Tekapo Power Scheme re-consenting: Lakeshore geomorphology and processes
Existing environment and future effects

Prepared for

Genesis Energy Limited

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Executive Summary

This report presents a description of the physical shoreline of Lake Tekapo and the effects of the existing Tekapo Power Scheme (TekPS) lake level operating regime on the physical shoreline processes. The report identifies shore types and provides an assessment of erosion of the shoreline. The effects of lake level management on shoreline processes and infrastructure such as roads and recreation and TekPS structures are mapped and described.

The description of the shoreline development after extension of the lake level range in 1954, and the ongoing lacustrine processes of waves and lake level variability that result in change to the beaches and physical shore environment provides a basis for assessing the projected future effects of continued operation of the TekPS with regard to shoreline change and how it relates to lakeshore infrastructure, private property and resource use.

Extension of the lake level range since 1951 has resulted in erosion of the hinterland backshore composed of hillslope, moraine and fluvial deposits. Retreat of the steeper hinterland backshore resulted in near vertical cliffs in some locations. Wave action eroding the base of these slopes during periods of high lake levels has resulted in episodic erosion of the cliff and retreat of the shoreline. Subaerial weathering has also slowly resulted in the retreat of the top of the slope.

The lake has a near-continuous gravel and sand foreshore. Bedload sediments from the Godley and Cass Rivers in particular, and other streams, and erosion of the hinterland contribute to the beaches around the lake. Alongshore transport by waves and nearshore currents moves this sediment away from the source locations of river and stream mouths and areas of backshore erosion. As such, the shore continues to develop where sediment is deposited. The resulting shore features include spits and forelands, barrier beaches, and pocket beaches.

The controlled water level regime contributes to the episodic nature of erosion where both high lake levels and wave energy are required to erode the base of backshore slopes, and to deposit beach sediments to the top and over barrier beach ridges. Low lake levels do not occur very often but can erode sediment from the nearshore shelf and take sediment offshore to deep water and out of the beach system.

There have been very few occurrences of low lake levels under the current operating regime. There have also been few high level occurrences in the last thirty years. This has resulted in stable areas of backshore, where the beach protects the base of steep slopes. However, there are sections of cliffed shore where the base of the cliff is at or below 710 m amsl, and there is only a narrow beach to dissipate wave energy. These cliffs are actively retreating. Subaerial weathering is an additional cause of erosion of steep cliffs and is part of the ongoing process of shore development.

The effects of continued TekPS operation will not change the physical shoreline processes from those presently existing and observed over the period of Genesis Energy operational management.

There is existing erosion and cliff top retreat of the lakeshore hinterland along the northern section of the Mt John walkway, and a short stretch of Lilybank Road may be subject to erosion in the medium to long-term. These areas will require consideration of management options within the next 35 years. Neither of these situations warrant changes to the lake level operational regime for the TekPS.

Based on projections of climate change on inflows to Lake Tekapo and the local wind environment, any changes are not likely to cause additional or adverse effects on the physical shoreline processes through to the mid 21st Century.

1. Introduction

1.1 Background

This report presents a description of the physical shoreline environment of Lake Tekapo and the effects of the existing Tekapo Power Scheme (TekPS) lake level operating regime on the shore processes. In addition, the projected future effects of continued operation of the TekPS are assessed with regard to shoreline change and how it relates to lakeshore infrastructure, private property and resource use. The report identifies and provides an assessment of erosion of the shoreline and identifies any adverse effects of lake level management on shoreline processes and infrastructure such as roads and recreation and TekPS structures.

Lake Tekapo is the uppermost hydro-storage lake in a series of power schemes running through Lakes Tekapo, Pukaki/Pūkaki, Ōhau, Ruataniwha, Benmore, Aviemore and Waitaki on the Waitaki River. The lake is situated in the north-eastern part of the Mackenzie Basin, at an altitude of about 700 metres above mean sea level (m amsl). The consented operating water level range on the lake is from 702.1 to 710.9 m amsl. In addition, under an electricity shortage scenario the lake can be taken down to an extreme minimum of 701.8 m amsl. The Design Flood Level is 713.05 m amsl. The area of the lake is approximately 87 km^2 (Pickrill and Irwin 1983).

Construction of a controlled outlet at the southern end of the lake was started in 1938, with the Tekapo "A" power station being commissioned in 1951. Water from the lake is diverted through a 1.6 km long tunnel, west of the natural outlet that is controlled by the Lake Tekapo Control Structure / Gate 16 (completed in 1954) at the head of the Tekapo River. Pre-1951 lake levels varied between 704.4 and 707.0 m amsl. In June 2011, the ownership and operational management of the Tekapo A and B power stations, fed by water from Lake Tekapo, were transferred from Meridian Energy Ltd to Genesis Energy Ltd as part of power generation asset restructuring by the New Zealand Government.

1.2 Content

The description of the existing physical lakeshore of Lake Tekapo contains information on the following:

- Base geology and geomorphology of the shore hinterland;
- Lakeshore geomorphology and shore sediments;
- Climatic parameters (as driving agents of the processes), including wind, precipitation and temperature ranges;
- Wave processes (including currents and sediment movement across and along the shore);
- Lake level analysis (temporal and spatial);
- Shoreline change; and

- Human modifications, resource use and infrastructure, including hazards and erosion control techniques.

The assessment of the effects of the TekPS on the physical lakeshore processes and geomorphological change includes:

- A description of projected future shore physical change and geomorphological development;
- Potential effects of high and low lake levels; and
- Effects on structures and land-use at the shore.

1.3 Information sources and past studies

In preparing this report, extensive desktop and archival research has been carried out. The report draws on information from a range of published and unpublished sources, primary field data and observations. Single (2019) provides an annotated bibliography of relevant source material, and a full reference list of consulted published articles, reports and studies relevant to describing the lakeshore geomorphology and physical lakeshore processes for Lake Tekapo.

Work by Single (2013a and 2013b) presents descriptions of the shore geomorphology and the effects of the historical TekPS operational regime on lakeshore development. These reports provide a basis for this current report.

Studies have been carried out on hazards relating to the lakeshore hinterland and lake levels. McGowan, Sturman and Owens (1995) assess the effects of dust storm events originating on the river bed and delta of the Godley River between 1989 and 1995. Kirk (1989) presented an assessment of the factors that lead to the dust storm events and considered that these were a result of natural environmental factors and could not have been foreseen or mitigated by artificial control of the lake level. Mountjoy *et al.* (2018) assessed the potential for hazards resulting from landslips or submarine slumping of deltaic sediments. Although such hazards are not an effect of the TekPS, they are part of the physical shore process background environment of the lake and can potentially affect the TekPS operation.

Although there is limited mapped information of shoreline change since commissioning of the TekPS, Single (2013b) identified areas where shore change related to the post-TekPS operating regime has occurred, and where future shoreline change may affect resource use of the lakeshore hinterland.

LiDAR survey data has been used for this current report to determine recent shoreline change and to identify the effects of this change on resource use.

2. Lake Tekapo shore geomorphology and processes

2.1 Geology and wider geomorphology

2.1.1 Broad setting and geology

The location and physical setting of the lake are shown in Figure 2.1. The lake occupies a glaciated valley, partially blocked by moraine and outwash deposits. The catchment for the lake is approximately 1,440 km^2, and includes glacial valleys, with the main tributaries being the combined Godley, Macauley and Coal Rivers at the northern end of the lake, and the Cass River on the western flank. Three smaller named tributaries feed into the lake. These are Mistake River on the western flank, and Washdyke Stream and Boundary Stream on the eastern flank of the lake opposite the Cass River delta. The outlets of Lakes Alexandrina and McGregor, on the western flank of the lake, also flow towards Lake Tekapo. A small island, Motuariki Island is located adjacent to the deepest part of the lake.

The lake is long compared to the width, with the long axis running approximately north south. Table 2.1 shows morphometric data for the lake and catchment. The maximum length is 27 km, and the maximum width, just north of Motuariki Island, is 6 km. The maximum depth is 120 m, located to the southwest of Motuariki Island. Although the mean depth of the lake is about 69 m, the sides of the lake are relatively steep from the lakeshore down to about 80 m, with the greater part of the lake basin north of Motuariki Island to about 2 km north of Mistake River between 80 and 120 m deep.

Table 2.1 Morphometric data for Lake Tekapo and catchment (from Pickrill and Irwin 1983)

Maximum length	27 km
Maximum width	6 km
Maximum depth	120 m
Mean depth	69 m
Surface area	87 km^2
Volume	6.003 km^3
Altitude	707 m
Catchment area	1440 km^2
Mean inflow	79 m^3 s^{-2}
Mean water retention time	880 days
Glaciated part of catchment	3%
Ratio catchment area: lake area	16:1
Main catchment areas of inflows	
Godley, Macaulay and Coal	748 km^2
Cass	214 km^2
Mistake	46 km^2
Alexandrina and McGregor	33 km^2
Boundary	27 km^2
Washdyke	26 km^2

Figure 2.1 Lake Tekapo location map (Source NZ Topomap series NZTopo50 BY17)

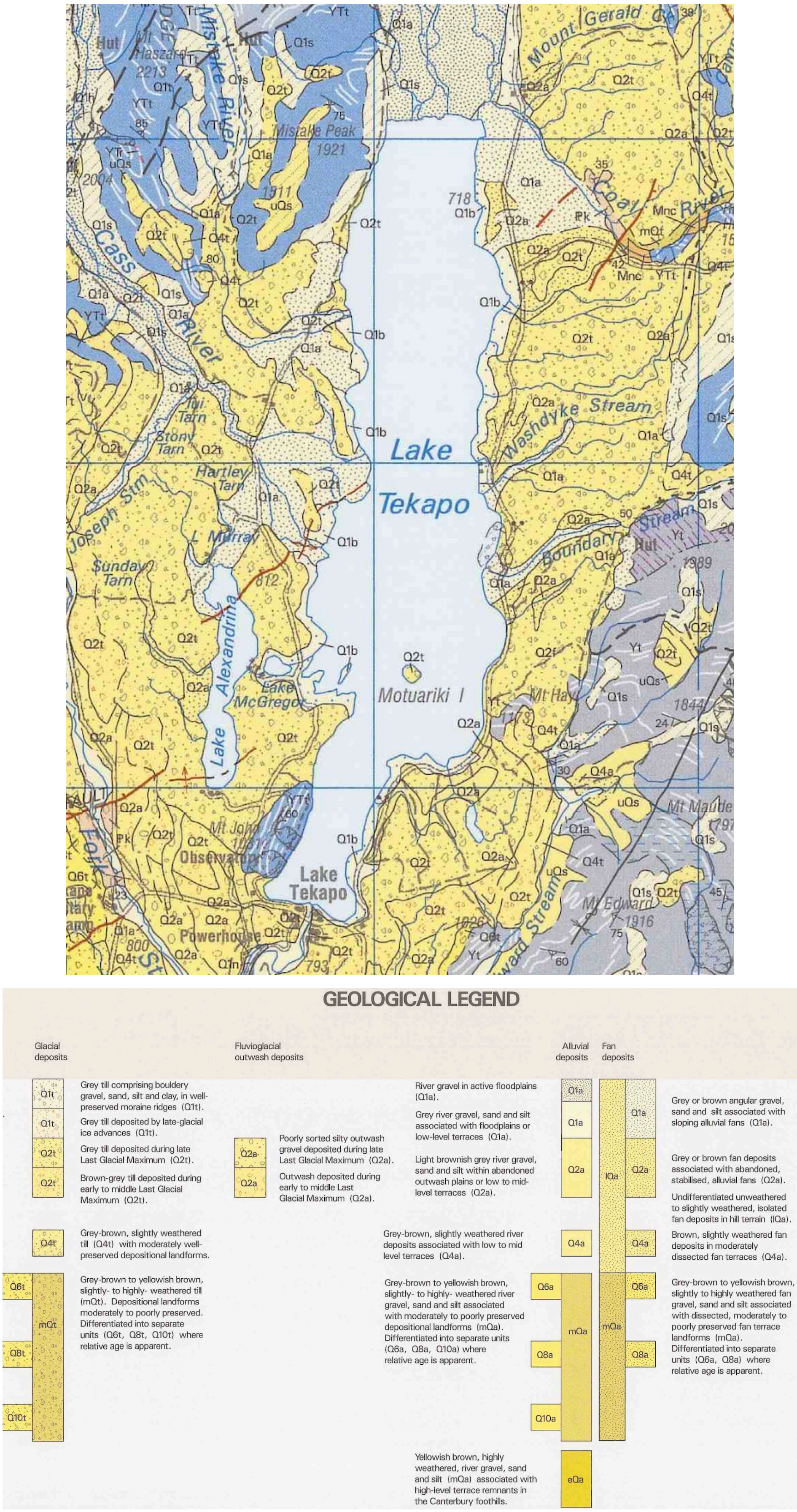

Figure 2.2 Geology of the area surrounding Lake Tekapo (from Cox and Barrell 2007)

The geology of the surrounding country is shown in Figure 2.2. The basis of the landscape is dominated by glacial till and outwash deposits, with the eastern shore formed into Mt John formation deposits and the western shore formed into Tekapo deposits, both laid down during the Otira Glaciation (80 to 14 ka BP). Torlesse indurated sandstone (greywacke and argillite) basements are exposed on the western shore. A block of low induration is situated at the north-western corner of the lake, while Mt John is comprised of greywacke and argillite of medium induration. It is ice-sculpted and has remnants of gravel preserved in discrete locations on the hill. Fluvial deposits dominate on the river deltas of the Cass and Godley Rivers and along a fan deposit at the mouth of Boundary Stream.

Tekapo township is built on terminal moraine deposits, from which the outwash plains extend into Mackenzie Basin.

2.1.2 Lakeshore geomorphology and sediments

The southern shore of Lake Tekapo is formed into moraine deposits, with terminal moraine along the southern shore fronting Tekapo township, and lateral and glacial edge moraine along the base of Mt John. The eastern and western shores are formed into more recent fluvial deposits and fans resulting from erosion of the surrounding hills. Fluvial deposits from the Godley, Macaulay and Coal Rivers dominate the northern shore. The river mouths combine to form a large deltaic landscape, while the shoreline builds southwards due to the abundant supply of sediment from upstream.

Figures 2.3 and 2.4 show the geomorphological character of the shoreline of Lake Tekapo. There are six main types of shore morphology around the lake relating to the nature of the sediment deposits. They are:

- Fluvial deposits at the main river mouths, forming large fans or deltas (Figure 2.5),
- Moraine deposits, comprised of a mixture of sediment sizes from fine loess to large boulders (Figure 2.6) eroding in some areas and stable in some areas,
- Hillslope deposits, comprised of reworked colluvium, sands, gravels and small boulders (Figure 2.7) – mainly eroding,
- Linear barrier beaches of gravel formed by alongshore transport of sediments infilling embayments along the shore (Figure 2.8),
- Pocket beaches of coarse sand to gravel sized sediment (Figure 2.9), and
- Hard rock shores where overlying sediments have been removed to expose the underlying basement rock (Figure 2.10).

There is a near-continuous beach around the shoreline of the lake, predominantly composed of gravel sediments with coarser particles up to cobbles and boulders where they have eroded from the backshore deposits. Fine sediments washed out of the glacial moraine and eroding hillslope deposits are lost from the beach through suspension and deposited on the lakebed. Small pockets of sand are present near river mouths but are usually in layers beneath fine to medium gravels. Fine sediments are exposed at low lake levels on the shore of Lake Tekapo adjacent to the inflow channel from Lakes Alexandrina and McGregor.

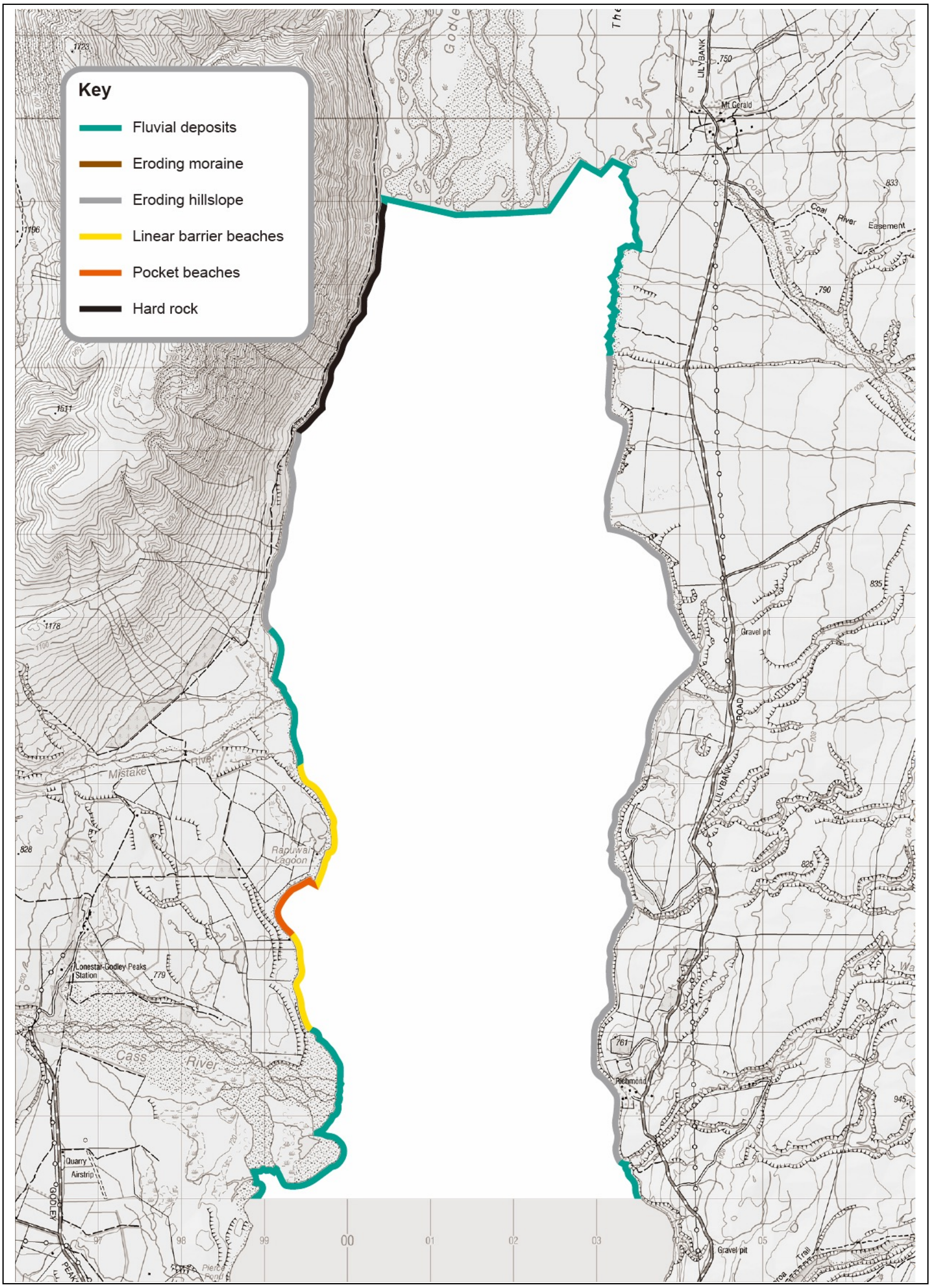

Figure 2.3 Northern section of Lake Tekapo showing the geomorphology of the shore (base map from NZTopo50-BY17 Lake Tekapo, with the shoreline at 710 m amsl)

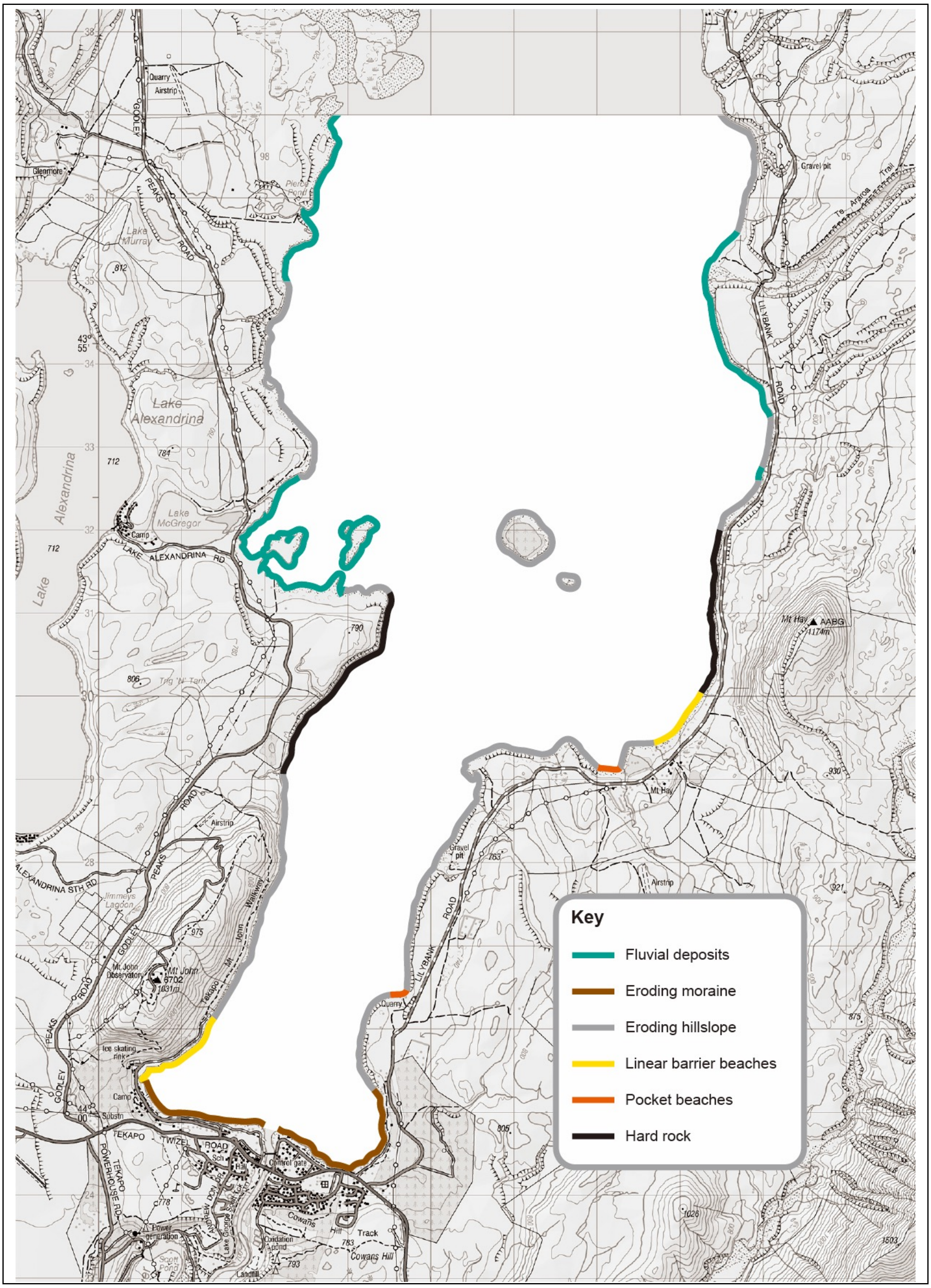

Figure 2.4 Southern section of Lake Tekapo showing the geomorphology of the shore (base map from NZTopo50-BY17 Lake Tekapo, with the shoreline at 710 m amsl)

Figure 2.5 Fluvial deposits of the Godley and Cass Rivers.

Figure 2.6 Examples of eroding moraine and glacial edge deposits.

Figure 2.7 Examples of eroding hillslope deposits on the eastern shore.

Figure 2.8 Linear gravel beach showing beach ridges, located on the western shore.

Figure 2.9 Pocket beach on eastern shore with a northerly aspect.

A

B

Figure 2.10 Examples of sections of hard rock shores. A) Northern section of Godley Peaks Road. B) Northern section of base of Mt John.

The overall character of the shore indicates a developing geomorphology. Most of the shore has beaches with sediments that are able to be moved by waves, and are dynamic, adjusting in response to changes in the process environment. There are sites that exhibit active erosional processes, that although are ongoing, occur intermittently and are related to periods of high water levels with strong winds generating erosive waves. Similarly, there are evolving accreting landforms such as barrier beaches and infilling pocket beaches. These areas appear to receive sediment in pulses related to erosion supplying the shore with sediment, and alongshore transport conditions associated mainly with waves from the northern quarters transporting sediment along both sides of the lake from the north to south.

2.2 Physical lacustrine process environment

Shoreline development on Lake Tekapo is related to the natural processes of wind-generated waves causing sediment movement across the beach and along the shore. Waves and nearshore currents work on the shore and backshore sediments. The energy of the waves controls the potential amount of work that can be done. The lake level controls where, with regard to the elevation on the shore profile, that work is done.

Waves are a result of three main factors as below:

1. The fetch (length of water) that wind blows across – due to the predominant wind direction (north to northwest) and the orientation of the valleys (north to south) for Lake Tekapo, this is generally the length of the lake, but can be the width of the lake if the wind is coming down the valleys to the east and west of the lake.
2. The strength of the wind – usually measured in m/s. For example, winds on Lake Tekapo can exceed 120 km/hr (over 33 m/s), although mean monthly maximum speeds are generally less than about 70 km/hr.
3. The duration of a given wind event – the longer the wind blows, the bigger the waves that can be made. Wind generated waves will move to the shore and break. Due to the relatively small size of Lake Tekapo the fetch is limited with regard to wave generation, so that the biggest waves that can be generated by a certain wind strength and duration of a wind event will not be achieved.

2.2.1 Climatic parameters

The channelling of the foehn (north-westerly) airstream down the lake results in the accelerated low level airflow, which enters Lake Tekapo at the northern end and from within the Godley and Cass River Valleys (McGowan *et al*. 1996). Table 2.2 shows the monthly and seasonal distribution of wind speeds. Figure 2.11 shows the mean annual frequency of wind direction for Mt Cook, which is representative of the wave generating wind directions that occur on Lake Tekapo. The windiest periods are in the spring and summer months, coincident with the main occurrence of foehn winds. This predominant wind direction is evident from Figure 2.11 where the dominant winds can be seen to be from the north-westerly quarter. At Tekapo Airfield on average there are 69 days per year with wind speeds greater than 61 km/hr, and 5 days per year with wind speeds greater than 94 km/hr. This is fewer than at Mt Cook, and result in a less energetic wave environment on Lake Tekapo than on the nearby Lake Pukaki.

Table 2.2 Mean monthly and annual wind speed (km/hr) (Top) and seasonal distribution and frequency (mean number of days) of strong winds (daily mean wind speed > 30 km/hr) (Bottom) (after Macara 2016, Tables 1 and 2)

Location	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Lake Tekapo	15.9	13.0	13.0	11.6	11.3	10.7	11.3	11.5	15.3	15.9	16.3	14.8	13.4

Location	**Summer**		**Autumn**		**Winter**		**Spring**		**Annual**
	Dist	Freq	Dist	Freq	Dist	Freq	Dist	Freq	Frequency
Lake Tekapo	28%	5	15%	2	18%	3	39%	7	17

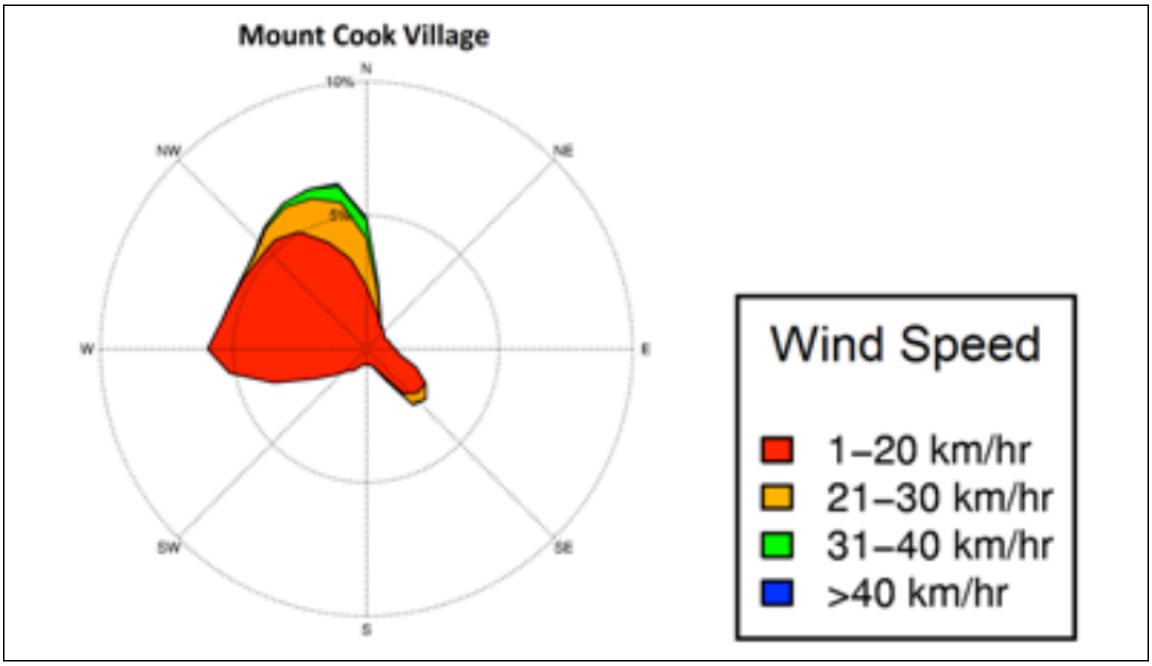

Figure 2.11 Mean annual wind frequencies (%) of surface wind directions from hourly observations (from Macara 2016, Figure 5)

The average annual rainfall for Tekapo is about 591 mm, spread fairly evenly through the year, but with slightly wetter winter and spring months than summer. On average, there are 12 days each year with snowfall.

The mean daily temperature range is from about 1 °C to 15 °C, with summer maximums around 29 °C and winter minimums around -8 °C. Table 2.3 shows the incidence of ground frosts for the Tekapo area. Ground frosts on the shore of the lake can retard the ability for waves to move sediment particles on the beaches.

Table 2.3 Frost occurrence and grass minimum temperatures (after Macara 2016, Table 18)

Location		**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Lake Tekapo	a	5.0	4.7	2.7	-0.1	-2.7	-5.1	-6.0	-4.5	-2.0	0.1	2.0	4.0
	b	-10.7	-9.5	-11.7	-12.5	-14.4	-21.1	-20.6	-21.6	-14.9.	-15.3	-11.1	-8.8
	c	3	3	7	13	21	25	27	25	18	12	8	4

a: Mean daily grass minimum (°C) b: Lowest grass minimum recorded (°C) c: Mean number of ground frosts per month

2.2.2 Wave processes

There have been no measurements of waves or currents on Lake Tekapo. However, Kirk (1988) made observations of wave heights and periods during gusty north-westerly conditions in July 1988. He noted wave breaker heights of between 1 and 1.5 m, and wave periods of 3 to 4 seconds. At the southern end of the lake, in the vicinity of the intake structure, refraction of the waves resulted in a strong longshore gradient in energy with longshore drifting of beach sediments towards the west under the high-energy wave conditions. He observed sediment of up to 200 mm in diameter moving in the breaker and swash zones of the beach.

Estimates of the potential wave environment for different wind conditions was carried out using LakeWave, a wind-wave hindcast model designed for fetch-limited, enclosed water bodies by NIWA. Wind speed ranges and wind directions used in the model were based on the long-term historical record input. The maximum wave heights are presented in Table 2.4 for strong wind conditions that occur during foehn events and southerly storms. Moderate easterly wind conditions were also modelled. Due to the limited fetch, maximum wave heights were achieved within two to three hours. LakeWave output also provides an indication of longshore transport potential for the different wave events. The model results are not representative of measured variable wind conditions that occur through a wind event but can be used to infer the potential work of waves and the resulting beach and shore geomorphological change. The model results are consistent with observations of Kirk (1988).

Table 2.4 Modelled maximum wave heights under various strong wind conditions

Direction	Wind Speed (m/s)	Duration (hrs)	Max Breaker Height (m)
270	16	3	1.29
315	16	3	1.74
315	24	2	2.14
315	33	2	3.36
50	8	4	0.89
50	16	3	1.66
180	16	2	2.23

The wave processes are topographically channelled along the north – south axis of the lake, with stronger winds generating larger waves from the north than from the south. Wave events from the north are generally of longer duration than those generated from the south. The result is a wave environment that presents waves breaking at a strong angle to the western and eastern shores but breaking nearly parallel to the southern and northern shores. Figure 2.12 shows examples from the LakeWave model output of the longshore transport direction for waves generated by 24 m/s north-westerly winds, and 16 m/s southerly winds.

These longshore transport processes are evident along the western and eastern shores through different shore geomorphological features including linear barrier beaches and spits, and alongshore sorting of sediments showing a dominant north to south transport of sand to coarse gravel sediments.

Breaking waves are generally steep and of a plunging type, and there is a narrow surf zone with little refraction of the angle of the wave in approaching the beach. Wave run-up on the beach is of a similar magnitude to the breaking wave height. Accretional berms are present at 1 m above the maximum lake level, but wave run-up in extreme conditions can also reach the base of backshore cliffs where they are present.

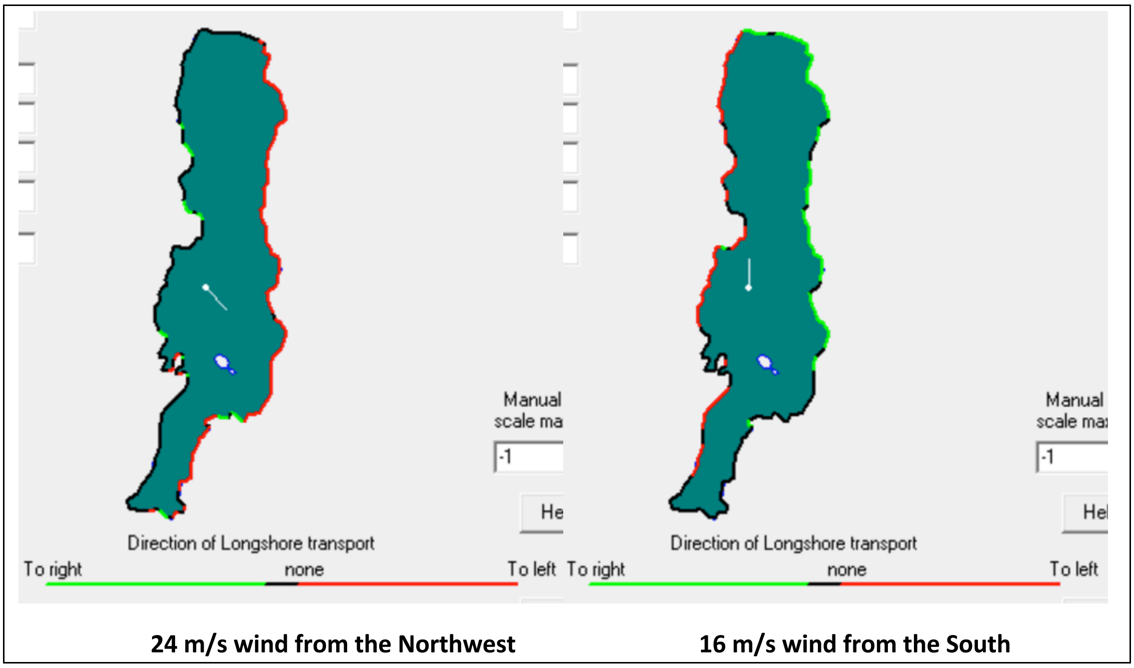

Figure 2.12 Longshore transport direction for waves generated by northwest and southerly winds. Transport direction is indicated in relation to standing on the shore looking lakeward.

2.2.3 Lake levels

The lake water level and the range of levels within the operating regime on Lake Tekapo determine the elevation range where the wave activity acts on the shore profile. Higher lake levels will place the zone of wave activity higher on the profile, and if coincident with high energy waves can cause erosion of the upper part of the beach with deposition of sediment at the limit of wave run-up and lower down the profile in the nearshore. At low levels wave action works on the lower part of the shore profile, removing the upper part of the profile from the zone of wave action, while the nearshore shelf and face are actively worked.

Figures 2.13 and 2.14 show the long-term record of the lake level fluctuation for Lake Tekapo. The change from a natural range to a controlled water level range is readily apparent from before and after 1951 to 1954. Records of the lake level prior to 1951 show a consistent annual range in water level from 704.6 m to 705.9 m amsl (metres above mean sea level), with a predominant range of about 1.3 m. There are also occasional excursions to high levels of 707 m amsl, with the highest in December 1925. The lowest recorded level during the period July 1925 to June 1952 was 704.4 m amsl in August 1932. This gives a total water level range of about 2.6 m.

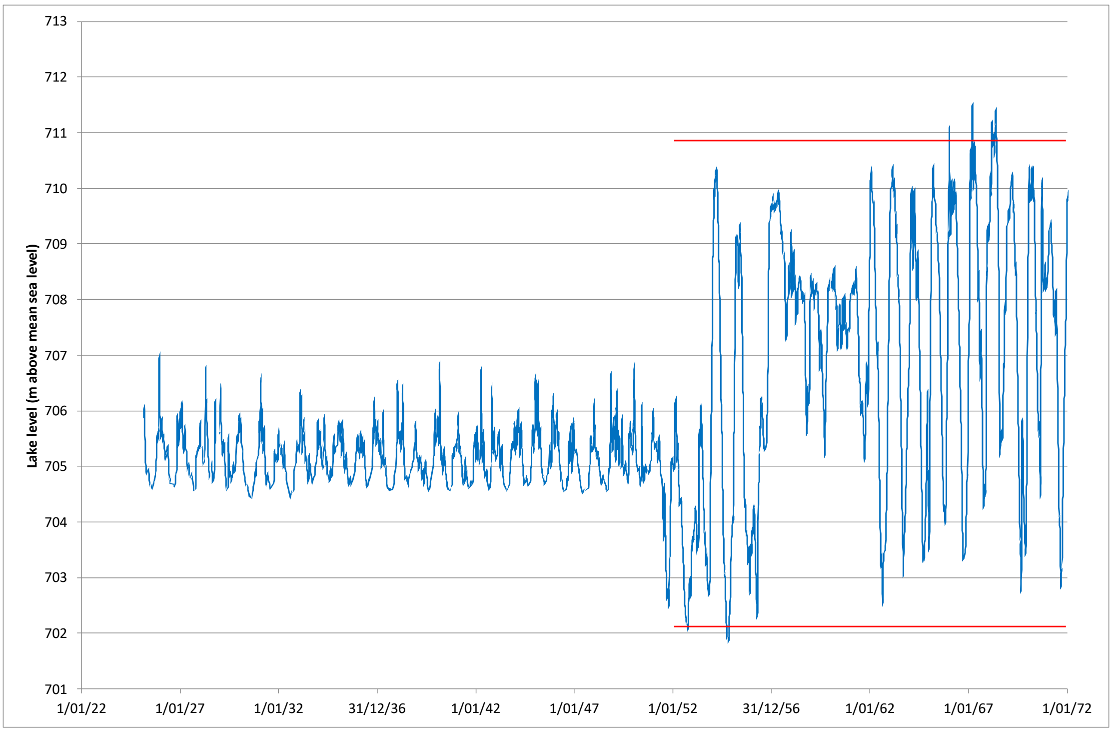

Figure 2.13 Lake Tekapo level record 1925 to 1972

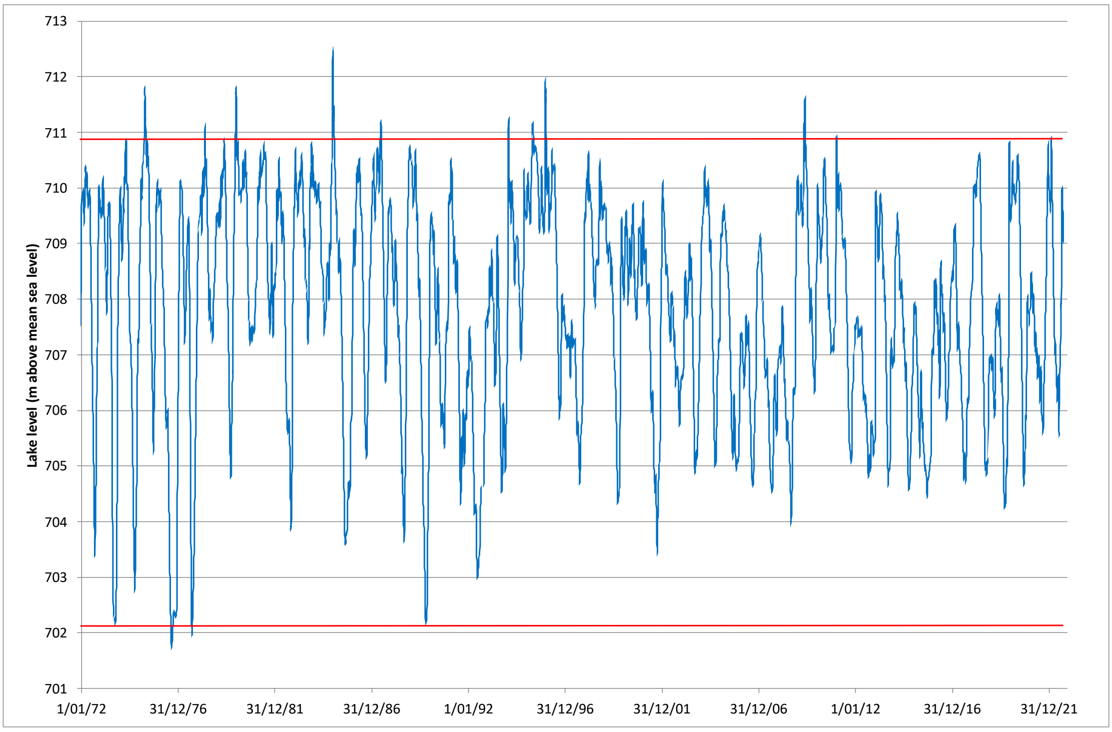

Figure 2.14 Lake Tekapo level record 1972 to November 2022 (source: Genesis Energy data). Red lines show consented winter maximum and minimum lake levels (note: the graph does not show range of consented variations to maximum and minimum levels throughout the year)

The consented minimum and maximum operating levels for Lake Tekapo vary through the calendar year to account for inflow and power generation demand variability, and to avoid coincidence of high water levels or low water levels with peak wind conditions during the spring and autumn equinoxes. The consented operating range for Lake Tekapo is:

Minimum Control Level: 704.1 m from 1 October to 31 March; and
702.1 m from 1 April to 30 September; and

(i) From 1 October to the following 31 March the minimum operating level for Lake Tekapo shall not decrease below 704.1m amsl except during any period during which the Electricity Commission (or any statutory body exercising like powers and functions to the Electricity Commission) determines: that reserve generation capacity is required to generate electricity; or

(ii) the National or South Island minzones (or their future equivalents) have been breached.

Maximum Control Level: 709.7 m from September to February;
710.0 m for March;
710.3 m for April and August;
710.6 m for May; and
710.9 m from June to July.

These levels are shown on Figure 2.15. The daily mean lake level for the period 1/1/2011 through to 31/12/2021 is also shown.

Since 1951, the water level range has extended approximately 2.7 m lower and 5.6 m higher than the range prior to the construction of the Lake Tekapo Control Structure. The lake level range since 1951 is mainly between 702.8 m amsl and 710.6 m amsl, a range of 7.6 m. However, since 1991, the lower part of the range has been entered less often, with the range mainly being between 704.7 m amsl and 710.2 m amsl.

The maximum level was 712.6 m amsl in December 1984, while the lowest level was 701.7 m amsl in August 1976. The most recent high level was in May 2009, when the lake reached 711.6 m amsl. The lake has been below 704.1 m amsl three times since 1991, with the most recent low level being in August 2008 with the lake at approximately 703.9 m amsl.

In June 2011, the ownership and operational management of the Tekapo A and B power stations, fed by water from Lake Tekapo, were transferred from Meridian Energy Ltd to Genesis Energy Ltd as part of power generation asset restructuring by the New Zealand Government. Since that time until the end of 2020, the minimum lake level was 704.19 m amsl (in September 2019), the maximum level was 710.87 m amsl (in December 2019), the mean level was 707.13 m amsl and the median level was 707.04 m amsl.

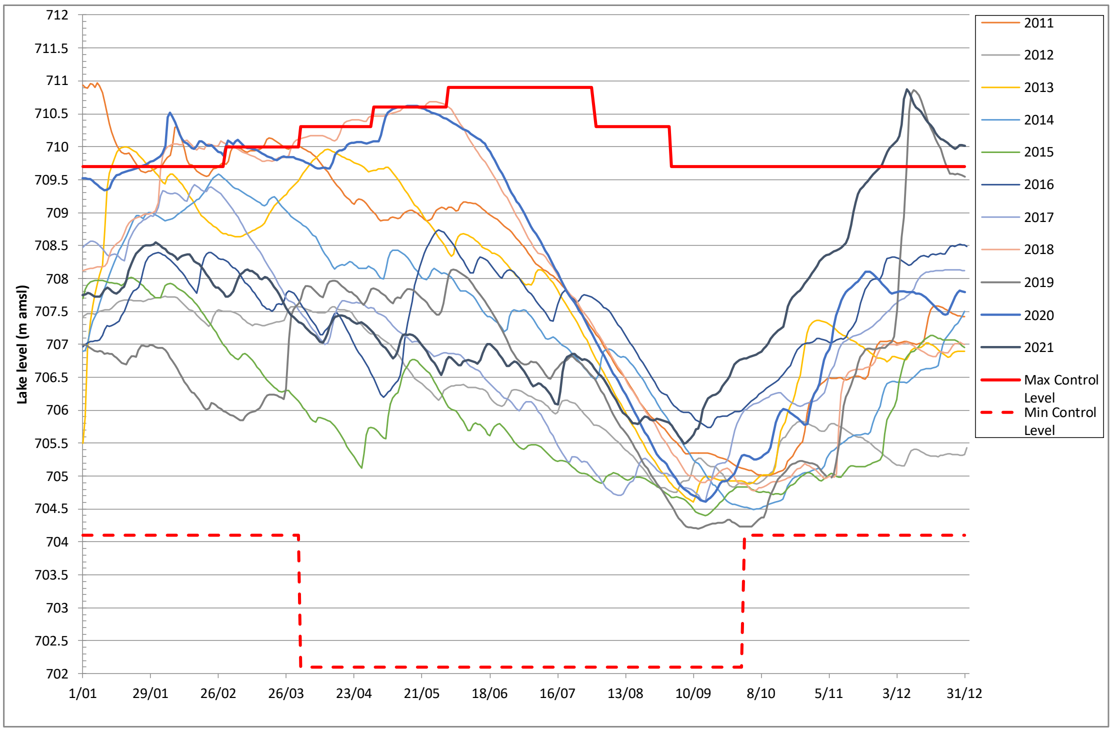

Figure 2.15 Lake level operating limits with daily mean level data from 2011 through 2021 superimposed (data from Genesis Energy Ltd)

Changes to the water level range since 1954 resulted in water level and wave action on the shore at elevations that were probably stable prior to the controlled water level regime. Consequently, since 1954 there has been adjustment of the shore geomorphology to the new water level range. The shore adjustment has generally taken the form of erosion. The rates of erosion at different times since control are unknown. However, it is likely that initial adjustment of the shore to the higher lake level was rapid, within the first five to ten years, as occurred on Lakes Pukaki and Benmore, and subsequent change has been at a slower rate but subject to episodes of rapid change associated with erosive events at specific sites. The character of these changes is consistent with other controlled lakes in the New Zealand high country.

The larger operating range has resulted in a wider and less defined across-shore distribution of the shore morphology. Constructional and erosional beach features such as berms and erosion scarps will form at an elevation relative to the level of the lake when there are waves to cause geomorphological change. It is a combination of lake level and storm events that influence where erosional processes occur on the shore profile. A high lake level combined with strong winds and storm waves can result in erosion of lake beaches or backshore that are not usually subject to wave action. In particular, the base of cliffs that are landward of beaches may be eroded by direct wave action or destabilised through removal of talus, debris accumulations or beaches that protect the base of the cliff from wave attack. A storm event during a period of low lake level can result in sediment being removed from the active beach to offshore (and potentially to deep water) and lost from the beach system. The result of these processes is evident on Lake Tekapo.

3. Shoreline change

The glacial origin of the basin of Lake Tekapo, and the ongoing fluvial and hill-slope processes that have contributed to the topography of the lake margins provide the background for the development of the shore by physical lacustrine processes of waves and currents transporting sediment across and along the shores at different water levels.

At the upper end of the operational range, erosion of the hinterland has resulted in scarps and cliffs formed into hill-slope and moraine deposits. Fluvial processes and shore erosion have also added sediment into the beach system. Waves breaking at an angle to the shore transport the sediment along the long axes of the shore. Therefore, although the shoreline is predominantly erosional in character, there are also accretional landforms such as pocket beaches, linear beaches and small spits of sand and gravel.

The development of the shore in relation to the operational range of water level is an ongoing process. However much of the shore is dynamically stable, in that in the short to medium-term, the beaches adjust to variations in wave energy and water level with a through-flow of sediments, either across or along the shore, and very little noticeable change to the character of the shore or the position of the landward limit of the active shoreline. Extreme events such as very high water levels (over 711 m amsl, such as in May 2009, December 2005 and December 1984), or very large waves can result in measurable long-term changes to some areas of the shore. Overtopping of barrier beaches and erosion of backshore deposits can lead to landward movement of the shoreline. The addition of the eroded sediment to the beach system can also lead to increases in the size of depositional features such as spits and linear barrier beaches fronting low-lying areas of the hinterland.

3.1 Shore development of Lake Tekapo

Raising the lake as part of the Tekapo Power Scheme development in the 1950's, resulted in the initiation of development of a new shoreline relative to the lake level range. The character of the shore is generally unchanged, in that the active processes of erosion of hillslope surfaces, inundation of areas of low sloping land and constructional features where sediment has moved along the shore to be deposited within embayments occurs as it had in the pre-control situation, but the vertical extent of shore change is extended over the controlled water level operating regime. The initial effect was erosion of the steep backshore hillslope and alluvial deposits (as located on Figures 2.3 and 2.4) and retreat of the landward limit of the active beach.

The largest retreat of the beach occurred on sections of the shore with a large effective fetch for wave generation and steep offshore slopes, where waves do not lose energy before breaking onto the shore, and there are erodible backshore sediments. In addition, unconsolidated cliff sediments are readily eroded as rain and groundwater loading of the regolith results in destabilisation of the slope. Overseas studies also indicate that any glacial till that may make up the nearshore shelf is particularly susceptible to erosion due to having a soft outer skin of fine sediment that is subjected to constant abrasion by coarser sediments moving over its surface.

The shoreline of Lake Tekapo can be considered as being at a juvenile or intermediate stage of evolution towards developing a new (stable) dynamic equilibrium state. At high lake levels, the limit of wave run-up, and in some areas the still, water line, reaches the toe of the cliffs forming much of the lake margin. The eroding cliffs are indicative of the landward retreat of the shore to accommodate the widening nearshore shelf related to the extended water level range. On lower sloping topography, linear beaches form an active margin to the relatively stable backshore.

Figures 2.3 to 2.10 show how the base geomorphology and overall character of the shore reflects this developing geomorphology. Figures 3.1 and 3.2 show examples where historical shore retreat and areas of construction of linear beaches are evident in the form of the beach and backshore.

Figure 3.1 Eroding moraine / glacial deposit cliff north of Mt John

Figure 3.2 Linear beach along the eastern shore

The sites that exhibit erosion show evidence that the process, although ongoing, occurs intermittently and is related to periods of high water levels with strong winds generating erosive waves. Similarly, the accreting landforms such as barrier beaches and infilling pocket beaches appear to receive sediment in pulses related to erosion supplying the shore with sediment, and alongshore transport conditions associated mainly with waves from the northern quarters.

The shoreline development is related to the natural processes of wind-generated waves causing sediment movement across the beach and along the shore. However, the changes to the water level regime have initiated changes to the shore at elevations that were probably stable prior to the artificial water level regime. The character of these changes is consistent with other controlled lakes in the New Zealand high country.

As shown in Figure 3.3, vegetation at the base and on the face of some cliff and scarped areas is indicative of recent periods of stability to the shore. However, there are also fresh erosion scars that indicate localised processes that could be a result of the effects of waves, currents, terrestrial hill-slope instability brought on by groundwater through-flows, animal movement on the face, earthquakes or gravity induced slumping, or a combination of these processes.

Figure 3.3 Eroded scarp below the northern Mt John walking track (location is the upper part of Figure 3.5)

There is evidence of agents of erosion other than lacustrine processes where rills and/or runnels have formed on the steep eroding slopes and fresh talus resulting from hillslope failure sits above the elevation of wave action.

Figures 3.4 and 3.5 show changes in the position of the top of the eroded scarp adjacent to two sections of the northern Mt John walking track. Major retreat of the scarp top occurred over time between 1977 and 2006. Available aerial photographs do not provide adequate information to pinpoint a specific event or series of erosion episodes. The base of the cliff is within the effect of potential wave action during the high lake levels of 1984 and 1996 and may have become unsupported due to erosion of the backshore at either or both of those times. The lake level reached an elevation just below the base of the steep slope of the cliff for a short period in December 2019 and again in December 2021 and January 2022. However, there is no evidence of erosion of sediment and reactivation of the cliff face due to wave action.

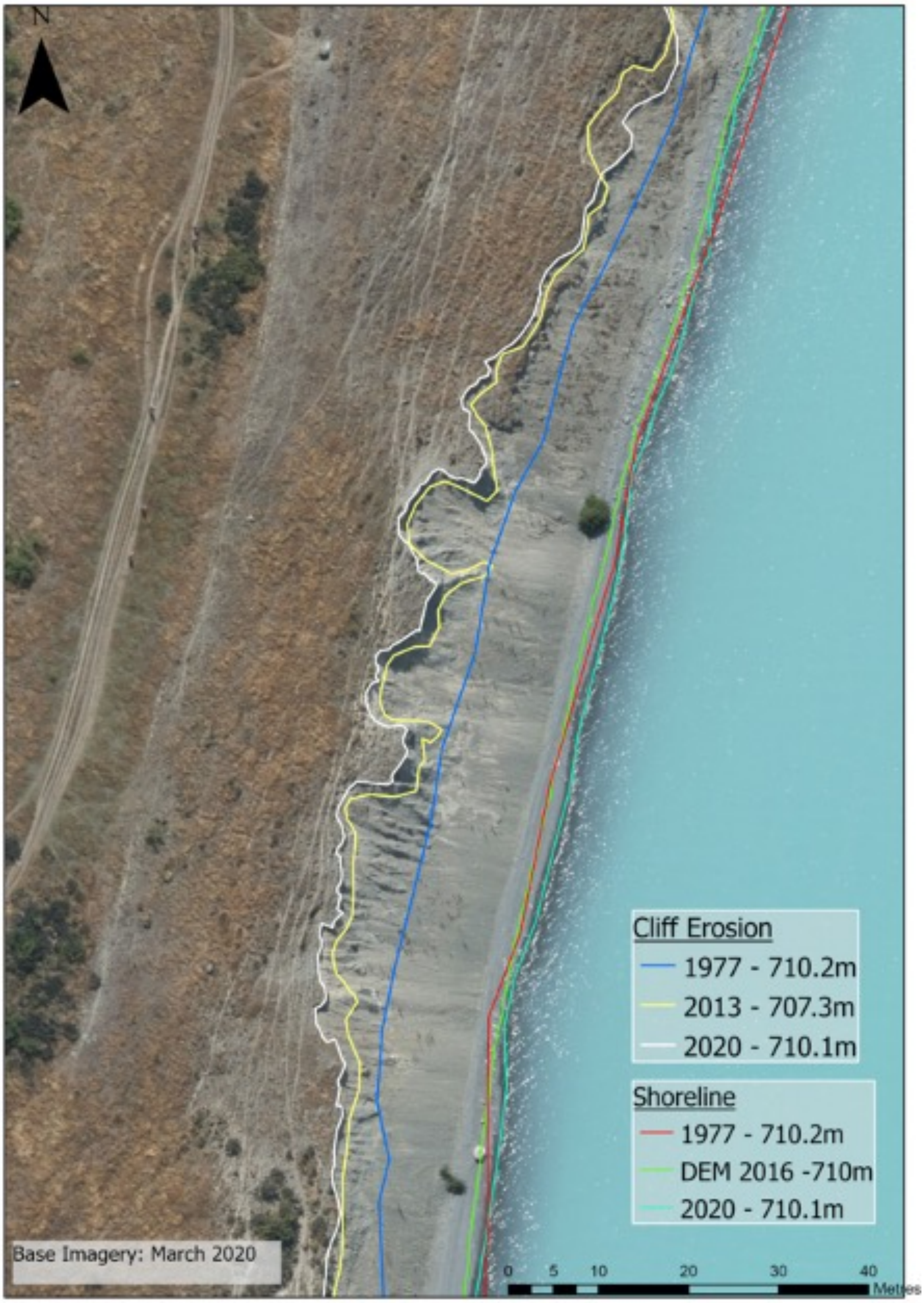

Figure 3.4 Changes in scarp top and shoreline position adjacent to the northern Mt John walkway

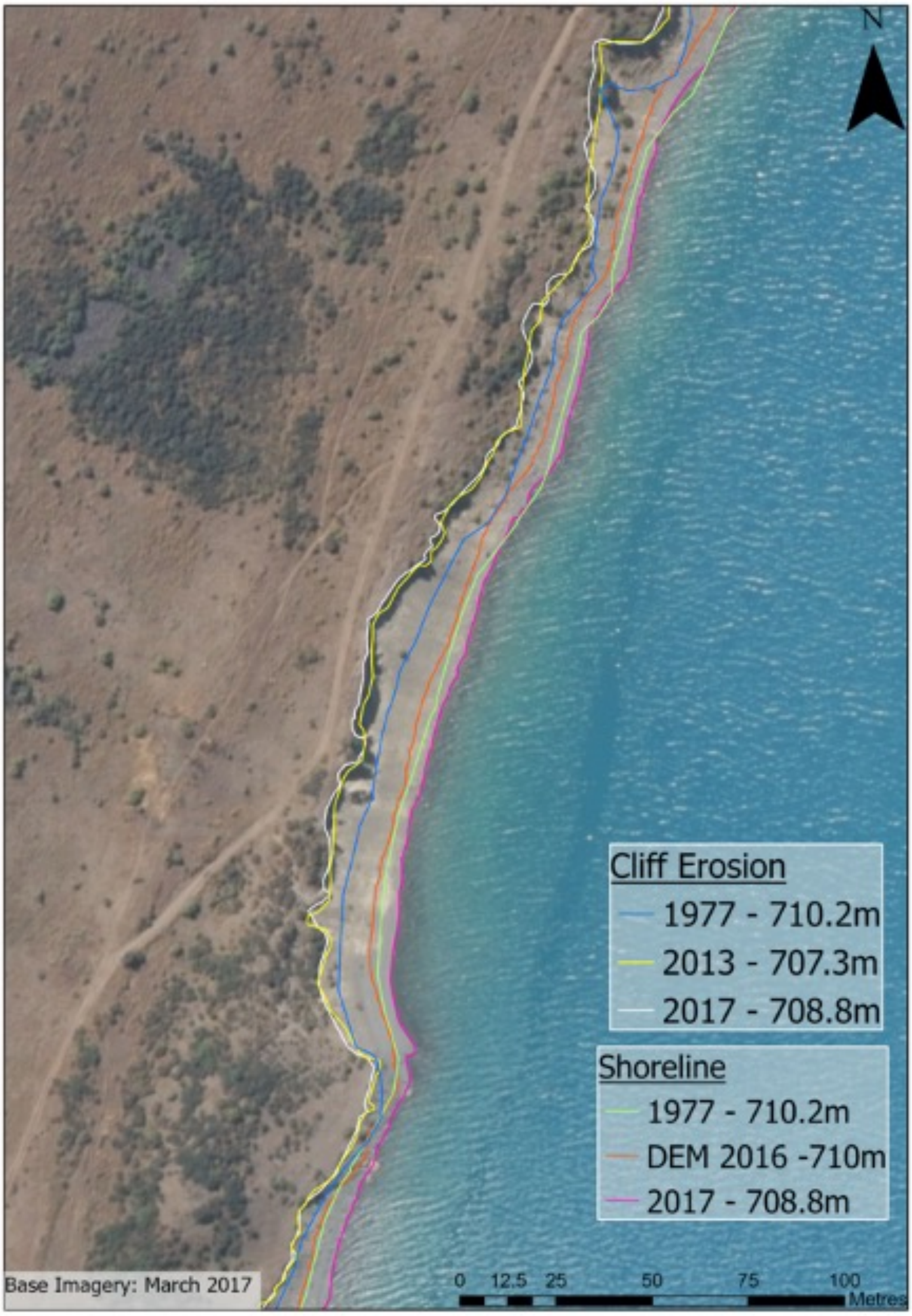

Figure 3.5 Changes in scarp top and shoreline position adjacent to the northern Mt John walkway

The change in shoreline position, as referenced by the 1977, 2016 and 2020 710 m waterline (Figure 3.4) is relatively small and is not indicative of landward movement of the beach profile. Measurable change to steep backshore slopes but only minor change to the beach is common around the shore of Lake Tekapo and is indicative of the shore being in a position of development at near-equilibrium with the wave environment and water level operating range. However continued retreat of the unstable cliff face and scarp tops is expected, as the steep slope develops towards an equilibrium form in response to the subaerial and lacustrine processes and sediment character.

The ready source of mobile sediments from river inputs and from backshore erosion will also continue to feed the linear beach system and constructional shore landforms such as spits and barrier beaches.

4. Geomorphology and use of the shore

4.1 Resource use and infrastructure

Intensive shoreline resource use is concentrated along the southern shore as shown in Figure 4.1. There are two paved boat ramps. One located near the camping ground and hot pools at the western side of the embayment (Figure 4.2), and one located on the right flank of the outlet channel. A walkway extends along most of the shoreline in front of the village but is well above the maximum lake level. A picnic area is located on the eastern side of the embayment. This area is low-lying relative to the water level operating range and is subject to inundation at high levels. All of the buildings and roads along the southern shore are above the maximum operating level. Any increase in use of the foreshore (for example for recreational purposes) and the lakeshore hinterland within the operating easement will require consideration of the operational water level range and potential ongoing development of the shore geomorphology.

Figure 4.1 Southern shore of Lake Tekapo, showing locations of the boat ramps (purple markers) and the Tekapo HS intake (red marker) (image from GoogleEarth, dated 20 September 2019)

Figure 4.2 Boat ramp and western end of the southern shore, showing the main recreational beach

Rocks are placed around the intake structure to prevent abrasion of the structure by gravel. Rock has also been placed along the top of the beach for this section of the shore.

Lilybank Road runs the length of the eastern shore of the lake but is generally located well above or away from the shoreline. There are a few areas where tracks lead off Lilybank Road to the lakeshore to provide access to flat areas behind the beach for recreational use and water access.

The farm buildings for Richmond Station (on the eastern shore approximately opposite the Cass River mouth) are located on a terrace that slopes down to the shore. Rock has been placed on the upper beach lakeward of one of the buildings (shown in Figure 4.3).

On the western side of the lake, Godley Peaks Road crosses the outlet channel joining Lake McGregor to Lake Tekapo. The road becomes a vehicle track north of Mistake River. The track hugs the flank of Mistake Peak for a distance of approximately 6 km. Slips from the hillside fall across and can damage this section of Godley Peaks Road. However there appears to be no wave-induced erosion of the lakeshore below the road. The slips are likely the result of subaerial hillslope processes and not due to lacustrine processes.

Figure 4.3 The shore in the vicinity of Richmond Station on the eastern shore of Lake Tekapo. A large farm building has rock apparently placed around the shore next to an old stream channel

Two residential buildings (Figure 4.4) are sited on a raised beach, approximately 5 m above the highest lake level between Pierce Pond and Lake McGregor. An older, derelict farm building is located on the backshore north of the northern building.

Figure 4.4 Residential buildings along the western shore of the lake near, and north of Lake McGregor

The southern section of the western shore abuts Mt John, where the shore includes embayments with barrier beaches, 10 m high actively eroding cliffs, exposed rock outcrops, older, stable cliffs, eroded lateral moraine and depositional, linear gravel beaches. A public walking track provides a northern route from Tekapo to Mt John and skirts the base of Mt John close to the top of the eroding cliff for a distance of approximately 2 km before turning inland for the ascent of Mt John.

4.2 Hazards resulting from shore processes

There are three main types of hazards associated with physical lakeshore processes. These are erosion (shoreline retreat), sedimentation and inundation resulting from extreme high water levels. In addition, there are hazards associated with soft sediments and shifting channel positions around the river mouths that require caution by anglers (for example) when traversing these areas.

Shoreline landform changes such as erosion of the backshore are not ‘hazards’ as such unless the change adversely affects the use of the shore or hinterland. For example, the erosion around Lake Tekapo presents a noticeable hazard to shore use in only a few areas. Widespread erosion along the eastern and western shores, where tussock and grassland has been “trimmed” by the slowly retreating shore, presents minimal hazard to shore use, but does present a loss of potential for future use of the land. Similarly, progradation of areas of the shore near the river mouths and where longshore transport of sediment has resulted in the development of linear and pocket beaches have not adversely affected the use of the shore, except for a few specific sites.

4.2.1 Southern shore (as shown in Figure 4.1)

There is a minor nuisance from sedimentation on the western boat ramp (Figure 4.1). Gravel and sand are transported along the southern shore from the east and along the western shore from the north. The southwest corner of the lake receives the sediment from both directions, and at times there is a build-up of sediment on the boat ramp. The ramp appears to be maintained by the local boat club.

The southern shore below the main village shops and east towards Lilybank Road shows evidence of past high water levels, with gravel berms, or beach ridges, constructed along sections of the shore. These ridges are vegetated with grasses and small shrubs and are at an elevation that would have been reached by waves during the December 1984 high-water-level event (water level 712.57 m amsl). Movement of gravel and sand by wave action at the upper part of the beach profile has not resulted in damage to the large trees along the shoreline.

Lake levels near the maximum operating range can result in inundation of the low-lying hinterland along the eastern end of the southern shore. This can cause water-intolerant vegetation to die and can result in damage to the trunks of trees and shrubs from abrasion by driftwood or sediment in wave swash. Low-lying infrastructure can become damaged or unusable for the period of the inundation event. The picnic area contains low areas that are flooded when the water level is above 709 m amsl, although there appears to be no persistent adverse effect of past inundation events.

There is no indication that inundation has threatened the integrity of SH8.

Artificial rock placement in the form of a rock revetment has been carried out in the area immediately adjacent to and to the west of the TekPS intake. This work was done to protect the backshore and intake access road from accelerated erosion during periods of high water levels in the 1980s. There is localised erosion at the western end of the placed rock, but there appears to be no immediate threat to the road or the stability of the revetment.

Sedimentation has occurred around the intake gates at the base of the intake tower prior to 1990. The dredged hole around the intake semi-continuously infills as it is within different zones of wave-current and gravity-induced sediment transport at high and low lake levels. Waves actively transport sediments towards the intake under high-energy waves at low lake levels. Under other conditions, the hole will continue to infill with large particles simply because wave agitation induces gravity sliding on the hole side-slopes.

4.2.2 Eastern shore

The eastern shore of Lake Tekapo is dynamic in the adjustment of the shore profile and morphology to the changes in the wave climate and water level. Although predominantly erosional in character, there are few sites where shore processes affect the human use of the shore. Lilybank Road is sited away from the active shore, and there are no areas of immediate or medium-term threats from erosion.

Rock placement lakeward of farm buildings at Richmond Station indicate a possible historical lakeshore or fluvial erosion hazard. It is the one area around the lakeshore where farm buildings are possibly subject to erosion or wave run-up processes. A number of streams enter the shore in the vicinity of the Richmond buildings, and there is a possible overflow or flood channel from the Washdyke Stream through the area.

4.2.3 Northern shore

The northern shore is geomorphologically dynamic but does not present specific hazards as effects of the TekPS operation. Ongoing deposition of sediment from the Coal, Macaulay and Godley Rivers contribute to lakeward progradation of the shoreline. The expanse of river delta changes with variation in the water level. A combination of processes can lead to dust hazards, as discussed by McGowan *et al.* (1995), and soft sediments around the lake edge can be hazardous to anglers walking the shore, and to boat landing. Although submarine bars can also be hazardous to boaters, there are no records of these hazards being experienced on Lake Tekapo. In particular, Environment Canterbury rules for boat operation on the Canterbury lakes provide for speed restrictions near to the shore.

4.2.4 Western shore

Inundation of the low-lying land in the vicinity of the Lake McGregor channel has potential to create nuisance for recreational use. High lake levels can also result in overtopping and flooding of Pierce Pond and Rapuwai Lagoon (south of the Cass River and Mistake River respectively). These waterbodies do not have a permanent open connection to Lake Tekapo, but it is likely that there is a groundwater flow connection through the barrier beach.

Although most of the erosional sections of the western shore do not present hazards to shore use, erosion of the cliff top below the northern route of the Tekapo – Mt John walkway prior to 2006 has continued with retreat in places of 1 to 6 m since 2013. The close proximity of the walking track, in its present location, to the scarp top presents a potential short-term hazard for use of the walkway.

Erosion of the vehicle track along Mt Mistake appears to be predominantly an effect of hillslope erosion processes. However, there are short lengths of shore where wave-induced erosion has destabilised the base of talus deposits of erosion slips. An example is shown in Figure 4.5.

Figure 4.5 Erosion of the base of an active hillslope slip along Godley Peak Road below Mt Mistake

5. Assessment of the effects of the Tekapo Power Scheme on the physical lakeshore processes and geomorphological change

5.1 Historical effects

Extending the water level range of Lake Tekapo to approximately 3 m lower and 5 m higher than the range prior to the completion of the TekPS has resulted in the development of a “new” shoreline. At the upper end of the range, erosion of the hinterland has resulted in scarps and cliffs formed into hill-slope and moraine deposits. Eroded material has provided “fill” to extend the width of the nearshore shelf.

Rates of change of the backshore and position of the landward limit of the active beach are not known for the period of initial geomorphological shore development post-control. There are no detailed surveys of the lakeshore prior to the TekPS, and no appropriate aerial photographs that can be ortho-rectified to allow assessment of change since before 1952. However, the magnitude of the historical change and the effect on shore use is relatively small in comparison to other large, artificial hydro-lakes in the Mackenzie Basin. Horizontal retreat of the backshore is in the order of up to a few tens of metres, and individual accretional features are less than 100 m^2 in area.

Erosion of the hinterland has also added sediment to the littoral beach system. A wider active beach profile accommodates the suite of dynamic beach features such as berms and scarps extending over the total vertical range of the operating levels. Waves breaking at an angle to the shore have transported the sediment along the shore. This transport has resulted in depositional or accretional landforms such as pocket beaches, linear beaches and small spits of sand and gravel.

In theory, initial change to the shore would have been relatively rapid, and probably occurred within the first ten years after raising the maximum water level. Gradual change to the upper limit of the beach is ongoing but is associated with high or flood levels coincident with wind-wave events. Depositional beach ridges are present on the backshore at the southern end of the lake. These are likely the result of high levels in 1984. The crest elevations and form of the barrier beaches (as located on Figures 2.3 and 2.4) also reflect wave processes at the upper limits of the operating range and at historical flood levels.

However, erosion and retreat of backshore cliffs is an ongoing process related to the continuing development of the shore to the modified water level range. It occurs at a slower and episodic rate in comparison to initial shore development. Cliff retreat is mainly evident where the backshore deposits are relatively erodible by subaerial processes and by wave run-up at high water levels, and where buffers of sediment protecting the base of the backshore slope after initial erosion has been removed (as shown in Figures 3.1, 3.3, 3.4 and 3.5).

5.2 Projected effects

5.2.1 Projected future shore physical change and geomorphological development

In theory the Lake Tekapo shore will develop to a dynamic equilibrium form and shoreline position. This is a function of the shore geomorphology and the process dynamics, in particular the wave energy. Because shore erosion is episodic, it is not linear over time, and average rates of historical change cannot be used to accurately quantify future change. However, field observations indicate that areas of the shore that are not exposed to high-energy waves are relatively stable, with vegetated backshore slopes and a stable nearshore shelf where wave energy is dissipated lakeward of the beach.

Figures 5.1 and 5.2 show projected areas of further shoreline development and change. Three types of shore development are indicative of accretional change (delta growth, spits, forelands and barrier beaches, and landward movement of the beach). Cliff and hillslope erosion are indicative of landward retreat of the shoreline and are of particular importance where erosion may impact on resource use of the shore. Areas where inundation is likely to occur in the future are based on existing areas of inundation. Also indicated on the figures are two locations where there is existing shore protection through rock revetment structures. These are at Richmond Station and along the southern shore adjacent to the TekPS intake structure. Areas of the shoreline that are denoted as likely to remain stable are not projected to retreat or prograde but are likely to exhibit dynamic adjustment of the active beach in response to the wave environment and supply of mobile sediment.

5.2.2 Delta growth

The deltas of the major rivers will continue to grow through input of bedload sediments to the lakeshore. These are natural lake processes and are not altered by the TekPS operations.

Mobile coarse sediments, gravel size and coarse sand, will remain in the zone of wave action, and will feed into local lakeward progradation of the shoreline and alongshore transport in the littoral zone to the north and south. In particular, coarse sediment will build out the shoreline at the Godley and Cass River deltas across the broad unvegetated braided river flood plain. Smaller rivers and streams such as the Mistake River, Boundary Stream, Washdyke Stream and other unnamed channels also contribute to the shore, with local delta and fan formations that project across the active beach and onto the nearshore shelf within the elevations of the operating range.

Finer bedload sediments such as sands and fine gravels will move alongshore, feeding into the linear beaches and constructional lakeshore features.

5.2.3 Spits, forelands and barrier beaches

These features are constructional landforms on the lakeshore. They are the natural consequence on Lake Tekapo, where the shore has an abundant supply of sediment and strong alongshore transport. For this reason, most of these features are situated on the eastern and western shores of the lake, and south of sources of mobile beach sediments (from rivers, streams and eroding cliffs).

Spits and forelands occur where there is a change in the planform of the shore, and the sediment transport power of wave energy reduces in the direction of sediment transport, resulting in deposition of sediment in the littoral zone. Barrier beaches occur when wave energy is normal to the shoreline, and sediment is carried up the beach and deposited with wave swash, and backwash does not move the sediment back down the beach.

The initial increase in the lake operating range with the TekPS, resulting in erosion of the hillslope and moraine hinterland, enhanced the growth of spits and forelands spread across the upper elevations of the operating range, and higher than those formed prior to the TekPS. The higher maximum lake level elevated the crest height of barrier beaches formed across pockets of low-lying hinterland.

The current operating regime controls the elevation of the crest of these features but does not cause a lacustrine process that would not be occurring naturally. The future operating regime will not result in new spits, foredunes or barrier beaches, but will continue the shoreline development process in the same character as the current regime.

5.2.4 Inundation and Landward movement of the beach

Low-lying areas of the backshore and hinterland are subject to inundation at high lake levels. The areas located on Figure 5.2 have vegetation that survives temporary inundation and are not exposed to high wave energy. At lower lake levels they do not have the same appearance as the active shores, so at high lake levels the vegetated areas appear flooded.

There are no new areas of inundation projected for future TekPS operation. However, as a consequence of the continuing development of the shoreline, sediment movement in the littoral zone is likely to result in small barrier beaches forming across these low-lying areas at an elevation between 708 and 710 m amsl. This has started to occur near the inlet from Lake McGregor. These small beaches are likely to grow in size as more sediment arrives from alongshore, and as a beach “form”, will move landward as they are subjected to waves at high lake levels.

Rapuwai Lagoon and Pierce Pond, located north and south of the Cass River, are impounded by large barrier beaches. These water bodies are presently inundated by water from Lake Tekapo during periods of high lake levels (above 710 m amsl) coincident with wave conditions from the south or southeast. This is unlikely to change in the future. However, there is potential for the barrier beach to build up as both areas of shore are close to mobile sediment sources. This could result in more flooding of the lagoon and pond from terrestrial waters flowing into them, but they will be less likely to be inundated by waters of Lake Tekapo.

5.2.5 Cliff and hillslope erosion

Cliff and hillslope erosion around the shoreline of Lake Tekapo is an ongoing process as the backshore topography develops slopes at an equilibrium to the sediments and the subaerial and lacustrine processes acting on them. The slope development and erosion are episodic, related to either, or a combination of, high lake level events where wave action erodes material at the base of the slope, and rainfall and/or snowfall and melt events where ground water seepage causes instability and erosion due to slope failure. The cliff and hillslope erosion located on Figures 5.1 and 5.2 are indicative of areas where the base of the steep (near vertical) slope is near or below the maximum lake operating level or the limit of wave run-up elevation at high lake level (about 711.0 to 712.0 m amsl).

Figures 3.4 and 3.5 show examples of the cliff slope development. Subaerial, or top down erosion is prevalent in erosion of the cliff shown in Figure 3.4, while the steeper slope in Figure 3.5 shows evidence of a combination of subaerial causes and lacustrine processes resulting in the slope development and landward movement of the shoreline. These sections of shore are within a 500 m stretch of the shore (near site number 29 on Figure 5.2) and are typical of the variability of the backshore slope development around the lake due to the complex composition of moraine and hillslope deposits in which the shore has formed.

The current operating regime has not changed the character of the cliff and hillslope erosion from the long-term shore development in response to the TekPS operation. However, the rate of slope development is on average slower than the initial ten to twenty years of adjustment after 1954.

The projected future changes in these areas of shore are expected to be of a similar episodic nature to the last twenty years, but rates of erosion are likely to slow as the backshore develops to more stable slope angles with regard to the sediment composition.

5.2.6 Stable shores and areas of existing shore protection

Stable shores are essentially adjusted to the operating range and lacustrine processes to an extent where variability in the beach and shore is a dynamic adjustment to short-term changes in the lake level and wave energy. The backshore is stable and usually vegetated. Minor, although measurable changes to the beach and nearshore shelf are of the same character as would occur on the natural lakeshore, although extended over the wider elevation range of the TekPS operating regime.

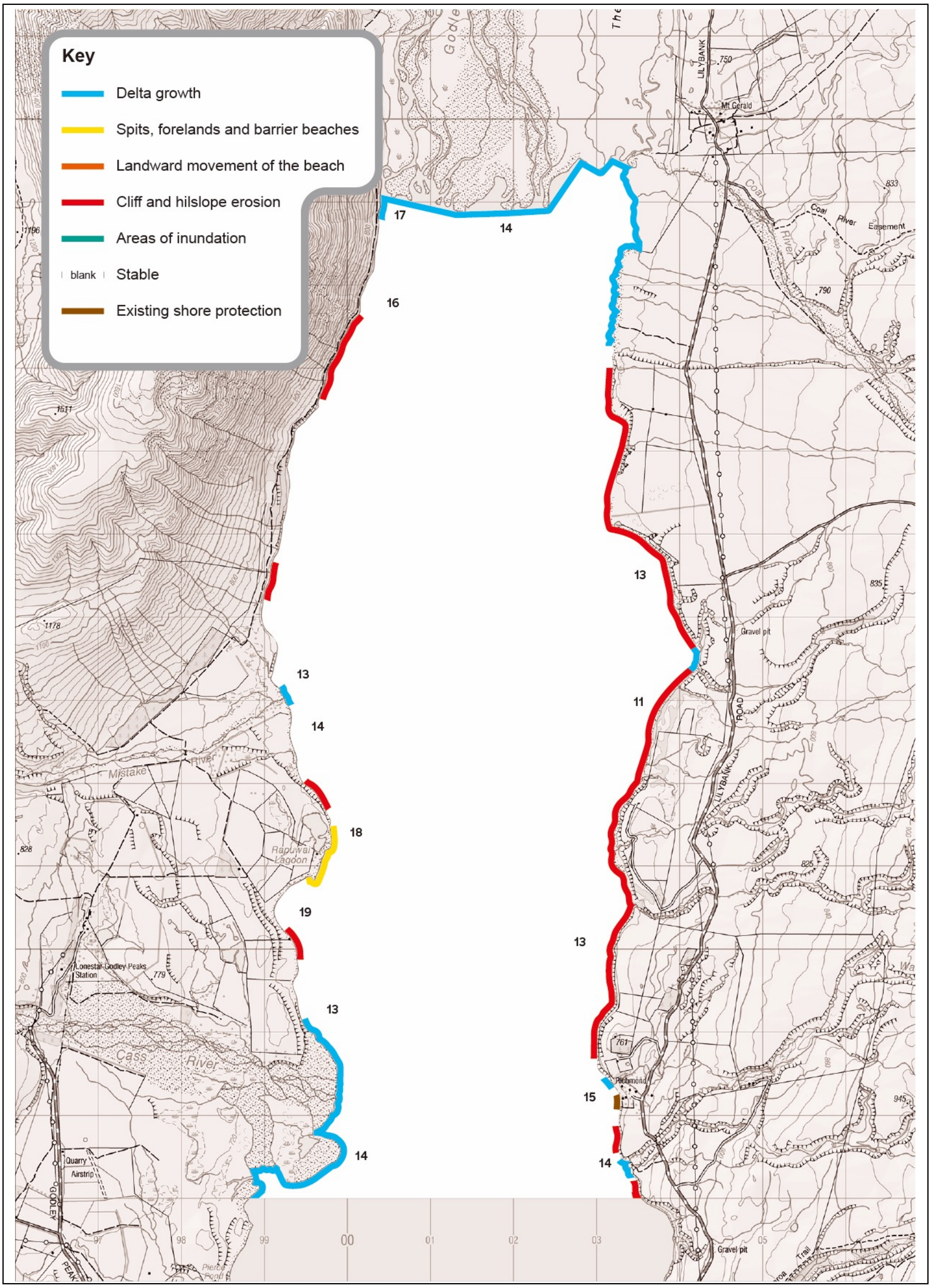

Figure 5.1 Northern section of Lake Tekapo showing sites indicative of potential effect of proposed lake level regime. Numbering relates to site numbers in Table 5.1 (base map from NZTopo50-BY17 Lake Tekapo, with the shoreline at 710 m amsl)

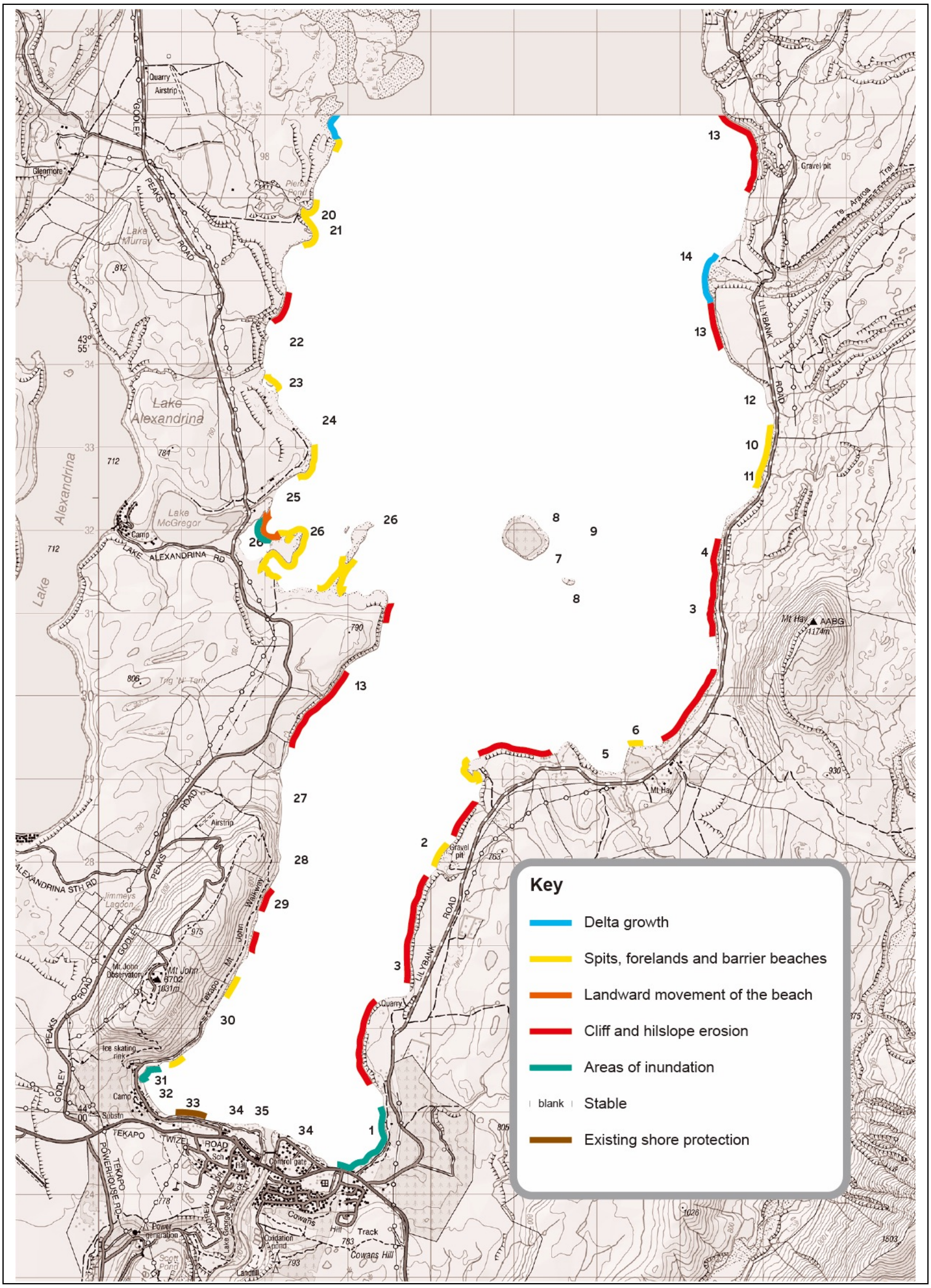

Figure 5.2 Southern section of Lake Tekapo showing sites indicative of potential effect of proposed lake level regime. Numbering relates to site numbers in Table 5.1 (base map from NZTopo50-BY17 Lake Tekapo, with the shoreline at 710 m amsl)

Extreme lake levels (over 711 m amsl) may lead to change to the backshore. Where the backshore slope is steep, there may be erosion of the base of the slope. However, on lower sloped backshores, or for barrier beaches, the change may be landward movement of the beach crest and deposition of sediments onto the backshore vegetation. These are characteristic lakeshore changes during flood conditions in combination with wave energy.

There are two sites where shore protection has been constructed. One site is along the southern shore adjacent to the TekPS intake structure (site number 33 on Figure 5.2). The shore protection is a rock revetment extending approximately 100 m to the west and 250 m to the east from the intake. The western part of the revetment covers the active beach to above the limit of wave run-up at the maximum operating level. The eastern part of the revetment is visible only on the upper shore but is present along the shore from the intake structure to a secondary structure to the east as shown in Figure 5.3.

Figure 5.3 TekPS structures and shore protection along the southern shore of Lake Tekapo (lake level approximately 707 m amsl)

The second location of shore protection is at Richmond Station on the eastern shore of the lake (site number 15 on Figure 5.1) shown in Figure 5.4. The shore protection is a revetment of loose rock. A farm building is present in this location on an aerial photograph from 1954. Although the date of construction of the revetment is unknown, aerial photograph analysis shows erosion of the shore in this vicinity between 1986 and 2006, but no change since 2006.

Figure 5.4 Shore protection at Richmond Station (lake level approximately 707 m amsl)

It is projected that there will be no change to the shores protected by structures under the future operation of the TekPS.

5.2.7 Potential effects of high and low lake levels

Single (2013a) identified potential hazards associated with high water levels that occurred during January 2013. Assessment of potential effects of high and low lake levels is based on theoretical process response relationships for lacustrine physical shore processes and field observations around Lake Tekapo.

In January 2013, the water level was within 100 mm of 710 m amsl for a period of about nine days. There were no high-energy wave events over this time, but breaking waves of less than 0.3 m high were present on the eastern and southern shore for some of the time. The shore appeared adjusted to the water level near the top of the operating range. Inundation in low-lying areas of the vegetated shore did not have long-term detrimental effects on the lakeshore geomorphology.

Generally, longer periods at high water levels (above 710 m amsl) would present greater potential for high-energy waves to occur coincident with a high-water level. This could contribute to additional erosion of the shore at elevations above 712 m amsl, as there will be potential for an increase in wave erosion events that affect the shore at an elevation of 711 to 712 m amsl. This means that around the shore, a band of shoreline including cliff faces could potentially be worked on by waves or wave run-up that has been hitherto subject only to subaerial processes and rare wave events.

The shore response to high water levels will vary around the shoreline due to differences in backshore topography, sediment character of the backshore and materials within cliffs, and the wave energy arriving at the shore. It is likely that erosion will continue to be episodic and after erosion of cliffs, the shore may be protected for some time by sediment deposited onto the beach from the cliff face.

Where erosion presents a potential hazard to shore assets and resource use at present, there is potential for the hazard to manifest sooner. This is because the higher likelihood of wave events occurring at high water levels means there is potential for retreat of the backshore and bluffs to occur more quickly than under the existing water level regime.

Areas where inundation is a hazard will become more susceptible to this hazard, it will occur more often, and is likely to have a more visible effect on the vegetation in low-lying areas.

Low water levels can result in changes to the beach profile at the edge of the nearshore shelf. Erosion events resulting from high-energy waves will cause sediment to move offshore, where it could be lost from the active profile. This is a loss from the sediment available to dissipate wave energy in the future and can lead to continued erosion of the nearshore shelf. As a consequence, at higher water levels waves will lose less energy from shoaling across the nearshore shelf and be larger when they break. This means there is potential for erosion of the upper beach for development of an equilibrium profile to the wave environment.

There are two further potential effects of low water levels. The first is that there will be more rocks and submarine projections near the surface, presenting a hazard to boating. The second is that there is potential for fine sediment deposited on the Godley and Cass River deltas to dry out and be available to as a source of sediment for wind conditions that could contribute to dust events, albeit not to any significant extent.

5.2.8 Effects on structures and land-use at the shore

Figures 5.1 and 5.2 present an assessment of the projected effects on the physical lakeshore environment of the continued operation of the TekPS under the existing operating regime and similar water level excursions as have occurred since 2011 (Figure 2.15).

It is likely that projected effects will be of the same character as historical effects identified from field observations. Examples of such areas are presented in Table 5.1. Areas where a threshold change in the geomorphological development of the shore is possible are also highlighted, identified and described in Table 5.1, with the site of such a change noted on Figure 5.1 or 5.2.

Table 5.1 Shoreline observations and projected future effects of the TekPS operation on lakeshore resource use (site numbers relate to Figures 5.1 and 5.2, starting from the southeast corner of the lake and going generally counter-clockwise)

Site Number	Shore Description	Projected future effects of TekPS
1	Low-lying, with large trees, picnic area and walking/cycling tracks	Regular inundation of land below 711 m, and occasional inundation of land between 711 to 712 m No change to current character of area
2	Gravel pits between shore and road	Potential for erosion due to groundwater flow from pit to shore No change to current character of area
3	Cliffs within ~50 m of road, gravel beach	Ongoing episodic erosion of cliff at slow rate No hazard to the road No change to current character of area
4	Cliffs within ~50 m of road, rock at base	Probably stable, but winnowing of fine sediments from wave splash at high lake levels may lead to slope instability No change to current character of area
5	Fine gravel beach with willow trees near top of main operating range	Additional sediment to beach due to alongshore transport from the north No change to current character of area
6	Barrier beach with low, swampy area to landward	Slow landward movement of barrier, reduction in size of swampy area Inundation of low-lying swamp area at high lake level No change to current character of area

Site Number	Shore Description	Projected future effects of TekPS
7	Beach scattered with large rocks and backed by pine trees	Continued erosion of backshore at high lake levels, addition of gravels to beach and loss of fine sediments from the nearshore shelf No change to current character of area
8	Trees and scrub at low elevation, low-lying wide beach	No change to current character of area
9	Rock hazards to boats	Boating hazard at higher levels when rocks are partially covered No change to current character of area
10	Road close to cliff edge but at high elevation	Ongoing episodic erosion of cliff at slow rate, offset by sediment contribution to the beach from Boundary Stream and adjacent streams Possible long-term hazard to Lilybank Road No change to current character of the area
11	Steep hillslope near stream mouth	Ongoing episodic erosion of cliff at slow rate, offset by sediment contribution to the beach from Boundary Stream and adjacent streams No change to current character of the area
12	Perched barrier beach and low-lying hinterland	Slow landward movement and increased height of barrier beach Occasional inundation of hinterland No change to current character of the area
13	Active cliff erosion, with cliffs >5 m high	Ongoing episodic erosion of cliff at slow rate Occasional re-activation of cliff erosion where presently stable Supply of sediment to alongshore transport No change to current character of the area
14	River fan and low-lying delta	Continued deposition of sediment at stream/river mouth, growth of delta/fan and supply of sediment for alongshore transport by waves No change to current character of the area
15	Richmond Station – rock structure lakeward of farm building; “Folly” near top of operating range	Potential for wave run-up to small building (“Folly”) Ongoing potential for erosion around base of revetment No change to current character of the area

Site Number	Shore Description	Projected future effects of TekPS
16	Road on steep hillslope with numerous slips; fractured rock basement and hard, rock cliff	Ongoing hillslope erosion, gullying and slumping Potential earthquake landslip hazard to road and impulse wave generation in Lake Tekapo Ongoing slow removal of sediment at base of active slips No change to current character of the area
17	Hillslope failure undercut by lacustrine processes	Ongoing hillslope erosion, gullying and slumping Potential earthquake landslip hazard to road and impulse wave generation in Lake Tekapo Ongoing removal of sediment at base of active slips during southerly wave conditions and potential hazard to Godley Peaks Road Continued delta accumulation from the Godley River No change to current character of the area
18	Rapawai Lagoon behind low barrier beach ridge	Slow landward movement of barrier beach Occasional flooding of lagoon No change to current character of the area
19	Low-lying farmland	Beach at elevation nearly equal to elevation of lower slopes of farmland No change to current character of the area
20	Pierces Pond situated behind low barrier beach	Slow increase in barrier beach height and width due to continued sediment supply from the shore to the north No change to current character of the area
21	Shoaling gravel and sand deposits at about 706 m elevation	Area will continue to shoal due to alongshore transport of sediment from the north, with an increase in the elevation of shoal surface Medium to long-term hazard to boating No change to current character of the area
22	Gravel beach at base of stable cliff – concrete bunker at limit of wave run-up	Continued beach development due to alongshore sediment transport from south and north Occasional inundation of old building in flood events (over 711 m amsl) No change to current character of the area
23	New houses on terrace above active beach ~725 m terrace elevation, with access road on lower terrace ~ 718 m elevation	Continued beach development due to alongshore sediment transport from south and north No change to current character of the area

Site Number	Shore Description	Projected future effects of TekPS
24	Gravel beach at base of stable cliff and house on high terrace ~720 – 725 m elevation	Continued beach development due to alongshore sediment transport from south and north Possible increase in elevation of top of beach with foreland accumulation of sediment No change to current character of the area
25	Low-lying channel mouth from Lake McGregor with willow trees on banks	Continued occasional inundation of low-lying channel Growth of beach due to accumulation of sediment from alongshore transport, and landward movement of the barrier beach *Possible enhancement of existing processes of change due to sediment pulses arriving at this section of shore*
26	Low-lying flat area with mobile barrier beach fed by gravels from south and north	Continued mobility of barrier beach gravels and growth of tombolo landforms joining high lake level shore to outlying high paleo-ridge lines Continued slow movement of barrier beach towards Godley Peaks Road Potential for occasional inundation of informal camping area lakeward of Godley Peaks Road Ongoing boating hazard by extended area of shoaling around islands at high lake levels *Possible enhancement of existing processes of change due to sediment pulses arriving at this section of shore*
27	Rock outcrops along eroding cliffs in Mt John Formation gravels and base rock, with stream channels to lake	Mainly stable shoreline, with some alongshore transport of gravels from north to south No change to current character of the area
28	Very fractured and erodible rock cliff	Continued slow episodic erosion of the cliff backshore with periods of stability when the base of the cliff is protected from waves by accumulations of beach sediments No change to current character of the area
29	Mt John Observatory walkway within 10 m of cliff edge	Continued episodic erosion of cliff Threat to walkway stability and short to medium-term to users of the walkway due to close proximity of cliff No change to current character of the area

Site Number	Shore Description	Projected future effects of TekPS
30	Northern end of 4WD track along southwestern shore	Ongoing episodic erosion and inundation of low-lying land at the end of track Areas of sediment accumulations due to alongshore sediment transport from the north No change to current character of the area
31	Low-lying swampy area lakeward of car park	Regular inundation of land below 711 m, and occasional inundation of land between 711 to 712 m No change to current character of area
32	Boat ramp on gravel beach	Ongoing intermittent sediment movement across ramp requiring maintenance removal for boat launching No change to current character of area
33	Lake Tekapo Intake Structure and revetment along length of shore	Placed rock revetment structure with mobile gravels along lakeward edge No change to current character of area Ongoing maintenance of structure at base and ends due to undermining by abrasion and loss of fine sediments, and end effect on the structure of waves at lake levels above 709 m amsl respectively
34	Large rocks on upper foreshore below the developed hinterland	Stable shore, subject to inundation at high operating range No change to current character of area
35	Beach ridges at limit of old high water events ~712 m elevation	Beach ridge deposits in the backshore that indicate the limit of high lake level events and extreme wave processes No change to current character of area

5.3 Climate change

Apart from climate change effects that modify demand for electricity, there are two aspects of projected climate change that are directly relevant to the effects of the TekPS operation on the physical lakeshore processes. The first is changes in the inflow regime, including changes in total inflows and seasonality of rainfall. The second aspect of climate change is changes in the wind environment.

The Ministry for the Environment *Climate Change Projections for New Zealand* (2018) states that there will be warmer temperatures throughout the country, wetter conditions in the west and south, drier conditions in the east and north, and heavier rain events. There will also be reduced glacier volumes and higher snowlines. There are also likely to be more north-easterly winds during the summer and autumn, and stronger westerly winds during spring. It is likely that higher wind speeds are prevalent during the equinox periods as with present conditions.

Modelling of the hydro-power generation potential with projected future climates by NIWA (Collins *et al.* 2020) found that lake inflows during low flow conditions would be slightly higher during winter/spring and slightly lower during summer by mid 21st Century. High inflows would slightly increase in volume during winter/spring and remain about the same during summer by mid 21st Century. However, they note that there is a high degree of uncertainty of climate change effects on inflows, and that most effects would be "relatively inconsequential over the next 35 years".

The effect of climate change on windiness and wave generation has been assessed with regard to changes in wave energy, the direction of wave approach to the shore and subsequent shoreline exposure to waves. Increased wind speeds and duration of wind events are unlikely to result in higher waves on Lake Tekapo as wave height is limited due to the fetch length for the dominant wind direction. A projected increase in easterly and south-easterly wind conditions could result in slightly higher waves on the western shore, but breaking wave heights are unlikely to be more than a few centimetres higher than present conditions.

A change in the temporal distribution of wind events and higher energy waves through the year due to climate change has potential to result in changes to the shore processes due to the coincidence of the waves with different lake levels to historical occurrences. However, the current seasonal maximum limits in the operating regime will not change so any climate change effects will be within current bounds.

5.4 Summary of effects of continued TekPS operation

The projected effects on the physical shoreline processes on Lake Tekapo of continued operation of the TekPS under the current operating regime are likely to be of the same character and order of magnitude as in the existing environment. The lakeshore has not reached an equilibrium state regarding the extended operating range since 1952. Near vertical cliffs and steep unstable slopes forming the backshore of much of the shoreline are a result of the "cut and fill" adjustment as waves at higher water levels erode sediment from the backshore, and a nearshore shelf develops over which wave energy is subsequently dissipated. Alongshore transport of eroded sediment has resulted in accumulation shoreline landforms such as barrier beaches, spits and forelands.

The process of shore adjustment to the "new" water level and wave environment is episodic, slow and ongoing. However, much of the shore exhibits a near-equilibrium state. The beach form adjusts dynamically to short-term changes in the process environment, while the position of the beach and shoreline is stable over the medium term (five to twenty years) but moves predominantly landward in the long-term.

The dynamic equilibrium, form and character of the shore with regard to the beach and nearshore shelf therefore sits lakeward of the slowly, but episodically changing backshore. As the backshore slopes erode and become less steep, they will become more stable. This occurs sooner on low antecedent slopes than on steep slopes. Protection of the backshore from wave erosion is provided where sediment eroded from the backshore contributes to the beach. Because of the wide range of antecedent slopes and sediment composition of the backshore, and the episodic nature of erosional events relating to the coincidence of erosive waves with high lake levels, the rate of shoreline adjustment to reach full equilibrium cannot be determined with confidence.

Therefore, the effects of the continued operation of the TekPS on the Lake Tekapo physical shore processes are as follows:

- Continued but episodic erosion of currently eroding cliffs,
- Continued alongshore transport of sediment from fluvial source (rivers and streams) and backshore erosion,
- Slow landward movement and elevation of barrier beaches, and
- Continued inundation of low-lying land and river and stream mouths at high lake levels.

Existing erosion and cliff top retreat of the lakeshore hinterland adjacent to a section of the Mt John Observatory walkway and erosion adjacent to a short section of Lilybank Road respectively require consideration of mitigation and management over the projected consented time-frame.

Projected climate change with higher inflows in spring and autumn but lower inflows in summer may result in greater coincidence of high lake levels with strong equinox wind events from the northwest quarter. The seasonal staging of maximum water levels in the operating regime was designed to mitigate or avoid these types of conditions, and so there is unlikely to be any increase in erosion due to climate change effects.

The character of the shore is likely to be unchanged with regards to those areas that are eroding, those areas susceptible to inundation and those areas where sediment deposition and accretion occur. The character of the low-lying areas subject to encroachment by sediment from alongshore transport (around the Lake McGregor inflow channel and the southwestern section of the lakeshore) is likely to continue to change with increases to the gravel component of sediments on the nearshore shelf exposed at low lake levels, and development of barrier beach ridges at the limit of wave runup.

6. Discussion and Conclusions

This report presents a description of the physical shoreline of Lake Tekapo and the effects of the existing TekPS lake level operating regime on the shore processes including shoreline development after extension of the lake level range in 1954, and the ongoing lacustrine processes of waves and lake level variability that result in change to the beaches. The report identifies and describes shore types and provides an assessment of erosion of the shoreline. The effects of lake level management on shoreline processes and infrastructure such as roads and recreation and TekPS structures are mapped and described.

The description of the existing physical shore environment provides a basis for assessing the projected future effects of continued operation of the TekPS with regard to shoreline change and how it relates to lakeshore infrastructure, private property and resource use.

Extension of the lake level range since 1954 has resulted in erosion of the hinterland backshore composed of hillslope, moraine and fluvial deposits. The eroded material was deposited onto nearshore shelf, provided sediment for the coarse sand and gravel beaches, and was supplied to the strong north-south and south -north alongshore transport systems.

Retreat of the steeper hinterland backshore resulted in near vertical cliffs, where the steep slope of the cliff was maintained by episodic wave action eroding the base of the slope during periods of high lake levels. Subaerial weathering has also slowly resulted in the retreat of the top of the slope towards a “relaxed” angle of repose with regard to the size range of the sediments.

The different backshore deposits present different sediment characteristics, with fluvial and hillslope deposits containing a narrow range of gravels and sand with some larger cobbles and boulders, and moraine deposits having a mix of fine sediments through to large boulders. These different deposits present different contributions to the shore. Fine sediments are lost to deeper water through suspension. Large boulders and cobbles and very coarse gravel, unable to be moved by wave action, remain in-situ, or move downslope due to gravity. Sands and gravels able to be moved by waves and currents on the beach and nearshore, are transported on and offshore and alongshore.

Fluvial and hillslope deposits dominate the shore sediments. The Godley and Cass Rivers in particular have large sediment loads that contribute to the beaches. Alongshore transport by waves and nearshore currents moves this sediment away from the source locations of river and stream mouths and areas of backshore erosion. As a result, the lake has a near-continuous gravel and sand foreshore. Coarser gravels and cobbles mantle the nearshore shelf and are covered by finer sediment moved offshore by waves and in suspension. The operational lake level range between 704.5 m to 710 m results in the nearshore shelf being exposed at low levels, and gravels are moved on the shelf by wave action at these times.

Changes in the alongshore energy flux occur as a result of the plan-view shape of the shoreline. Where the energy for alongshore transport of sediment drops, sediment is deposited, forming spits and forelands, barrier beaches, and pocket beaches. These depositional shore features are evolving and growing due to the long-term supply of sediment from updrift.

The controlled water level regime contributes to the episodic nature of erosion where both high lake levels and wave energy are required to erode the base of backshore slopes ,and to deposit beach sediments to the top, and over barrier beach ridges. Low lake levels do not occur very often but can erode sediment from the nearshore shelf and take sediment offshore to deep water and out of the beach system.

Under the current operating regime, there have been very few occurrences of low lake levels, with the lake level not having been below 704 m since 2007. There have also been few high level occurrences in the last thirty years (see Figure 2.14). This has resulted in stable areas of backshore, where the beach protects the base of the backshore. However, there are sections of cliffed shore where the base of the cliff is at or below 710 m amsl, and there is only a narrow beach to dissipate wave energy. These cliffs are actively retreating (sites numbered 13 on

Figures 5.1 and 5.2). Subaerial weathering is an additional cause of erosion of steep cliffs and is part of the ongoing process of shore development.

Based on the historical development of the shore of Lake Tekapo to the controlled lake level regime since 1952, and the relatively slow rates of ongoing change, and evidence of stability for much of the shore, it is projected that the effects of continued TekPS operation will not change the physical shoreline processes from those observed over the period of the current consents and operating regime. The current operating regime and seasonal variations in the consented operating range are appropriate in managing adverse effects of the geomorphological development of the shore.

There is an existing hazard to use of the lakeshore hinterland along the northern section of the Mt John walkway due to erosion and retreat of the cliff top. A short stretch of Lilybank Road (site number 4 on Figure 5.2) may be subject to hazard due to erosion in the medium to long-term and may require consideration of management options within the next 35 years. However, neither of these situations warrant changes to the lake level operational regime for the TekPS.

Based on projections of climate change on inflows to Lake Tekapo and the local wind environment, any changes are not likely to cause additional or adverse effects on the physical shoreline processes through to the mid 21st Century. Other climate change effects on the local weather such as rainfall intensity and the temperature range are unlikely to require changes to the operational regime of the TekPS.

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