarere Coastal Hazard Assessment (Tonkin and Taylor, 2013), has been used in this assessment.

This methodology to determine the coastal erosion hazard zones (CEHZ) includes the cumulative addition of:

- Predicted climate change effects;
- Expected long term erosion rates;
- Episodic storm induced erosion and short term fluctuations in shoreline movement;
- Dune stability; and
- Inlet migration.

4.1.1 Open Coast

The equation below models the coastal erosion hazard zones for the open coast:

$$\mathbf{CEHZ\ (open\ coast) = [LT]T+SLR+ST+DS+FS} \qquad \mathbf{(1)}$$

Where:

CEHZ = The width of the coastal erosion hazard zone for open coast sandy shoreline (m).

LT = Historic long term rate of horizontal shoreline movement (m/yr).

T = Planning time frame (years).

SLR = Horizontal coastline retreat due to possible accelerated sea level rise (m).

ST = Horizontal distance of shoreline retreat from both storm induced erosion and short term fluctuations in the long term trend of shoreline movement (m).

DS = Horizontal retreat of the vertical erosion scarp based on the angle of repose for loose sand (m).

FS = Factor of Safety/uncertainty (m).

4.1.2 Components

4.1.2.1 Planning time frame (T)

The three timeframes described in the project brief have been applied. These timeframes are defined below:

- Current Erosion Hazard Zone (2014) – CEHZ;
- 2064 Erosion Hazard Zone (50 years) – 2064EHZ; and
- 2114 Erosion Hazard Zone (100 year) – 2114EHZ.

4.1.2.2 Sea level rise effects (SLR)

The frequency of wave attack, on the fore dunes, is likely to increase with future sea level rise. It is likely that this will lead to increased erosion, even at beaches that have been relatively stable over time.

As with the Waikawa to Waitarere Coastal Hazard Assessment (Tonkin and Taylor, 2013), it is not considered appropriate to make any adjustments for vertical land displacement (uplift from earthquakes) when considering sea level rise during the 100 year planning period.

The approach that has been used is to assume that the sediment supply and active beach width remains constant during a change in sea level (equilibrium beach concept). The beach profile is likely to respond to these conditions with an upward and landward transition over time (Komar, McDougal, Marra, & Ruggiero, 1999). The landward translation of the beach profile (SLR) can be defined as a function of sea level rise and the active beach slope. This method of describing the equilibrium beach concept is a variation of the Bruun rule and is given in equation 2 below.

$$SLR = \frac{\Delta s}{\tan \alpha} \qquad (2)$$

Where:

SLR = landward translation of the beach profile (m)

Δs = predicted rise in sea level (m)

α = average intertidal slope

The predicted sea level rise has been assumed to be 0.31 m to 2064 and 0.95 m to 2114, which are the most recent estimates from the (Ministry for the Environment (MfE), 2008).

An analysis of surveyed cross sections, which can be seen in Appendix B, shows that the average inter-tidal slope, at both Castlecliff and Koitiata, is approximately 1:50.

Using these assumptions, and the model described above, the potential landward movement of the beach has been calculated for both of the sea level rise scenarios. The results are summarised in Table 4.1 below:

Table 4.1 - Landward Movement due to Sea Level Rise

Planning Time Frame	Inter-tidal slope	Sea level rise (m)	SLR Distance (m)
2014 - 2064	1:50	0.31	**15.5 m**
2014 - 2114	1:50	0.95	**47.5 m**

4.1.2.3 Long terms rates of shoreline movement (LT)

The historic trend in the movement of the shoreline position at Castlecliff is discussed in Section 3.2. The analysis of historic aerial photographs showed that the shoreline has been accreting at a rate of approximately 1.6 m/yr.

It is important to note that future shoreline movement may differ from the historical trend due to changing climatic patterns associated with the Inter-decadal Pacific Oscillation (IPO) and global climate change.

It is also important to note that the rate of accretion at Castlecliff is also likely to be influenced by the North Mole at the mouth of the Whanganui River. If the condition of the mole were to deteriorate it is likely that the rate of accretion would decrease.

As a conservative approach to the determination of the Coastal Erosion Hazard at Castlecliff, the long term rate of horizontal shoreline movement (LT) has been considered to be zero. This means that continued accretion of the beach is not included in the model.

4.1.2.4 Short term shoreline movement (ST)

Both storm induced erosion and fluctuations around the long term trend of shoreline movement are included in the short term erosion rate.

The most obvious cause of short term erosion is the effect of severe wave storms attacking the coast. However, one must also consider short term fluctuations over a longer period than a single storm event. These fluctuations include responses to natural variations in climatic conditions such as the El Nino Southern Oscillation (ENSO), which usually occur on a 3-7 year cycle.

To determine the likely magnitude of short term shoreline movement it is usual to examine aerial photographs or survey information that have been gathered at frequent intervals over a period of time. Unfortunately, there is not a sufficient quantity of this data to make an accurate estimate of short term shoreline move at either of the beaches in this investigation. However, Tonkin and Taylor (2013) calculated a conservative estimate of 30 m, and applied that as the ST factor along the entire coast between Waikawa and Waitarere. It is considered that this conservative estimate is appropriate to apply at Castlecliff and Koitiata.

4.1.2.5 Dune stability (DS)

As defined by Tonkin and Taylor (2013), the dune stability factor delineates the area of potential risk landward of the erosion scarp. This parameter is based on the height of the existing backshore and the angle of repose for loose dune sand (34^{o}), and is described by equation 3 below.

$$DS = \frac{h}{2(\tan\alpha)} \qquad (3)$$

Where:

DS = dune stability factor (m)

h = height of the existing backshore

α = angle of repose for loose dune sand

The maximum height of the dunes at Castlecliff was taken as 9 m and 3 m at Koitiata. These values were determined from the survey information contained in Appendix B. Dune stability factors were calculated from these heights using the equation described above, and the results are contained in Table 4.2 below.

Table 4.2 - Dune Stability Factor (DS)

Beach	Dune Stability Factor (DS)
Castlecliff	**6.7 m**
Koitiata	**2.2 m**

4.1.2.6 Factor of Safety

Dune to the uncertainties in the short term shoreline movement (ST) it is appropriate to allow a factor of safety in the determination of the Coastal Erosion Hazard Zones. In keeping with the Waikawa to Waitarere Coastal Hazard Assessment (Tonkin and Taylor, 2013), a factor of safety of 5 m was deemed to be appropriate for this assessment.

4.1.3 Inlets

The methodology discussed above is appropriate for modelling Coastal Erosion Hazard Zones along the open coast. Due to the stabilising effects of the moles at the mouth of the Whanganui River it was considered appropriate to model the beach at Castlecliff as an open coast.

However, as discussed in section 3.1, the shoreline at Koitiata is influenced significantly by the mouth of the Turakina River.

As discussed by (Shand, 2012), it is appropriate to modify equation 1 to account for inlet morphological behaviour. Dr. Shand presented the equation below as the appropriate equation for assessing the Coastal Erosion Hazard Zone for an inlet.

$$\boldsymbol{CEHZ(inlet) = IMC - ([LT]T + SLR + DS + FS)} \qquad (4)$$

Where:

IMC = Inlet Migration Curve.

And all other values are the same as for equation (1), describing the open coast.

Essentially the inlet migration curve replaces the short term shoreline movement (ST) component of the open coast equation.

4.1.3.1 Inlet migration curve

According to (Shand, 2012), the Inlet Migration Curve (IMC) is derived by fitting a curve to the most landward locations of the inlet shoreline migration envelope.

For the analysis of the Koitiata shoreline migration the digitised shorelines shown in Figure 3.1 were used to develop the IMC that is shown in Figure 4.1.

4.1.3.2 Managed inlet migration curve

As can be seen in Figure 4.1, the inlet migration curve comes close to properties in the settlement of Koitiata. Since the location of the inlet migration curve is strongly influenced by past river alignments, it is considered reasonable to consider the potential to manage the location of the inlet to keep it away from the properties. This could potentially be achieved through the use of river training works such as groynes to control the alignment of the inlet, such as is done at Waikawa.

Working on the assumption that the channel could be maintained on a similar alignment to that seen in 1982, the Managed IMC, shown in Figure 4.2, was developed.

Figure 4.1 - Koitiata Inlet Migration Curve

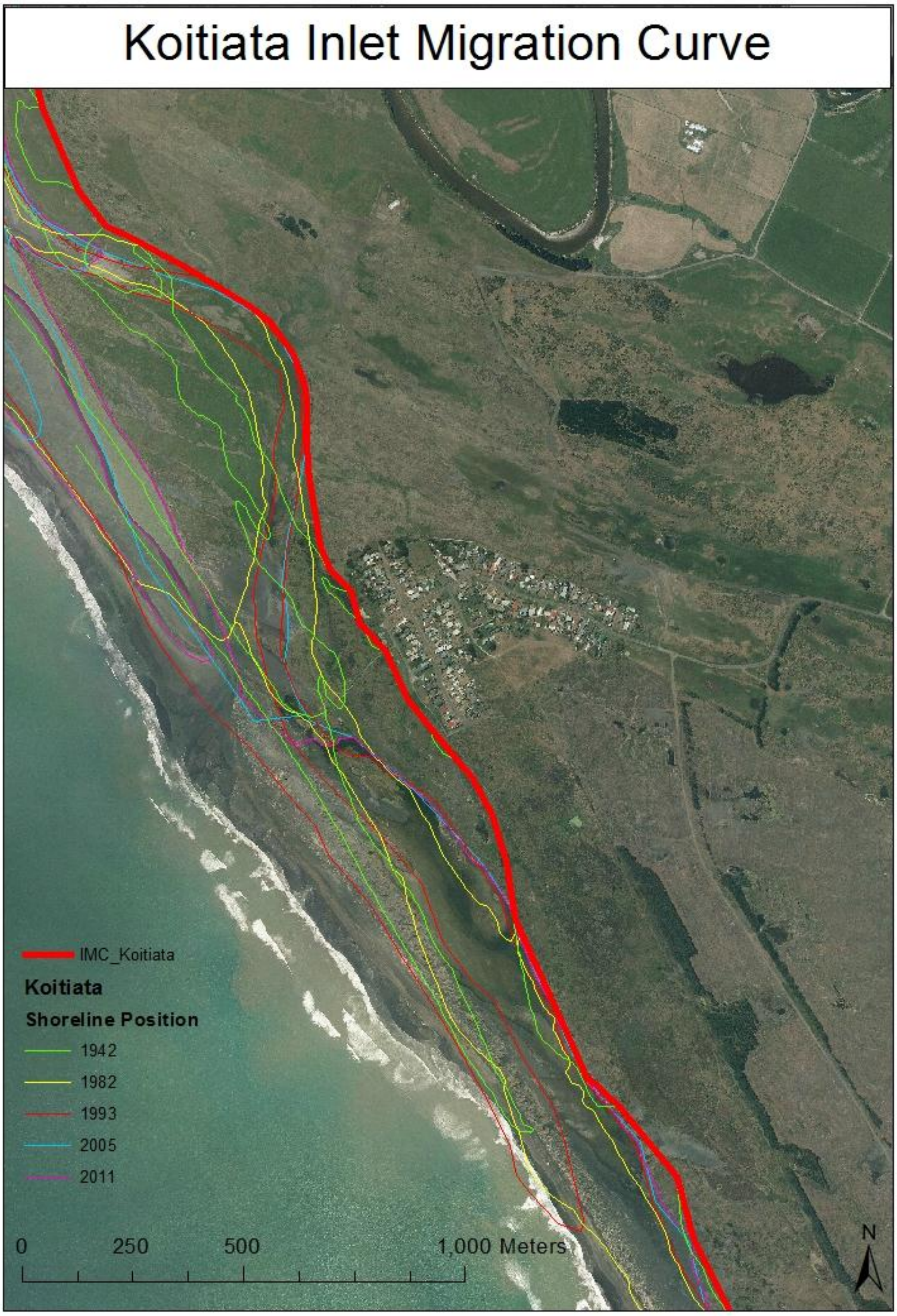
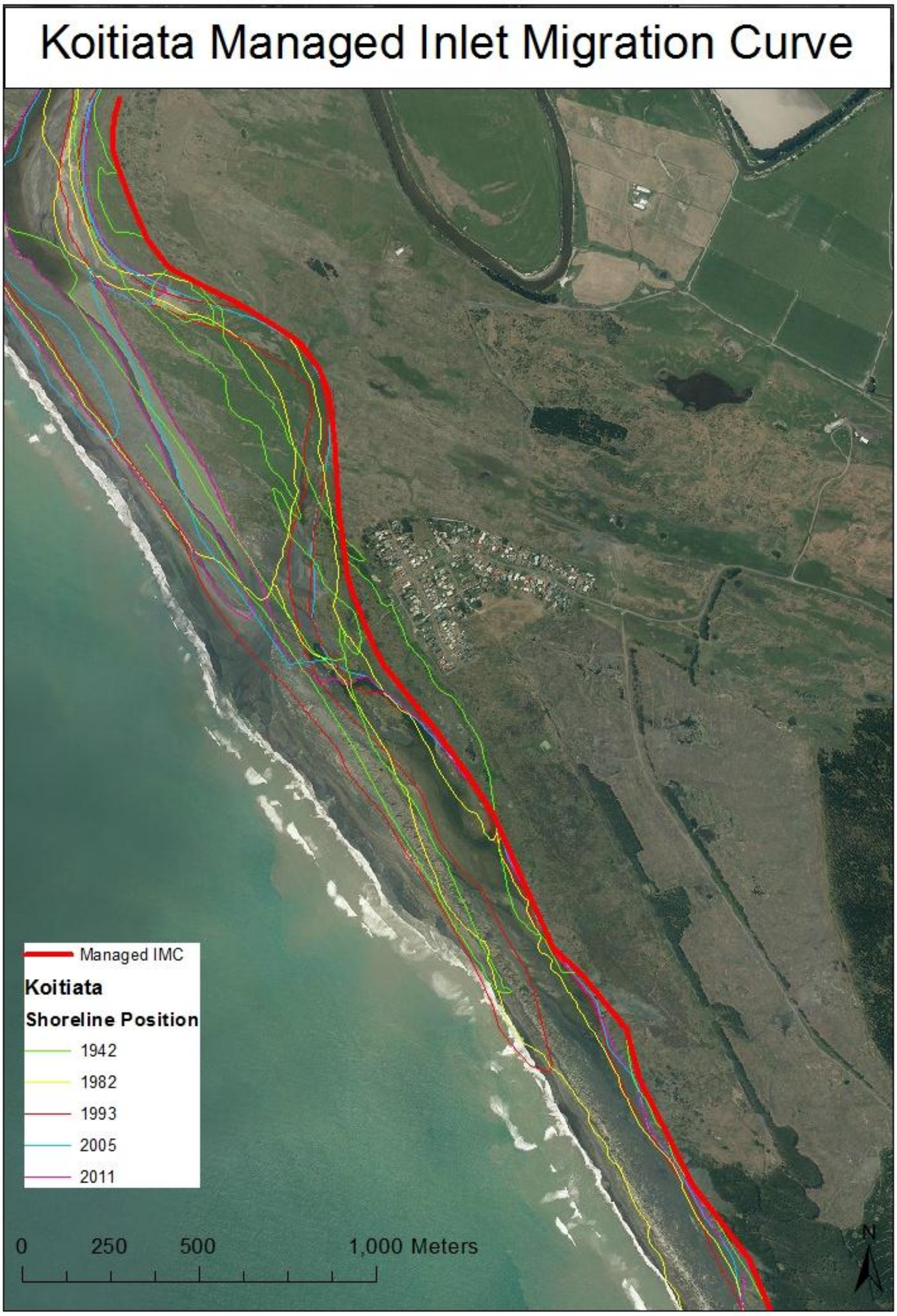


Figure 4.2 - Koitiata Managed Inlet Migration Curve



4.2 Coastal Erosion Hazard Zone Results

Table 4.3 below presents a summary of the CEHZ distances calculated for the planning timeframes at Koitiata and Castlecliff.

Table 4.3 - CEHZ Results

Beach	SLR 2064 (m)	SLR 2114 (m)	LT (m/yr)	ST (m)	DS (m)	FS (m)	CEHZ		
							Current (m)	2064 (m)	2114 (m)
Castlecliff	15.5	47.5	0	30	6.7	5	41.7	57.2	89.2
Koitiata	15.5	47.5	0	IMC	2.2	5	7.2	22.7	54.7

4.3 CEHZ Mapping

4.3.1 Castlecliff

The seaward line of vegetation, which was digitised from the 2011 aerial imagery, was used as the CEHZ offset origin. The CEHZ is measured horizontally inland from the baseline at right angles to the general alignment of the foreshore. The Coastal Erosion Hazard Zones have been mapped digitally and are shown on the 2011 aerial photograph in Figure 4.3, overleaf.

4.3.2 Koitiata

The Koitiata IMC was used as the CEHZ offset origin. The CEHZ is measured horizontally inland from the IMC at right angles to its general alignment. The coastal erosion hazard lines have been mapped digitally and are shown on the 2011 aerial photograph in Figure 4.4. A smaller scale version of this image, focused on Koitiata itself is shown in Figure 4.5.

4.3.3 Koitiata Managed CEHZ

The Koitiata Managed IMC was used as the CEHZ offset origin. The CEHZ is measured horizontally inland from the IMC at right angles to its general alignment. The coastal erosion hazard lines have been mapped digitally and are shown on the 2011 aerial photograph in Figure 4.6. A smaller scale version of this image, focused on Koitiata itself is shown in Figure 4.7.

Figure 4.3 - Castlecliff Coastal Erosion Hazard Zones

Figure 4.4 - Koitiata Coastal Erosion Hazard Zones

Figure 4.5 - Koitiata CEHZ

Figure 4.6 - Koitiata Managed Coastal Erosion Hazard Zones

Figure 4.7 - Koitiata Managed CEHZ

5. Coastal Inundation Hazard Assessment

The Coastal Inundation Hazard Zones (CIHZ) of Castlecliff and Koitiata have been assessed for storm surge and wave run up events. Inundation from river flooding or tsunami events have not been modelled as they did not form part of the project brief.

5.1 Components of Storm Surge and Wave Run-Up

Storm surges are caused by coastal storms raising sea levels through a combination of the drop in atmospheric pressure and wind driving the sea onto land. The rising of the sea level in response to falling atmospheric pressure is known as barometric set-up. Wind set-up is the change in water levels due to the wind. Note: wind set-up can be of two types, being either that caused on open coast or differential effects across an estuary.

The "stillwater" level is considered to be the combination of the astronomical tide, barometric set-up and wind set-up.

In addition to the stillwater level, there is a near-shore increase in water levels caused by waves approaching land. This is called wave set-up.

For the open coast a significant component of the peak water level reached on land is the wave run-up. Wave run-up is defined as the sum of wave set-up and wave swash.

5.1.1 Astronomical Tide

The astronomical tide is caused by the gravitational attraction of the sun and moon on the Earth's waters. The astronomical tides levels are estimated based on around 600 components and presented in the New Zealand Nautical Almanac and other publications. The almanac presents detailed data on the Port Taranaki site and further data on the Secondary Ports site at Whanganui River Entrance. This data is summarised in Table 5.1 below.

Table 5.1 – Astronomical Tide Levels

Astronomical Tide Levels	Port Taranaki		Whanganui River Entrance	
	(m above Chart Datum)	(m above Wellington Datum)	(m above Chart Datum)	(m above Wellington Datum)
Mean High Water Springs (MHWS)	3.5	1.806	2.8	1.106
Mean High Water Neaps (MHWN)	2.7	1.006	2.2	0.506
Mean Sea Level (MSL)	1.94	0.246	1.7	0.006
Mean Low Water Neaps (MLWN)	1	-0.694	1.3	-0.394
Mean Low Water Springs (MLWS)	0.2	-1.494	0.7	-0.994

5.1.2 Barometric Set-Up

Depressed atmospheric pressures cause a rise in water levels. This is sometimes referred to as a bulge of water following the centre of the depression. The general increase in water levels is one centimetre per hectapascal (or millibar) drop in atmospheric pressure. Conversely there is also a corresponding drop in sea level associated with rises in atmospheric pressure.

The standard equation for calculating the barometric set-up is:

$$\Delta H_{BAR} = z(1014 - pa)$$

Where $\Delta H_{BAR} =$ Surface elevation change (m)
$z =$ Barometric factor with standard value of 0.01
$pa =$ Atmospheric pressure at sea level (HPa or mb).

The value of z varies from place to place slightly, but the given factor is a good guide. When a depression moves quickly the change in water level is superimposed as a surge on prevailing water levels. The surge behaves as a long wave with a wave length approximately equal to the width of the depression. Along the open coast these long waves may increase in amplitude as a result of shoaling on the near-shore bathymetry, while within harbours amplitudes may increase or decrease depending on the harbour geometry and conveyance capability through the mouth. The response of sea level to pressure changes occurs relatively slowly, taking in the range 2 to 12 hours, and affects large areas in an approximately uniform manner (Tonkin and Taylor, 2002).

Barometric set-up can also be harmonically enhanced by the speed of travel of the storm. This occurred in central parts of New Zealand in Cyclone Giselle (the “Wahine” storm) in April 1968 (Heath, 1979).

5.1.3 Wind Set-Up

The surface shear stress caused by the wind (called the geostrophic wind) travelling over the sea surface drives water from the prevailing wind direction. An on-shore wind thus drives a “wedge” of water against the land. The magnitude of the height of this wedge component is known as the wind set-up. There are complex equations available to calculate the wind set-up dependant on several factors including:

- Intensity, duration and direction of high winds;
- Coastline bathymetry (the wind set-up is greater in shallow waters); and
- Coastline geometry. The concave shape of the coastline on the west coast of the Manawatu-Wanganui Region is minorly conducive to enhancing surge levels. (This is a much documented phenomenon during hurricanes, with significantly elevated levels on the Gulf of Mexico coastline in the Caribbean Sea.)

5.1.4 Total ‘Stillwater’ Level

The total “stillwater” level is the combined total of the astronomical tide, barometric set-up and wind set-up. These may not act with peak magnitude simultaneously. For example the peak set-ups may occur at low tide (although generally there would not be a significant attenuation in set-ups by the preceding or succeeding high tide); similarly the surge on various parts of the New Zealand coast caused by both Cyclones Giselle (1968) and Fergus (1996) occurred on neap tides.

5.1.5 Wave Set-Up

Wave set-up is a super-elevation of the water surface over normal surge elevation due to onshore mass transport of water by wave action alone. It is caused by energy dissipation due to the shoaling of incoming waves, and is more pronounced in environments with steeper beach slopes and hence the depth of breaking is closer to the shoreline.

It is smaller in restricted fetch environments, low beach slopes and shallow water depths (Tonkin and Taylor, 1999).

5.1.6 Wave Run-Up

The wave run-up component is the elevation above the combined level from the other components reached by the wave swash. It is dependent upon breaking wave height and period, beach slope and the resistance characteristics of the beach sediment. It increases with wave height, period and beach slope and decrease with coarser sediment.

It is also affected by degree of sheltering from headlands, islands or reefs, and wave angle with the shoreline.

5.2 Methodology

In order to provide a consistent approach to the consideration of coastal inundation hazards in the Horizons region, the methodology used in the Waikawa to Waitarere Coastal Hazards Assessment (Tonkin and Taylor, 2013), has been applied.

Coastal inundation at both Castlecliff and Koitiata has been assessed for the three timeframes required as part of the brief. These scenarios being:

• 2014	The existing situation;
• 2064	Possible inundation levels for the next 50 years; and
• 2114	Possible inundation levels for the next 100 years.

Design levels for each scenario were assessed for tidal conditions plus wave effects. At Castlecliff the wave effects have been assessed assuming that the coastline can be considered as an open coast. At Koitiata the waves effects have been assessed assuming that the maximum wave heights are limited by the depth of the Turakina River inlet.

The equations below were used to model the 1% AEP still water plus 1% AEP wave effects.

Wave run up (including wave set up)

$$CIHZ = MHWS + S_s + \gamma + SLR + R_{2\%} \qquad (5)$$

Inlet Wave effects

$$CIHZ = MHWS + S_s + \gamma + SLR + Iw \qquad (6)$$

Where:

MHWS= Mean High Water Springs

S_s = Storm surge

$R_{2\%}$ = 2% wave run-up elevation (including wave set up)

γ = IPO/ENSO/annual variation in MLOS of 0.25 m.

SLR = Sea Level Rise

Iw = Maximum wave at river mouth based on average water depth.

5.2.1 Components

5.2.1.1 Mean higher water springs

Mean High Water Springs at both Castlecliff and Koitiata has been assumed to be 1.106 m (Wellington Datum). This value is taken from the New Zealand Nautical Almanac (see Table 5.1) – Whanganui River mouth.

This location provides an accurate estimate of MHWS at Castlecliff. However, as noted by (Blackwood, 2007), the tidal range decreases southwards along the coastline. Hence, although MHWS will be slightly lower at Koitiata, by using the same level (of 1.106 m) a conservative estimation of the CIHZ will be derived.

5.2.1.2 Storm surge

A storm surge component of 0.9 m has been chosen for both Castlecliff and Koitiata. This estimate of the effects of barometric set up and wind set up was chosen as it is in keeping with the assumptions made at Waikawa and Waiterere, which are considered to be appropriate for the beaches under consideration in this assessment.

5.2.1.3 Wave run up (R2%)

To estimate wave run up elevation there are a number of empirical formulae that are commonly used by engineers. In recent assessments of wave run up on the beaches of the west coast of the horizons region four such formulae have been applied. These formulae are those of (Holman, 1986), (Ruggiero, Komar, McDougall, Marra, & Beach, 2001) as modified by (Tonkin and Taylor, 2002), Mase (1989) and Hedges & Mase (2001). These formulae are below:

Holman

$$R_{Max} = C\left({}^{g}/_{2\pi}\right)^{0.5}\beta H_B T \qquad (7)$$

Where:

R_{Max} = Maximum wave run-up above the stillwater elevation (m);

C = A coefficient that varies from 0.83 (rocky slope) to 1.5 (smooth slope), a value of 1.07 was found by (Tonkin and Taylor, 1999) to fit fine sandy beaches;

β = Beach slope;

H_B = Breaking wave height (m), based on a transformation of $H_{1\%}$; and

T = Wave period.

Ruggiero et al

$$R_{Max} = 0.27C(\beta H_B L)^{0.5} \qquad (8)$$

Where the additional parameters are:

C = A coefficient that was found by (Tonkin and Taylor, 2002) to be 0.9 for several eastern Bay of Plenty beaches

L = Wave Length (m)

Mase

$$\frac{R_{2\%}}{H_0} = \left(1.86\xi_0^{0.71}\right) \qquad (9)$$

Where:

H_0 = Deepwater significant wave height; and

ξ_0 = Iribarren number.

Hedges and Mase

$$R_{2\%} = (0.34 + 1.49\xi_0)H_S \qquad (10)$$

Where:

H_S = Deepwater significant wave height.

5.2.1.4 Components of wave run up at Castlecliff

As part of the Storm Surge and Wave Run-up Design Levels for Foxton Beach (Blackwood, 2007), the estimates of significant wave heights at Wanganui developed by the DSIR Hydrology centre were considered to be low for the high energy environment in the Taranaki Bight. Having considered estimates of wave heights and periods, Blackwood arrived at the following wave characteristics for Foxton Beach.

HS = 12 m

H1% = 18.36 m

T_p = 14.5 s

It is considered that these characteristics provide a good estimate of the 1% AEP storm at Castlecliff.

5.2.1.5 Beach slope (β)

A slope of 0.02 m/m was assumed to be representative of the beach slope profile from the beach surveys contained in Appendix B.

5.2.1.6 Iribarren number (ξ0)

The Iribarren number, or surf similarity parameter, is a dimensionless parameter that is defined as:

$$\xi_0 = \frac{\tan \alpha}{\sqrt{H_0/L_0}} \qquad (11)$$

Where:

L_0 = deepwater wave length.

Using this formula, the Iribarren number at Castlecliff has been calculated to be 0.104.

5.2.1.7 Wave run up estimates

Table 5.2 below, summarises the wave run-up elevations calculated by each of the methods described above.

Table 5.2 - Estimates of wave run up elevation

Method	**Wave run up (m)**
Holman	7.11
Ruggiero et al	2.67
Mase	4.47
Hodges & Mase	5.94

The elevation of wave run up calculated using the method described by Ruggiero et al appears to be low, while the estimate from the Holman estimate is on the high side, compared with the size of waves that experience suggests would be expected at Castlecliff. For this reason an average of the run ups calculated by the Mase and Hodge & Mase methodologies has been used to estimate wave run up for Castlecliff for a 1% AEP storm event.

The 1% AEP storm wave run up at Castlecliff is estimated to be 5.21 m.

5.2.1.8 Sea level variation (γ)

(Tonkin and Taylor, 2013) noted that sea level variation occurs due to thermal expansion and contraction due to changes in sea surface temperatures and associated currents. This variation in sea level is related to climate cycles of varying time periods.

The Waikawa to Waitarere Coastal Hazards Assessment concluded that a sea level variation of +/- 0.25 m would apply to both the 50 and 100 year scenarios. This is also considered to be an appropriate sea level variation to be applied at Castlecliff and Koitiata for the 2064 and 2114 scenarios.

It is also considered appropriate to include this sea level variation in the assessment of the current inundation hazard to allow for La Niña effects.

5.2.1.9 Sea level rise

As defined in the project brief (see section 1.1), sea level rise is taken as 0.31 m for the 2064 scenario and 0.95 m for the 2114 scenario.

5.2.1.10 Inlet wave effects

Wave heights in an inlet are considered to be depth limited. According to wave theories the maximum height of such a wave is defined by a breaker ratio. This breaker ratio is defined as the ratio of wave height to water depth (H/d). In the Waikawa to Waitarere a breaker ratio of 0.78 was used to calculate the wave height likely to be seen in an inlet. This breaker ratio is at the high end of ratios that have been determined by laboratory research, while real world observations suggest that a ratio of 0.5 is a more realistic ratio.

For the purposes of this assessment a breaker ratio of 0.78 has been assumed for Koitiata. This assumption allows for the reduction in inlet effects at higher water levels.

The depth of water was calculated from the total stillwater level and an average inlet bed level of 0.6 m that was surveyed in 1986 when the inlet passed through the Turakina Beach Southern XS (Appendix B).

The table below summarises the estimated 1% AEP inlet wave heights at Koitiata.

Scenario	Total Stillwater level (m)	Water depth (m)	Max wave height (m)
2014	2.256	1.656	1.29
2064	2.566	1.966	1.53
2114	3.206	2.606	2.03

5.3 Coastal Inundation Hazard Results

Table 5.1 below summarised the components and final coastal inundation levels for the existing, 2064 and 2114 scenarios.

Table 5.1 - Inundation components and final inundation levels

Parameter	**Scenario**		
	Current	**2064**	**2114**
MHWS (m Wellington Datum)	1.106	1.106	1.106
Sea level rise (m)	0	0.31	0.95
Storm surge (m)	0.9	0.9	0.9
Sea level variation (m)	0.25	0.25	0.25
Wave run up (m)	5.21	5.21	5.21
Inlet wave height (m)	1.29	1.53	2.03
Castlecliff CIHZ (m)	**7.216**	**7.776**	**8.416**
Koitiata CIHZ (m)	**3.546**	**4.096**	**5.236**

5.4 Coastal Inundation Hazard Mapping

The inundation levels at Castlecliff and Koitiata have been mapped using a Digital Elevation Model derived from LiDAR data of the respective beaches. These Coastal Inundation Hazard Zones have been plotted on the 2011 aerial photographs, and can be seen in Figure 5.1 and Figure 5.2.

Figure 5.1 - Castlecliff CIHZ

Figure 5.2 - Koitiata CIHZ

6. Summary

The shorelines at Castlecliff and Koitiata have been assessed for coastal hazards. For each of the beaches a comprehensive CEHZ (Coastal Erosion Hazard Zone) and CIHZ (Coastal Inundation Hazard Zone) assessment was undertaken.

CEHZs were assessed for the current (2014), 50 year (2064) and 100 year (2114) periods. Table 6.1 below summarises the CEHZ set back distances. The setback at Castlecliff is measured from the toe of the foredunes (as seen in 2011) and from the derived Inlet Migration Curve at Koitiata.

Table 6.1 - Summary of CEHZ setback distances

Site	**CEHZ Setback Distances**		
	2014	**2064**	**2114**
Castlecliff	41.7 m	57.2 m	89.2 m
Koitiata	7.2 m	22.7 m	54.7 m

The CEHZ setbacks at Koitiata are from the Inlet Migration Curve (IMC). These have been plotted from both the IMC and a managed IMC. The managed IMC was derived assuming that some river training works are undertaken to prevent the river inlet from coming close to and threatening the settlement at Koitiata.

CIHZs were assessed for the same periods as the CEHZs. The 1% AEP elevations (above Wellington Datum) are summarised in Table 6.2 below.

Table 6.2 - Summary of CIHZ elevations

Site	**CIHZ Elevations**		
	2014	**2064**	**2114**
Castlecliff	7.216	7.776	8.416
Koitiata	3.546	4.096	5.236

7. Bibliography

Blackwood, P. (2007). Storm Surge and Wave Run-up Design Levels for Foxton Beach. Horizons Regional Council.

Heath, R. (1979). Significance of Storm Surges on the New Zealand Coast. New Zealand Journal of Geology and Geophysics Vol. 22 No. 2, 259-66.

Holman, R. (1986). Extreme Value Statistics for Wave Run-up on a Natural Beach. Coastal Engineer Vol. 9.

Komar, P. D., McDougal, W. G., Marra, J. J., & Ruggiero, P. (1999). The rational analysis of setback distances: Applications to the Oregon Coast. Shore and Beach, 67(1), 41-49.

Ministry for the Environment (MfE). (2008). Coastal Hazards and Climate Change. A guidance manual for Local Government in New Zealand. 2nd Edition.

Ruggiero, P., Komar, P. D., McDougall, W. G., Marra, J. J., & Beach, R. A. (2001). Wave Runup, Extreme Water Levels and the Erosion of Properties Backing Beaches. Journal of Coastal Research, 17 (2), 407-419.

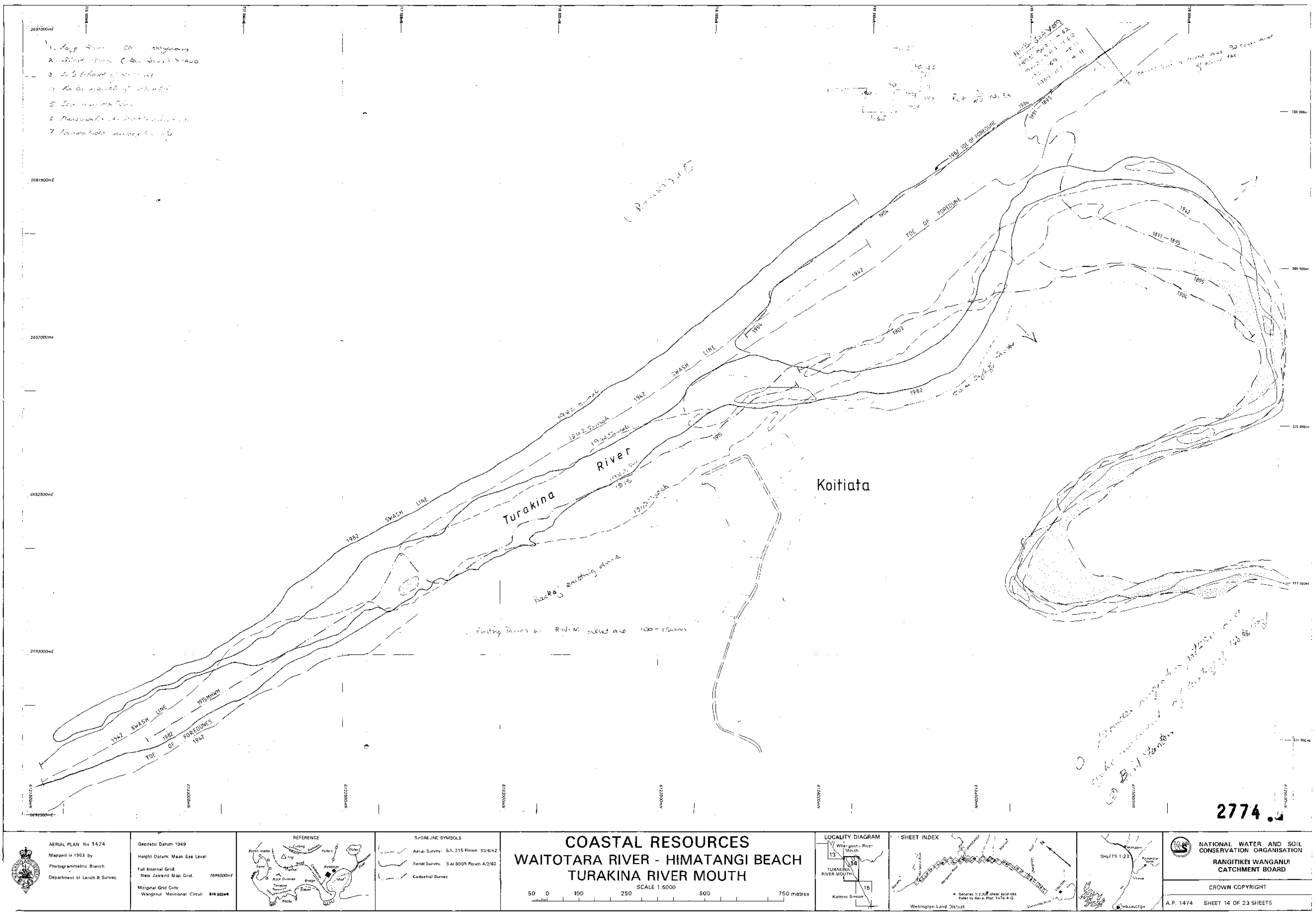
Shand, R. D. (2012). Geomorphological Assessment and Shoreline Analysis of Waikawa, Ohau and Hokio Inlets. Horizons Regional Council.

Tonkin and Taylor. (1999). Tauranga District Council: Storm Surge Innundation Study for Tauranga Harbour. Tauranga District Council.

Tonkin and Taylor. (2002). Whakatane District Council: Coastal Hazard Analysis. Prepared for Whakatane District Council and Environment Bay of Plenty.

Tonkin and Taylor. (2013). Coastal Hazard Assessment - Waikawa to Waitarere. Horizons Regional Council.

Appendix A 1983 Aerial Plan – Turakina River Mouth



2774

AERIAL PLAN No 1474
Mapped in 1983 by
Photogrammetric Branch
Department of Lands & Survey.

Geodetic Datum 1949
Height Datum: Mean Sea Level
Full Internal Grid:
New Zealand Map Grid. 2696500mE
Marginal Grid Cuts:
Wanganui Meridional Circuit: 574 500mN

REFERENCE

SHORELINE SYMBOLS
Aerial Survey: S.A. 215 Flown 30/8/42
Aerial Survey: S.N 8005 Flown 4/2/82
Cadastral Survey

COASTAL RESOURCES
WAITOTARA RIVER - HIMATANGI BEACH
TURAKINA RIVER MOUTH

SCALE 1:5000
50 0 100 250 500 750 metres

LOCALITY DIAGRAM

SHEET INDEX
• Denotes 1:2000 sheet localities
Refer to Aerial Plan 1474 A-G
Wellington Land District

NATIONAL WATER AND SOIL CONSERVATION ORGANISATION

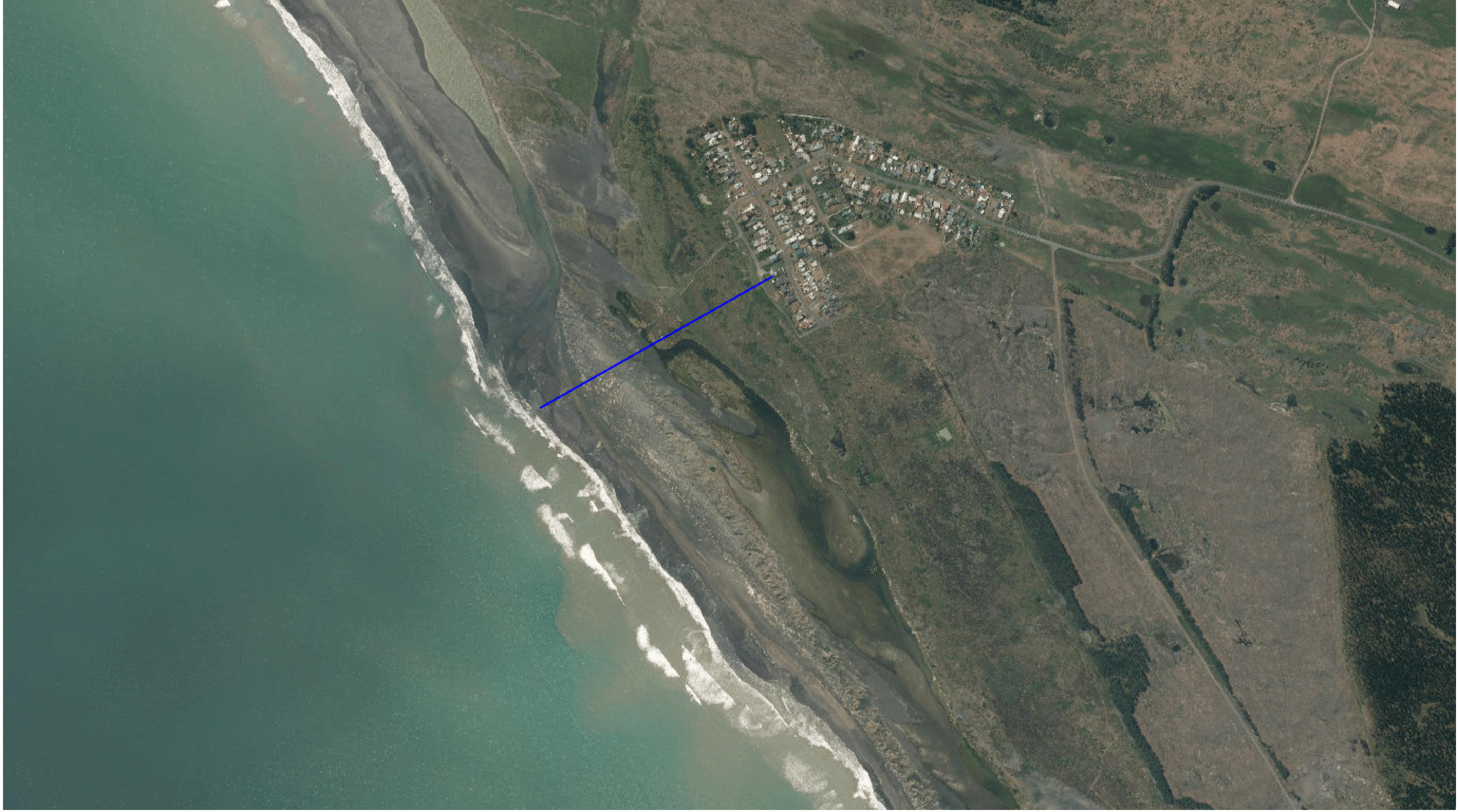
RANGITIKEI WANGANUI CATCHMENT BOARD

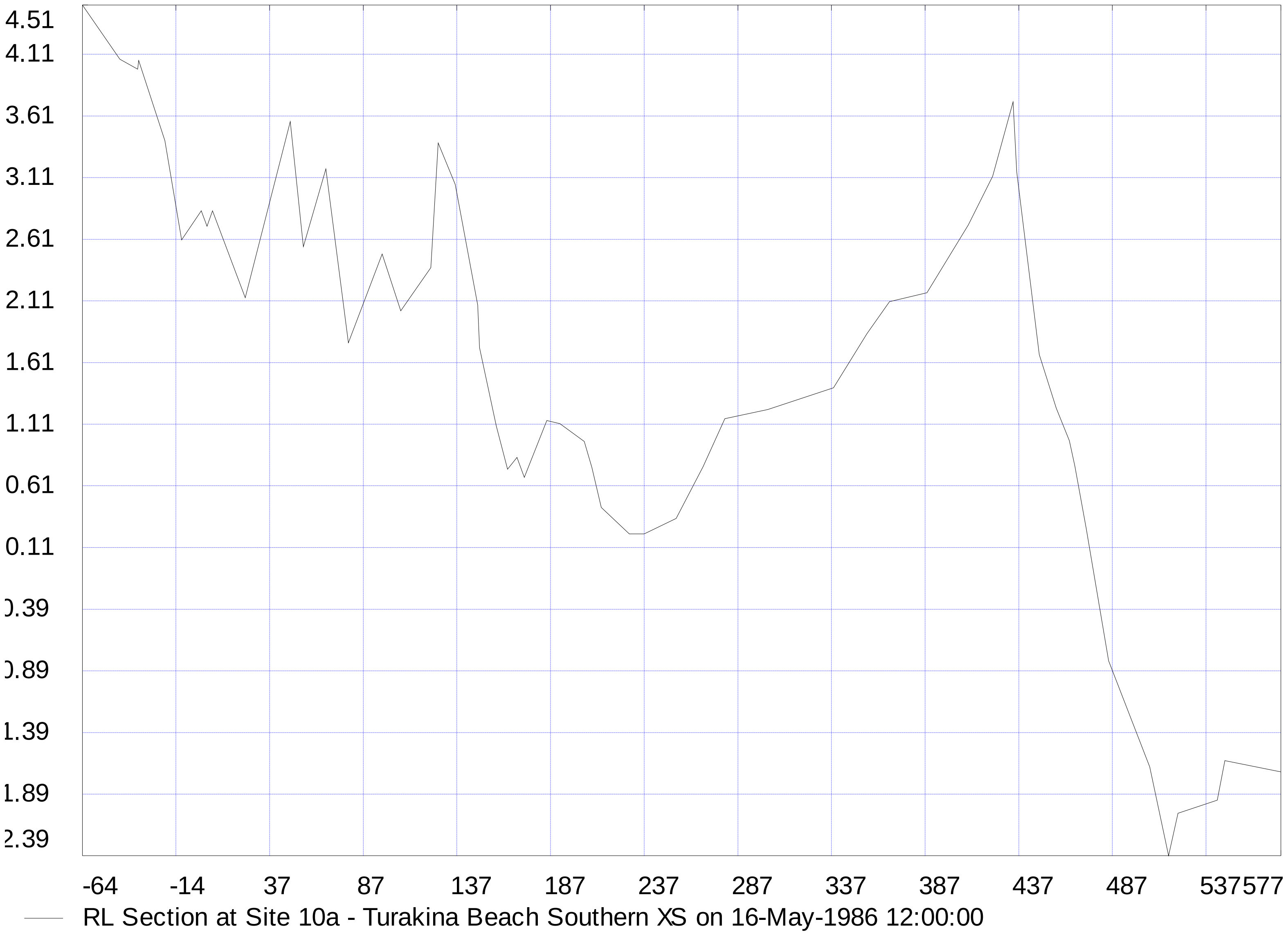
A.P. 1474 SHEET 14 OF 23 SHEETS

Appendix B Cross Sectional Surveys of Castlecliff and Koitiata Beaches

10a - Turakina Beach Southern XS

Scale 1 : 8000

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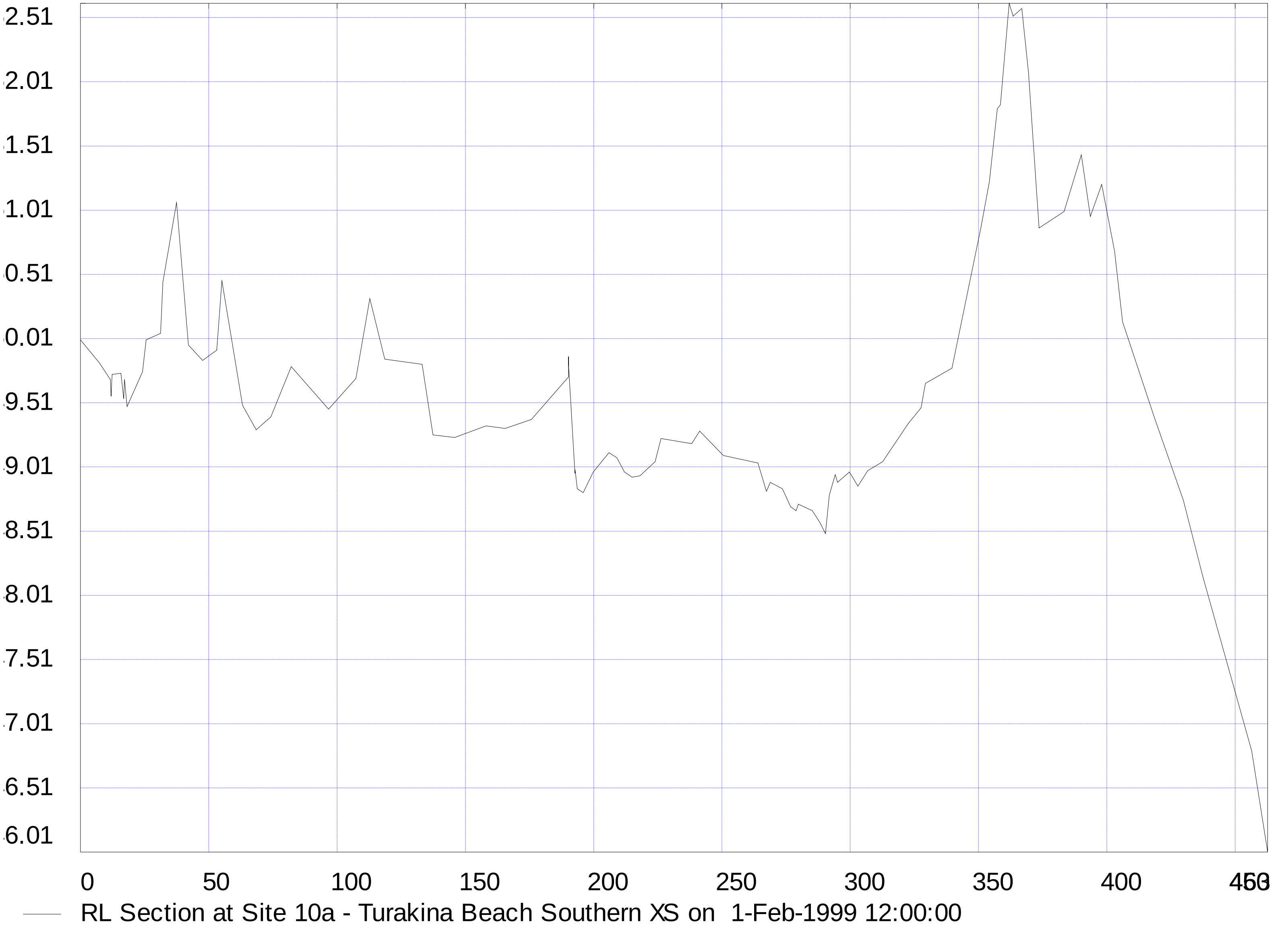
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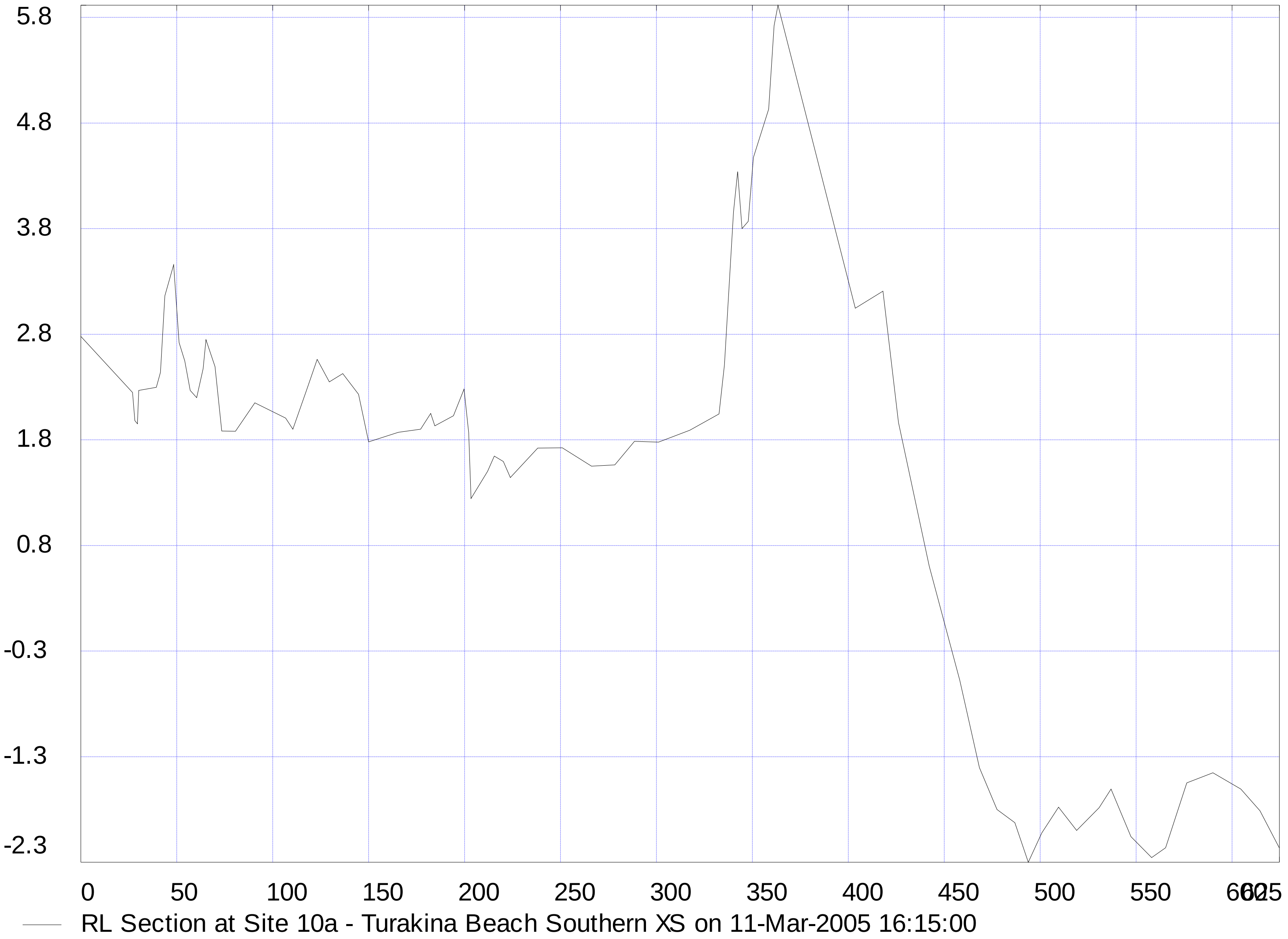
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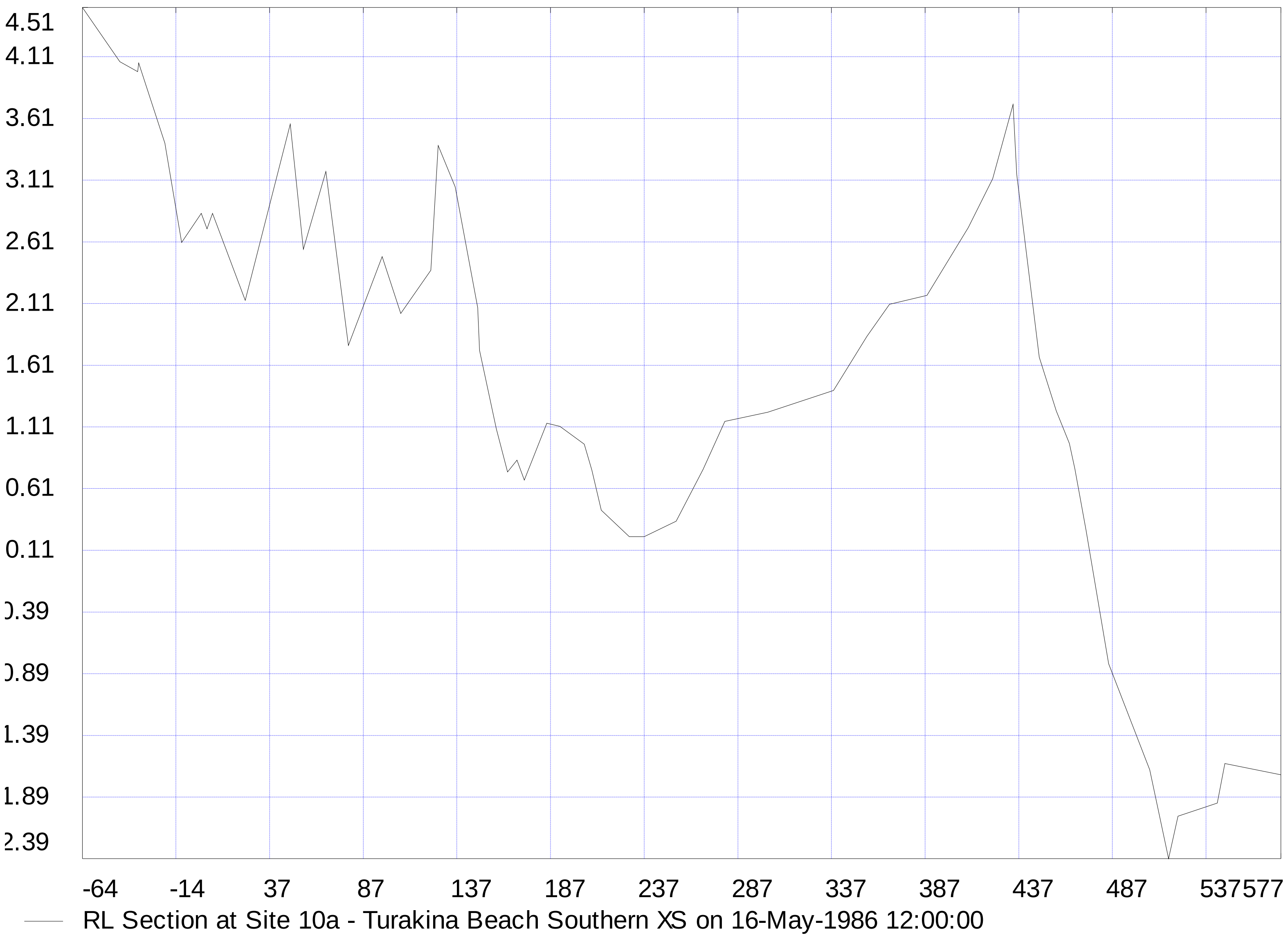
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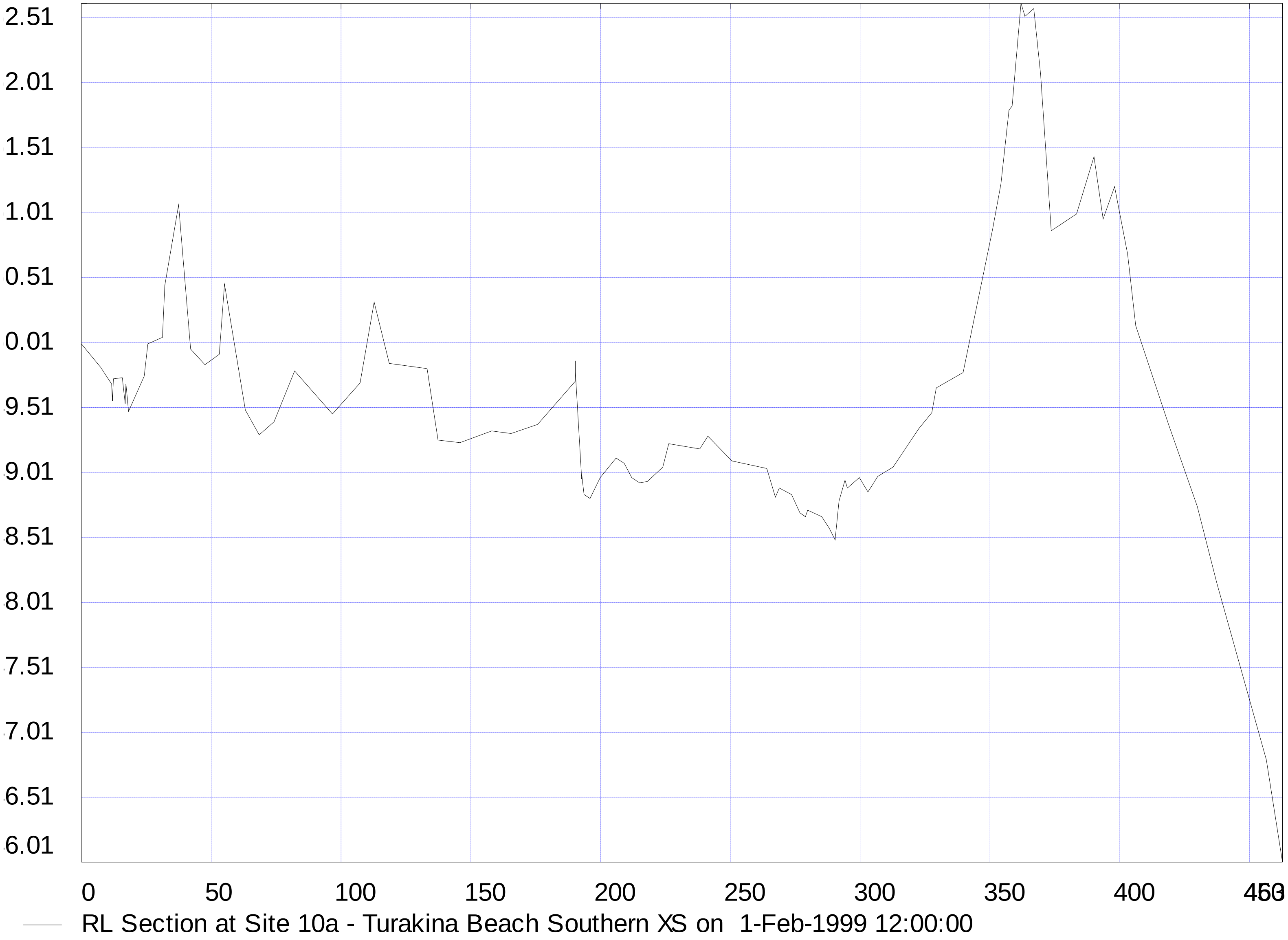
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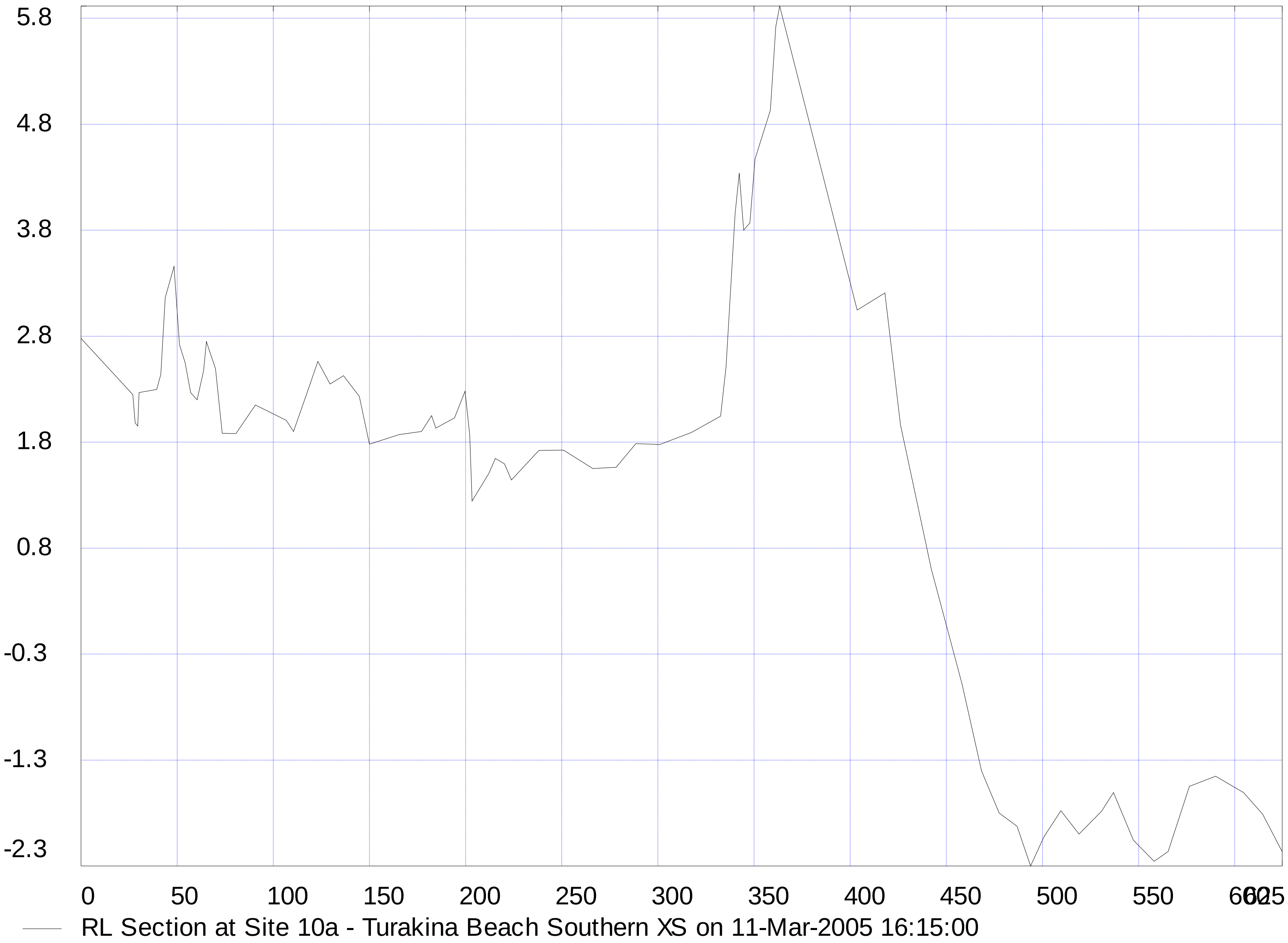
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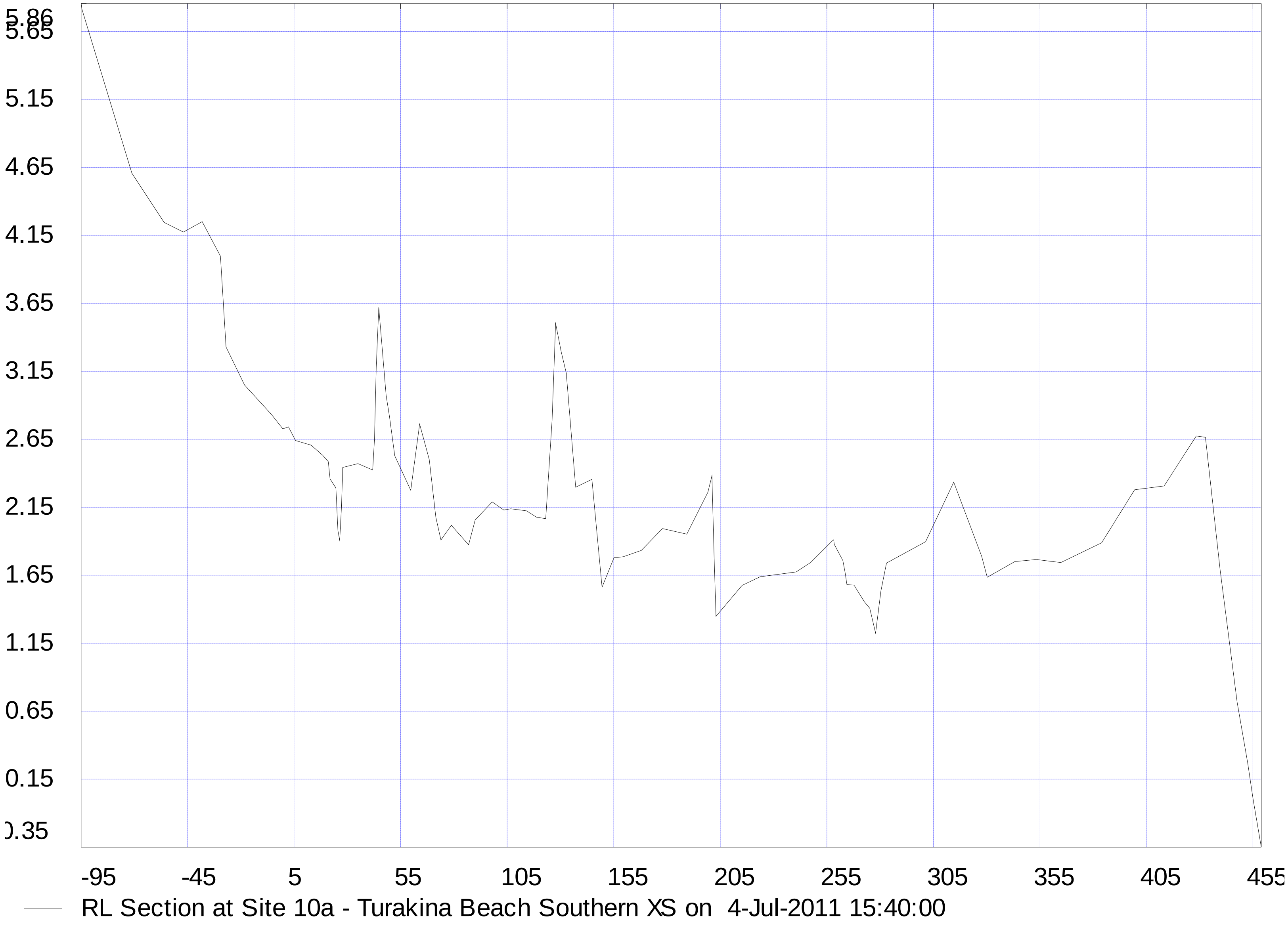
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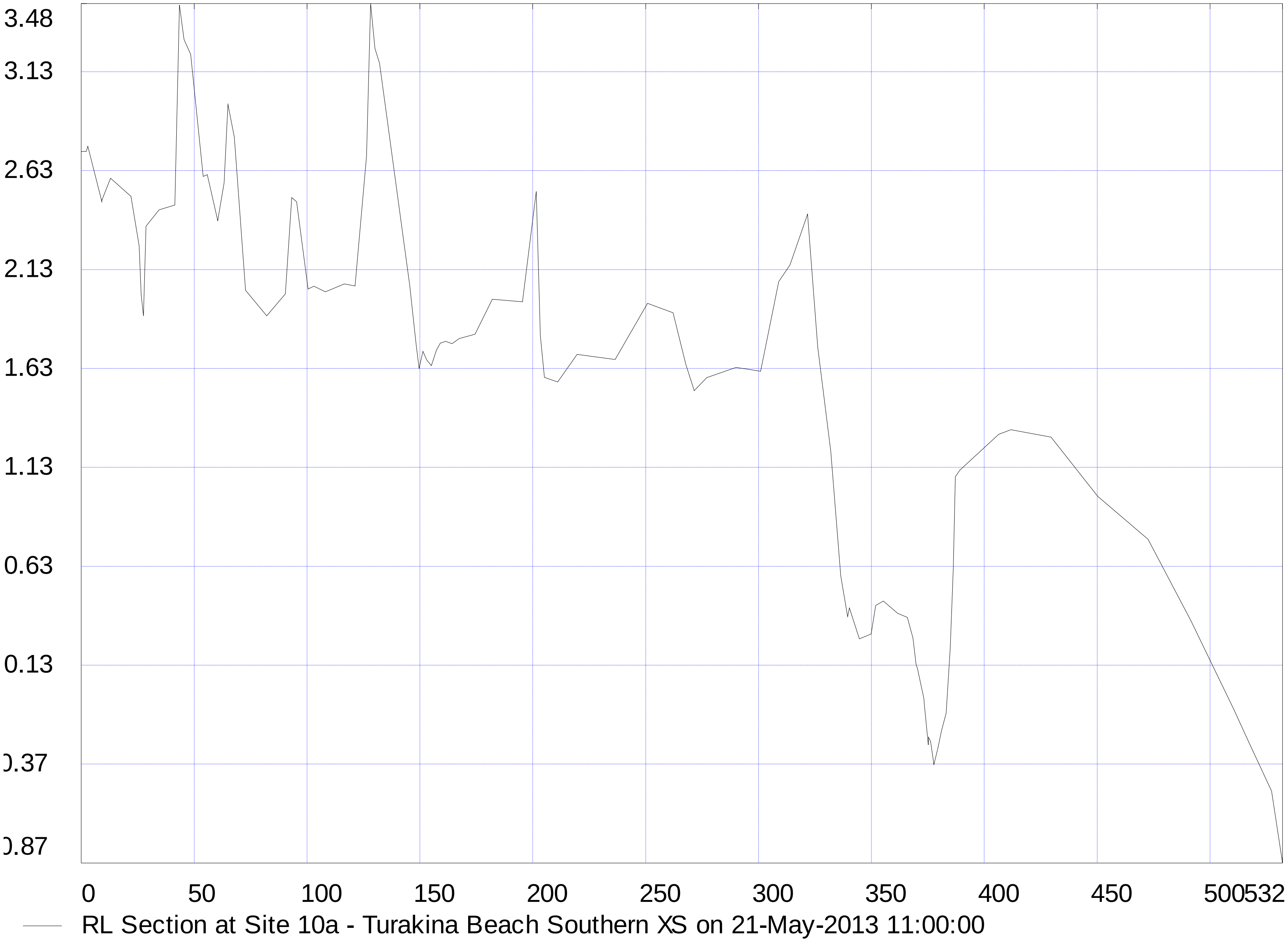
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10b - Turakina Beach Northern XS

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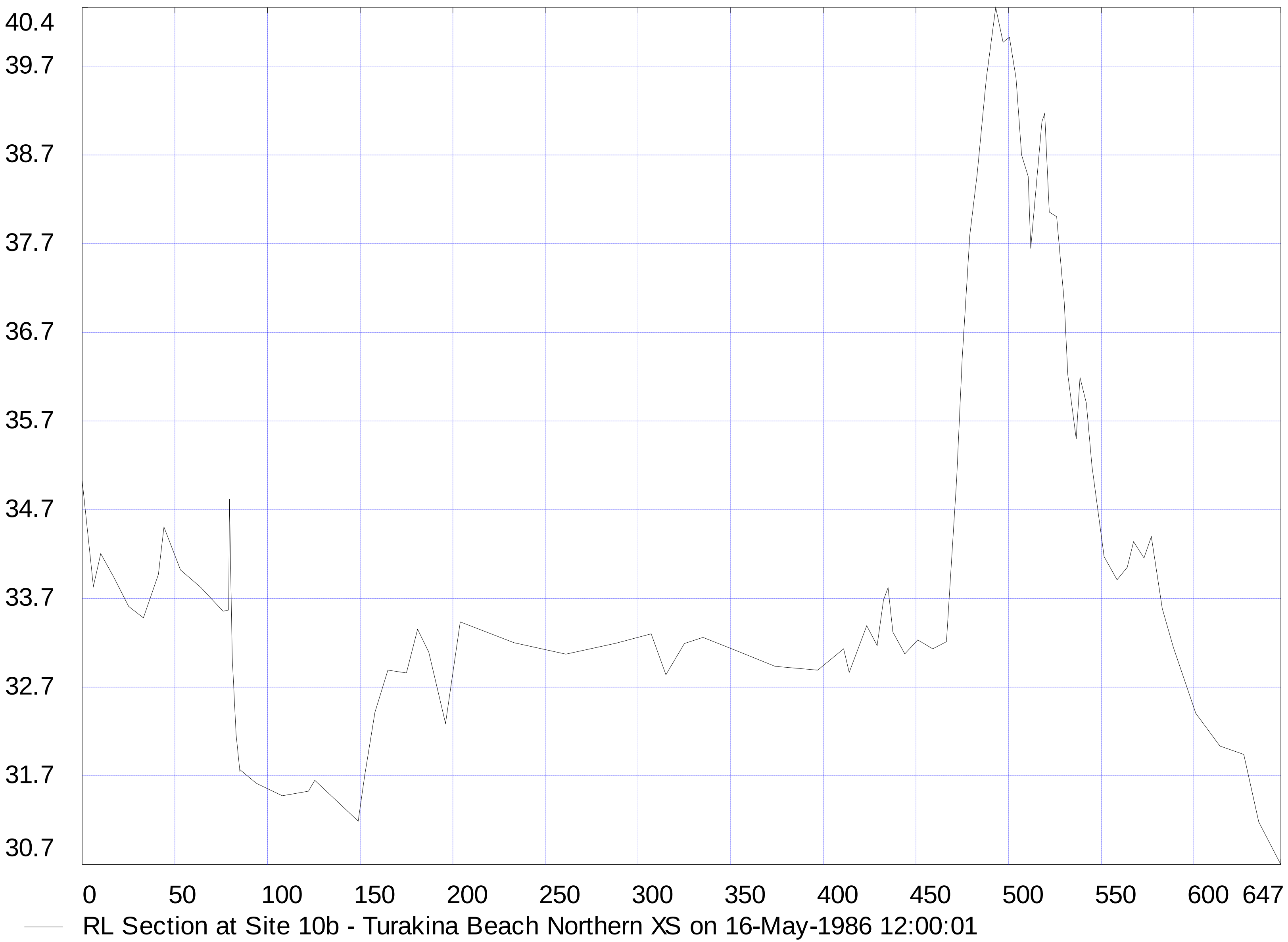
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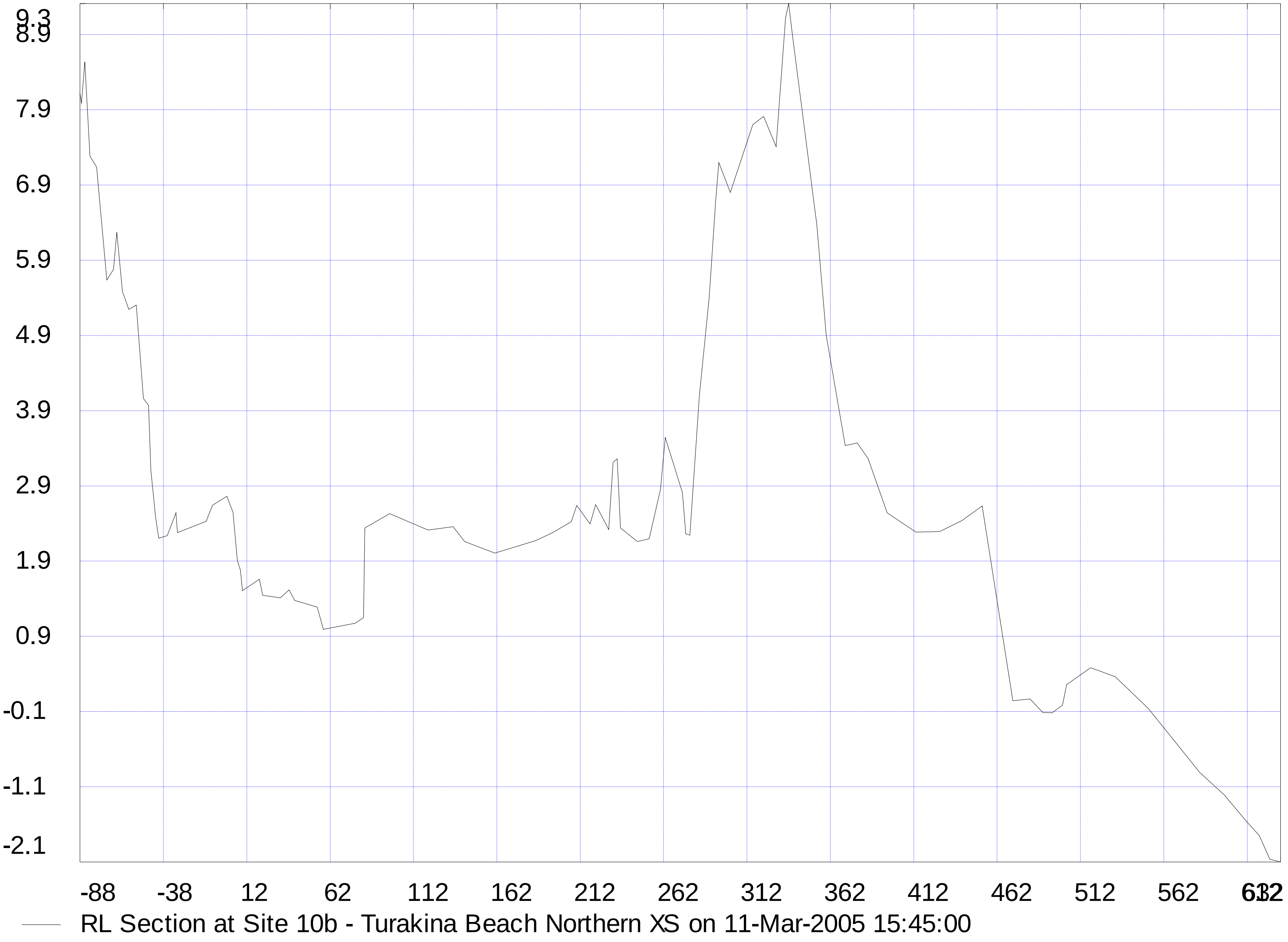
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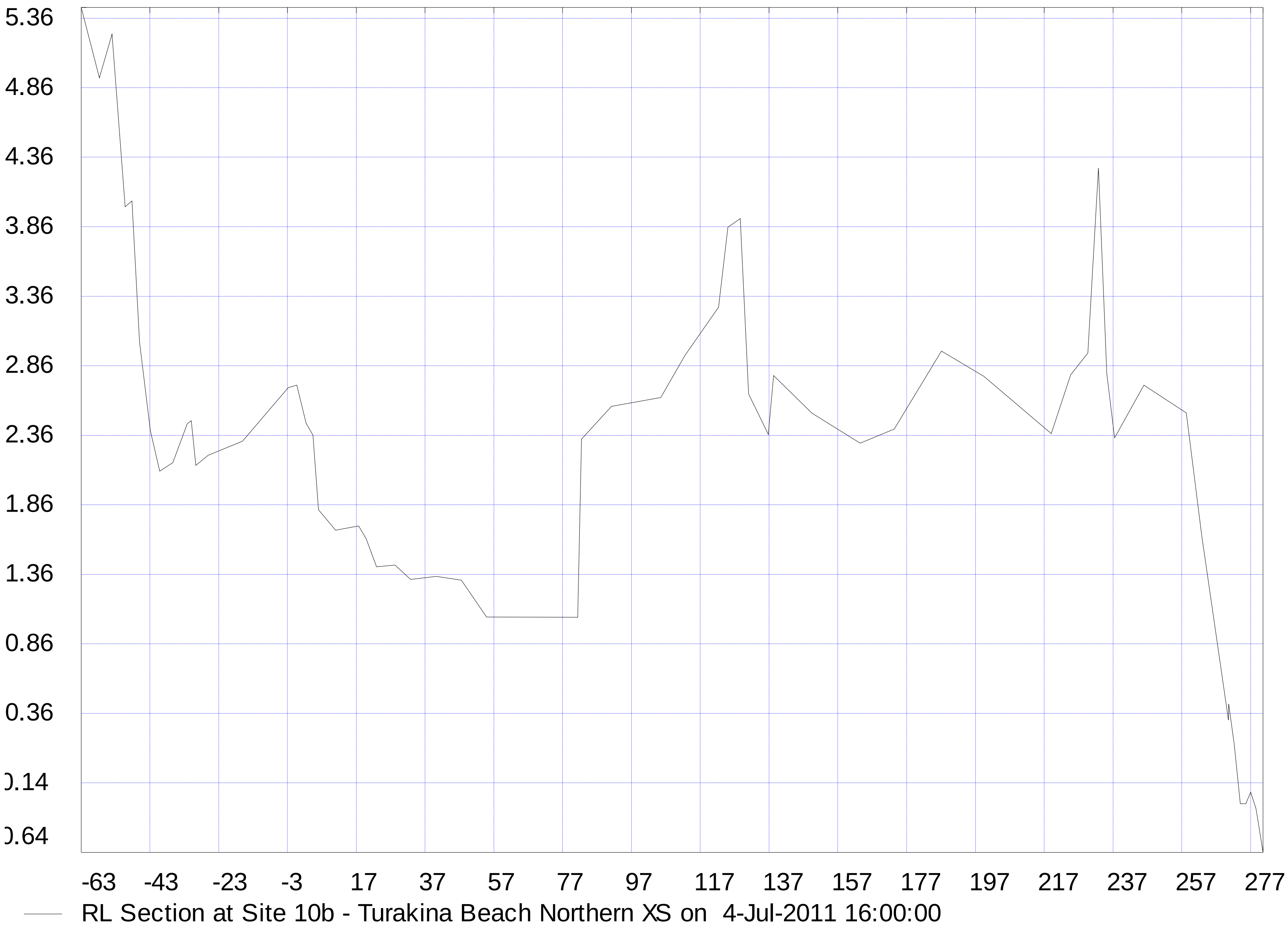
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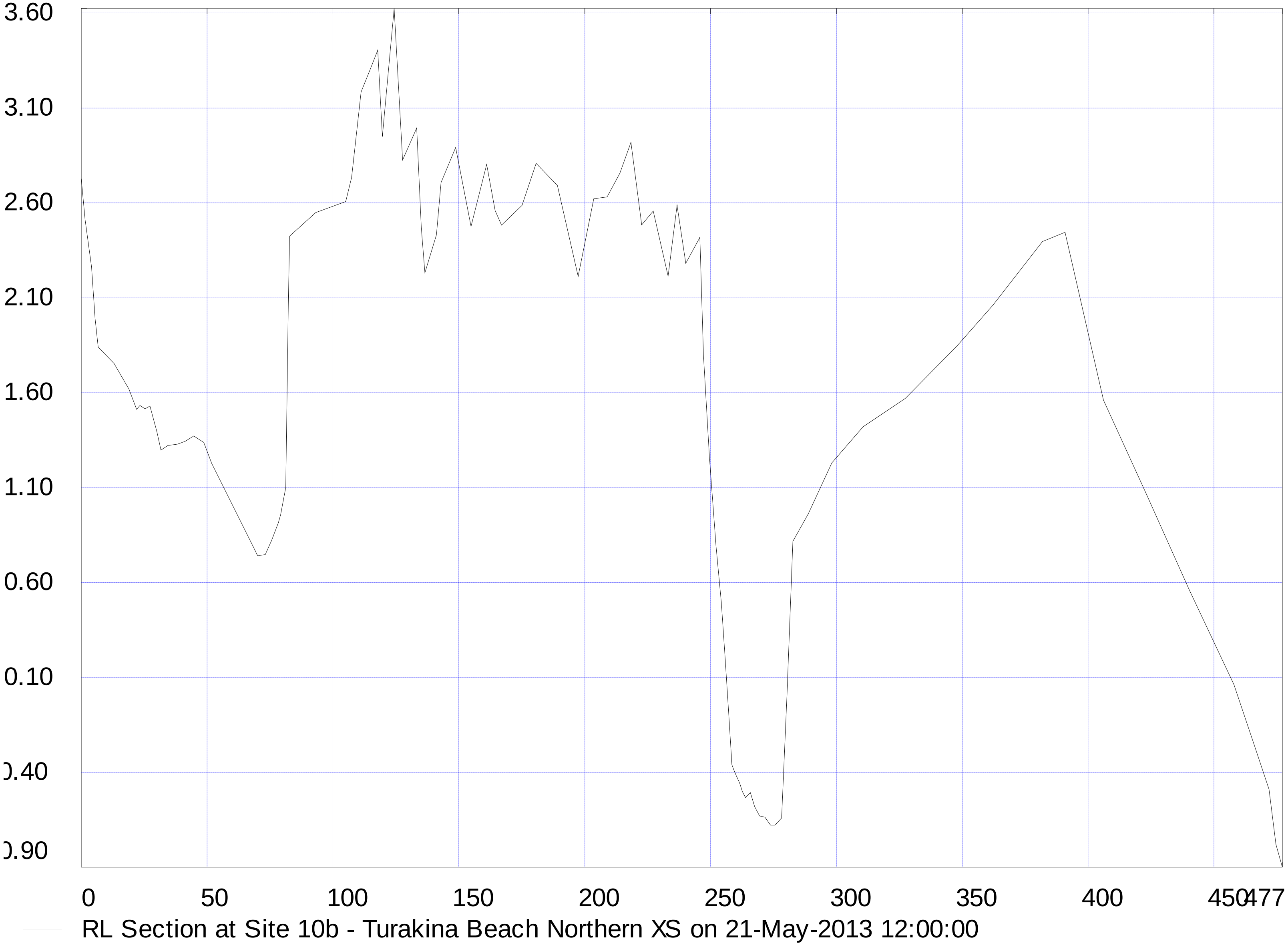
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3 - Castlecliff Beach

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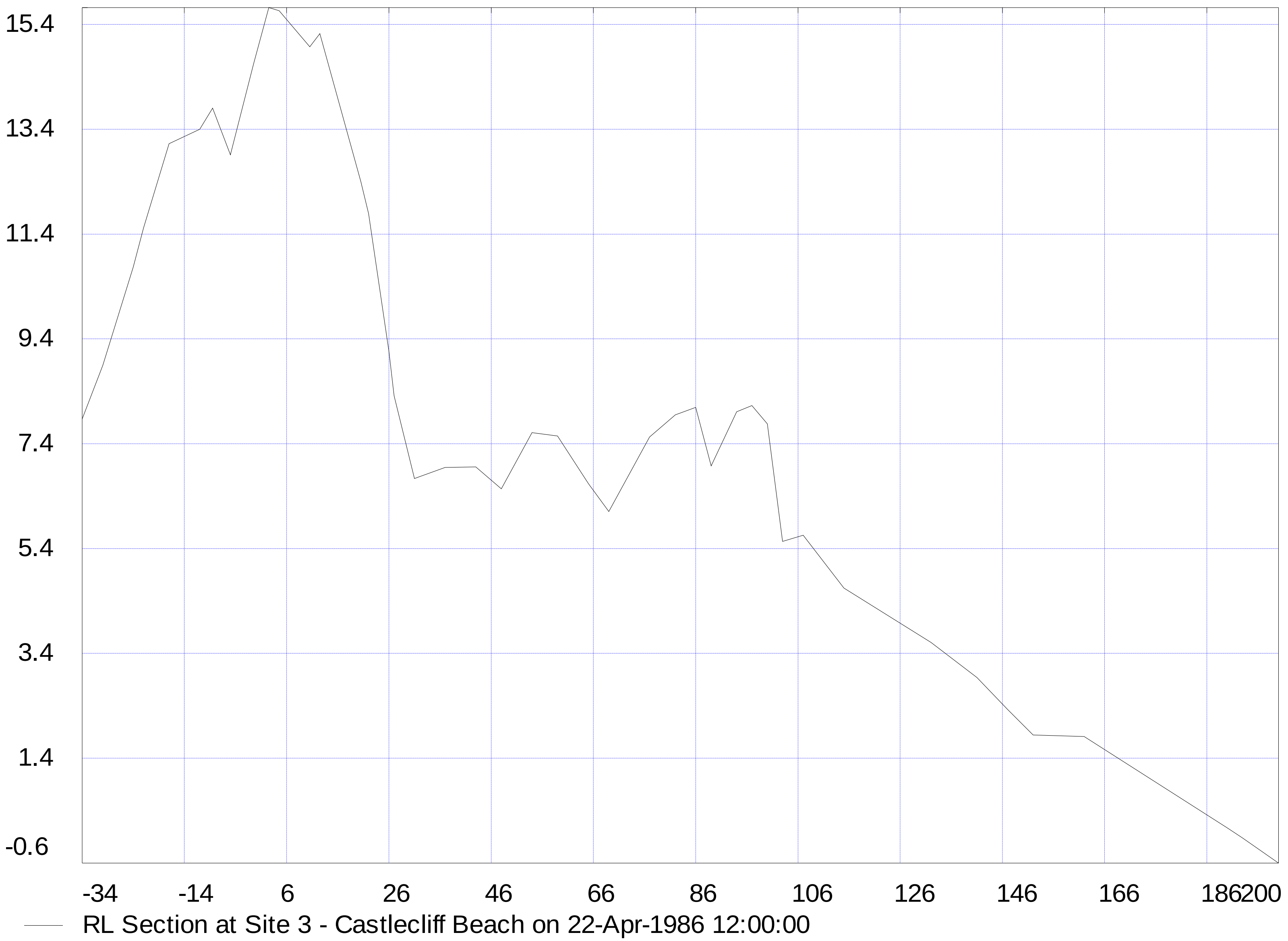
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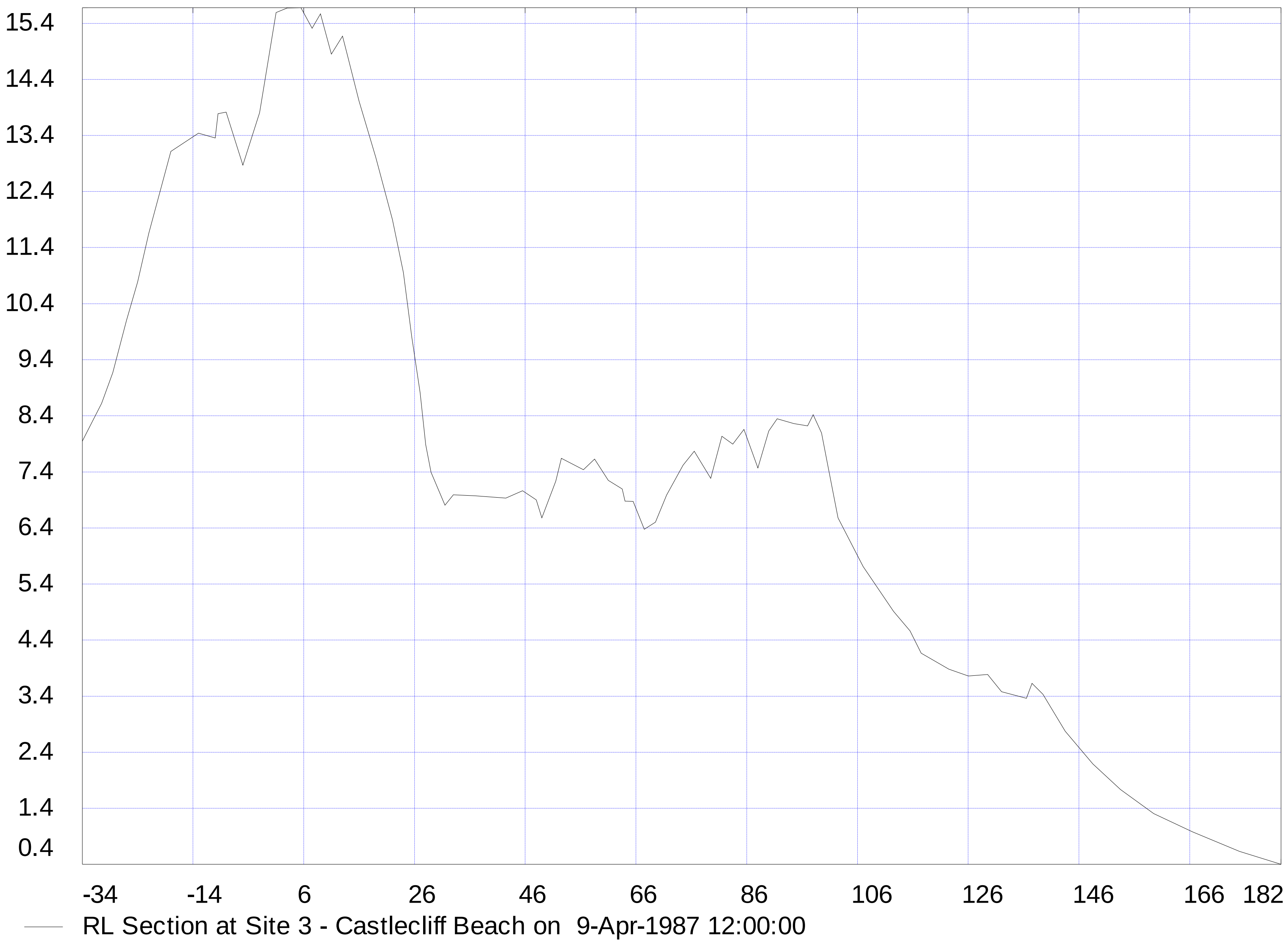
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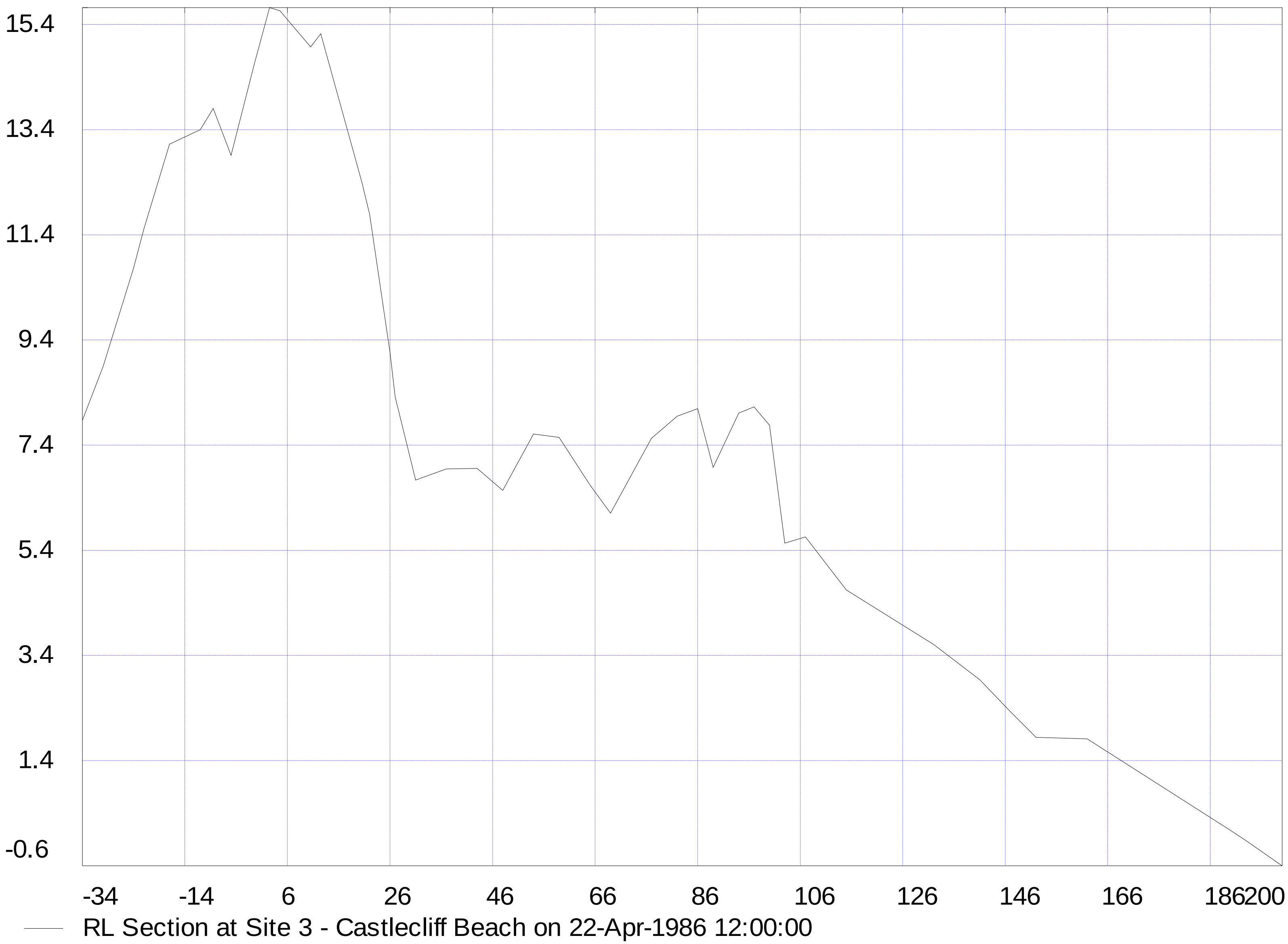
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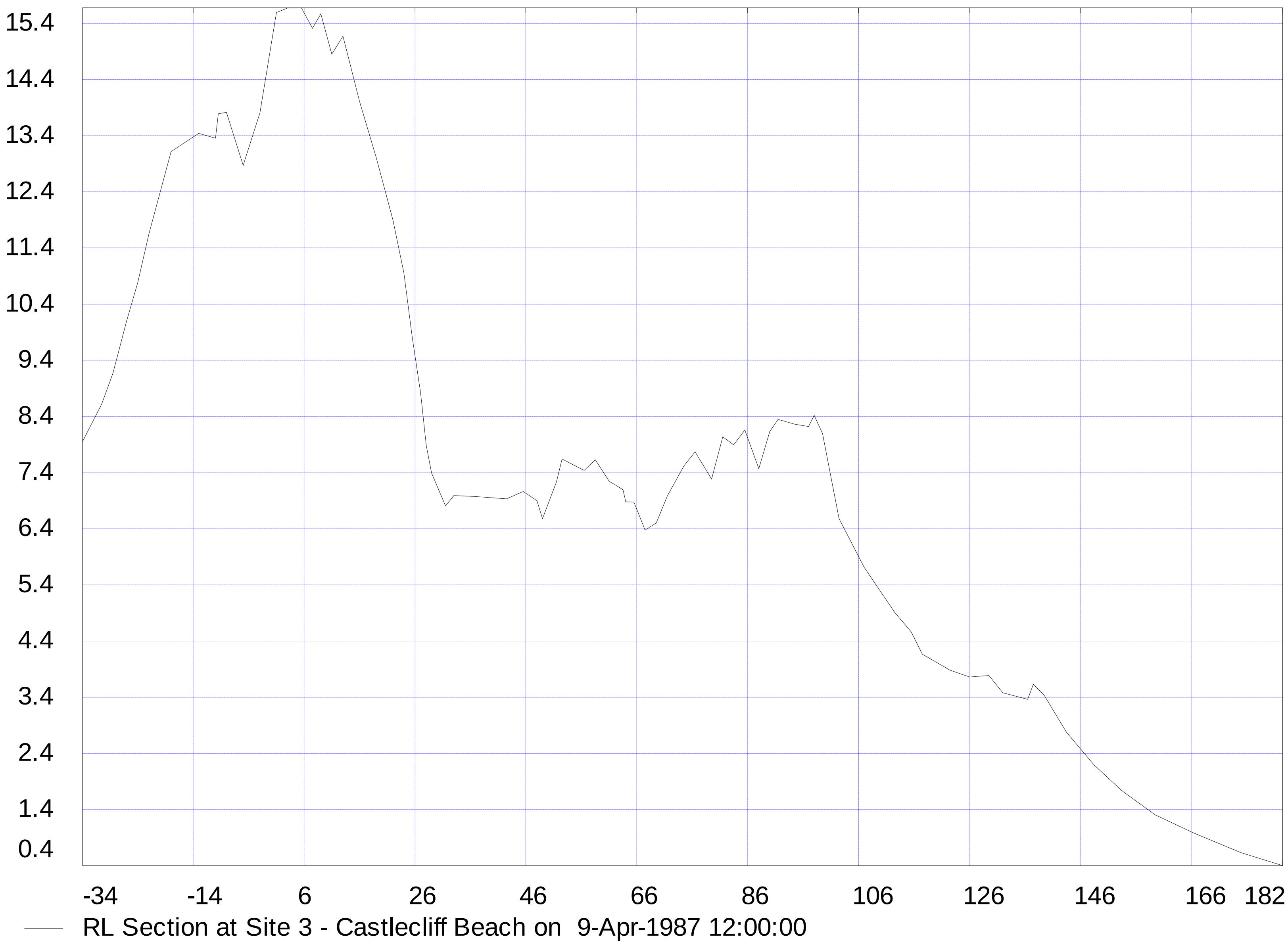
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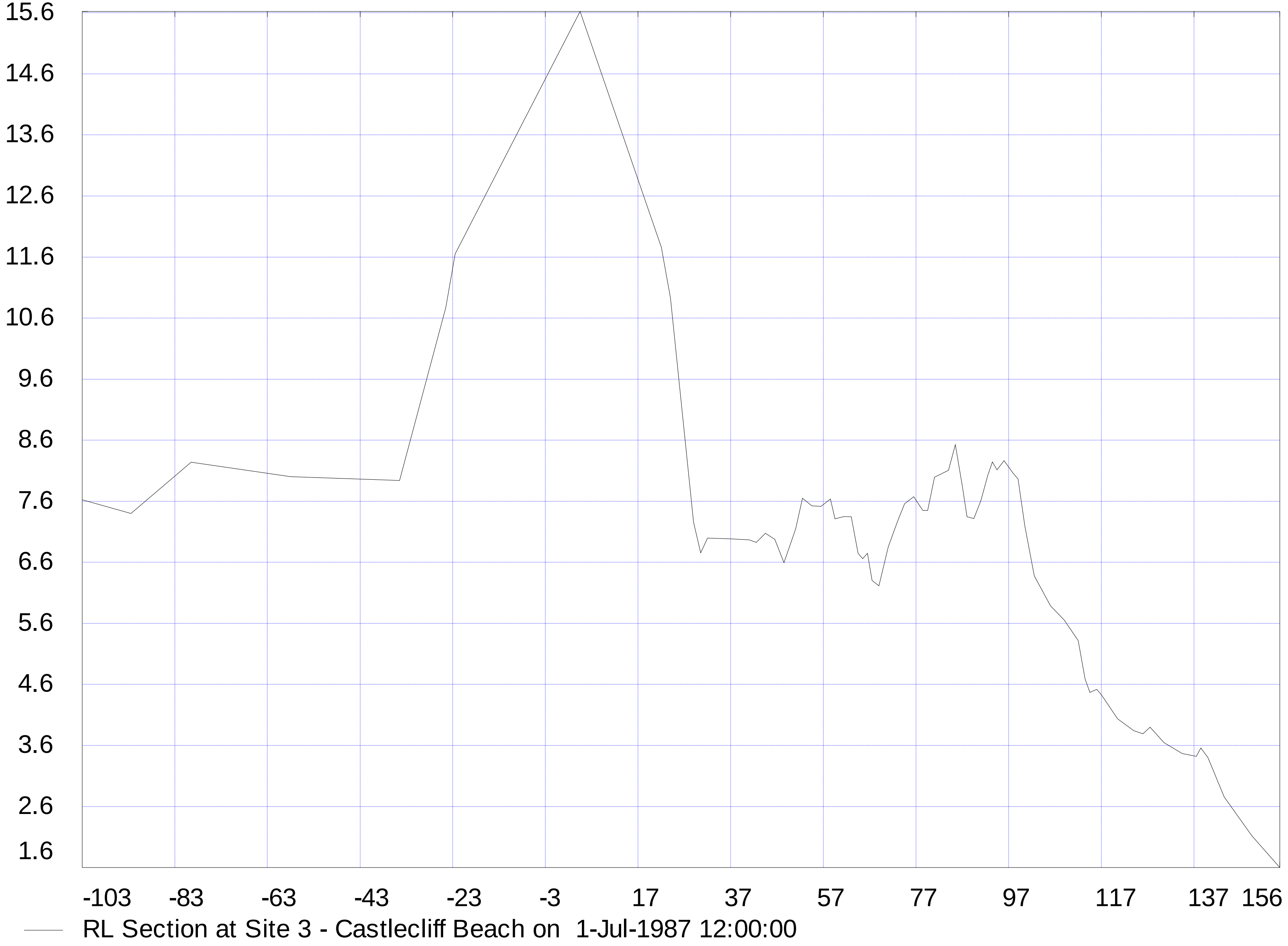
182
RL Section at Site 3 - Castlecliff Beach on 9-Apr-1987 12:00:00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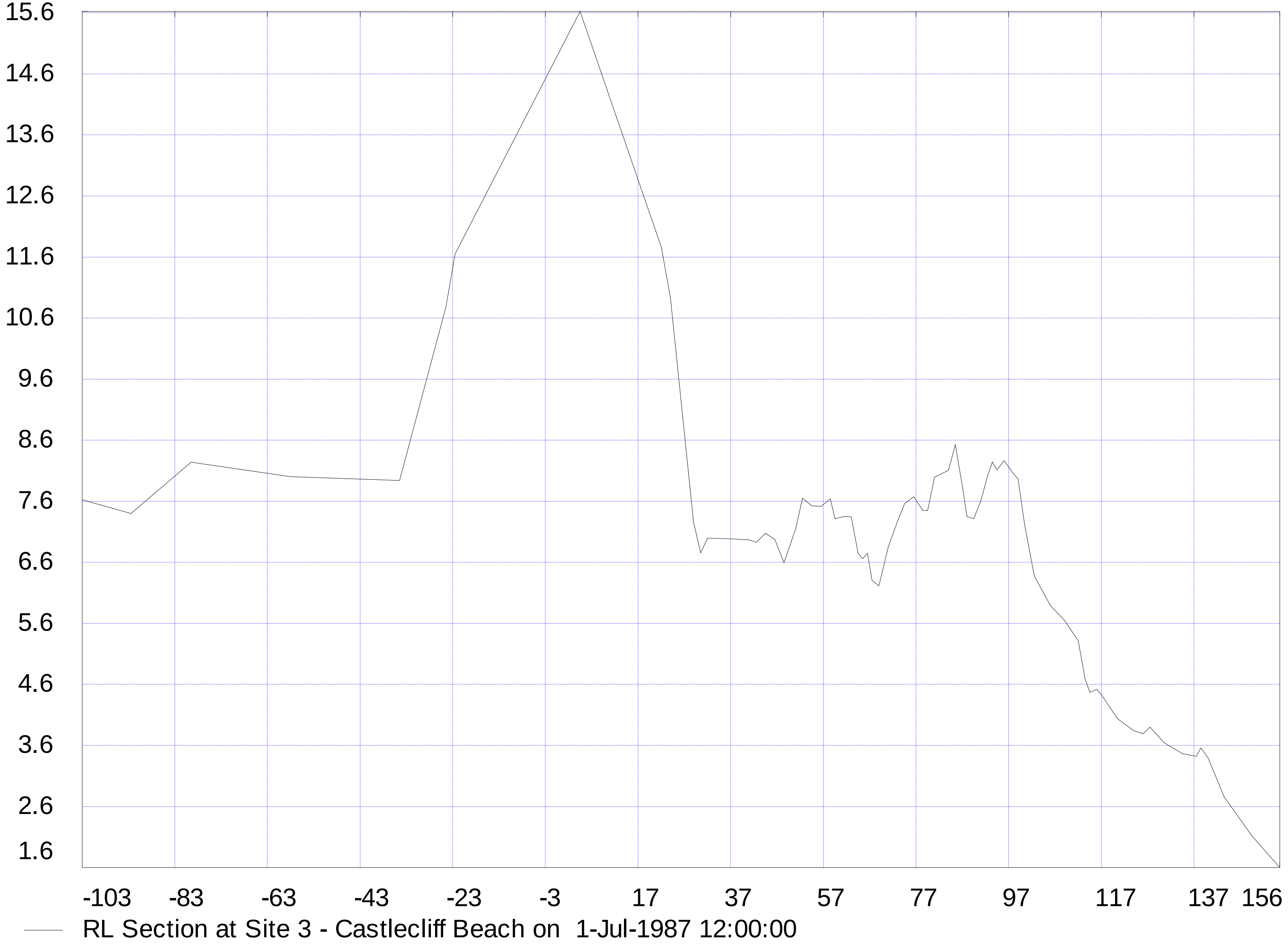
12.6
11.6
10.6
9.6
8.6
7.6
6.6
5.6
4.6
3.6
2.6
1.6
-103
-83
-63
-43
-23
-3
17
37
57
77
97
117
137
156
RL Section at Site 3 - Castlecliff Beach on 1-Jul-1987 12:00:00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1.6
-103
-83
-63
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37
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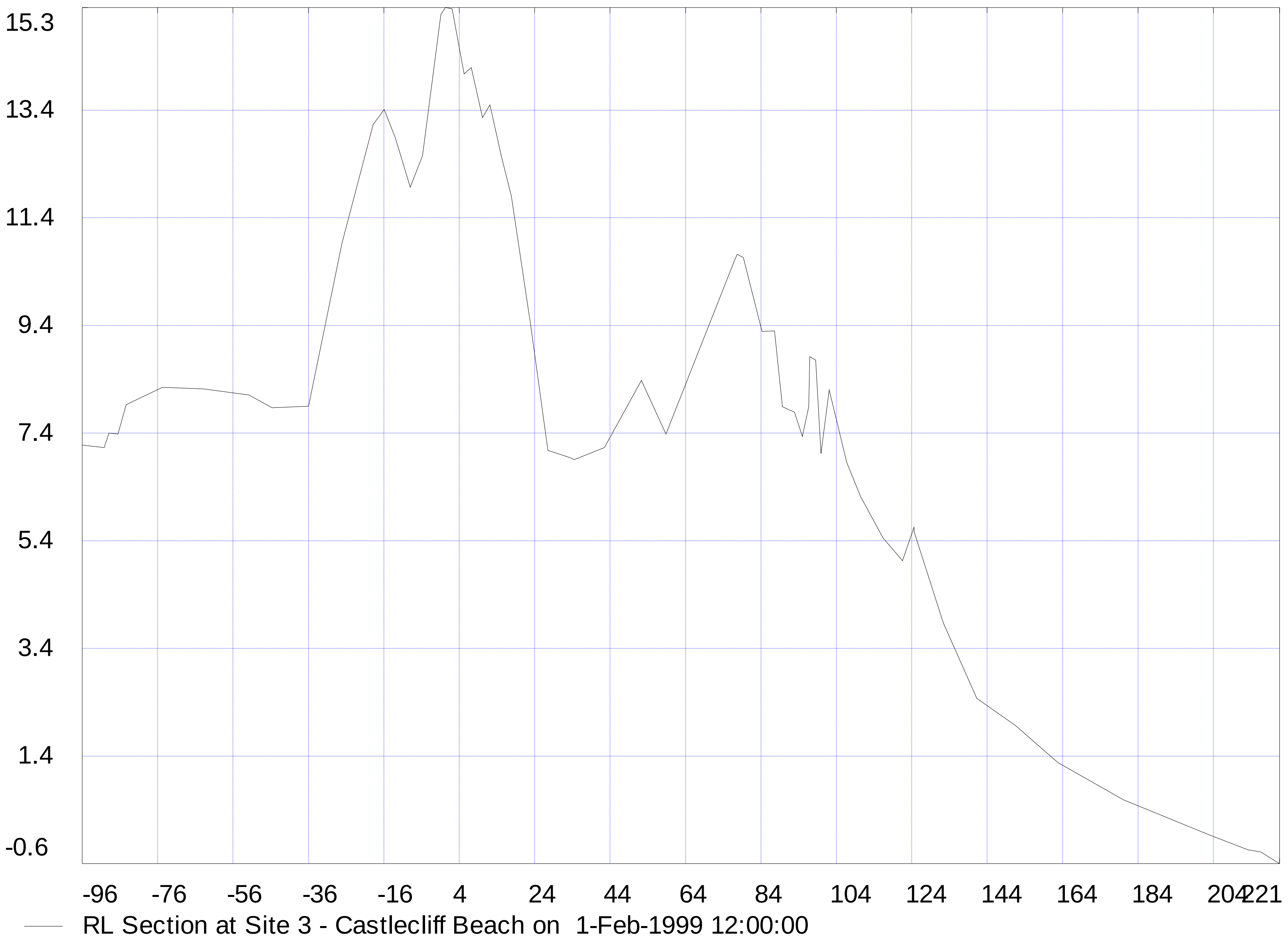
77
97
117
137
156
RL Section at Site 3 - Castlecliff Beach on 1-Jul-1987 12:00:00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7.4
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1.4
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-96
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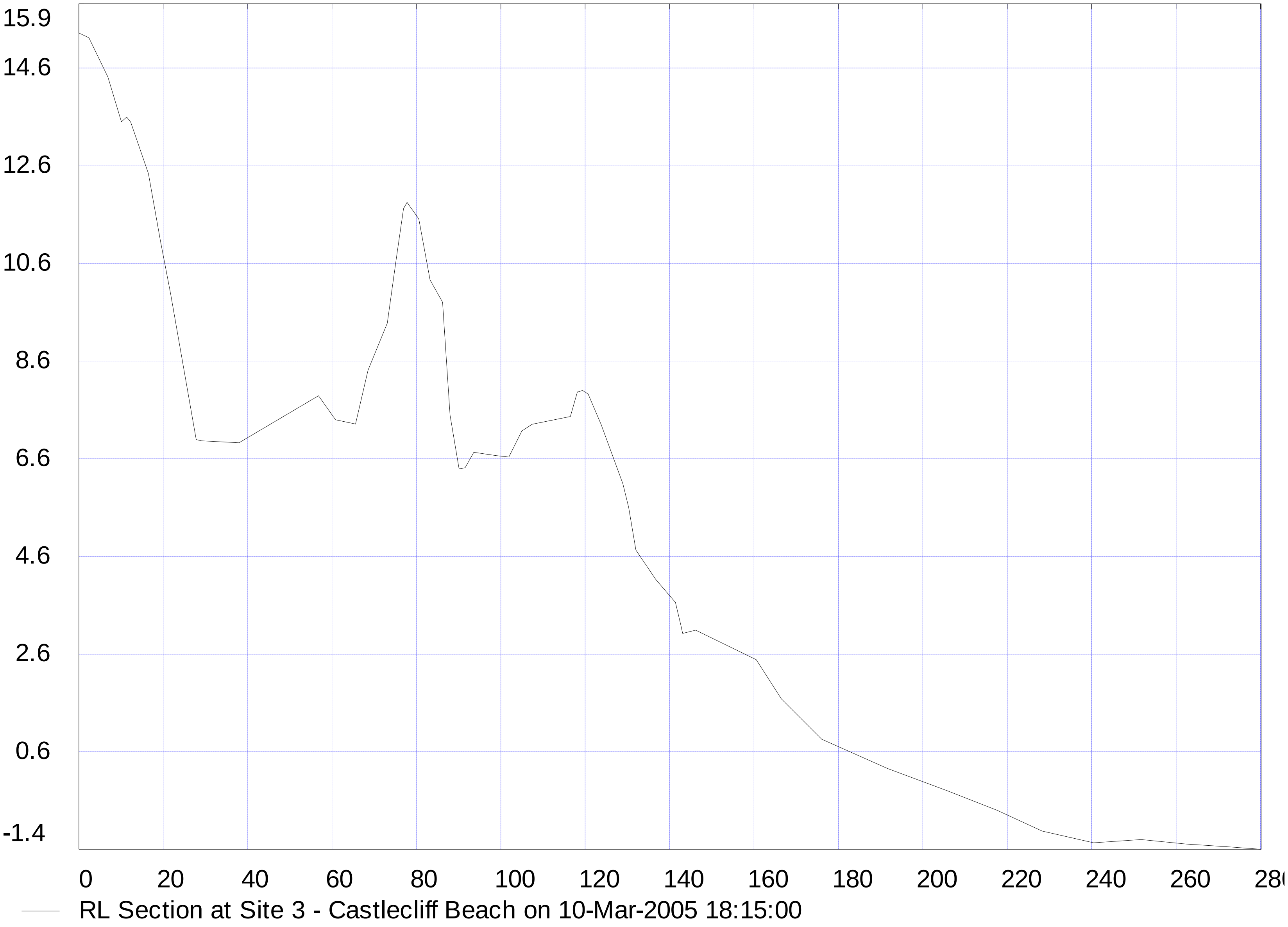
-56
-36
-16
4
24
44
64
84
104
124
144
164
184
204
221
RL Section at Site 3 - Castlecliff Beach on 1-Feb-1999 12:00:00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8.6
6.6
4.6
2.6
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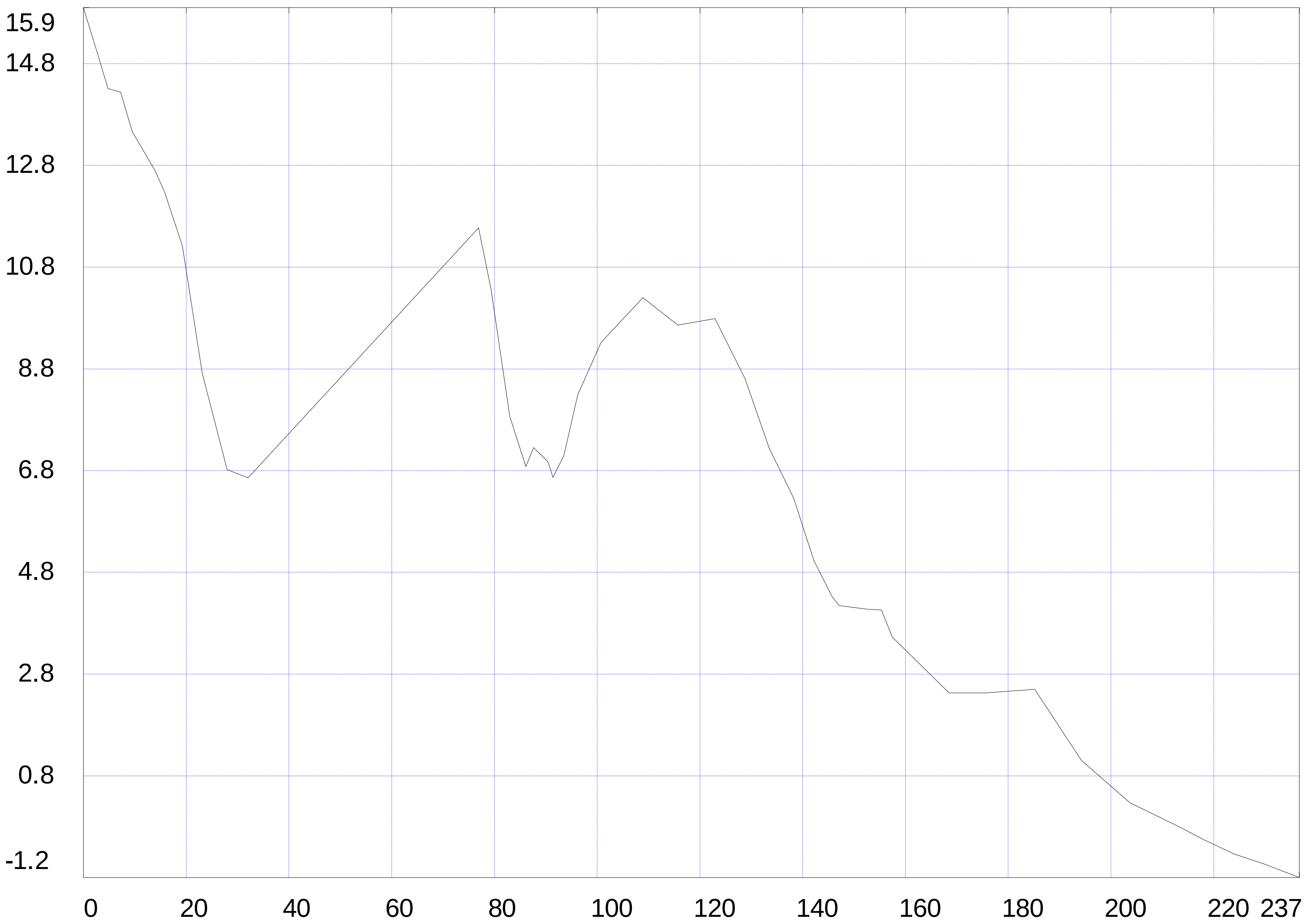
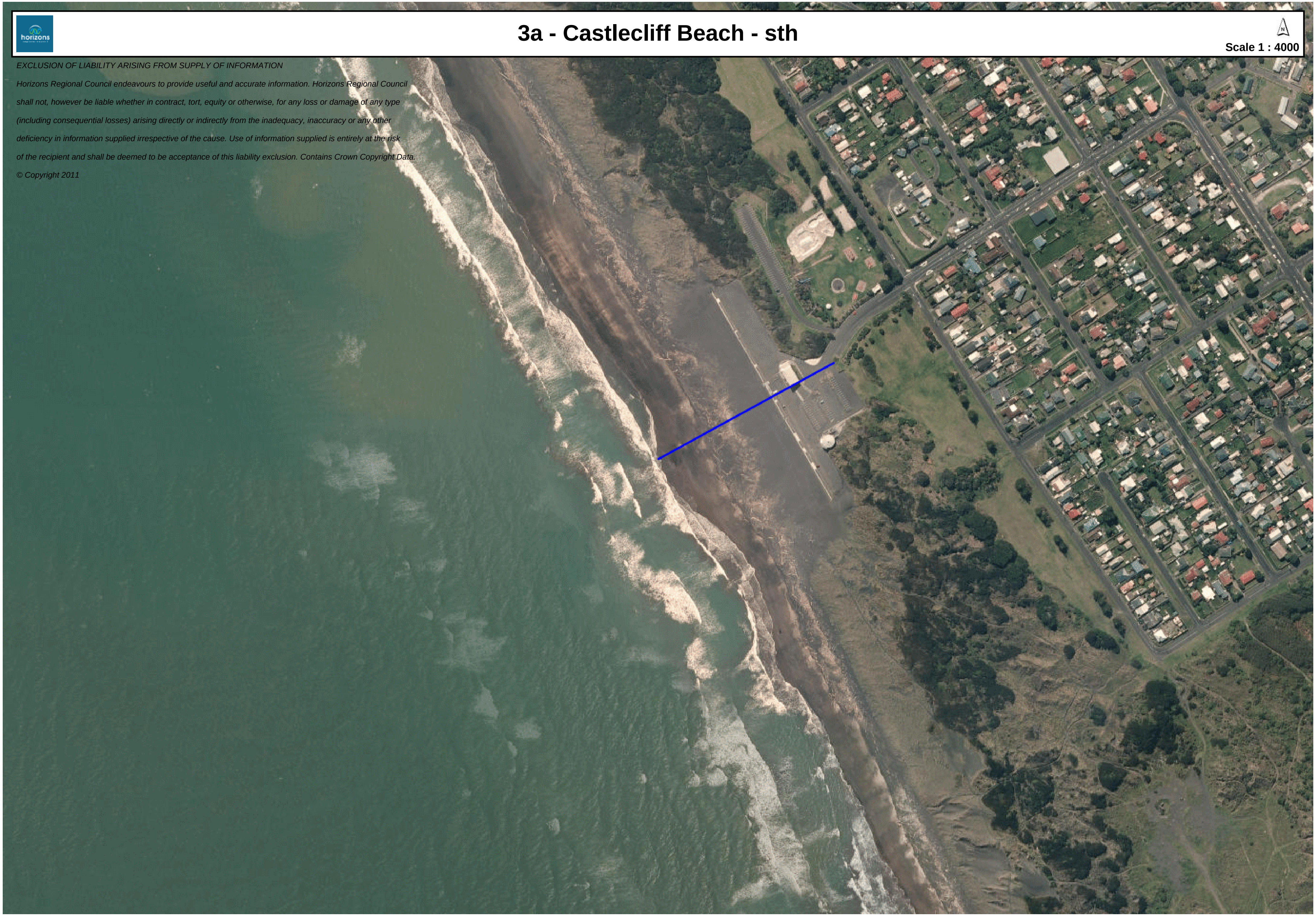
-1.4
0
20
40
60
80
100
120
140
160
180
200
220
240
260
28
RL Section at Site 3 - Castlecliff Beach on 10-Mar-2005 18:15:00

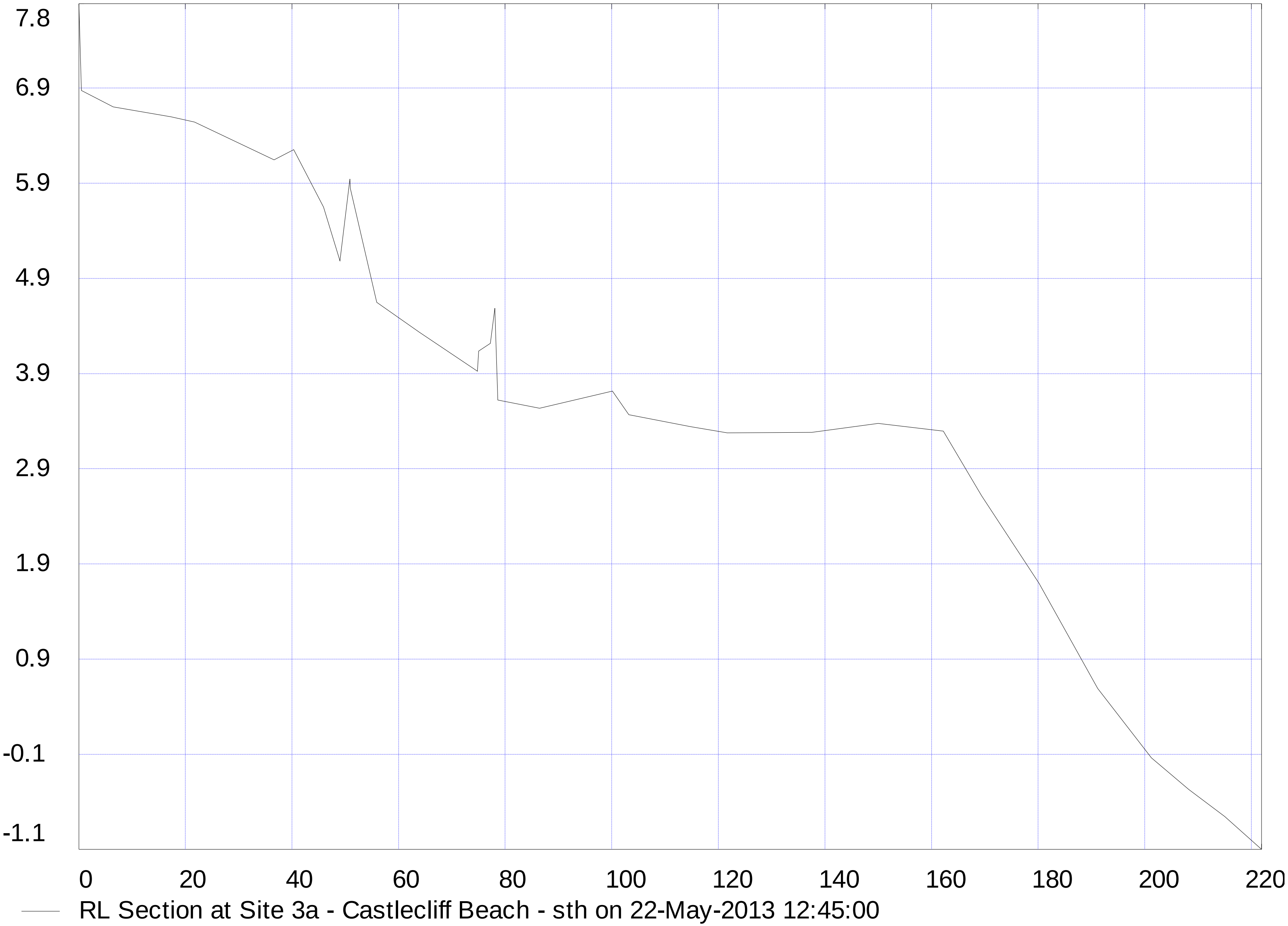


RL Section at Site 3 - Castlecliff Beach on 22-May-2013 12:00:00

3a - Castlecliff Beach - sth

Scale 1 : 4000

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-1.1
0
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60
80
100
120
140
160
180
200
220
RL Section at Site 3a - Castlecliff Beach - sth on 22-May-2013 12:45:00