Coastal Otago flood event
3 June 2015

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Overview

A low-pressure system to the southeast of the South Island brought heavy rainfall to coastal Otago on 3 June 2015. This report summarises that rainfall event, the observed river flows and water levels that resulted from the rainfall, and describes the Otago Regional Council's (ORC) response to the situation. The situation is compared with previously observed events, including April 1923, March 1929[1], and April 2006.[2,3] The report includes details of the effects on South Dunedin and the relationships between sea level, rainfall, groundwater and surface-water levels.

Although the highest-rainfall totals were observed in and around the Dunedin City urban area, the event was reasonably widespread, also affecting the Waitaki, Clutha and Central Otago districts. In Dunedin, the rainfall totals were reasonably uniform across the main urban area. This pattern was not evident in other recent rainfall events where heavy falls generally occurred in the hilly areas around the city. The 1-day rainfall total at Musselburgh (142mm) was the 2nd highest since records began in 1918, and is currently estimated to have a return period of 63 years. Such an event has a 27% chance of occurring in any 20-year period, a 55% chance of occurring in any 50-year period and an 80% chance of occurring in any 100-year period. Elsewhere across the city, the estimated return period for 1-day rainfall totals ranged from 18 years (Dunedin Airport) to 50 years (Pine Hill).

River flows generally peaked in the late evening of 3 June. There were no major flooding issues directly attributable to high-river flows, although Lindsay Creek (at Palmers Quarry) and Silver Stream (at the Gordon Road spillway) both overtopped their banks, and part of Henley was flooded. However, the widespread, persistent rainfall resulted in significant flooding due to surface runoff and excess stormwater in a number of locations, including South Dunedin and many other parts of Dunedin city, Milton, part of Mosgiel and on the Clutha delta. A large number of landslides were also observed around the Dunedin City district.

Sea level peaked around the 3.30pm afternoon high tide, which was a lower-than-average spring tide. This was not the highest sea level in the month leading up to the rain event, despite the low-pressure system that crossed the region on 3 June, which resulted in a storm-tide level 0.25m higher than would have occurred under normal atmospheric conditions.

An analysis of the Silver Stream and Water of Leith flow records shows that the frequency and magnitude of flood peaks has been noticeably greater during the previous ten years (2006-2015) than during the preceding 40 years.

[1] *Flood hazard of Dunedin's urban streams*, Report prepared by the Otago Regional Council, ISBN 978-0-478-37680-7

[2] *Mosgiel Flood Event 25/26 April 2006 and future action,* Report No. 2006/689, Prepared for Otago Regional Council Policy and Resource Planning Committee, 17 November 2006

[3] *Natural Hazards on the Taieri Plains*, Report No. 2012/0897, Prepared for Otago Regional Council Engineering and Hazards Committee, 18 July 2012

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1. Introduction

On 1-2 June 2015, a low-pressure system moved slowly to the southeast across the South Island. By 3 June, the low was just east off the coast of the South Island, with three stationary fronts originating from the centre (Figure 1). The position and duration of this low-pressure system created conditions for steady, heavy rainfall in eastern Otago and inland towards Central Otago throughout the day. As a result of the rain that fell on 3 June, every coastal catchment from Oamaru south to Balclutha experienced some degree of flooding. This report summarises the rainfall, river flows and water levels recorded during the event, and Otago Regional Council's (ORC) response to the situation.

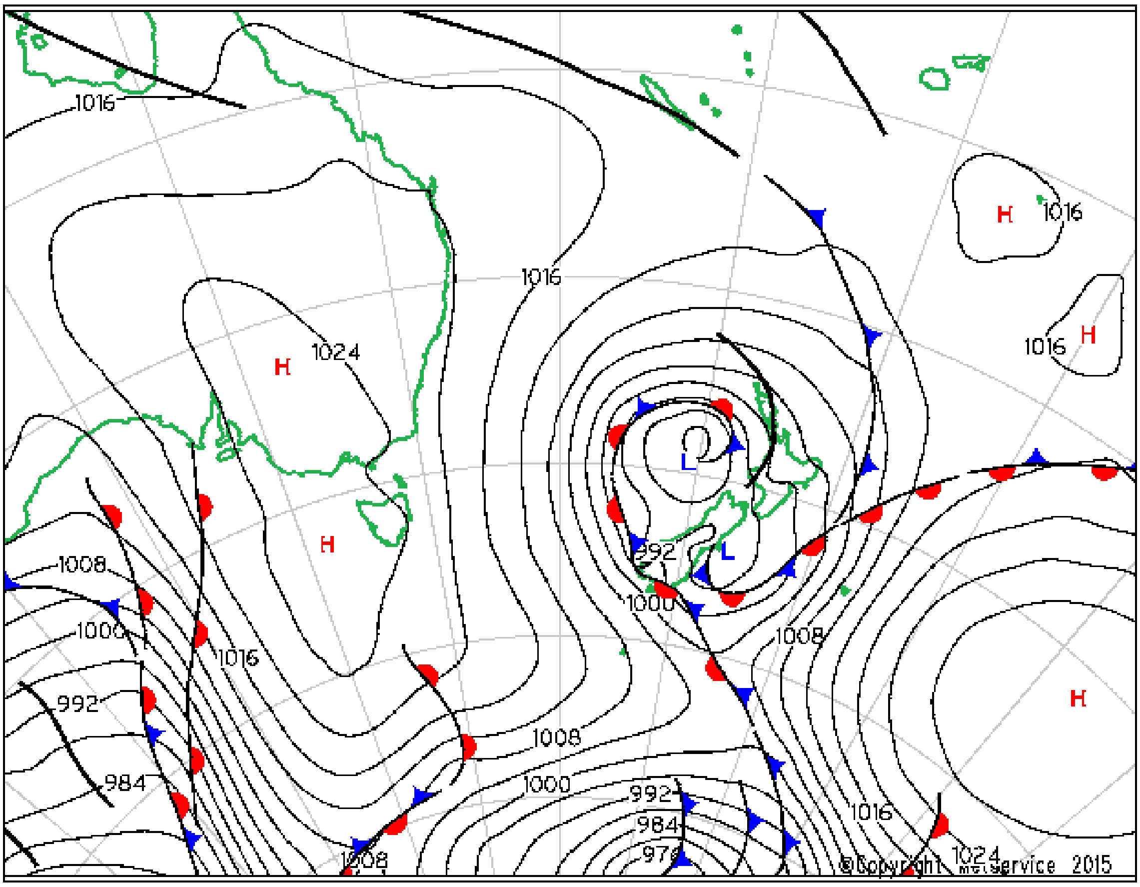

Figure 1. **Situation map for 6am on 3 June, 2015 (MetService)**

2. Weather warnings, flow advisories and territorial authority notifications

This section describes, in chronological order, the MetService weather warnings received by ORC, the changes to those warnings as the event progressed and the actions that ORC staff took to disseminate rainfall and flow advisories to territorial authorities and to the public.

2 June, 2015

A severe weather warning was issued by MetService at 9am on 2 June, predicting heavy rainfall over an 18-hour period, beginning at 6am on 3 June, and ending at midnight. The warning was for 80 to 100 mm of rainfall about the hills and ranges of Dunedin and Clutha, with 50-70 mm possible elsewhere. Peak intensities of 10 to 15 mm per hour were expected, and experience during previous events was that the heaviest intensities would occur in the ranges, with lower intensities in lower-lying areas. This warning was repeated at midday and 9pm on 2 June. On the afternoon of 2 June, the ORC Flood Manager (FM)[4] contacted the Emergency Management Officer (EMO) for the Clutha District Council (CDC) about pre-flood activities defined in the joint CDC/ORC Milton 2060 Action Plan. The MetService warning correctly predicted the onset of heavy rain, with intensities increasing noticeably between 5am and 6am on 3 June (Figure 2).

3 June, 2015: 9am until midday

At 9am on 3 June, slightly different advice was received from MetService: Predicted rainfall totals were the same, but the timing was over a 17-hour timeframe (from 9am Wednesday 3 June until 2am Thursday 4 June). By that time, about 30mm had already fallen at the Pine Hill, Sullivans Dam and Musselburgh gauges, at an intensity of 5 to 8 mm per hour. This warning did not specify whether the rain that had already fallen was additional to, or inclusive of, the predicted totals. The warning described the outlook as *'Persistent rain, heavy at times, expected to ease overnight'.* Following this updated warning, the FM made initial contact with the EMOs for the Waitaki and Dunedin City districts as to possible flood effects. At that time, the predicted rainfall totals were not expected to cause major flooding issues for rivers in coastal Otago.

3 June, 2015: Midday until evening

By late morning, observations from rain gauges across the Dunedin area, including of low-lying areas, showed ongoing rainfall of a high intensity.

Around this time, MetService also received updated results from their in-house forecasting model. Guidance in this new model run suggested that the intensities being recorded in gauges would last longer and possibly into the evening hours. This prompted the MetService forecast team to re-assess and update the warning to respond to this new information. As such, the warning issued at 12:06pm on 3 June represented a significant change from earlier warnings, as it predicted another 80 to 100 mm of rain, on top of what had already fallen, in the 14 hours until 2am Thursday. By that time, 50-60 mm of rain had already fallen across Dunedin (Figure 2), and hourly rainfall intensities had increased to between 9 and 12 mm per hour.

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[4] Because of the duration of the event, the lead FM role was assigned to a number of people throughout the event, and in many cases, the FM delegated other staff to undertake the actions listed in this section

The Otago Civil Defence and Emergency Management (CDEM) Group activated in a monitoring role. Meteorological and hydrological information were provided to the Otago Group Controller and the ORC Executive Team. The FM made telephone contact with the DCC (Dunedin City Council)'s EMO at 12:45pm, and confirmed that the rainfall intensities now predicted may result in the Silver Stream overtopping at the Gordon Road spillway. The FM was informed that the DCC Emergency Operations Centre (EOC) had been activated. Another eight telephone calls to the DCC's EOC as to predicted flows, and the likely effects of the Silver Stream, Water of Leith, Lindsay Creek and Kaikorai Stream overtopping their banks, were made between 1:39pm and 5:10pm. ORC staff carried out targeted inspections of the Water of Leith, Lindsay Creek, Kaikorai Stream, Milton and parts of the Taieri into the evening, with a focus on condition and performance of ORC flood-protection and land-drainage assets. Observations were reported back to the FM and evaluated by engineering and hazards staff. As a precautionary measure, preparations were made for the Riverside spillway to be lowered should the Taieri reach the trigger flows that have been agreed with landholders.

Between 3:15 and 3:35pm, the ORC FM engaged the autodial system to ring the Silver Stream flood warning list, the Pomahaka at Glenken 1st list and used the Twitter text alert system to notify people of high-river flows in the Clutha and Dunedin areas. The 2nd Glenken list was rung at 4:15pm. A media release was issued at 5:00pm, warning that the Silver Stream was expected to overtop at the Gordon Road spillway, and a second release at 8:30pm reiterated this message.

3 June 2015: Evening

Between 5:15 and 6:20pm, further high-flow advisories using the autodial system were issued for the Kakanui and Taieri rivers (first time), Silver Stream and Pomahaka rivers (again), and Twitter was used to notify people of high-river flows in the Clutha and Dunedin areas (again) and the North Otago and Taieri areas (first time). A telephone call was made to the Central Otago District Council's (CODC) EMO at 7:40pm to discuss possible high-river levels in Central Otago, particularly in the Manuherikia Valley. The Otago Group Controller and ORC Executive Management Team continued to be updated on the situation.

At 8:27pm, staff became aware that the autodial system was not working correctly (i.e. that the autodial campaigns were running very slowly and were not getting through the ring lists in a timely manner). The FM immediately updated all the Twitter text alert feeds. Attempts were made to remedy the autodial system during the evening, but it continued to run slowly. The FM also arranged for ring lists to be contacted manually, and this occurred between 8:52pm and 10:50pm.

The last MetService warning for this event was at 9pm on 3 June, predicting another 30 to 40 mm of rain in the Dunedin and Clutha area, concluding at 2am on 4 June. The actual total for this period was about 20 mm. Rainfall intensities did reduce after 2am, with light rain continuing until 6am. The FM and staff continued to monitor the situation overnight, including liaising with operations staff on the Taieri Plain, who monitored pump stations and conditions at the Gordon Road spillway on the Silver Stream.

4 June, 2015

The MetService severe weather warning for the Dunedin and Clutha area was lifted at 7am on 4 June. The Taieri and Clutha rivers were still high, and the FM arranged for the three Taieri at Outram, and first three Clutha at Balclutha 'ring lists' to be contacted manually, starting at 7:30am, as the autodial system was still not working reliably. The autodial system was switched off at 9:00am, and the 4th and 5th Clutha at Balclutha 'ring lists' were contacted manually at 9:30am. Further telephone calls to the CDC's EMO regarding flooding issues on the lower Clutha were made throughout the day.

The autodial fault occurred as a result of a bug in the system software that the supplier has since resolved. It is noted that the provision of advisories by way of the autodial system was envisaged to be a temporary service and would cease once the Twitter alert service had been proven to be reliable.[5]

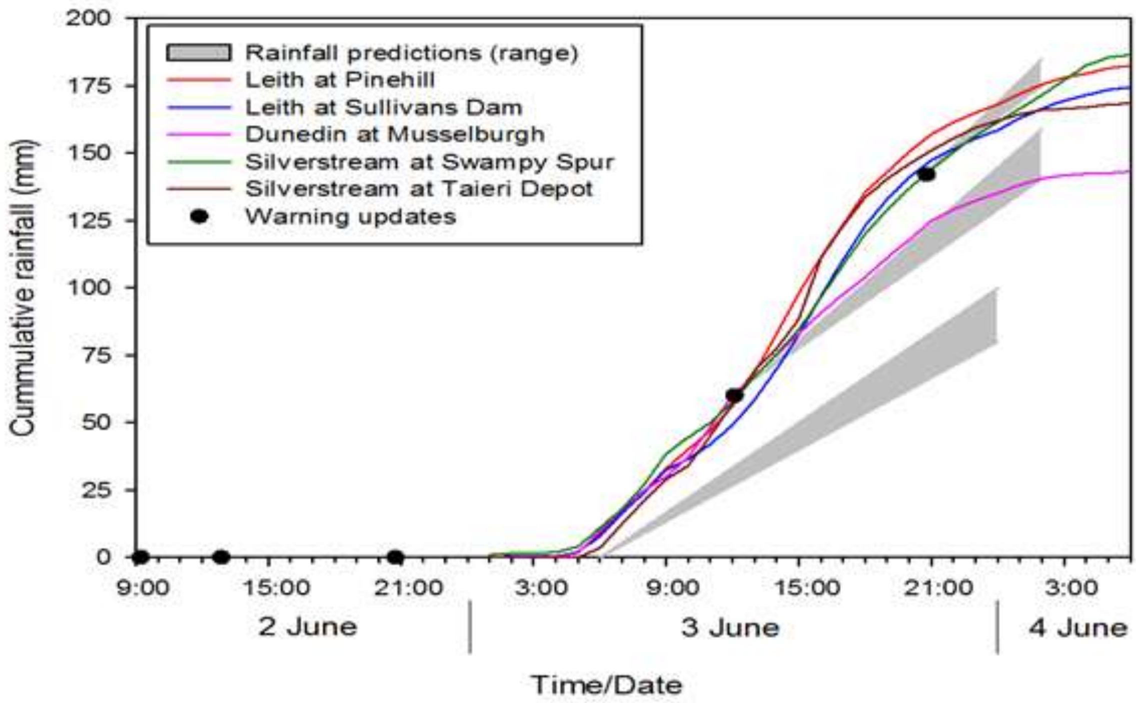

Figure 2. **Observed rainfall accumulations at rain-gauge sites around Dunedin from 9am on 2 June until 6am on 4 June (coloured lines). Predicted rainfall accumulations provided by MetService warnings are shown for comparison (grey bands), including the effect of the updated warnings as the event progressed.**

[5] *Use of the Twitter Alert Service for River and Lake Level Information in Otago*, Report No.2012/1147, Prepared for Otago Regional Council Engineering and Hazards Committee, 22 November 2012

2.1. Water info statistics and social media

The average number of visits and page views of the Water Info website per day is 500 and 3,000, respectively.[6] On 3 June 2015, there were over 10,500 visits to the site, and 123,500 page views. On the following day, visits and page views were 5,000 and 50,000, respectively. Visitors to the website during this period were mainly from Dunedin (44%), followed by Christchurch (22%) and then Auckland (20%). The flood advisories issued by ORC were collectively viewed by almost 12,000 people on Facebook.

The automated flow-phone system normally averages just over 100 calls per week. On 3 June alone, there were almost 600 calls to the system. The number of calls peaked at 100 per hour between 8pm and 10pm on 3 June.

[6] A 'visit' is when a user visits the website and views one or many pages. A 'page view' is when a user looks at any page on the website. For example, if a user goes to the site (initially the home page) and then looks at the data for five flow sites that will be six 'page views'.

3. Rainfall

3.1. Total rainfall

The highest-rainfall totals during this event were observed in close proximity to the Dunedin City urban area (Figure 3). The event was widespread, however, with rainfall also affecting the North Otago, Clutha and Central Otago areas, although observed totals were less than in Dunedin.

The rainfall totals for this event were reasonably uniform at Musselburgh, the surrounding hills and the East Taieri Plain (Figure 4 and Table 1). This pattern was not evident in other recent heavy-rainfall events in April 2006, May 2010 and June 2013, where the heaviest rainfalls occurred in the hilly areas around the city, and lighter falls occurred on the lower-lying land. To the west and southwest of Dunedin City, totals were slightly lower in the June 2015 event, but also reasonably consistent (e.g. Deep Stream, Dunedin Airport and Table Hill).

Peak 1-hour and 3-hour rainfall intensities were heavier in the upper Water of Leith than at Musselburgh (Table 2 and Figure 5). The heaviest band of rain crossed the Musselburgh gauge between 10am and midday on 3 June, before pushing up into the hill catchments further west between 1pm and 5pm (Figure 5).

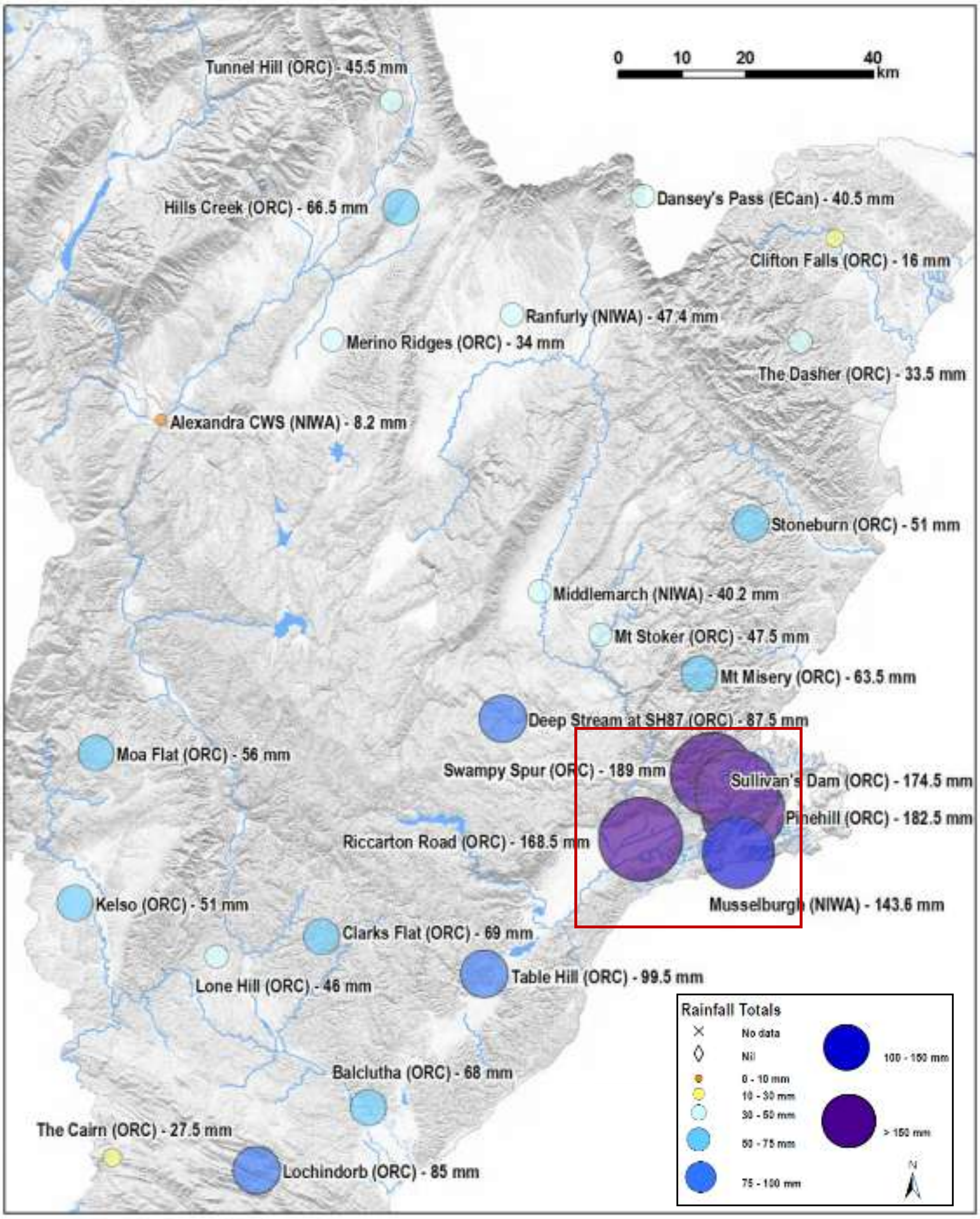

Figure 3. **Rainfall totals observed at rain gauges in coastal and Central Otago, midnight on 3 June to 6am on 4 June 2015 (30 hours). The agency responsible for each gauge is also listed. The area within the red box is shown in Figure 4. The Dunedin Airport site is not shown as this site only provides 9am (daily) readings.**

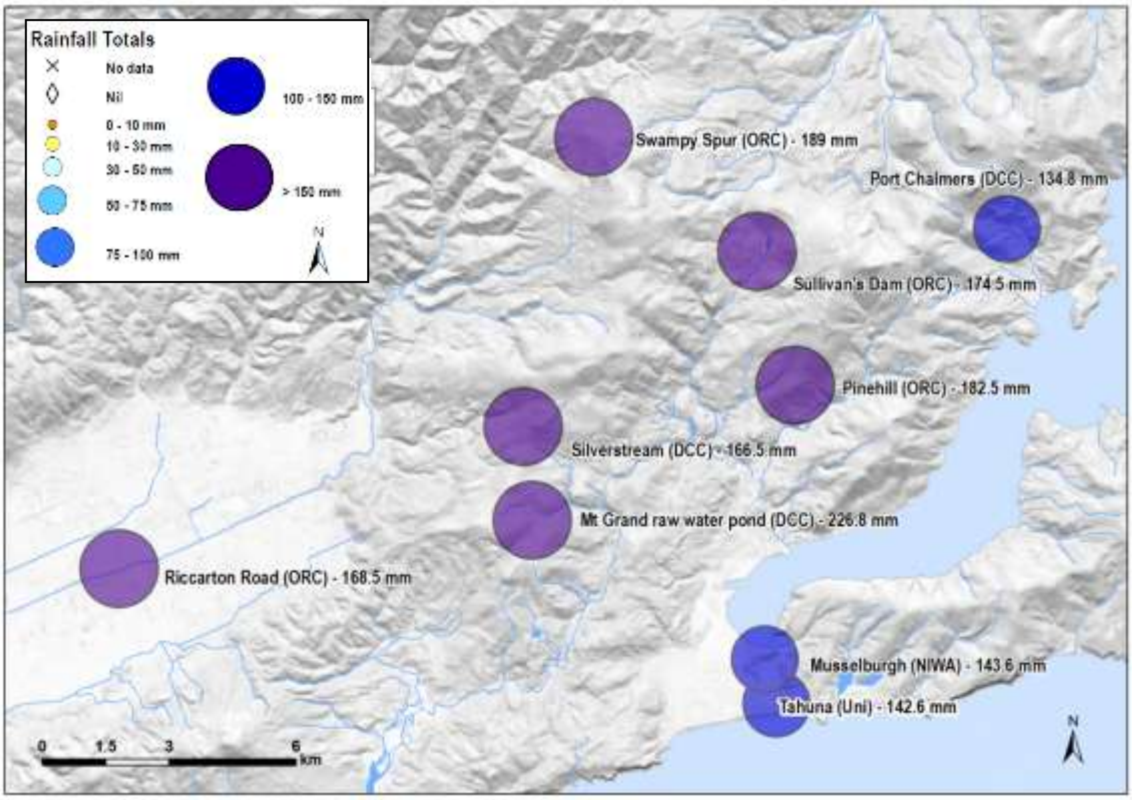

Figure 4. **Detailed map showing rainfall totals observed at gauges in and around the Dunedin City urban area, midnight on 3 June to 6am on 4 June 2015 (30 hours). The agency responsible for each gauge is also listed.**

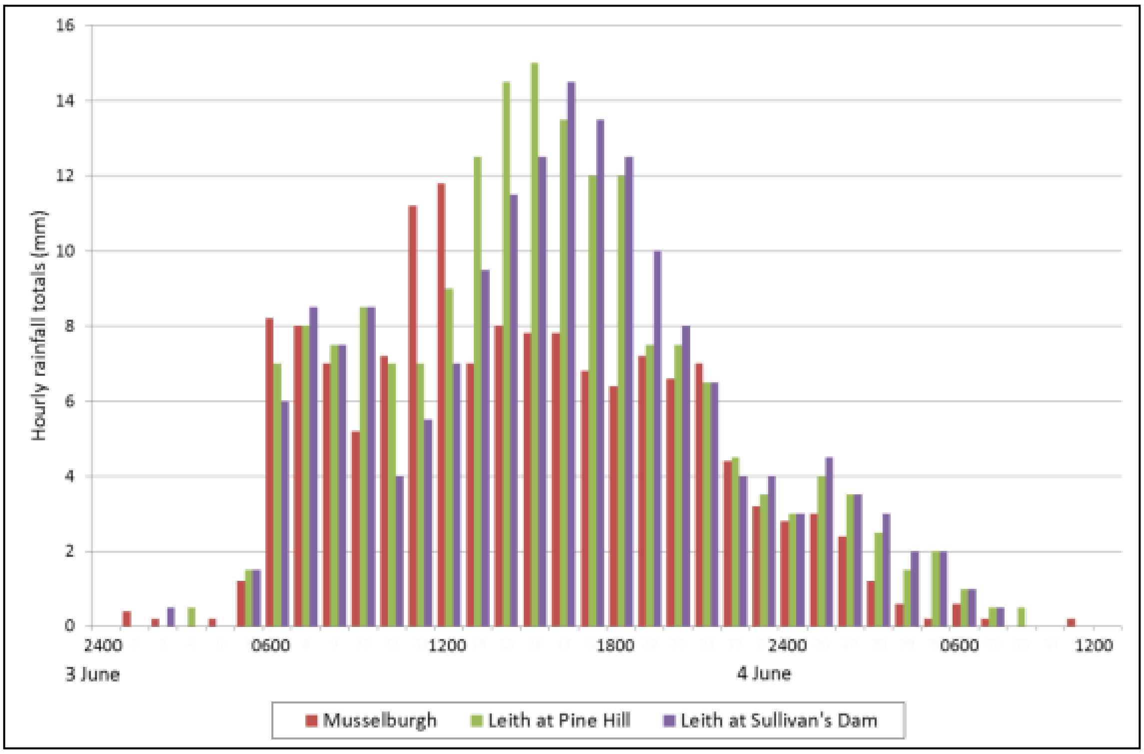

Figure 5. **Hourly rainfall totals at the Musselburgh, Pine Hill and Sullivans Dam rain gauges, midnight on 2 June 2015 until 12pm on 4 June 2015**

Table 1. 1-day rainfall totals and rankings for the 3 June 2015 event

Location (catchment)	Year daily records began	1-day rainfall (mm)	Ranking	Comments
Sullivans Dam (Water of Leith)	1967	172	3rd equal	Highest was 217.5mm in April 2006
Pine Hill (Water of Leith)	1979	180	Highest	2nd highest was 156.5mm in April 2006
Musselburgh (South Dunedin)	1918	142	2nd highest	Highest was 229mm in April 1923[7]
Swampy Spur (Silver Stream)	2007	181.5	Highest	2nd highest was 164mm in May 2010
Riccarton Road (Silver Stream)	1988	168	Highest	2nd highest was 164.5mm in April 2006
Deep Stream (Taieri)	1993	87.5	Highest	2nd highest was 85.5mm in April 2006
Dunedin Airport (Taieri)[8]	1962	86.8	2nd highest	Highest was 123mm in April 2006
Table Hill (Tokomairiro)	2011	98	Highest	2nd highest was 86mm in February 2012
Moa Flat (Pomahaka)	1988	56	10th highest	Highest was 86.5mm in February 2012

[7] During the March 1929 event (the largest flood event on record in the Leith catchment – see Section 4), 104.1mm was recorded over a 24-hour period at Musselburgh. This is the 5th highest total on record.

[8] 9am daily reading only

Table 2. **Peak 1-hour and 3-hour rainfall intensities for the 3 June 2015 event. In some cases, the length of record for which these values can be calculated is shorter than for the daily readings shown in Table 1.**

Location (catchment)	Year instantaneous records began	1-hour rainfall (mm)	Ranking	3-hour rainfall (mm)	Ranking
Sullivans Dam (Water of Leith)	2000	15.0	4th equal	41.5	2nd highest
Pine Hill (Water of Leith)	1979	16.5	5th highest	33.0	5th equal
Musselburgh (South Dunedin)	1997	11.8	6th highest	30.2	Highest
Swampy Spur (Silver Stream)	2007	12.5	6th equal	35.5	2nd highest
Riccarton Road (Silver Stream)	1988	14.5	6th equal	25.5	6th highest
Deep Stream (Taieri)	1993	13.0	18th highest	25.5	5th highest
Table Hill (Tokomairiro)	2011	9.0	6th equal	24.5	3rd highest

3.2. Rainfall probability

To understand the probability of an event of this magnitude occurring, an analysis of 24-hour rainfall totals was undertaken, and the results are shown in Table 3. Two methods were used to estimate the likelihood of the 3 June event: An event-based analysis using actual data observed at the site, and an estimate for that location derived from the HIRDS programme.[9]

[9] HIRDS - High Intensity Rainfall Design System. A program supplied by NIWA that estimates rainfall frequency at any point in New Zealand. It can be used to assess the rarity of observed-storm events.

Table 3. Estimated return periods for rainfall sites in and around Dunedin City

Site	Length of record (years)	Data type[10]	Maximum 24-hour rainfall, June 2015	Estimated return period (years)	
				Observed data	Using HIRDS
Sullivans Dam (Water of Leith)	48	Daily manual / instantaneous	172	23	30-40
Pine Hill (Water of Leith)	36	Instantaneous	180	50	100
Musselburgh (South Dunedin)	97	Daily manual / instantaneous	142	63	>100
Swampy Spur (Silver Stream)	8	Instantaneous	181.5	Insufficient data	40
Riccarton Road (Silver Stream)	27	Instantaneous	168	20	>100
Deep Stream (Taieri)	22	Instantaneous	87.5	Insufficient data	30-40
Dunedin Airport (Taieri)	53	Daily manual	86.8	18	10

The Musselburgh rain gauge has the longest continuous-rainfall record within the Dunedin area (beginning in 1918), and therefore provides the most accurate estimate of likelihood for an event of this magnitude. The analysis using observed data shows that, at the Musselburgh site, the return period of the June 2015 event is about 63 years, while the return period derived from the HIRDS programme is greater than 100 years. The June 2015 total is considerably less than the highest recorded 24-hour total (Table 1), and an event of this magnitude or greater has now occurred twice in less than 100 years. A return period of less than 100 years is therefore more credible than the estimate derived using the HIRDS programme.

The Pine Hill rain gauge has a shorter record than Musselburgh, and the June 2015 event was the highest on record (Table 1). There have now been two 24-hour events of 156.5mm or more at this site over a 36-year period, and the estimated return period for the June event (using the actual data) of 50 years is therefore realistic. The estimated return period at the Sullivans Dam rain gauge site is 23 years, which also appears reasonable, given that this is the 4th highest event over a 48-year record.

Experience shows that estimated return periods can change significantly when another large event is added to the record. The same event-based analysis (using actual data observed at the site) was repeated for the Musselburgh and Pine Hill sites, but excluding the June 2015 event from the record (i.e. as if the analysis had been undertaken just before this event). This analysis showed that the estimated return period for an event of the same magnitude as 3 June 2015 would have been 100 years or more at both the Musselburgh and Pine Hill sites.

[10] It is noted that at the Musselburgh and Sullivans Dam sites, the data used for this analysis comprises a combination of daily manual (9am) readings and 'instantaneous' (15 minute readings). The instantaneous record at these two sites began in 1997 and 2000, respectively.

4. River flows

The most significant flows were observed in Dunedin City (Water of Leith, Lindsay Creek and the Kaikorai Stream), and in the Deep Stream and Tokomairiro west branch catchments (Table 4). Peak flows in Lindsay Creek and the Water of Leith were the second and third highest, respectively, since continuous records began in 1979 and 1963.

Table 4. Maximum flows recorded at key sites in the rivers affected by flood flows during 3 and 4 June 2015. The rank is provided for peak flows, which are within the top ten observed since records began.

Site	Records began	Maximum flow (cumecs)[11]	Date/time of peak	Rank
Kakanui at Clifton Falls Bridge	Apr 1981	139	3/6 18:45	
Kauru at Ewings	Nov 1991	25	3/6 17:45	
Shag at The Grange	Oct 1989	60	3/6 40:45	
Waikouaiti at confluence	Feb 2010	64	4/6 01:50	
Leith at Leith Street	Feb 1963	100	3/6 17:50	3rd
Lindsay Creek at North Road Bridge	Oct 1979	29.2	3/6 18:25	2nd
Silver Stream at Gordon Road	Jan 1970	129	3/6 19:50	6th
Taieri at Outram	Apr 1968	745	4/6 07:30	
Deep Stream at SH87	Apr 1992	359	3/6 21:10	2nd
Nenthorn at Mt Stoker Road	Nov 1982	39	4/6 04:05	
Taieri at Sutton	Aug 1960	141	4/6 12:00	
Tokomairiro at West Branch Bridge	Dec 1981	72	3/6/20:50	5th
Pomahaka at Glenken	Jun 1992	389	3/6 20:45	6th
Pomahaka at Burkes Ford	Aug 1961	635	4/6 10:05	8th
Clutha at Balclutha	Jul 1954	1,621	4/6 09:15	

Anecdotal evidence exists of other large floods occurring in the 20th century, and the March 1929 flood, in particular, is considered to be the largest event in the Water of Leith since European settlement, with an estimated flood peak of between 200 and 250 cumecs. The ten highest estimated flood peaks in the Water of Leith since 1923 are shown in Figure 6, and this highlights that flood events experienced since 1963 have been considerably smaller than the two events in the 1920s.

[11] 1 cumec = 1 m³ of water / second

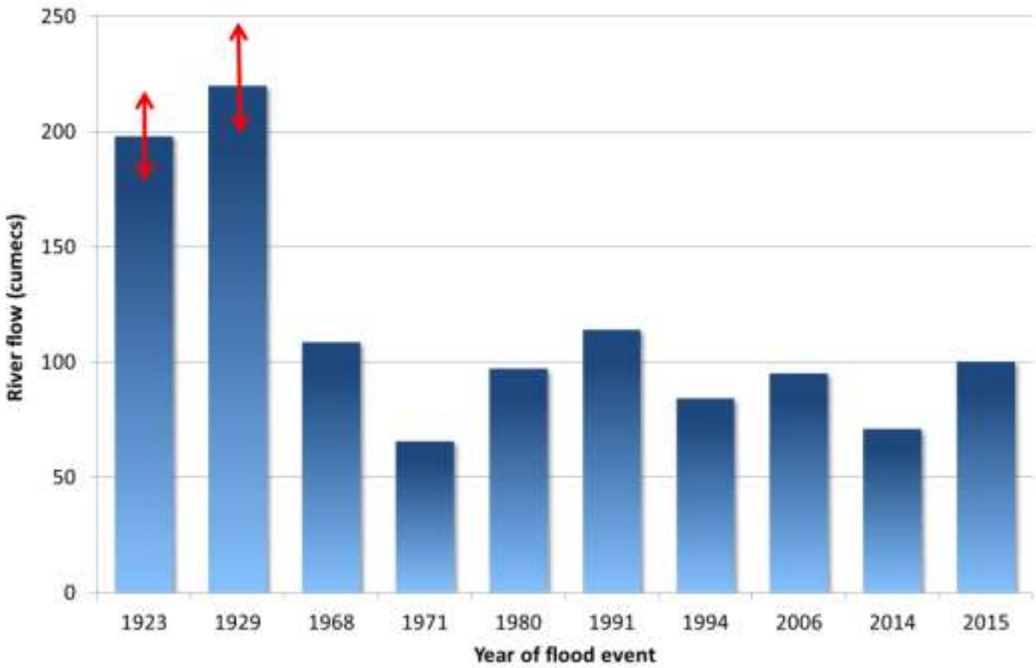

Figure 6. **Estimated flood peaks since 1923 in the Water of Leith - 10 highest flows. The accuracy of the 1923 and 1929 flood peaks is less reliable than those observed after continuous records began in 1963.**

Table 5 and Table 6 show peak flows over a certain threshold in the Water of Leith and the Silver Stream since records began.[12] These tables highlight the number of high-flow events that have occurred in the last 10-year period, compared to previous decades.

Table 5. **Peak flows (in cumecs) in the Water of Leith >60 cumecs, for 10-year periods commencing in 1965**

1965 – 1975		1976 – 1985		1986 - 1995		1996 - 2005		2006 – June 2015	
109	Mar 68	97	Jun 80	114	Feb 91			95	Apr 06
65	Jun 71			84	Mar 94			64	Jul 07
								71	Apr 14
								100	Jun 15

[12] 60 and 100 cumecs, respectively. These flows generally do not have an effect beyond the main river channel, but the river can rise quickly from here to a flow where it does start to overtop the river bank.

Table 6. Peak flows (in cumecs) in the Silver Stream >100 cumecs, for 10-year periods commencing in 1970

1970 – 1975 (6 years)		1976 – 1985		1986 - 1995		1996 - 2005		2006 – June 2015	
123	Nov 71	109	Aug 78	101	Mar 86			264	Apr 06
107	Jun 72	194	Jun 80	143	Mar 94			159	Jul 07
		108	Oct 82	106	Jul 94			116	May 10
		100	May 83					133	May 10
		110	Mar 84					107	Aug 12
								128.0	Apr 14
								127.7	Jun 15

4.1. Flow probabilities

An updated assessment of the probability of the peak flows observed on 3 June occurring has been undertaken, using the full length of continuous record. The results are shown in Table 7. The return period for the peak flow in the Water of Leith is about 30 years, although this assessment does not include the historical flood events in the 1920s that occurred before the start of continuous observations. The inclusion of these events would have the effect of reducing the estimated return period.

The estimated return period of the peak flow in the Silver Stream is 6.5 years. Observations of this event show that the Silver Stream began to overtop at the Gordon Road spillway, as discussed in Section 9.

The return-period analysis for the Taieri River at Outram and for sites in North Otago and the Clutha district shows that flow peaks of the magnitude observed on 3 June can be expected to occur quite frequently.

Table 7. Estimated return periods for key flow sites in coastal Otago

Site	Length of record (years)	Maximum flow (cumecs)	Estimated return period (years)
Kakanui at Clifton Falls	33	139	2.3
Leith at Leith Street	52	100	30[13]
Lindsay Creek at North Road Bridge	36	29	22
Silver Stream at Gordon Road	45	129	6.5
Taieri at Outram	47	745	4.3
Tokomairiro at West Branch Bridge	34	72	10
Pomahaka at Glenken	23	389	6
Clutha at Balclutha	61	1,621	2.5

[13] This assessment does not include estimates of historical flood events in the 1920s.

5. Sea level[14]

Changes naturally occur in sea level due to normal astronomical tides. Predicted tidal elevations are based on the standard barometric pressure at sea level of 1012 hPa. However, actual levels are influenced by changes in atmospheric pressure and, to some extent, by wind, with an additional wave setup at the coast when a sea-swell is running (not measured by the gauge). In general, for every decrease of 1 hPa from the average pressure, storm-tide levels increase by about 1 cm.

At 9am on 3 June, barometric pressure at the Musselburgh weather station was reported as 992.6 hPa. This is lower than standard atmospheric pressure at sea level (1012 hPa), although it is not the lowest barometric pressure observed at Musselburgh in the preceding 12 months (Figure 7).

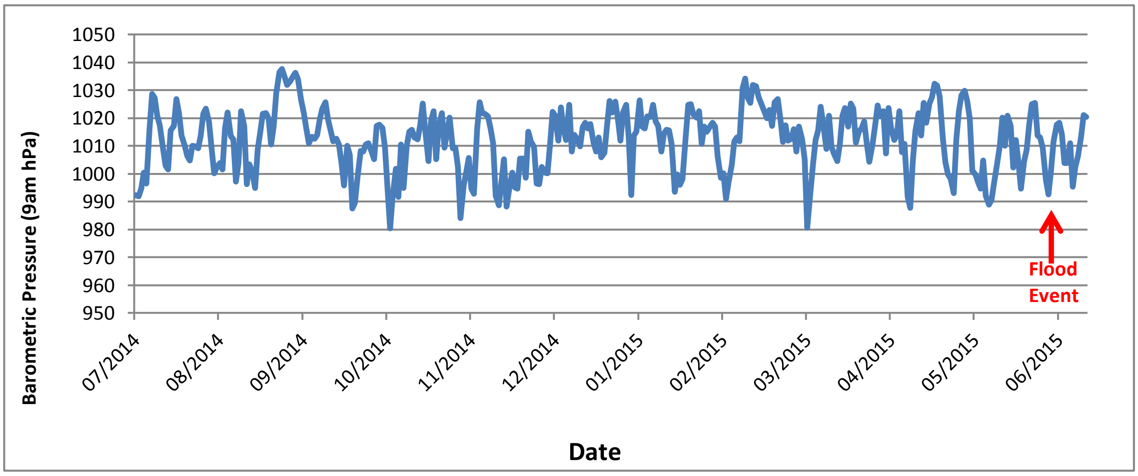

Figure 7. Barometric pressure record from Musselburgh climate station, South Dunedin

Sea level was on a natural rise, due to falling barometric pressure, leading up to the rain event, and on 3 June 2015, it reached a peak around the 3.30 pm afternoon high tide (which was a smaller-than-average spring tide). This was not the highest sea level in the month leading up to the rain event, as higher spring tides (by about 0.2 m) occurred between 15-19 May (Figure 8). The highest sea level observed at the Green Island sea-level recorder (see Figure 20 for location) since records began in 2003 was 1.77m, in May 2013.

[14] Dr Rob Bell, of NIWA, helped to prepare this section

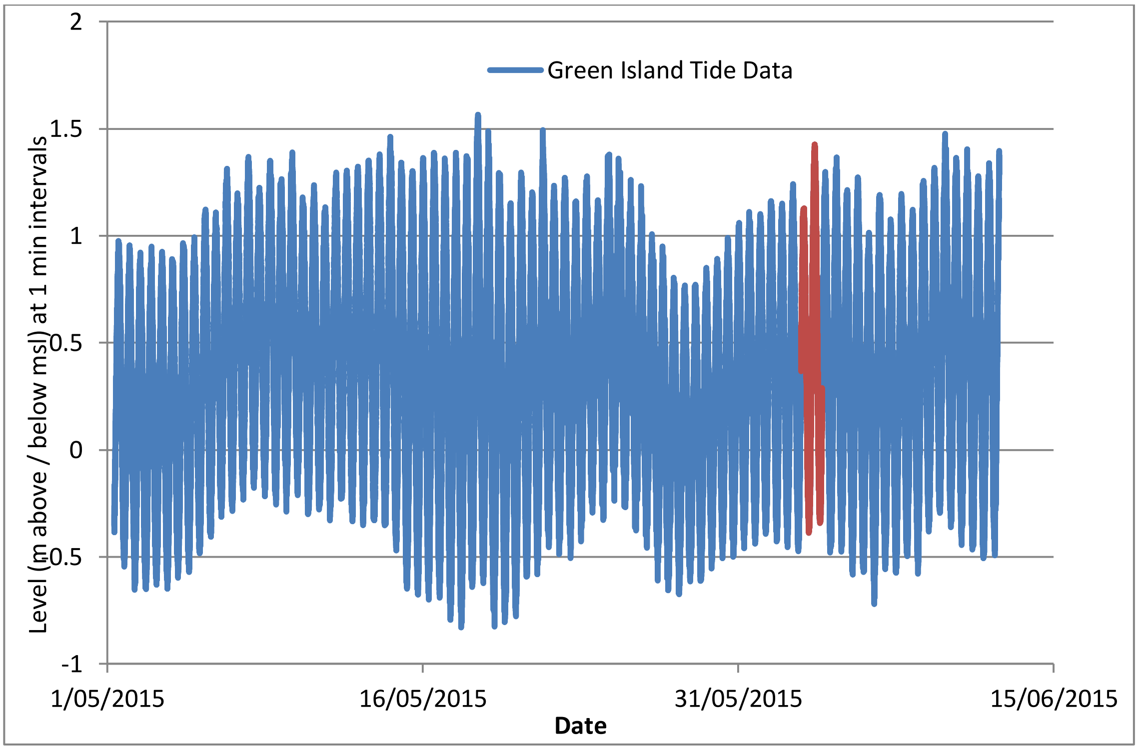

Figure 8. **Green Island tide record from 1 May 2015 to 12 June 2015**

Figure 9 shows that the actual storm-tide level (black line) at the Green Island gauge on 3 June was up to 0.25m higher than the predicted high tide, due mainly to the setup (blue line) from the low-pressure system that crossed the region (down to 989 hPa).

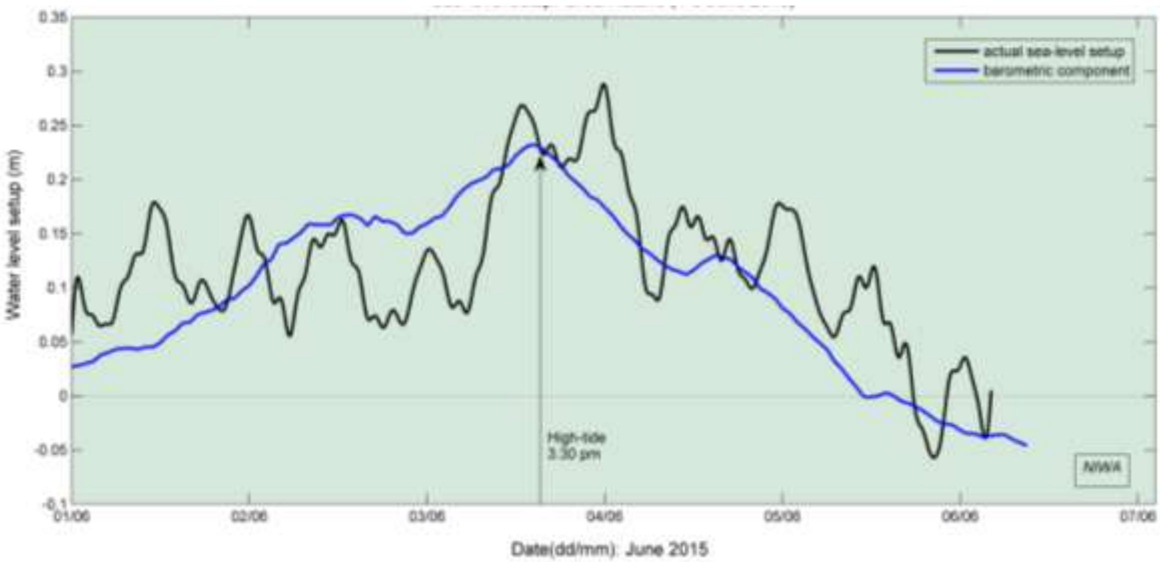

Figure 9. **Sea-level setup at Green Island (1-6 June 2015)**

6. Flooding effects – South Dunedin

The South Dunedin area was affected by widespread and prolonged flooding as a result of the rainfall that fell on 3 June, as illustrated in Figure 10 and Figure 11.

Figure 10. **View of the South Dunedin area, looking southeast from near Forbury Corner, towards Tonga Park and St Kilda. Photo taken late afternoon on 3 June 2015 (courtesy Otago Daily Times).**

Figure 11. **View of the South Dunedin area, looking northeast from Forbury Park Raceway towards Forbury. Photo taken 4 June 2015 (courtesy Otago Daily Times).**

6.1. Surface flooding

ORC staff undertook a reconnaissance trip on the morning of 4 June and observed water was still ponding across much of this area, as illustrated in Figure 12 to Figure 14. This inspection indicated that the area bounded by King Edward Street and Hillside, Prince Albert, Victoria and Forbury roads had been most affected, with little sign of inundation further east.[15] It is noted that the lowest part of South Dunedin at Tainui is known to have been affected by floodwater before, as shown in Figure 15. Considerable localised variability in water depths was observed on 4 June, depending on slightly undulating local topography (e.g. Figure 13).

ORC initiated a survey to identify maximum flood-water levels across the most affected parts of South Dunedin, and to confirm the negligible flood-water depths observed outside this area. This work began late on 4 June, with further work undertaken on 5 and 9 June. Corroborating forms of evidence were sought to obtain a reliable indicator of water level at particular locations. This involved identifying multiple evidences within a given area and checking results for agreement.

Evidence typically consisted of flood debris in small areas on footpaths, or at road intersections. Flood debris was especially prevalent along King Edward Street, Prince Albert Road and Richardson Street, with large deposits of material typically consisting of bark chips located along the road carriageway and footpath. Flood evidence was less prevalent along the northern and western side of the survey area (Hillside Road/Surrey Street). The survey equipment used is able to determine horizontal and vertical positions to an accuracy of 0.03m.[16]

Figure 12. Ponding of surface water on Loyalty Street, South Dunedin, 4 June 2015

[15] Despite the lowest-lying land in South Dunedin being in the suburb of Tainui, in the eastern part of South Dunedin.
[16] Smeaton, D. 2015. *Report on South Dunedin Flood Survey – June 2015.* Report to Otago Regional Council.

Figure 13. Ponding of surface water on Dalgety Street, South Dunedin, 4 June 2015

Figure 14. Ponding of surface water on Bradshaw Street, South Dunedin, 4 June 2015

The locations of the 150 surveyed flood-debris marks are shown in Figure 16, colour-coded to represent the depth of inundation at each location. It is noted that these are typically located on roads. Depths were calculated by determining the difference between the elevation of the debris mark and the underlying ground level at that location (extracted from LiDAR flown in September 2009). Figure 16 does not show any clear spatial pattern in terms of flood depths across South Dunedin, confirming the initial observation of ORC staff that localised variations in topography were probably the main driver of flood depth. The pale-yellow areas mapped on Figure 16 have elevation less than 1m (relative to current mean sea level), and are usually associated with the deeper flood waters. It is noted that the area to the east of the map is also low lying, but the absence of debris marks suggests that it did not experience significant inundation.

The survey data does show a clear pattern in terms of water elevation relative to mean sea level, as shown in Figure 17. Water level was highest towards the northwest (Forbury Corner) and gradually slopes towards the south and east (i.e. the water-level contours generally follow the topography of the gently southeast sloping plain that comprises the South Dunedin area).

As noted above, the exception to this is the lack of evidence of significant floodwater ponding in the lowest part of South Dunedin at Tainui. Further work is required to determine the reason for the apparent lack of significant floodwater ponding in this area.

Figure 15. Ponding of surface water at the southern end of Normanby Street, April 1923, and the same view during normal conditions today (Google StreetView). This location is shown on Figure 16.

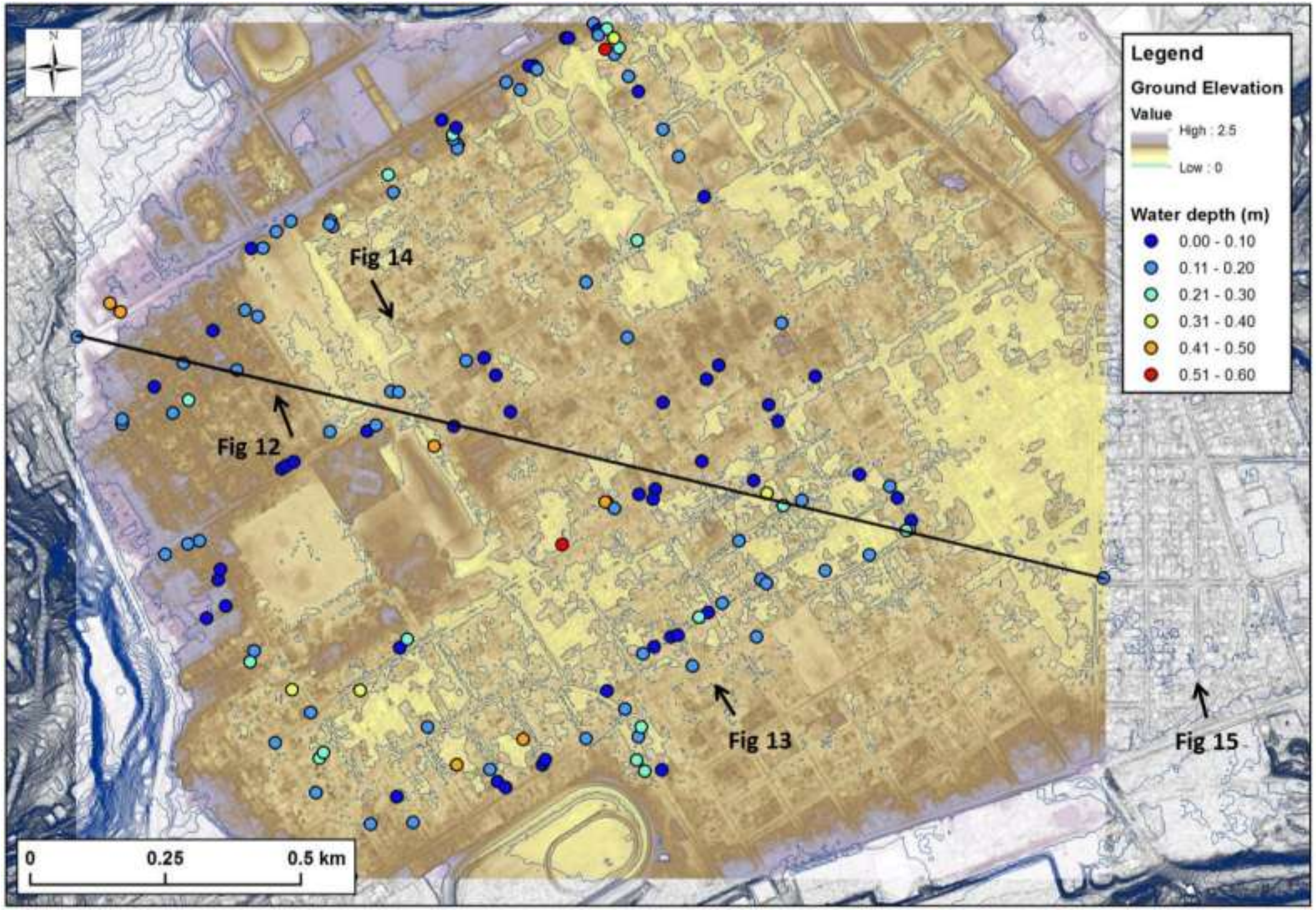

Figure 16. **Map of South Dunedin, with elevation colour scale showing topography between 0 and 2.5m above mean sea level. Contour interval is 1m. Profile line as shown in Figure 17 and Figure 18. Elevation is relative to mean sea level.**

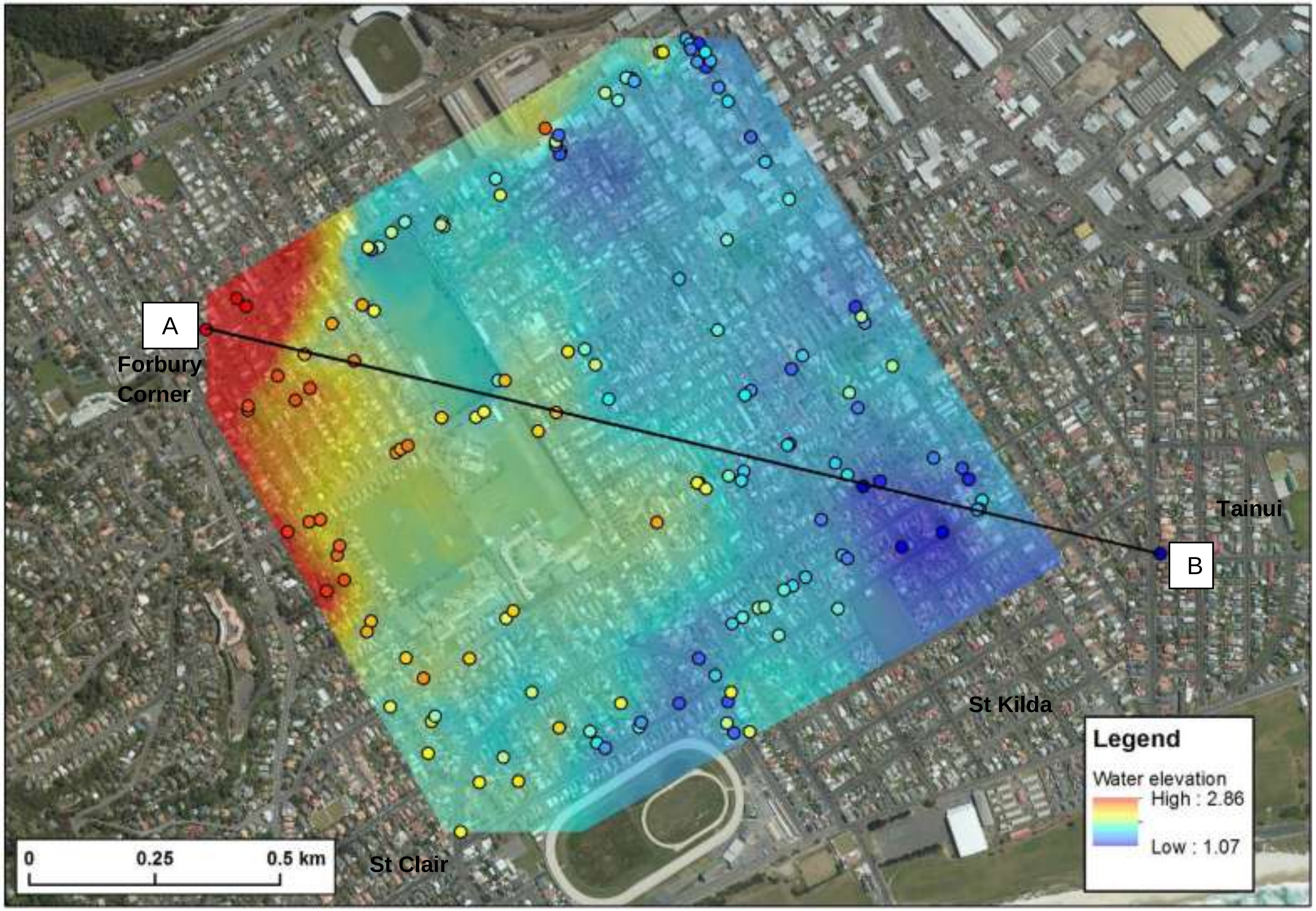

Figure 17. **Surveyed flood-water elevations (dots), and interpolated water-surface elevation across South Dunedin. Profile Line A-B as shown in Figure 16 and Figure 18.**

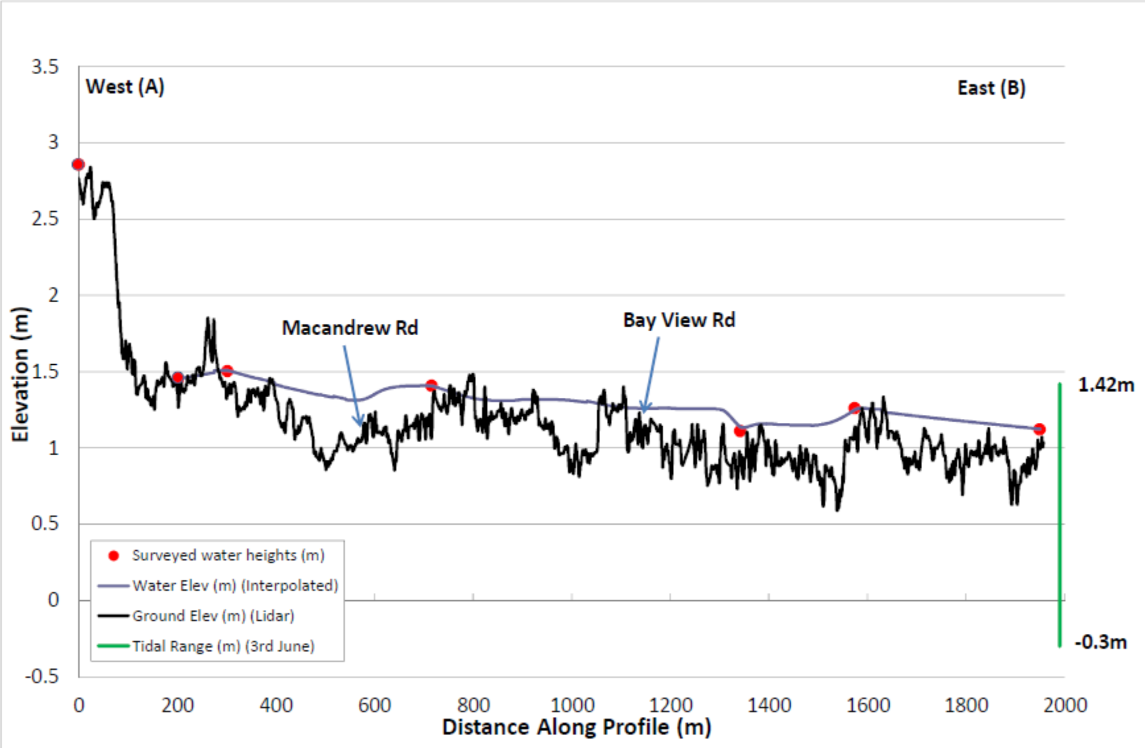

Figure 18. **Elevation transect shown on Figure 17. The black line is ground elevation, and the blue line is the interpolated maximum flood elevation from Figure 17. The red dots are actual observations of water level in close proximity to the transect line. Water surface has a gradual slope from west to east. The green line shows the range between the highest and lowest sea levels observed at the Green Island sea-level recorder on 3 June. Elevations are relative to current mean sea level.**

The water which ponded in South Dunedin consisted of rain that had fallen on the flats themselves and stormwater runoff from the surrounding hill catchments. The major catchments and the natural-topographic boundary of the South Dunedin catchment are shown in Figure 19. It is noted that the DCC stormwater network does not necessarily follow the natural catchment boundary. In particular, some of the stormwater from the northern-most sub-catchment may be diverted away from South Dunedin by DCC stormwater drains.

The approximate size of the natural South Dunedin catchment, as shown in Figure 19, is 14.8 km^2. For comparison, the Lindsay Creek and Water of Leith catchments are 12.5 km^2 and 42 km^2, respectively.

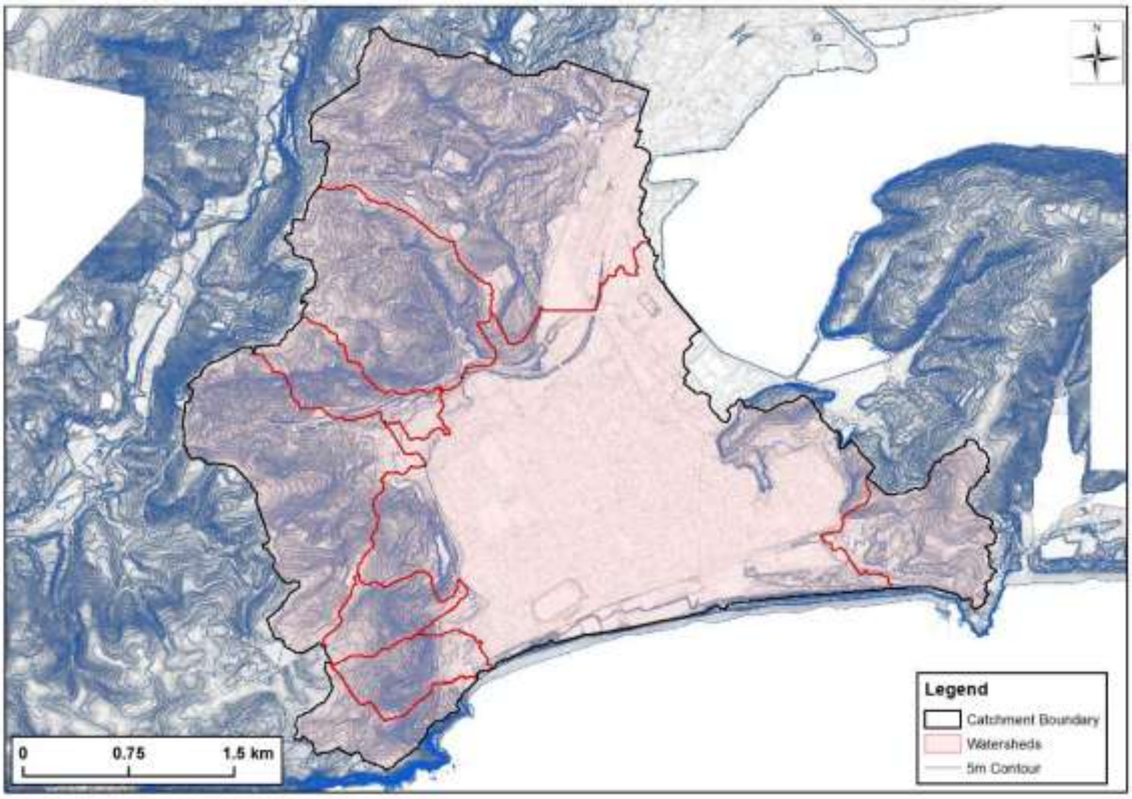

Figure 19. **Contour map showing the natural boundary of the South Dunedin catchment (black line) and sub-catchments (red lines)**

6.2. Groundwater level: Observations

6.2.1. Background

Between 2009 and 2014, ORC established four groundwater-monitoring bores across South Dunedin (Figure 20). These bores record water-level readings in 15-minute increments. Water level from the three bores established in 2009 helped in modelling investigations, which confirmed anecdotal reports that the South Dunedin water table is closely linked to the surrounding sea level at both the ocean and the harbour margins.[17]

This section discusses groundwater level at each bore before 3 June and its behaviour during the rain event. Pre-rain-event groundwater levels (2 June at 11:45 pm) were compared to the entire monitoring record; however, only water levels from 1 May 2015 are presented here (in Figure 21 to Figure 24). Rainfall signature can be seen in all four monitoring bores.

[17] Otago Regional Council (ORC). 2012. *The South Dunedin Coastal Aquifer & Effect of Sea Level Fluctuations*. ISBN 978 0 478 37648 7. October 2012.

Figure 20. **Location of ORC monitoring bores, Musselburgh pumping station rain gauge and Green Island sea-level recorder**

In wells or piezometers that are tapping confined and leaky aquifers, the water levels are continuously changing as the atmospheric pressure changes. Water levels rise in response to low-atmospheric pressure and fall during high pressure. This response can sometimes be seen in unconfined aquifers (such as below South Dunedin), but to a lesser extent.

The monitoring bores in South Dunedin are shallow bores, with the water table close to the surface. Fluctuations in groundwater levels at the Kennedy Street and, to a lesser degree, Tonga Park are from tidal influences as opposed to barometric influences. Changes in sea level at the nearby Green Island site before and during this event are described in Section 5.

6.2.2. Kennedy Street groundwater bore[18]

The Kennedy Street bore is located closest to the coast, and groundwater levels display a cyclic pattern, suggesting that there is tidal influence on water levels at this location. As mentioned in Section 5, the tide was at a natural cyclical peak due to a full moon and low barametric pressure. Therefore, groundwater levels at Kennedy Street were also at a cyclical peak. Due to the tidal influence, the groundwater levels before the flood have been taken from the average-daily groundwater level, as shown in blue in Figure 21. Average-daily groundwater levels before the flood were above average for this monitoring

[18] Note that this section differs from the version presented to the ORC Technical Committee on 22 July 2015, as a result of further analysis

bore (average-daily groundwater level (gwl): 0.603 metres above sea level (masl); 2 June average-daily gwl: 0.674 masl). It is likely that the rain events that occurred on 12 and 26 May 2015 also contributed to a higher-groundwater level than average. Groundwater levels rose 0.997 m above the average-daily groundwater level for 2 June during the rain event on 3 June 2015 to a maximum level of 1.671 masl, which is 0.261m *above* the surveyed-ground level at this bore (1.41 masl).

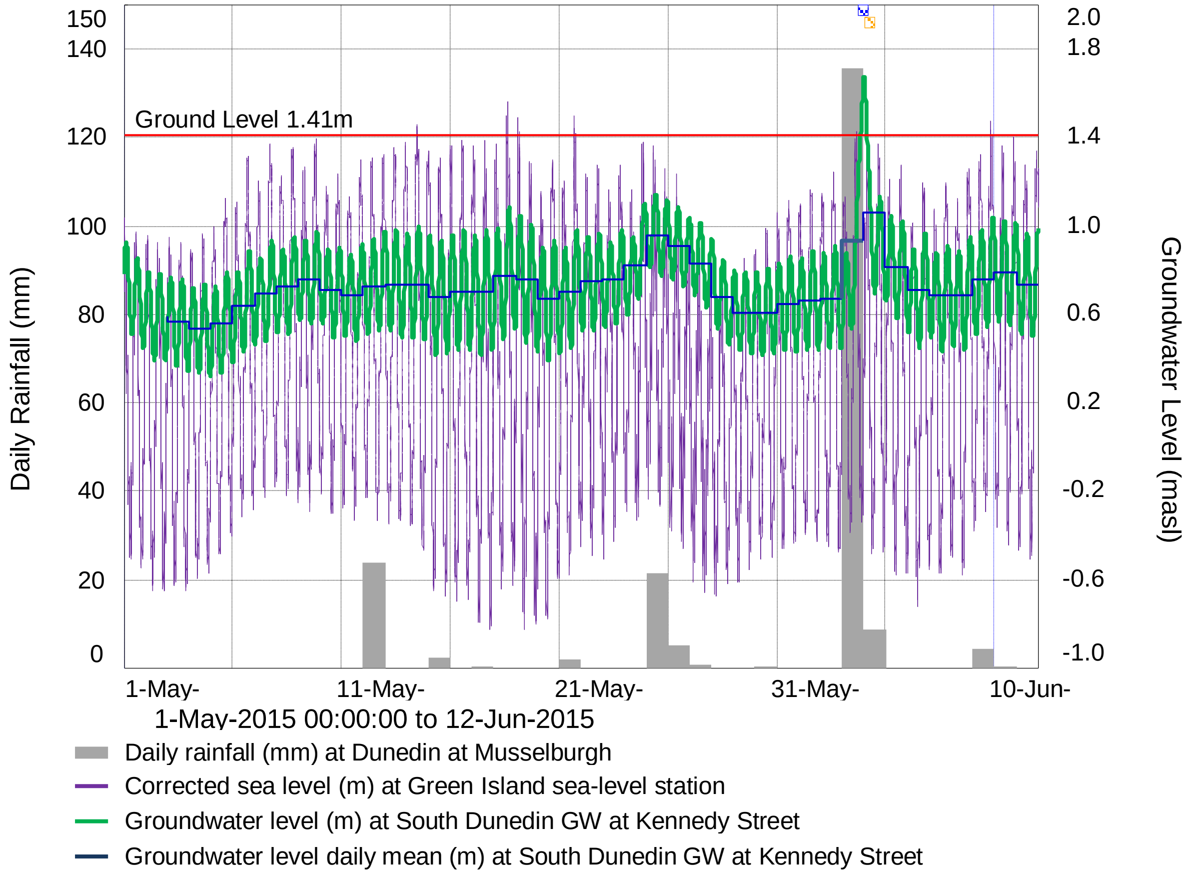

Figure 21. **Kennedy Street continuous and average-daily groundwater record, Green Island tidal data and daily rainfall from 1 May - 12 June 2015. Ground level is 1.41 masl.**

6.2.3. Tonga Park groundwater bore

Groundwater levels before the flood were at average level for this monitoring bore (average gwl: 0.557 metres above sea level (masl); 2 June at 11:45 pm: 0.644 masl), although there is an increasing trend in groundwater level, possibly due to rain events that occurred on 12 and 26 May 2015. Groundwater levels rose 0.722 m during the rain event on 3 June 2015 to a maximum level of 1.366 masl, which is 0.346 m *above* the surveyed-ground level at this bore (1.02 masl). It is noted that the interpolated water-surface elevation (Figure 17) at Tonga Park is about 1.4 masl, similar to that recorded at the bore, and indicating that this site was possibly measuring floodwater as a result of the 3 June event.

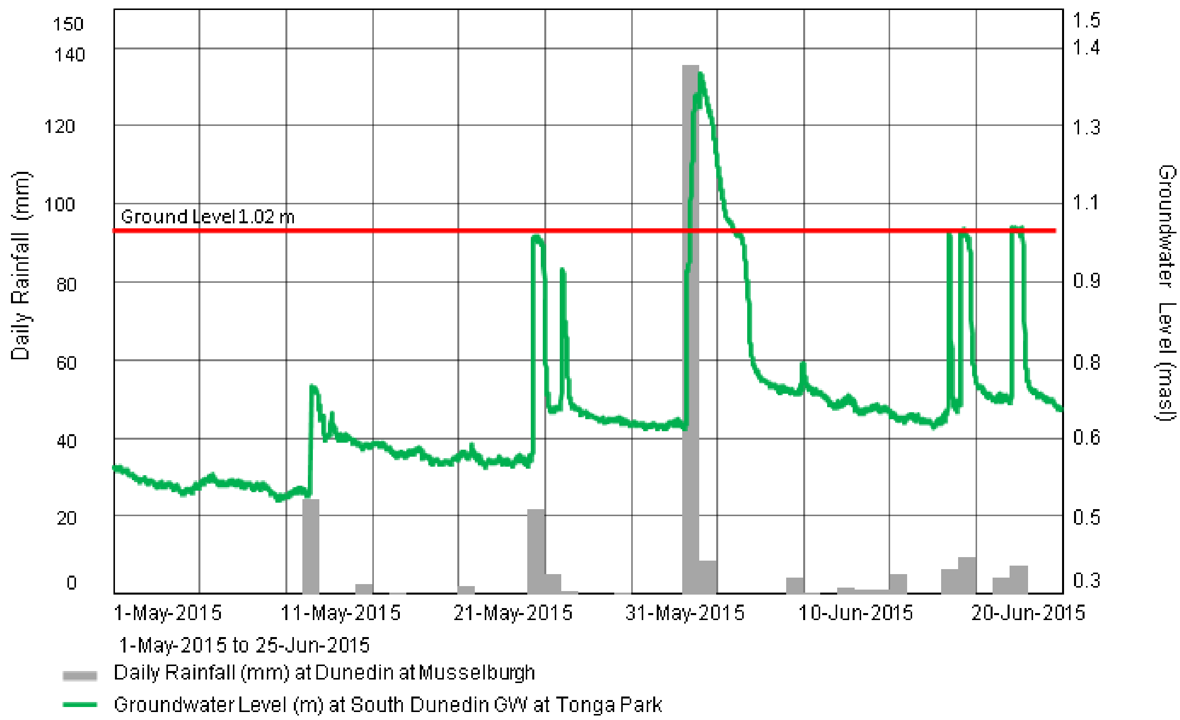

Figure 22. **Tonga Park continuous groundwater record from 1 May - 25 June 2015. Ground level is 1.02 masl.**

6.2.4. Culling Park groundwater bore

The groundwater-monitoring bore at Culling Park has a shorter monitoring record than the other three sites, as this bore was installed in May 2014. Groundwater levels before the flood were above average at this location (average gwl: 0.075 masl; 2 June at 11:45 pm: 0.198 masl). This may be as a result of the shorter groundwater record decreasing the average water level. Nevertheless, it is possible that the rain events that occurred on 12 and 26 May 2015 contributed to a slightly higher groundwater level than average. Groundwater levels rose 0.707m during the rain event on 3 June 2015 to a maximum level of 0.905 masl, which is 0.075m *above* the surveyed-ground level at this bore (0.830 masl).

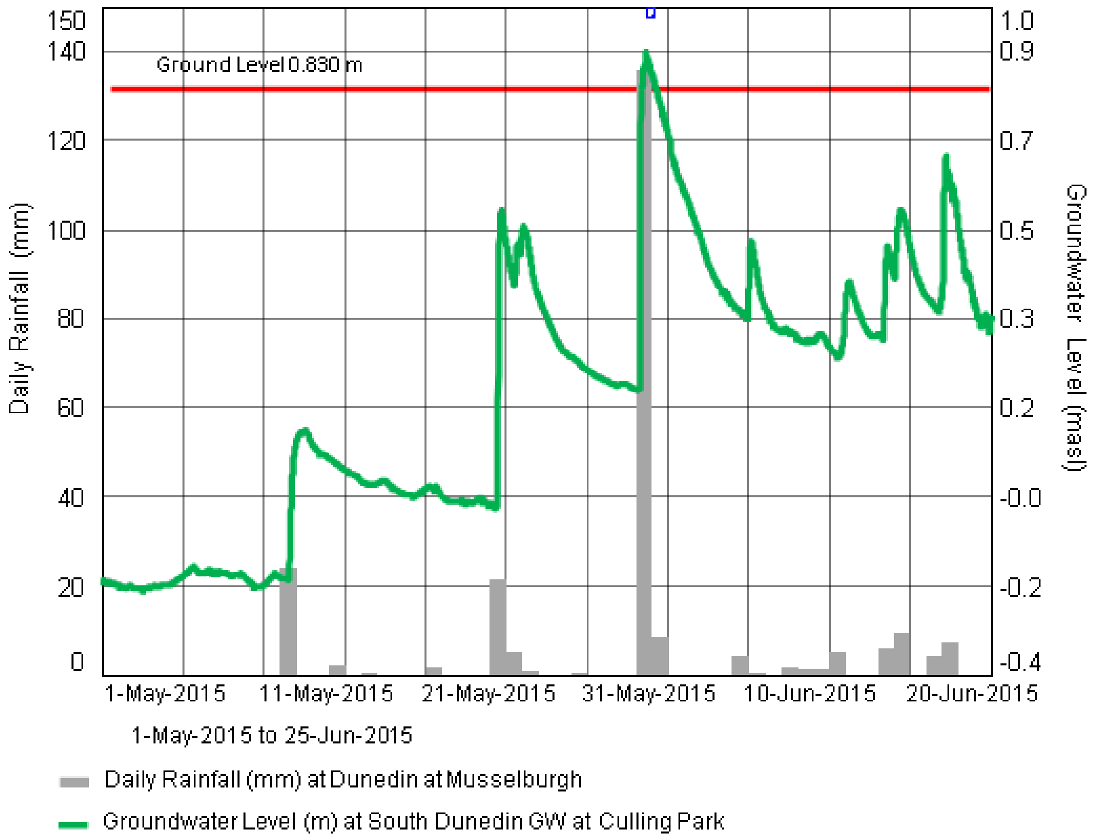

Figure 23. **Culling Park continuous groundwater record from 1 May - 25 June 2015. Ground level is 0.830 masl.**

6.2.5. Bathgate Park groundwater bore

Groundwater levels before the flood were slightly above average for this monitoring bore (average gwl: 0.689 masl; 2 June at 11:45 pm: 0.751 masl), probably as a result of rain events that occurred on 12 and 26 May 2015. Groundwater levels rose 0.238 m during the rain event on 3 June 2015 to a maximum level of 0.988 masl, which is 0.532 m *below* the surveyed-ground level at this bore (1.52 masl).

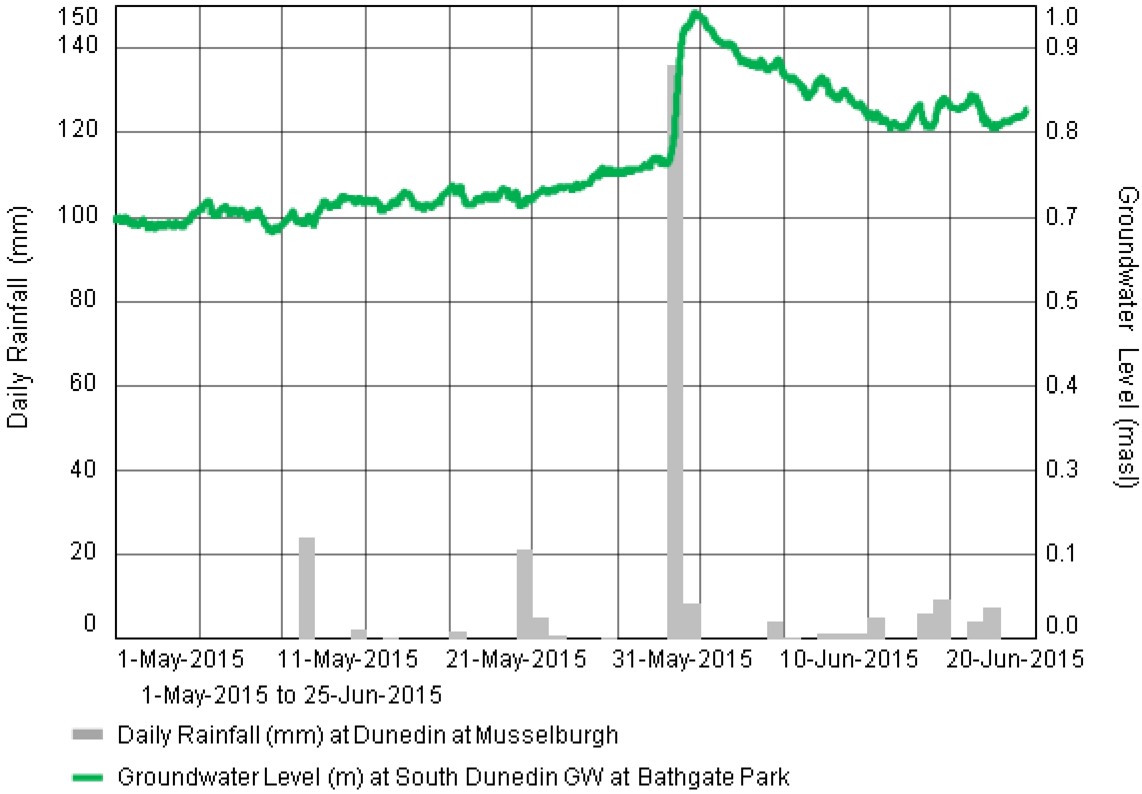

Figure 24. **Bathgate Park continuous groundwater record from 1 May - 12 June 2015. Ground level is 1.52 masl.**

6.2.6. Groundwater observations: Summary

Groundwater levels from three bores (Kennedy Street, Tonga and Culling parks) rose above ground level as a result of the rain event that occurred on 3 June 2015 (Figure 25). Groundwater levels at Bathgate Park were 0.53 m below ground level. Groundwater may have contributed to the surface flooding in the low-lying areas of South Dunedin. However, elevated groundwater levels close to ground level may have prevented surface water from infiltrating into the ground and dispersing into the aquifer below.

Figure 25. Location of groundwater above and below ground level in South Dunedin. Red – metres above ground level; black – metres below ground level

The large proportion of the South Dunedin area that is now covered by impermeable surfaces (buildings, concrete and asphalt) will also restrict the infiltration of surface water into the ground. The imperviousness of the South Dunedin area has been assessed at 60% overall, although is much higher in the commercial and industrial areas in the north of the area (Figure 26) where imperviousness can approach 100%.[19]

[19] Dunedin 3 Waters Strategy – South Dunedin Integrated Catchment Management Plan 2010-2060. URS and OPUS.

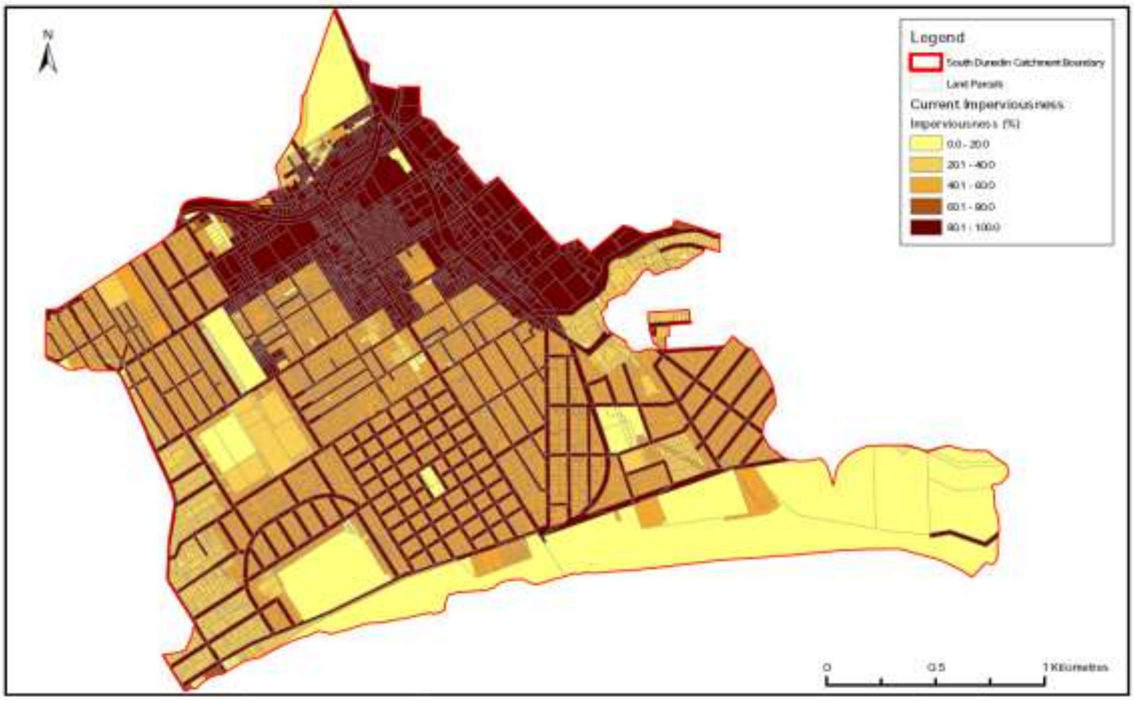

Figure 26. **Map showing the current level of imperviousness, as defined by URS and Opus for the DCC**

6.3. Indications of the future

Mean sea level at the port of Dunedin is inferred to have risen at an average rate of 1.3 mm/year since 1900, which equates to a rise of about 15 cm over that time.[20] Sea level has been continuously monitored at Green Island since 2002. Although this site has a short record for deriving long-term trends, the data is of high quality, with a frequent (1-minute) recording interval and an instrument accuracy of ± 1 mm. The average level of the sea at Green Island has increased at a reasonably consistent rate of 3.3 mm/yr since 2002, which is higher than the longer-term average determined for Dunedin.

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report projects that global sea-level rise by 2100 will likely be in the range of 0.26 to 0.98 m (relative to the 1986-2005 period), with a caveat that a further rise could occur if ice-sheet collapse accelerates. The most recently available guidance to local government in New Zealand regarding sea-level rise over the next 100 years (in line with the timeframe in the New Zealand Coastal Policy Statement) is from a NIWA guidance document, *Pathways to Change*, (Britton *et al*., 2011).[21] This report advises that a 1.0 m rise by 2115 relative to 1990 mean sea level should be considered for New Zealand regions at this stage. The Proposed Regional Policy Statement for Otago includes Policy (3.3.1): “Ensure Otago’s people and communities are able to adapt to, or mitigate, the effects of sea-level rise, over no less than 100 years, using a sea-level rise of at least 1 m by 2115, relative to 1990 mean sea level and adding an additional 10mm per year beyond 2115”.

[20] Hannah, J. and Bell, R. 2012. *Regional sea level trends in New Zealand.* Journal of Geophysical Research, Vol 117, C01004.
[21] Britton, R.; Dahm, J.; Rouse, H.; Bell, R.; Blackett, P. (2011). Coastal adaptation to climate change: Pathways to change. Externally peer-reviewed report prepared as part of the Coastal adaptation to climate change, NIWA publication. 106 p.
http://www.niwa.co.nz/sites/default/files/pathways_to_change_nov2011.pdf

Regardless of the uncertainty in the magnitude and rate of future sea-level rise, groundwater levels in South Dunedin will continue to increase above their current levels during the next century. It is during (or immediately after, due to a lag effect) periods of elevated sea level that surface ponding in the lowest-lying parts of South Dunedin is more likely to occur, particularly if rainfall occurs at the same time. The initial effects of sea-level rise will be to increase the frequency at which the upper range of extreme sea levels is experienced. Surface ponding may therefore start to occur more often, and for longer periods.

The South Dunedin coastal aquifer is an urban aquifer that is not used as a groundwater resource. As a result, no aquifer-parameter information has been collected about it (e.g. transmissivity, storativity, hydraulic conductivity, etc.). No investigation bores to determine the aquifer's geological profile at depth have been undertaken, apart from at the Tainui Wastewater Treatment Plant. A geological profile of an aquifer and its parameters are required to estimate how much drawdown would occur from pumping.

Beca Group Limited (Beca) completed a report in 2014[22] identifying potential engineered solutions for protecting the Harbourside and South City from direct impacts of sea level rise. The company preferred the option that involved lowering groundwater by placing deep wells (up to 70 m) along coastal (including harbour) fringes, following Victoria Road, Tahuna Road, Cavell Street, Portsmouth Drive and Strathallan Street. Groundwater levels would be maintained at 30-50 m below ground level at each well with the level being maintained at current elevation between wells. At higher values of sea-level rise, this mitigation option would, according to Beca, be supplemented with installation of bunds to prevent inundation during high-tide events and raising sections of some roads to maintain a viable traffic corridor at all times. Observations of surface ponding during the 3 June event show that a mitigation option like that would need to address the effects of water being displaced from roads onto private land (figures 12, 13, 14 and 15).

The option preferred by Beca is designed for protecting the area from the direct impacts of sea-level rise. It does not look at lowering groundwater levels in low-lying areas of South Dunedin (although that was put forward as Option 3 in the report). Drawdown of groundwater levels close to the pumping wells at the coastal perimeter would occur from the pumping. The extent of the drawdown would depend on the hydraulic conductivity of the aquifer and the pumping rate of each bore. In the drawdown zone, it is possible there would be an unsaturated zone in the underlying aquifer into which surface water (rain, overland stormwater) could infiltrate. However, given the amount of rainfall that fell in a short period of time on 3 June and overland stormwater that was present, along with the high degree of impervious surfaces (Figure 26), it is possible that the infiltration rate into the aquifer would not have been fast enough to prevent flooding.

For the areas of the aquifer that are at distance from the coastal-perimeter pumping wells, it is unlikely groundwater levels would change as a result of pumping. If a rainfall event of the same or greater magnitude to 3 June 2015 occurred, it is possible the same amount of flooding would occur in South Dunedin.

[22] Beca Group Ltd, 2014. Assessment of Options for Protecting Harbourside and South City from Direct Impacts of Sea Level Rise. Report prepared for the DCC.

7. Flooding effects – Water of Leith and Lindsay Creek

In general, the Leith Flood Protection Scheme performed within expectations, although localised erosion, damage to stream banks and plantings, and loss of riprap did occur in some areas, as detailed below. As noted above, the peak flow recorded in the Water of Leith on 3 June was about 100 cumecs. This is the second-highest flow recorded in the last 50 years and about half the flow estimated to have occurred in 1929 (Figure 6). ORC staff conducted preliminary inspections, and once water levels receded sufficiently, a damage survey and cross-sections (at key locations) were commissioned and completed. The results will form a key part on ongoing design work and capital planning.

In the Cumberland Street to Dundas Street reach, the scheme performed as expected, with minimal damage. Remedial works are required for replacement of riprap over a length of about 20 m to protect the toe foundation of existing walls and the abutment from further scour.

High flows caused scouring and loss of the foundation toe under a localised section of the scour wall on the true-right bank below the Dundas Street Bridge. Repairs to this scoured wall will probably be undertaken in 2015/ 2016, as part of the Dundas Street to St David Street stage of the Leith Flood Protection Scheme. Other localised scour occurred in this reach, too.

The recent flood-protection upgrade between St David Street to Union Street performed satisfactorily. There was no damage to the left bank. On the right bank, riprap has been scoured away over a 100 m length of the recently completed lower-right bank pathway (Figure 27). The riprap lost over the lower 38 m has resulted in a fall height greater than 1 m from the walkway to the riverbed. Options are being evaluated to remediate the fall height, for the interim access has been restricted by a barrier to eliminate the fall risk. Hydraulic loadings to the balustrades, compounded by significant build-up of debris, resulted in failure of the fixings to the concrete foundation. This failure has been attributed to a construction defect rather than design deficiencies. These defects have been remedied by the contractor. The turf and botanical plantings withstood the event with minor remediation and clean-up requirements.

Figure 27. Water of Leith before and after: Looking upstream from the University of Otago Staff Club. Note the loss of some riprap on the true-right bank.

In the Union Street to Leith Street reach, the left bank has two regions of scouring about 5 m long to about 4 m above the bed. Scouring on the right bank of the bend immediately downstream of the ITS Building was reported, to a depth of 1.8 m and about 1 m under the existing wall had occurred. On the left bank, material had been deposited on the beach. The existing channel-confinement walls and banks performed as expected. Remedial works will be undertaken as soon as practicable to stabilise the suspected scour under the wall on the right bank.

The Leith to Forth Street reach experienced loss of riprap walls by scour from their base; however, overall the flood-protection works in this reach performed as expected. The exception was the rapid expansion of the water way and circulating whirlpools that resulted in additional scour. Remedial works required are removal of the riprap from the berm into the channel. The left-bank wall is a temporary construction until the Leith Street footbridge becomes widened. Repairs can be via placement of riprap over the scoured area. The right-bank wall may require a localised design review to establish a streamline without initiating circular-flow patterns.

The Clyde Street to Forth Street reach suffered no damage, other than debris collecting on left-bank balustrade of the walkway ascending from the Clyde Street Bridge. The scheme works performed as expected.

The Water of Leith debris traps also performed as intended. The Woodhaugh Street boulder trap collected the bulk of the Leith debris (Figure 28), with the Malvern Street debris trap further upstream collecting a lesser amount of material. As soon as flood waters receded, contractors were engaged to clear the traps. A landslide occurred at the northern end of Malvern Street, which partially blocked the channel but did not negatively affect channel capacity during the event. This landslide debris was cleared in the days following the flood.

The Lindsay Creek debris trap caught what little material came down to that point (Figure 29). Numerous sections of Lindsay Creek experienced significant bank erosion, as shown in Figure 30 to Figure 32.

Figure 28. Water of Leith debris trap at Malvern Street (left) and Woodhaugh Street boulder trap (right) during the event, 3 June 2015

Figure 29. **Lindsay Creek debris trap at Bethunes Gully during the event, 3 June 2015**

Figure 30. **Bank erosion undermining a shed alongside Lindsay Creek at Kelvin Road, 4 June 2015**

Figure 31. Bank erosion alongside Lindsay Creek at Kelvin Road, 4 June 2015

Figure 32. Bank erosion alongside Lindsay Creek at Norwood Street, 4 June 2015

8. Flooding effects – Kaikorai Stream

A number of flood-related issues were observed in the Kaikorai catchment, relating to bank overtopping, bank erosion and stormwater runoff. Areas particularly affected included:

- the low-lying area near the intersection of Brighton Road and Main South Road (near the State Highway (SH) 1 underpass)
- the intersection of Kaikorai Valley Road and Stone Street, as well as much of Kaikorai Valley Road, below this point (Figure 33)
- SH1 at Green Island (Figure 34) was closed due to flooding, with north-bound traffic diverted through Green Island.

All these areas were identified as being within the Kaikorai Valley floodplain in the recent ORC report created to help inform the review of the natural-hazard provisions of the Dunedin City District Plan.[23]

Figure 33. Examples of surface flooding on Kaikorai Valley Road, midday on 3 June 2015

Figure 34. The northbound lane of the Dunedin Southern Motorway, east of the Carnforth Street underpass. Left: Normal conditions (Google StreetView); Right: During the peak of flooding at approximately midday on 3 June.

[23] *Flood hazard of Dunedin's urban streams*, Report No. 2014/0868, Otago Regional Council.

At 12:30pm, a car and tree were reported in Kaikorai Stream, wedged in an NZTA box culvert under SH1 at Burnside (Figure 35), with a tree and other debris further upstream caught up under a bridge (Figure 36). ORC operations staff contacted NZTA's contractor, but they were unable to remove the blockage in a timely manner because of other priorities. ORC staff had removed all blockages by 4:35pm.

Figure 35. Car and tree lodged in culvert beneath SH1 at Burnside, 3 June 2015

Figure 36. Tree and debris trapped under bridge at Burnside, 3 June 2015

A number of blockages were reported in Abbots Creek. One was a small garden shed, sited on top of the creek bank, which suffered scouring. The shed collapsed into the channel, further exacerbating localised-erosion issues. A number of residents of Flower Street phoned to complain about inadequately sized culverts at the Fulton Hogan sand quarry next to Abbots Creek, which appear to have caused localised flooding to those properties. Fulton Hogan is assessing the situation at the request of the affected landowners.

9. Flooding effects – Taieri Plain

While the flows of the main waterways that cross the Taieri Plain (Taieri and Waipori rivers, Silver Stream and Owhiro Stream) were elevated, they were not exceptionally high, and were usually contained within their banks with only localised overtopping. There were exceptions to this, and these are described below, along with those areas on the Taieri Plain that were most affected by floodwater.

9.1. Ponding and overland flow

As expected, during high flows in the Taieri River, water overtopped the river banks and extensively flooded the berm areas and the Taieri River floodway (Figure 37), but no overtopping of the main floodbanks was recorded. The Henley spillway, downstream of Otokia, operated between about 10am on 4 June and 2am on 5 June (Figure 38), resulting in extensive ponding in the Henley floodway, as would be expected in a rainfall event of this type. Much of the land surrounding the settlement of Henley was flooded, particularly at the southern end of the township (Figure 39). The flooding resulted from runoff from the coastal hills not being able to be discharged into the Taieri River due to high-water levels and accumulating on low-lying areas.

The threshold of operation of the Riverside spillway was not reached and no water from the Taieri River spilled into the Upper Pond (Figure 40). However, water from other sources resulted in a maximum water depth of about 1.2 m in the Upper Pond, with a total stored volume of 1.5 million cubic metres (4% of the Upper Pond's total capacity). Sources of floodwater included the northern hill catchments (including Mill Creek), internal runoff and the Silver Stream (after it overtopped at the Gordon Road spillway).

The Silver Stream overtopped at the Gordon Road spillway, between about 4pm and 10pm, on 3 June. Figure 41 shows the overtopping locations were mainly at the downstream end of the spillway, and that overtopping was of a considerably smaller scale than during the April 2006 event. The spillway is part of the Lower Taieri Flood Protection Scheme and overtopping is expected during high flows in the Silver Stream. Spilled water from the Silver Stream made its way downslope towards the Upper Pond, and combined with other sources of floodwater, contributed to flooding and ponding in a number of areas.

Extensive flooding was observed upslope (to the northeast) of the Lower Taieri Flood Protection Scheme Cutoff Bank (Figure 42). This ponding was due to runoff from the northern hill catchments, rainfall accumulation and from the Silver Stream overtopping after the brief operation of the Gordon Road Spillway.[24] The extent of ponding behind the Cutoff Bank was not as great as during the April 2006 flood event, due to less overtopping at the spillway and an improved connection between the area behind the Cutoff Bank and the Upper Pond (improvements made by the ORC after the 2006 flood event).

Overtopping of Mill Creek in the vicinity of Dukes Road north caused localised ponding without significant damage.

[24] *'Update to Taieri Plain flood hazard mapping for Dunedin City District Plan'* Report No. 2015/0960. '. Report to ORC Technical Committee, 3 June 2015.

Debris marks indicate that local surface runoff exceeded the drainage-network capacity in the vicinity of Wyllies Crossing, and observations indicate that blockage of culverts occurred in this location. Water overtopping from drains, combined with water conveyed by swales and overland-flow paths, caused localised flooding in the area (Figure 43).

Observations made by ORC staff during and after the event confirmed the criticality of the swales and overland-flow paths in conveying runoff from the hill catchments and complementing the ORC rural-drainage network (e.g. Figure 44).

Figure 37. Taieri River berms and floodway looking southwest, downstream of Allanton – 4 June 2015

Figure 38. Henley spillway (downstream of Otokia) operating – 4 June 2015 11.45am

Extensive ponding was also recorded in the Lower Pond (Figure 45 and Figure 46) due to water overtopping the Owhiro Stream right bank, runoff from the southern hill catchments and rainfall accumulation. Extensive flooding occurred on the flanks of the coastal hills south of the Lower Pond mainly due to runoff from the southern hill catchments and the Owhiro Stream (Figure 46).

Extensive flooding occurred in the vicinity of Quarry Creek, south of Mosgiel. Cemetery Road and the grounds of East Taieri School were flooded. Flooding occurred in Gow and McGlashan streets (industrial area south of Mosgiel) (Figure 47), as has occurred previously.

The Miller Road spillway located on the left bank of the upper section of the contour channel operated during the event. Spilled water flowed overland and reached the Lee Canal. The Otokia Road spillway, located further downstream on the contour-channel left bank, did not operate. Overtopping of the contour-channel left bank caused localised inundation between Miller Road and Dow Road. Localised scouring was also observed in the upper section of the contour channel.

A section of low-level floodbank, located on the western edge of Lake Waipori (in the vicinity of McPherson Road) and a section of low-level floodbank at the northwestern end of Lake Waihola, were overtopped, causing localised ponding.

Figure 39. Aerial view towards the south of floodwater at Henley – 4 June 2015

Figure 40. Ponding in the Upper Pond, view is towards the southwest – 4 June 2015

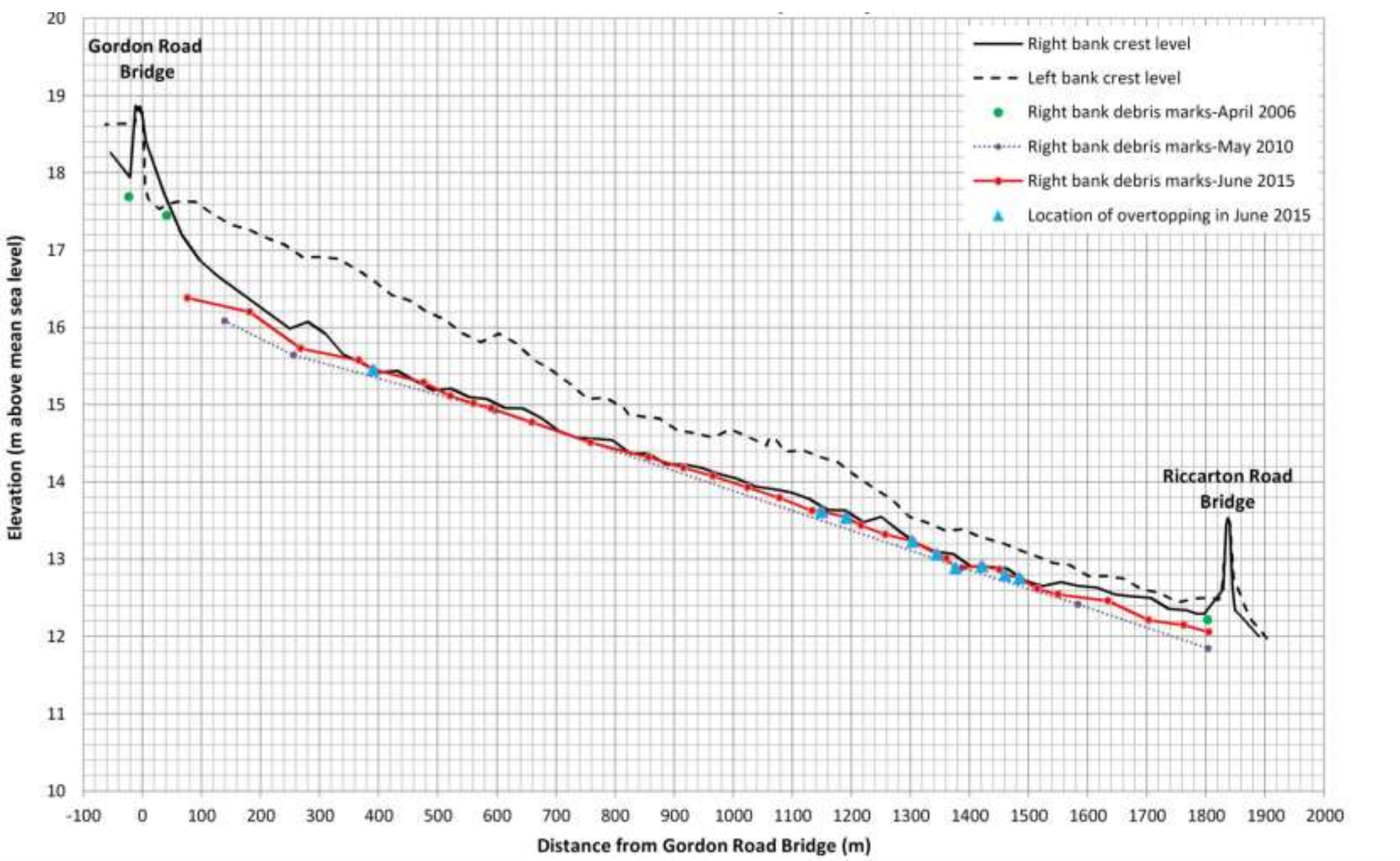

Figure 41. **June 2015 maximum water level in the Silver Stream in relation to the top of the left and right floodbanks, between Gordon and Riccarton roads. Flood-debris marks collected after the April 2006 flood event are also plotted.**

Figure 42. **Ponding behind the Cutoff Bank; view is towards the south – 4 June 2015**

Figure 43. **Debris marks indicative of overland flow and ponding in the vicinity of Wyllies Crossing – 4 June 2015**

Figure 44. **Example of overland-flow path conveying runoff from the hill catchments to an ORC drain between Riccarton Road and Gordon Road – 4 June 2015**

Figure 45. **Ponding in the Lower Pond; view is towards the southwest – 4 June 2015**

Figure 46. **Ponding in the Lower Pond (note the overtopping of the Owhiro Stream true- right bank) and at the flanks of the coastal hills – 4 June 2015**

Figure 47. **Flooding in Gow (left) and McGlashan (right) streets, Mosgiel – 3 June 2015 (photos courtesy of PW Engineering and Payne Aluminium)**

9.2. Taieri land drainage pumping stations

The Waipori pump station achieved the necessary pumping capacity to maintain drain levels and convey floodwater (Figure 48).

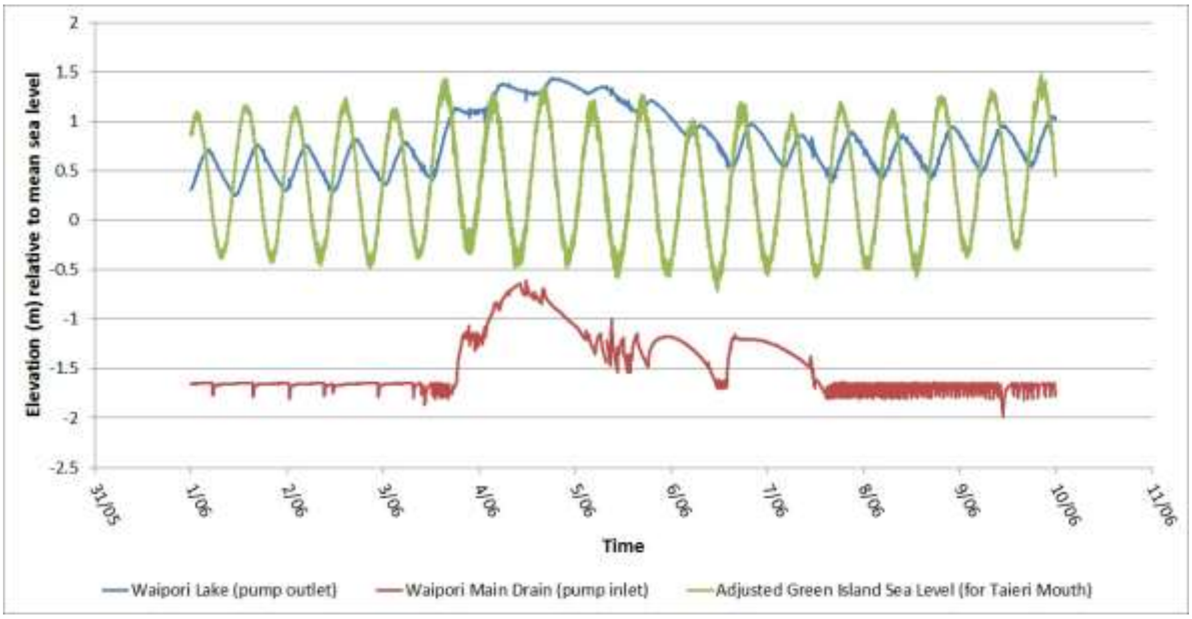

Figure 48. Main drain level at Waipori pump station, level of Lake Waipori and sea level, 1 to 9 June 2015

Landholders indicated their satisfaction that the event had been contained. The flood conditions were a valuable learning experience, and provided an opportunity to refine the control system. It had not been possible to commission the pump station with all pumps running simultaneously with a high-discharge head before. Low voltages were noted in the pump house, tripping all pumps several times, each time requiring a manual reset. As a result of this, the pump station was manned by operations staff and then contractors for the first 24 hours of the event to ensure that the system operated as required. The reasons why the pumps were tripping were diagnosed and corrected by adjustments to the motor-control parameters over the two days succeeding the event. The knowledge gained from this event will be applied to other pump stations in the future.

The pump at Scroggs pumping station generated a swilling action because of the inlet drain shape and flow conditions, which resulted in cavitation and reduced efficiency of the pump. The event resulted in overtopping of the floodbank from the receiving side back into the pump well. Therefore, there was no point running the pump further, and so it was stood down until the water level declined on the discharge side. Subsequently, the pump failed on 6 June due to moisture entering the motor through a chaffed control cable. The pump has been repaired and a number of actions assigned to improve future performance.

Henley pumping station ran continuously without any complications.

Lake Ascog pumping station has two pumps; it required one pump to handle the event in the catchment.

Mill Creek pumping station consists of two pumps. Dead poplar trees overhanging the power supply lines to the station were scheduled to be removed by Delta at the start of the flood event, resulting in a temporary power outage to the station. The consequence of the dead trees being downed into the drains was that a number of branches hampered the station's operation. As a consequence of the debris being in the drain channel, ORC required an excavator for 8 hours to keep the screens clear.

Silver Stream pumping station has three pumps, which operated as required. Water arrived at the station from overland paths, resulting in a significant amount of debris build-up on the screens. An excavator was required on site for 8-9 hours clearing screens. The amount of material removed equated to ten truckloads. At this time of year, the grass dies and drains have been mowed. A significant amount of the material that blocked screens and culverts resulted from drain mowing.

10. Flooding effects – Tokomairiro catchment and Milton

The rainfall and peak flows in the west and north branches of the Tokomairiro River were high but not exceptional (Figure 3 and Table 4).

The CDC floodbank downstream of SH1 prevented the Tokomairiro River from affecting low-lying properties in the Mill Street area, with some freeboard (Figure 49), and the CDC pump appeared to be assisting in the removal of surface runoff from Milton.

Figure 49. The floodbank (left) and pump station outlet (right) at Milton, downstream of SH1, 3 June 2015

Observations by ORC staff during and after the event indicate that, in general, the ORC's scheduled drainage network on the Tokomairiro Plain operated well. A number of drains were conveying water at full capacity (with little or no freeboard), while others (such as the upgraded T3 drain above Tokoiti Road) were operating at less than capacity. Other natural 'swale' features mapped for the Milton 2060 Flood Risk Management Strategy were also observed to be carrying floodwater during the event. These features were observed to be conveying rural stormwater flows into the Milton urban area on the eastern side of the township[25], and Figure 50 shows floodwater still ponding in these features at midday on 4 June. This confirms that the additional rural diversion work identified in the Milton 2060 Strategy would further protect the urban area and reduce flooding within the township.

Floodwater affected properties in Milton, as well as a number of roads in the area. Floodwaters again ponded in the naturally low-lying area at the southern end of Ajax Street (Figure 51), and one property in Ajax Street was evacuated, along with one each in Chaucer, Lowery and Johnson streets. All four properties were also evacuated in July 2007. Other residents reported significant amounts of water on their properties, but they did not have to evacuate.

The road from Tokoiti to Toko Mouth was closed for several days following the event due to floodwaters across the road.

[25] J. Witt, CDC, *Pers.comm.* 7 July 2015.

Figure 50. **Residual floodwater in swale features, 4 June 2015. The left image shows the area to the east of Milton (looking southwest), and the right image shows the area to the north of Milton (looking northeast), with SH1 visible.**

Figure 51. **Aerial view of floodwater on Ajax Street (centre) Milton, with Union Street (SH1) to the right, 4 June 2015**

11. Flooding effects – Lower Clutha and Pomahaka

The Clutha delta experienced three significant rain events over the month ending 21 June 2015. The cumulative effect of these events was compounded by high seas and a sand bar that formed at the Koau mouth of the Clutha River, impeding gravity drainage from the catchments.

Over this month, a total of 156 mm of rain fell at Nugget Point. The first rain event (30 mm) on 24 May was concentrated over the Groyne Farm area, east of Kaka Point Road, and resulted in significant inundation of farmland. This water was not able to drain completely before the second, larger event on 3 June (Figure 3). The 3rd event on 12-16 June (10 mm) was spread out and less intense, but compounded the flooding sustained earlier in the month.

The Paretai pump station performed well. The heavy rainfall provided an opportunity to study the new control-systems performance while operating under high-head and flow conditions (Figure 52). This exercise has resulted in a refinement of the control philosophy. These changes will provide benefits in the future, both for optimising the effectiveness and improving the reliability of the pump station assets.

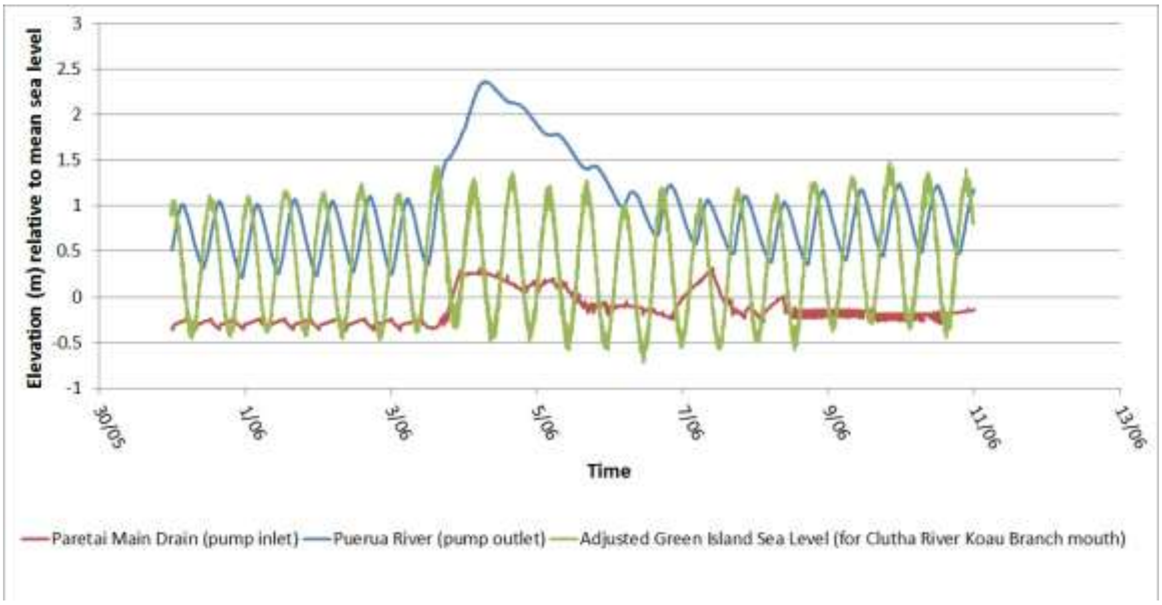

Figure 52. Paretai pump station inlet water level, outlet water level (Puerua River) and sea level, 1 to 10 June 2015

The Kaitangata pump station maintained the necessary flow capacity for the 3 June event. There was one noteworthy incident where pump 2 failed to start due to a fault with the high-level sensor.

The Inch Clutha pump station performed well.

The Barnego pump station operated according to the stations setting's and pump capacities. Most of the water in the catchment was able to exit through the gravity gate as the level of water in the Clutha River declined.

12. Flooding effects – Inland Otago

Rainfall intensities further inland were generally less significant than those in and around Dunedin City (Figure 3), and the CODC did not observe any major flooding related issues.[26] One exception was at Black Jacks Creek, 3km south of Roxburgh, where a culvert under SH8 was washed out by flash flooding, closing the road for two days (Figure 53). The nearest rain gauge is Moa Flat (17km to the south), where the 56 mm of rain recorded was the 10th highest 1-day rainfall on record. This suggests that the flooding in Black Jacks Creek resulted from localised heavy rainfall within the catchment.

Figure 53. Flooding at Black Jacks Creek at SH8, 3 June 2015

[26] T. Andrews, CODC. *Pers.comm.* 6/7/2015

13. Landslides

Numerous landslides on hillslopes in the Dunedin City district occurred as a result of the 3 June rainfall event, and an example of the Harbour Cone area on the Otago Peninsula is shown in Figure 54. Staff from ORC and GNS Science completed a programme of observations and an assessment of landslide activity after this event, as well as collating observations from other agencies. They are currently undertaking further work to compare the level of activity during the June 2015 event with previous heavy-rainfall events. A separate report summarises the programme of work instigated by ORC in 2012 to improve the understanding of landslide hazard within the Dunedin City district.[27]

Figure 54. Aerial view of Harbour Cone, with landslide locations marked with red arrows, 16 June 2015

[27] Report 2015/1003. *Updated landslide hazard information for Dunedin City*, Prepared for Technical Committee, Otago Regional Council, 22 July 2015.

14. Discussion

Generally speaking, the rainfall and its effects had precedent and verified existing knowledge and information on flood hazard in Otago. However, the event enabled the body of knowledge to be extended and information to be refined. For example, nine flow gaugings were completed over the peak of this relatively brief high-flow event, including the highest-gauged flows on record at the Waitahuna River site (77 cumecs) and the Water of Leith (93 cumecs - just 7 cumecs below its peak flow), and the highest-gauged flows in 25 years on the Pomahaka River.

A traditional current metre gauging from the SH87 Bridge at Outram was obtained, and this has helped to corroborate recent flood gaugings using Heli-gauging techniques developed by ORC using more modern flow measuring technology (as shown in Figure 55).

The Heli-gauging technique also enabled flow gaugings to be conducted on the Tokomairiro River in locations that are normally inaccessible, due to road closures in times of flood. Additional information including photographs and observations of surface flooding was also collected, some of which have been incorporated into this report.

Figure 55. Heli-gauging underway on the Tokomairiro River using a kayak-mounted acoustic Doppler current profiler (ADCP) flow-measuring device

Models and information systems developed to support engineering design and land-use planning decisions, such as numerical hydraulic models of the Water of Leith and Lindsay Creek and mapping of flood hazard to support DCC's Second Generation Plan (2GP) review, were used by staff during the event to inform decision-making and flood advisories.

Staff responded quickly during an event in which the scale and geographic extent changed rapidly. The event had effects that were wider than Dunedin City and a flooding risk existed in other parts of Otago after rainfall within the city eased. ORC's response to the event benefitted from staff making direct observations at strategic locations and providing regular and accurate reports back to the staff responsible for planning, intelligence, operations and communications.

It is noted that ORC's Long-Term Plan 2015-2025 has a number of initiatives that will help further reduce or manage risks associated with the type of rainfall that occurred in June. Those include:

- completing the Leith Flood Protection Scheme
- continuing to work with Otago's territorial authorities to integrate natural-hazard information into district plans
- with DCC, developing a natural-hazard risk-management strategy for South Dunedin[28]
- developing a flood forecasting system for the Water of Leith and Lindsay Creek and improving the effectiveness of the forecasting models for the Taieri River and Silver Stream
- investigating options to improve drainage of the Upper Pond (Lower Taieri Flood Protection Scheme and East Taieri Drainage Scheme)
- providing real-time public access to operational information for the Paretai, Kaitangata and Barnego pump stations (Lower Clutha Flood Protection and Drainage Scheme).

[28] *South Dunedin Groundwater hazards and Summary,* Report No. 2014/0957, prepared for Otago Regional Council Technical Committee, 15 July 2014.