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That the report be noted.

REPORT

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Prepared For: Technical Committee
Prepared By: Michael Goldsmith, Manager Natural Hazards
Jean-Luc Payan, Senior Investigations Engineer
Rebecca Morris, Groundwater Scientist
Chris Valentine, Manager Engineering
Scott MacLean, Manager Operations
Lu Xiaofeng, Resource Scientist Hydrology
Nineva Vaitupu, Senior Environmental Data Officer
Ben Mackey, Natural Hazards Analyst
Date: 8 July 2015

Subject: **Coastal Otago Flood event 3 June 2015**

1. Précis

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

Although the highest rainfall totals were observed in and around the Dunedin City urban area, the event was reasonably widespread, and also affected 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 heavy rainfall events where heavy falls generally only 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 late evening on 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 smaller-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, resulting in a storm tide level 0.25m higher than would have occurred under normal atmospheric conditions.

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[1] *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

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

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 10 years (2006-2015) than during the preceding 40 years.

2. 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 response to the situation.

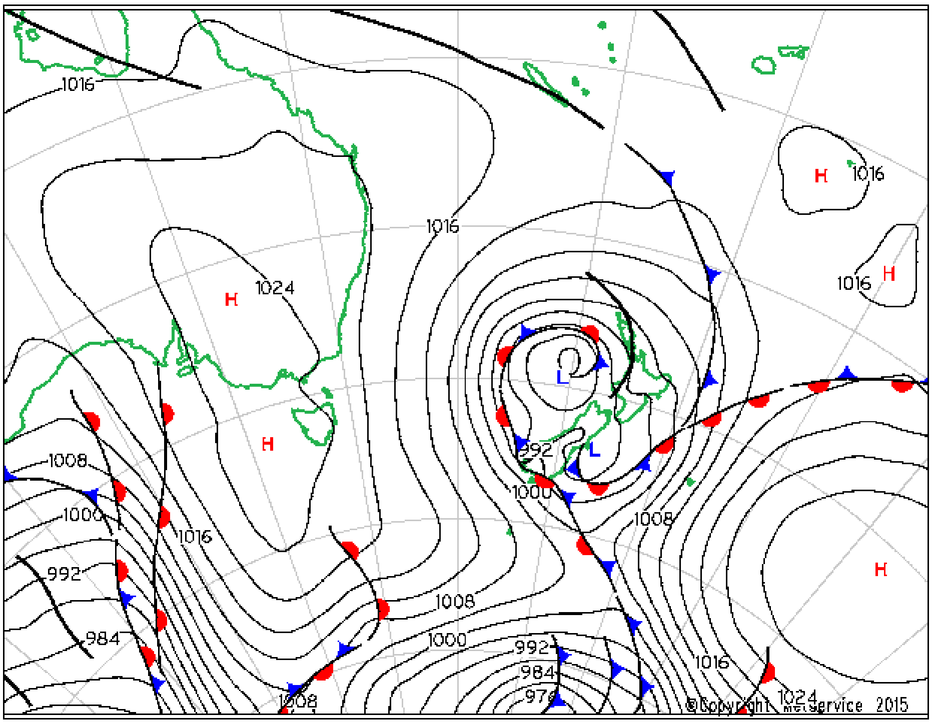

Figure 1. Situation map for 6am on 3 June, 2015 (MetService)

3. 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 taken by ORC staff 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 which predicted heavy rainfall over an 18 hour period, commencing at 6am on 3 June, until midnight. The Warning was for 80 to 100mm of rainfall about the hills and ranges of Dunedin and Clutha, with 50-70mm possible elsewhere. Peak intensities of 10 to 15mm 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)[3] contacted the Emergency Management Officer (EMO) for Clutha District Council (CDC), in regards to pre-flood activities defined in the joint CDC/ORC

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[3] Because of the duration of the event the lead Flood Manager 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.

Milton 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 til 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 til 2am Thursday 4 June). By that time, approximately 30mm had already fallen at the Pine Hill, Sullivans Dam and Musselburgh gauges, at an intensity of 5 to 8mm 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 EMO's for the Waitaki and Dunedin City districts in regards 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 til evening

By late morning, observations from rain gauges across the Dunedin area, including on 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 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 100mm of rain, on top of what had already fallen, in the 14 hours til 2am Thursday. By that time, 50-60mm of rain had already fallen across Dunedin (Figure 2), and hourly rainfall intensities had increased to between 9 and 12mm per hour.

The Otago 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 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 activated. Another 8 telephone calls to the DCC EOC in regards 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 also 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 the Twitter system 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 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 rung 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 40mm of rain in the Dunedin and Clutha area, concluding at 2am on 4 June. The actual total for this period was approximately 20mm. Rainfall intensities did reduce after 2am, with light rain continuing on 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 rung 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 rung manually at 9:30am. Further telephone calls to the Clutha District Council EMO regarding flooding issues on the lower Clutha were made throughout the day.

The reason for the autodial fault was apparently a bug in the system software that the supplier is working to resolve. 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[4].

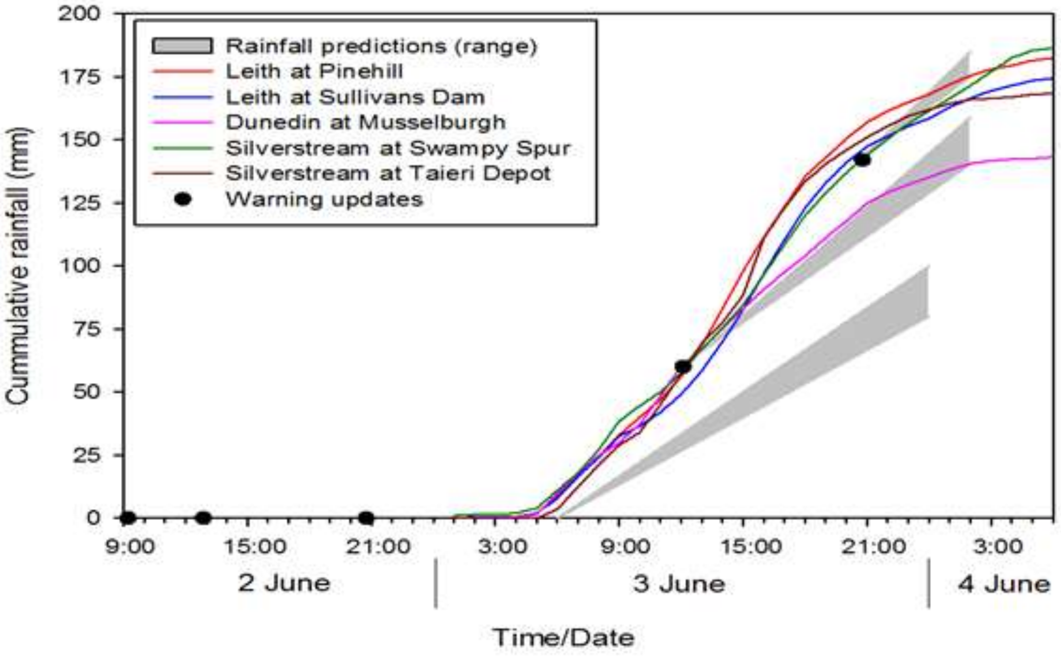

Figure 2. Observed rainfall accumulations at rain gauge sites around Dunedin from 9am on 2 June until 6am on 4 June (coloured lines). Predicted rainfall accumulations provided by MetService Warnings are shown for comparison (grey bands), including the effect of the updated Warnings as the event progressed.

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[4] *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

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.[5] 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 predominantly from Dunedin (44%), followed by Christchurch (22%) and Auckland (20%). The flood advisories issued by ORC were collectively viewed by almost 12,000 people on Facebook.

The automated Flowphone 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.

4. Rainfall

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 much 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).

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[5] 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’.

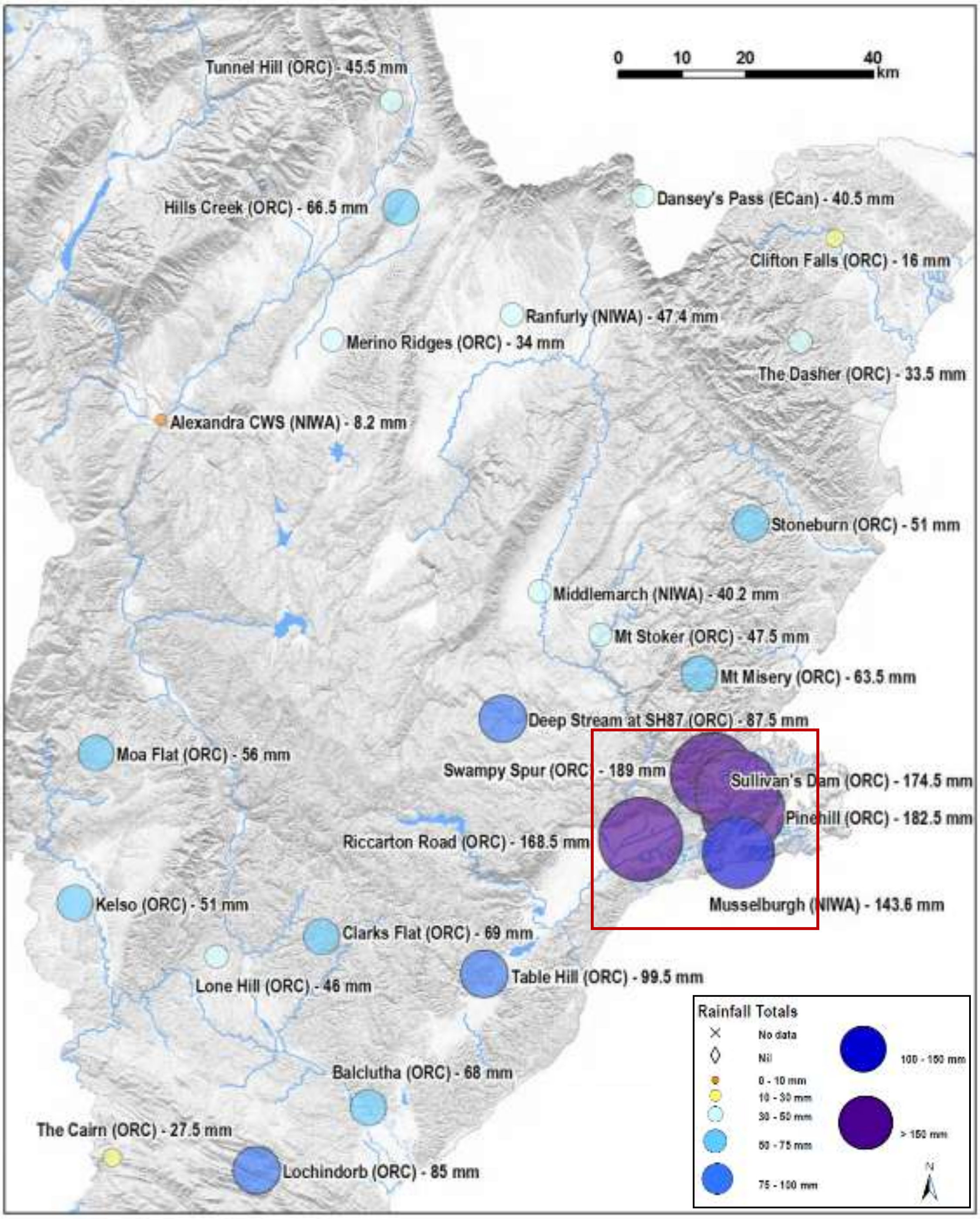

Figure 3. Rainfall totals observed at rain gauges in coastal and central Otago, midnight on 3 June to 6am on 4 June 2015 (30 hours). The agency responsible for each gauge is also listed. The area within the red box is shown in Figure 4. The Dunedin Airport site is not shown as this site only provides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

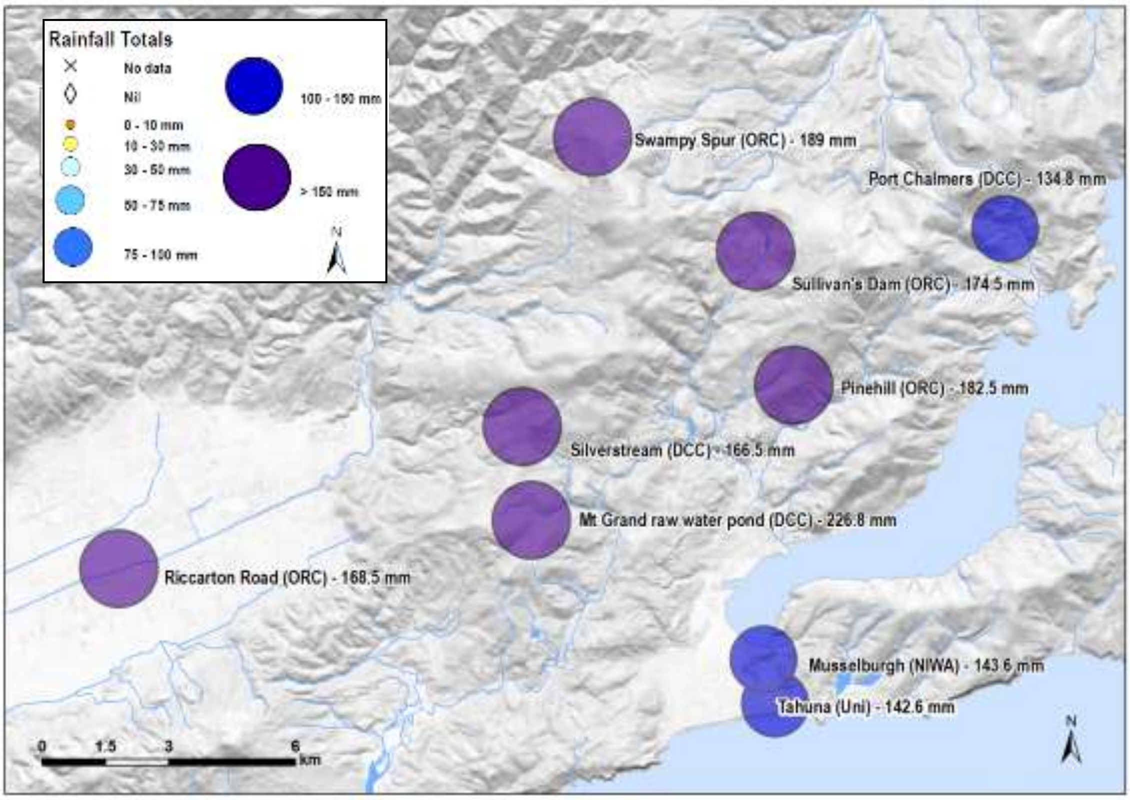

Figure 4. Detailed map showing rainfall totals observed at gauges in and around the Dunedin City urban area, midnight on 3 June to 6am on 4 June 2015 (30 hours). The agency responsible for each gauge is also listed.

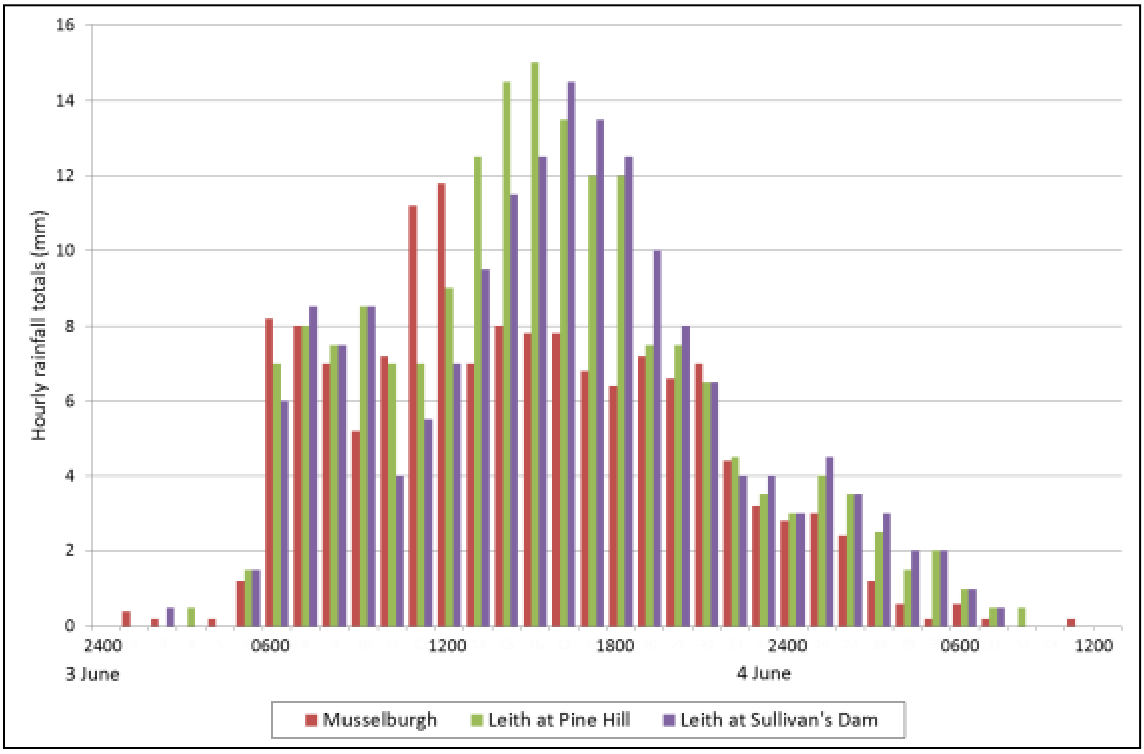

Figure 5. Hourly rainfall totals at the Musselburgh, Pine Hill and Sullivan's Dam rain gauges, Midnight on 2 June 2015 until 12pm on 4 June 2015

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
Sullivan's 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[6]
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)[7]	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

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
Sullivan's 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

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

[7] 9am daily reading only.

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 program.[8]

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

Site	Length of record (years)	Data type[9]	Maximum 24-hour rainfall, June 2015	Estimated Return Period (years)	
				Observed data	Using HIRDS
Sullivan's 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 (commencing 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 approximately 63 years, while the return period derived from the HIRDS program 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 program.

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 Sullivan's 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 prior to 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.

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[8] 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.

[9] It is noted that at the Musselburgh and Sullivan's 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 2 sites commenced in 1997 and 2000 respectively.

5. River Flows

The most significant flows were observed in Dunedin City (Water of Leith, Lindsay Creek and Kaikorai Stream), and also in the Deep Stream and Tokomairiro West Branch catchments (Table 4). Peak flows in Lindsay Creek and the Water of Leith were the 2nd and 3rd highest respectively since continuous records commenced 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 10 observed since records began.

Site	Records began	Maximum Flow (m³/s) or cumecs)	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 1929 flood in particular is considered the largest event in the Water of Leith since European settlement, with an estimated flood peak of between 200 and 250 cumecs. The 10 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 1920's.

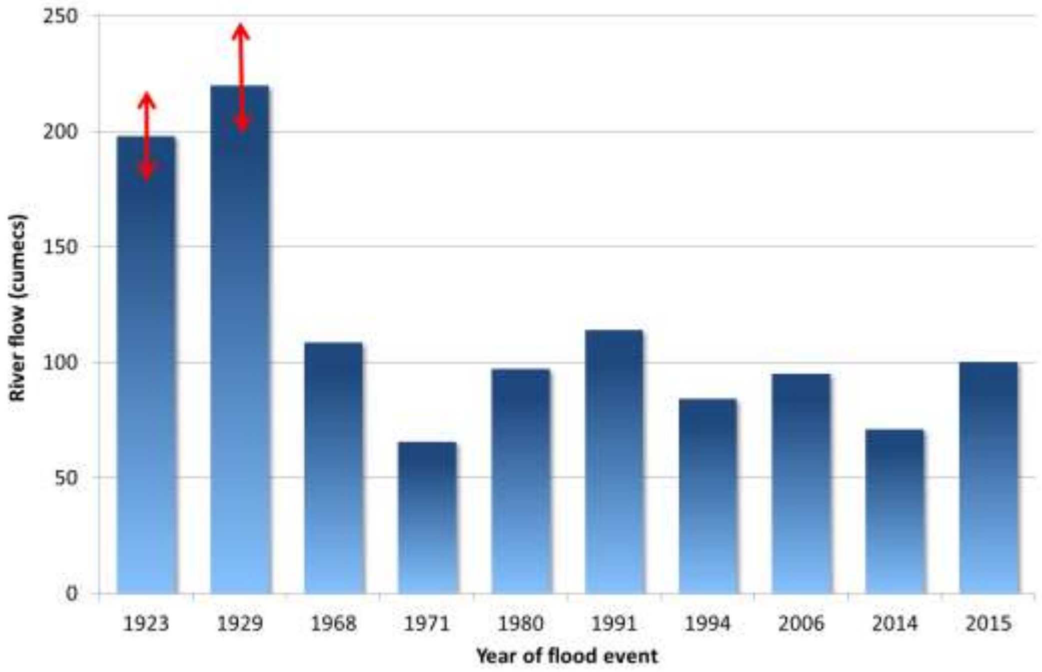

Figure 6. Estimated flood peaks since 1923 in the Water of Leith - 10 highest flows. The accuracy of the 1923 and 1929 flood peaks is less reliable than those observed after continuous records commenced in 1963.

Table 5 and Table 6 show peak flows over a certain threshold in the Water of Leith and the Silver Stream since records began.[10] 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 (m^3/s or cumecs) in the Water of Leith >60 cumecs, for 10-year periods commencing in 1965

1965 – 1975 (10 years)		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

Table 6. Peak flows (m^3/s or 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

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[10] 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.

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 of this assessment are shown in Table 7. The return period for the peak flow in the Water of Leith is approximately 30 years, although this assessment does not include the historical flood events in the 1920's which occurred prior to the commencement 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 from this event show that the Silver Stream began to overtop at the Gordon Road Spillway during this event, as discussed in Section 10.

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 reasonably frequently.

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

Site	**Length of record (years)**	**Maximum Flow m³/s (cumecs)**	**Estimated Return Period**
Kakanui at Clifton Falls	33	139	2.3
Leith at Leith Street	52	100	30[11]
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	1621	2.5

6. Sea-level[12]

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 approximately 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 not the lowest barometric pressure observed at Musselburgh in the preceding 12 months (Figure 7).

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

[12] The preparation of this section was assisted by Dr. Rob Bell of NIWA.

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 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 in 15-19 May (Figure 8). The highest sea level observed at the Green Island sea level recorder (see Figure 18 for location) since records began in 2003 was 1.77m, in May 2013.

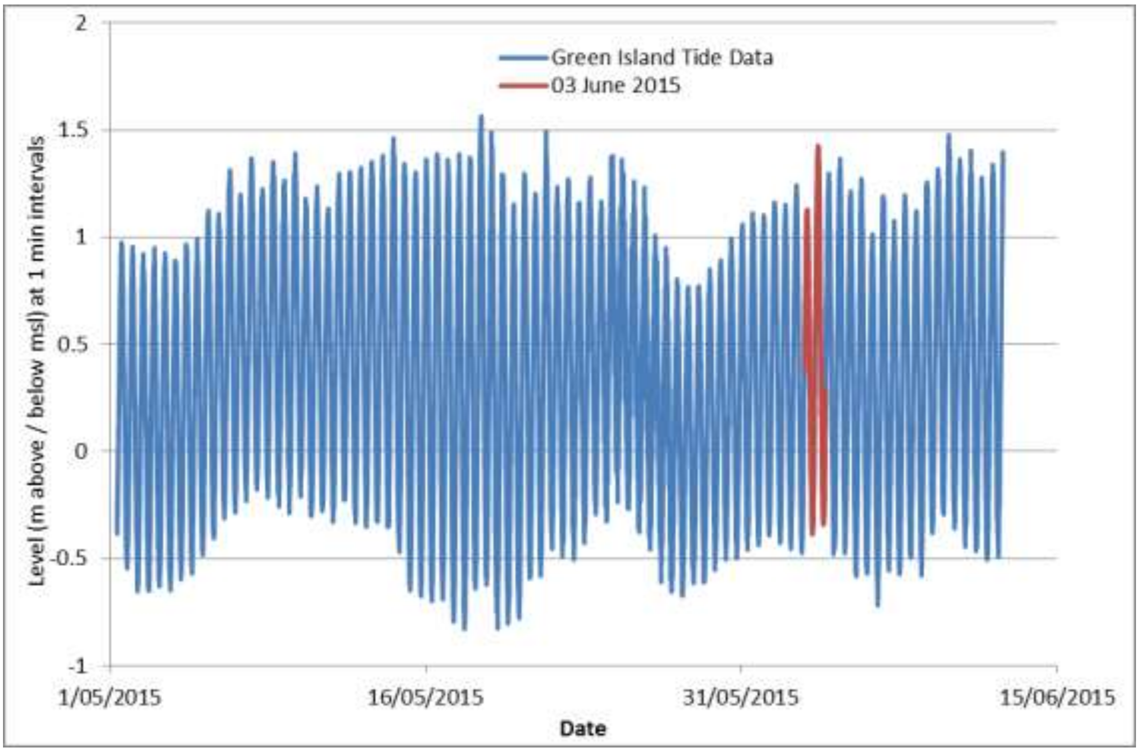

Figure 8: Green Island Tide record from 1 May 2015 to 12 June 2015

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).

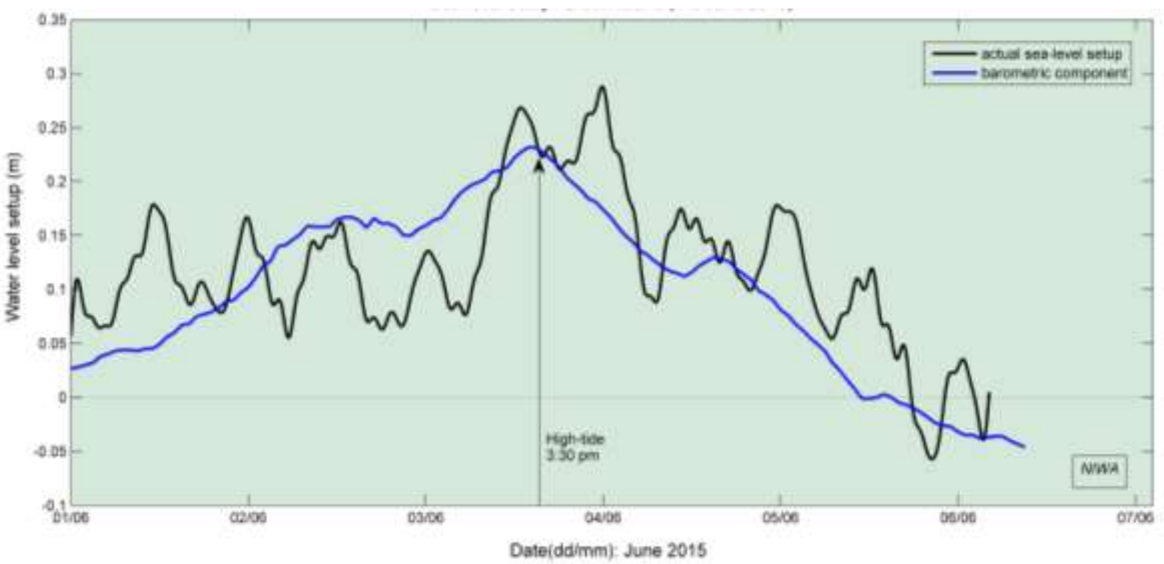

Figure 9. Sea-level setup at Green Island (1-6 June 2015)

7. Flooding effects – South Dunedin

The South Dunedin area was affected by widespread and prolonged flooding as a result of the rainfall which fell on 3 June. 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 10 to Figure 12. 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.[13] It is noted that the lowest part of South Dunedin at Tainui is known to have been affected by floodwater previously, as shown in Figure 13. Considerable localised variability in water depths was observed on 4 June, depending on slightly undulating local topography (e.g. Figure 11).

ORC initiated a survey to identify maximum flood water levels across the most affected parts of South Dunedin, and also to confirm the negligible flood water depths observed outside this area. This work commenced late on 4 June, with further work undertaken on 5 and 9 June. Corroborating forms of evidence were sought in order 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.[14]

Figure 10. Ponding of surface water on Loyalty Street, South Dunedin, 4 June 2015

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[13] Despite the lowest-lying land in South Dunedin being in the suburb of Tainui, in the eastern part of South Dunedin.

[14] Smeaton, D. 2015. *Report on South Dunedin Flood Survey – June 2015*. Report to Otago Regional Council.

Figure 11. Ponding of surface water on Dalgety Street, South Dunedin, 4 June 2015

Figure 12. 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 14, 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 14 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 14 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 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 15. 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 south-east sloping plain which 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 13. 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 14.

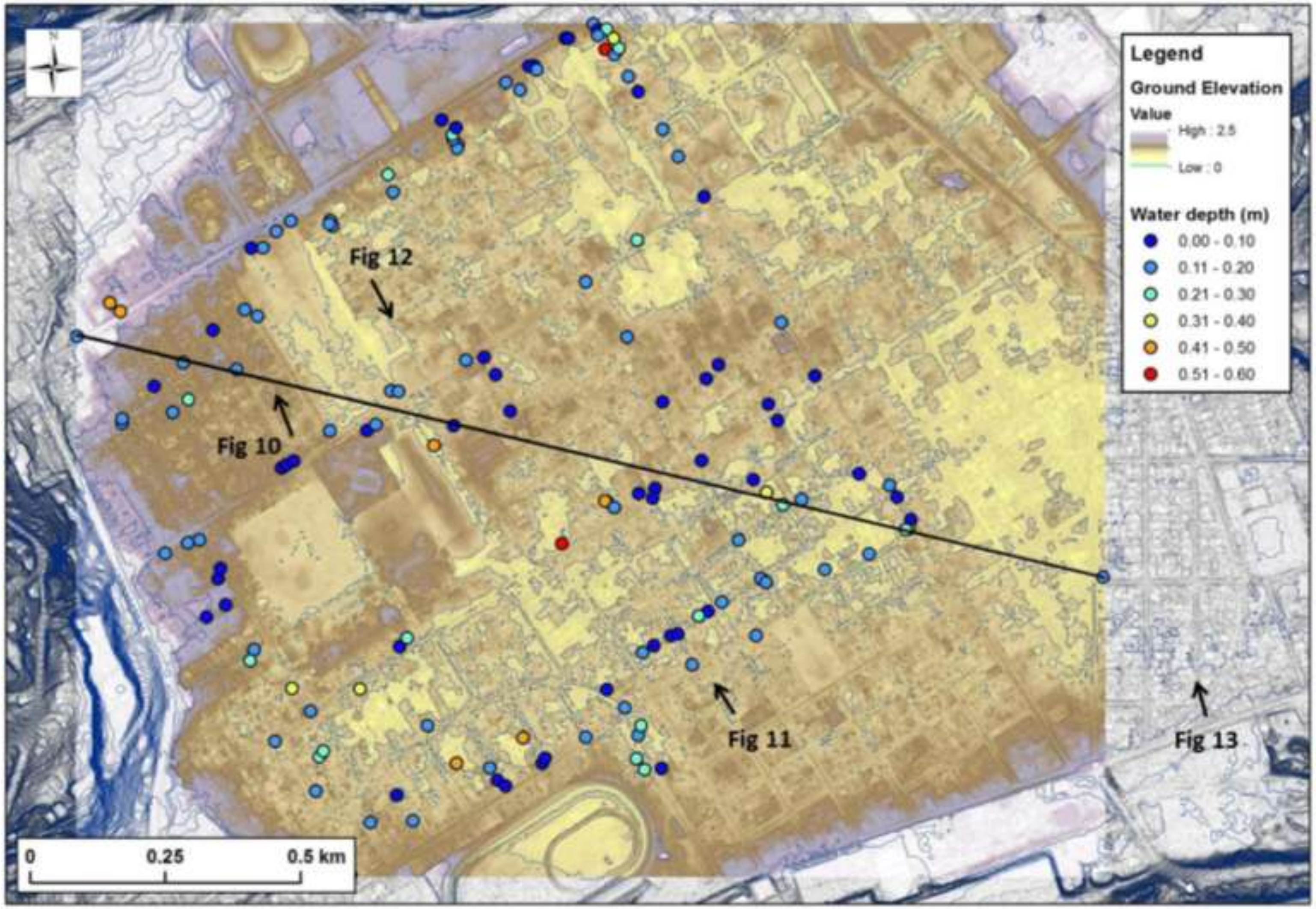

Figure 14. Map of South Dunedin with elevation colour scale showing topography between 0 and 2.5m above mean sea level. Contour interval is 1m. Profile line as shown in Figure 15 and Figure 16. Elevation is relative to mean sea level.

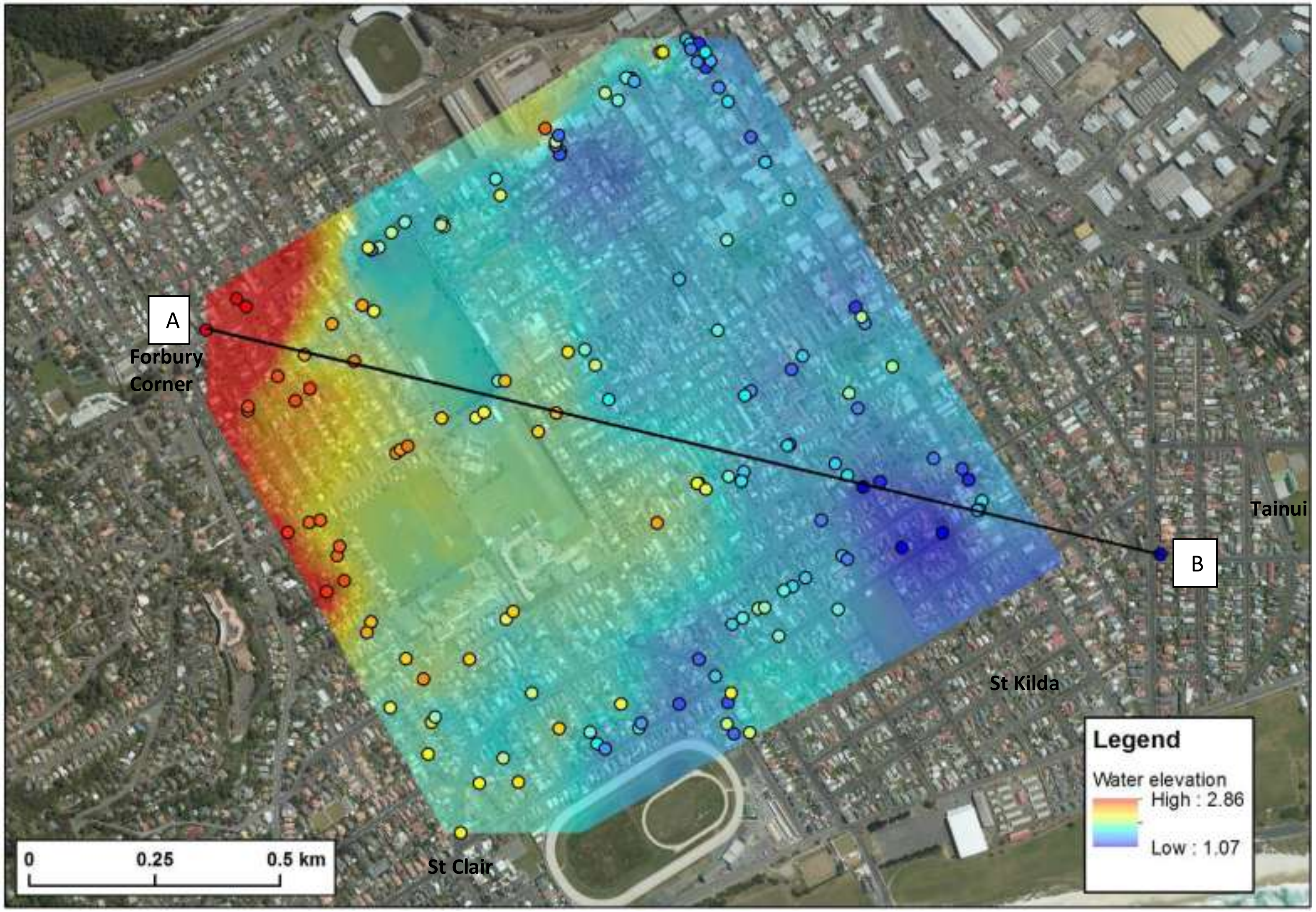

Figure 15. Surveyed flood water elevations (dots), and interpolated water surface elevation across South Dunedin. Profile Line A-B as shown in Figure 14 and Figure 16.

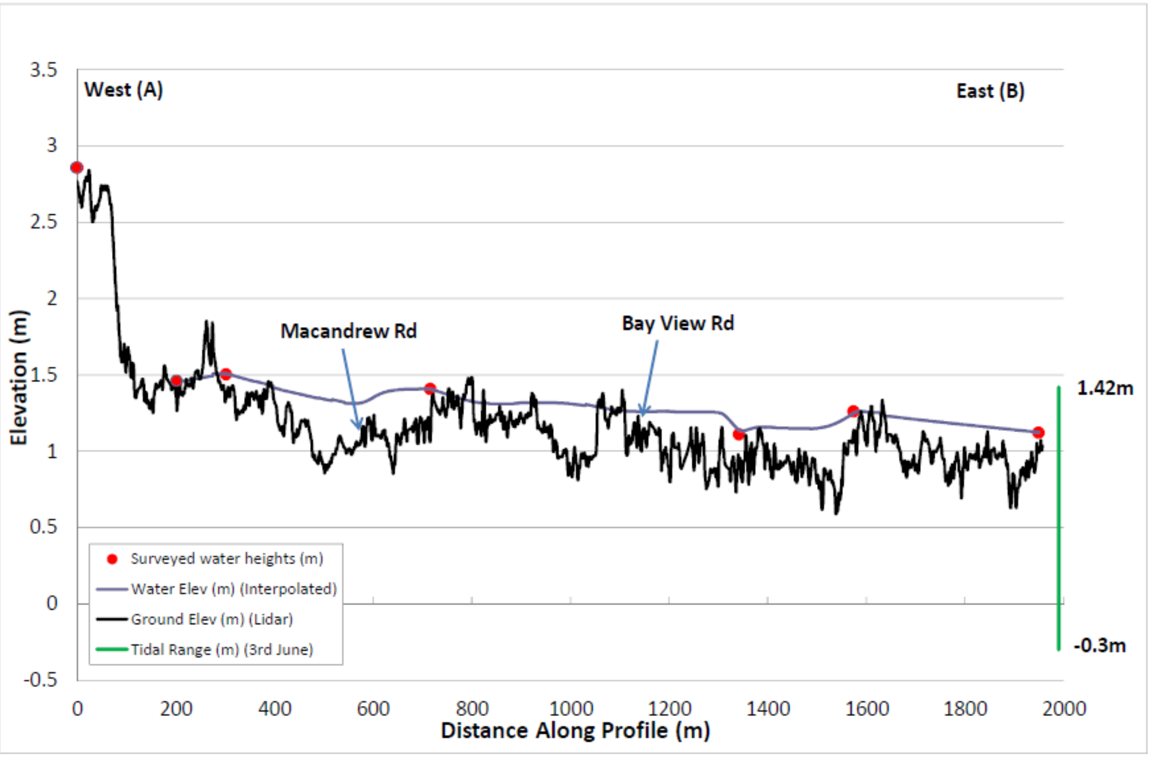

Figure 16. Elevation transect shown on Figure 15. The black line is ground elevation and the blue line is the interpolated maximum flood elevation from Figure 15. The red dots are actual observations of water level in close proximity to the transect line. Water surface has a gradual slope from west to 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 was rain which fell on the flats themselves as well as stormwater runoff from the surrounding hill catchments. The major catchments and the natural topographic boundary of the South Dunedin catchment are shown in Figure 17. It is noted that the DCC stormwater network does not necessarily follow the natural catchment boundary – in particular, some of the stormwater from the northernmost 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 17, is 14.8km^2. For comparison, the Lindsay Creek and Water of Leith catchments are 12.5km^2 and 42km^2 respectively.

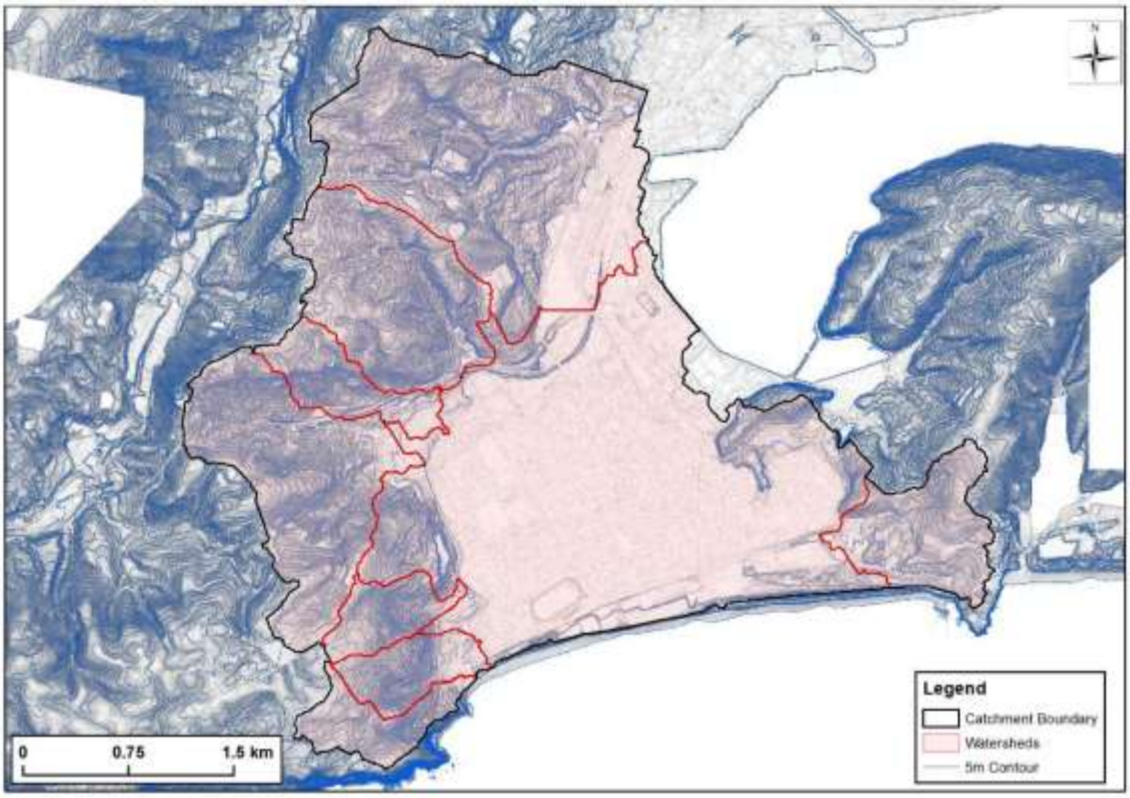

Figure 17. Contour map showing the natural boundary of the South Dunedin catchment (black line) and sub-catchments (red lines)

Groundwater level - observations

Background

Between 2009 and 2014, 4 groundwater monitoring bores were established by ORC across South Dunedin (Figure 18). These bores record water level readings in 15 minute increments. Water level from the 3 bores established in 2009 assisted with 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.[15]

This section discusses groundwater level at each bore prior to 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 19 to Figure 22). Rainfall signature can be seen in all 4 monitoring bores.

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

Figure 18. 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 much less 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 preceding and during this event are described in Section 6.

***Kennedy Street groundwater bore*[16]**

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 6, 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 prior to the flood have been taken from the average daily groundwater level as shown in blue in Figure 19. Average daily groundwater levels prior to the flood were above average level for this monitoring 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).

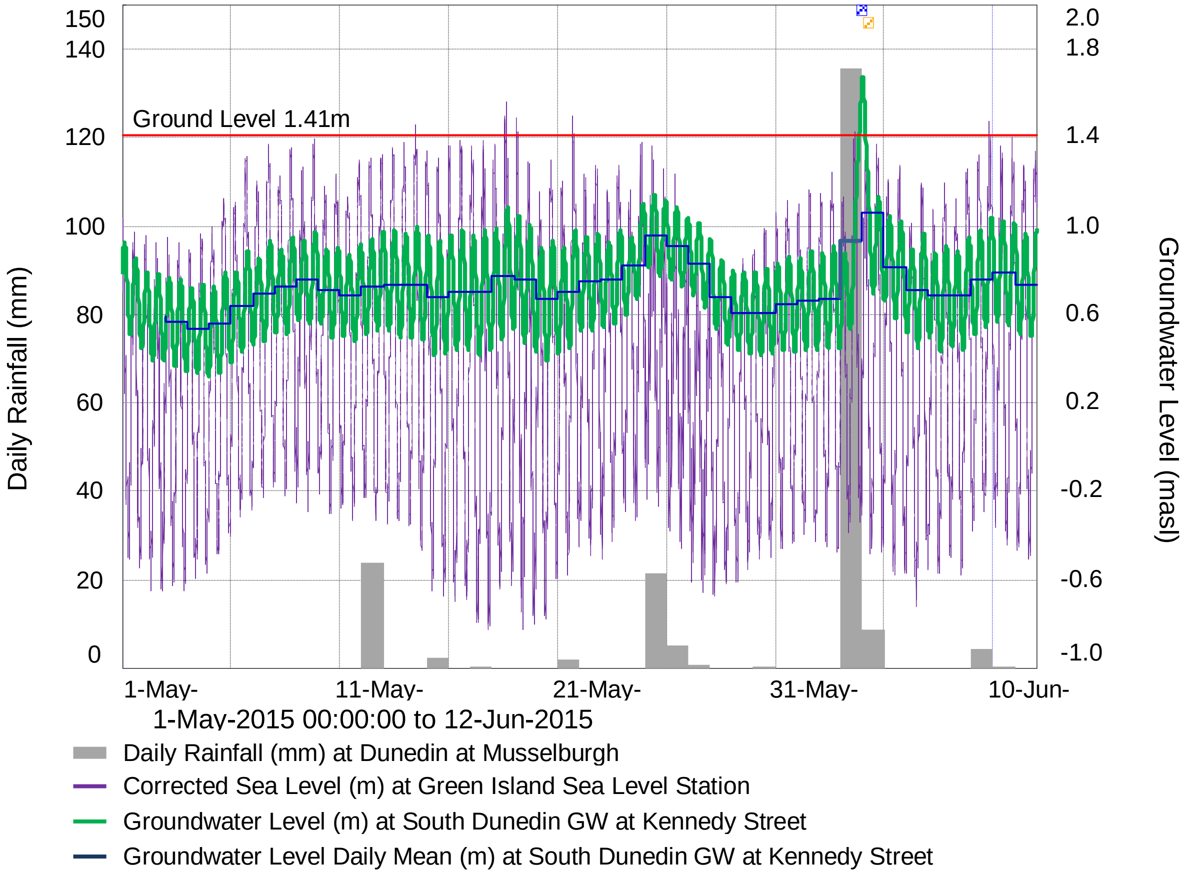

Figure 19: Kennedy Street continuous and daily average groundwater record, Green Island Tidal data and daily rainfall from 1 May - 12 June 2015. Ground level is 1.41 masl.

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[16] Note that this section has been edited and differs from the version presented to the ORC Technical Committee on 22 July 2015.

Tonga Park groundwater bore

Groundwater levels prior to 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), though an increasing trend in groundwater level is seen likely 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 15) at Tonga Park is approximately 1.4 masl, similar to that recorded at the bore, and indicating that this site was likely measuring floodwater as a result of the 3 June event.

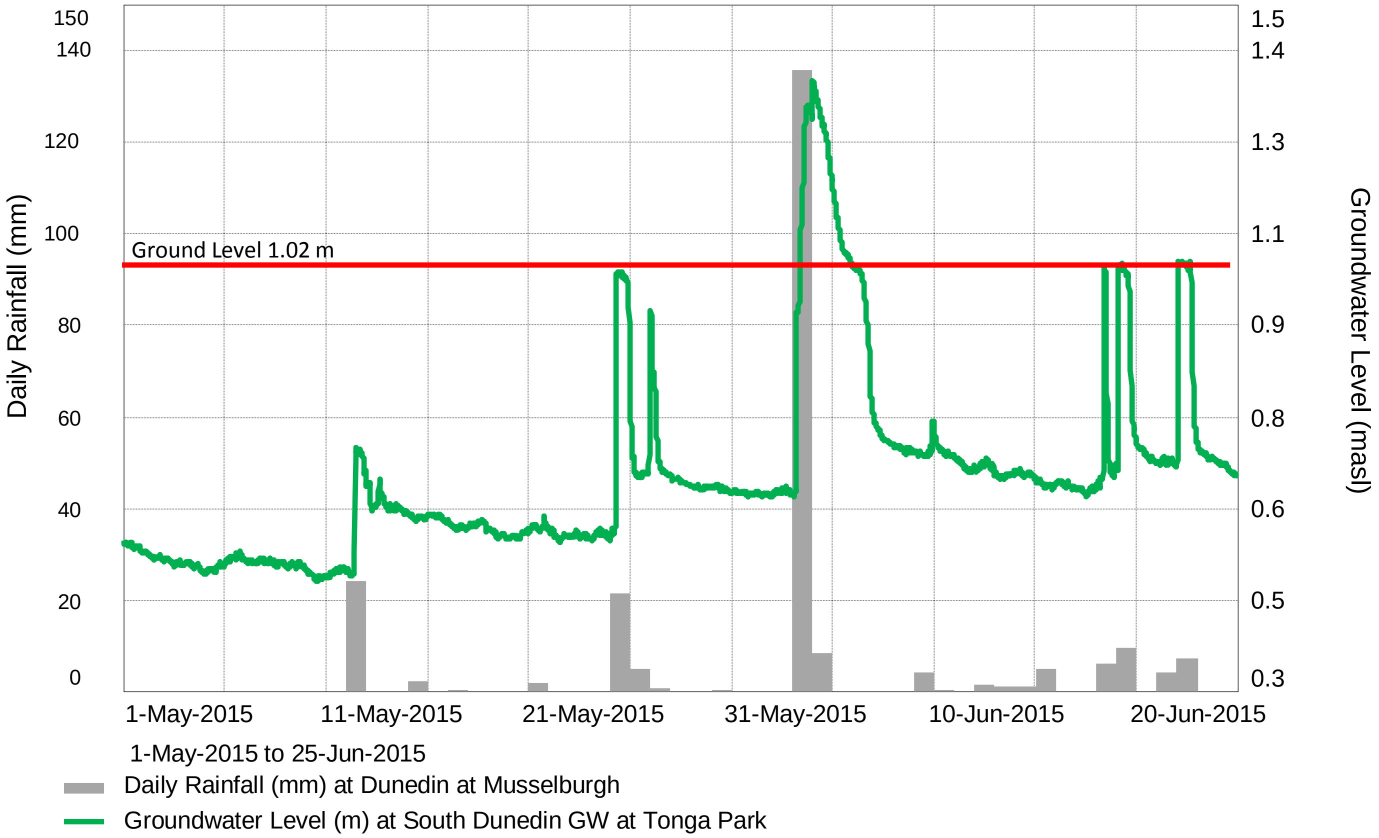

Figure 20: Tonga Park continuous groundwater record from 1 May - 25 June 2015. Ground level is 1.02 masl.

Culling Park groundwater bore

The groundwater monitoring bore at Culling Park has a shorter monitoring record than the other 3 sites, as this bore was installed in May 2014. Groundwater levels prior to the flood were above average level 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, never the less it is likely 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).

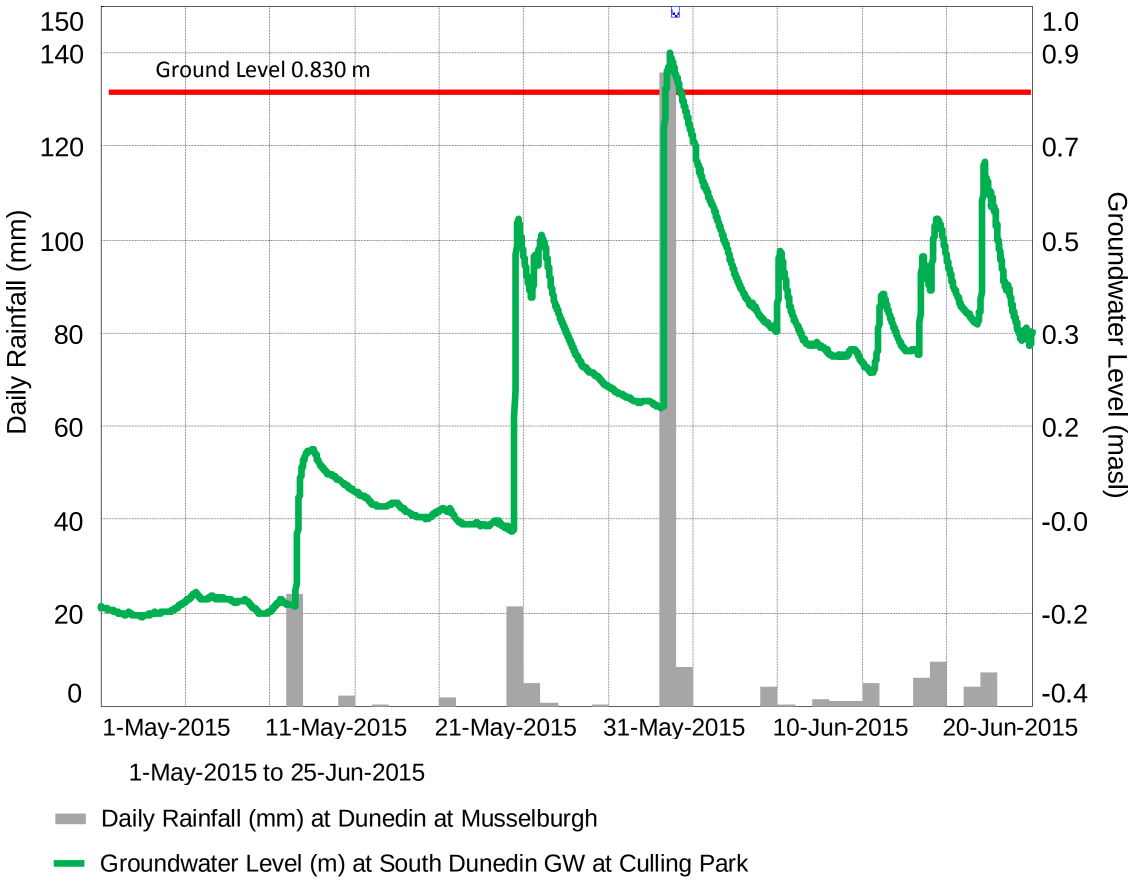

Figure 21: Culling Park continuous groundwater record from 1 May - 25 June 2015. Ground level is 0.830 masl.

Bathgate Park groundwater bore

Groundwater levels prior to the flood were slightly above average level for this monitoring bore (Average gwl: 0.689 masl; 2 June at 11:45 pm: 0.751 masl), most likely 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 22: Bathgate Park continuous groundwater record from 1 May - 12 June 2015. Ground level is 1.52 masl.

Groundwater observations summary

Groundwater levels from three bores (Kennedy Street, Tonga and Culling Park) rose above ground level as a result of the rain event that occurred on 3 June 2015 (Figure 23). Groundwater levels at Bathgate Park were 0.53m 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 23: 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 which 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 24) where imperviousness can approach 100%.[17]

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

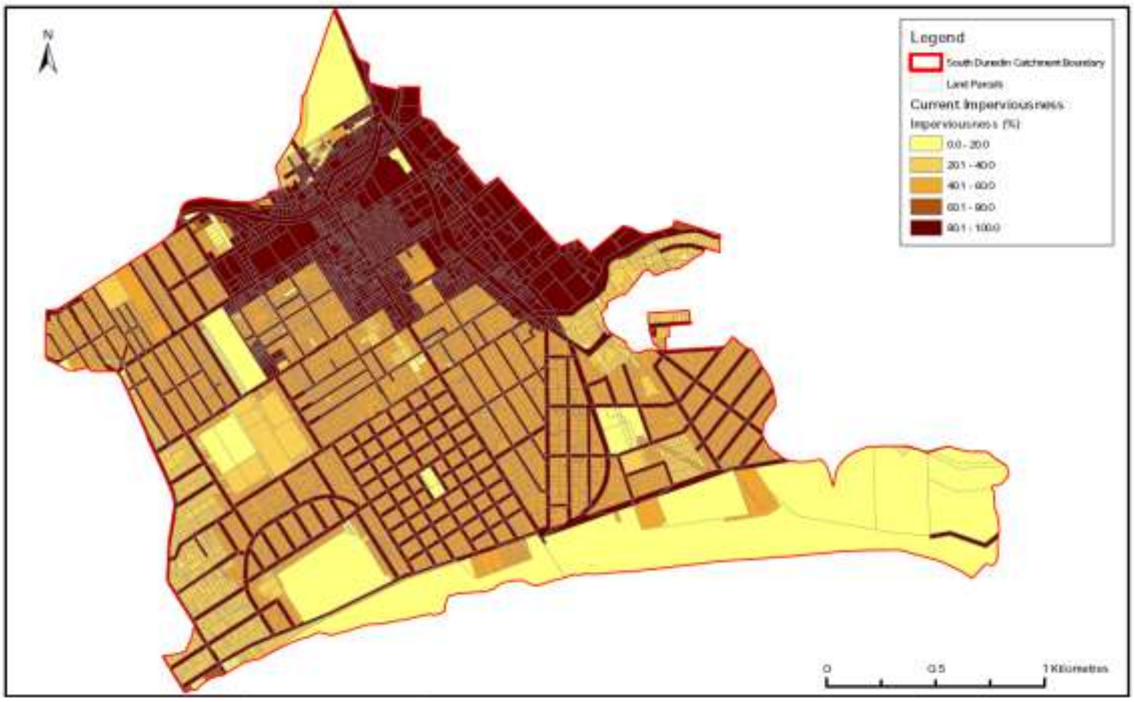

Figure 24. Map showing the current level of imperviousness, as defined by URS and Opus for the DCC

Indications of the future

Mean sea level at the port of Dunedin is inferred to have risen at an average rate of 1.3mm / year since 1900, which equates to a rise of about 15cm over that time.[18] 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 ± 1mm. The average level of the sea at Green Island has increased at a reasonably consistent rate of 3.3mm/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 0.98m (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 NZ Coastal Policy Statement) is from a NIWA guidance document Pathways to Change (Britton et al., 2011).[19] This advises that a 1.0 m rise by 2115 relative to 1990 mean sea level should be considered for sea-level rise for New Zealand regions at this stage. The Proposed Regional Policy Statement for Otago has the 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 metre by 2115, relative to 1990 mean sea level and adding an additional 10mm per year beyond 2115.

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

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[18] Hannah, J. and Bell, R. 2012. *Regional sea level trends in New Zealand.* Journal of Geophysical Research, Vol 117, C01004.

[19] 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

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 utilised as a groundwater resource. As a result, no aquifer parameter information has been collected about the aquifer (e.g. transmissivity, storativity, hydraulic conductivity etc.). No investigation bores to determine the aquifer geological profile at depth have been undertaken, apart from at the Tainui Waste Water Treatment Plant. The aquifer geological profile and parameters are required to estimate how much drawdown would occur from pumping.

Beca Ltd completed a report in 2014[20] identifying potential engineered solutions for protecting the Harbourside and South City from direct impacts of sea level rise. The option preferred by Beca Ltd 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 level would be maintained at 30-50 m below ground level at each well with groundwater level maintained at current elevation between wells. At higher values of sea level rise this mitigation option would, according to Beca Ltd, 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 10, 11, 12 and 13).

The option preferred by Beca Ltd 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 that surface water (rain, overland stormwater etc) could infiltrate into. However, given the amount of rainfall that fell in the short period of time on 3 June and overland storm water that was present, along with the high degree of impervious surfaces (Figure 24) 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 the 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.

8. Flooding effects – Water of Leith and Lindsay Creek

The Leith Flood Protection Scheme as a whole 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 approximately 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 has commissioned a detailed damage inspection report of the Water of Leith, and this work is underway. The work could not commence earlier as the water level was still too high to provide safe access and allow for sufficient observation of the river bed. Preliminary inspections have been undertaken by ORC staff.

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

High flows resulted in scouring and loss of the foundation toe under a localised section of the scour wall on the true right bank below the Dundas St Bridge. Repairs to this scoured wall will probably

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[20] Beca Ltd, 2014. *Assessment of Options for Protecting Harbourside and South City from Direct Impacts of Sea Level Rise*. Report prepared for the Dunedin City Council.

be undertaken as part of the Dundas St to St David St stage of the Leith Flood Protection Scheme works in 2015/ 2016. Other localised scour occurred in this reach too.

The recent flood protection upgrade between St David St to Union St performed satisfactorily. There was no damage to the left bank. On the right bank riprap has been scoured away over a 100m length of the recently completed lower right bank pathway (Figure 25). The riprap lost over the lower 38 metres has resulted in a fall height greater than 1m from the walkway to the river bed. 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 25. Water of Leith before and after – looking upstream from near the Staff Club. Note the loss of some riprap on the true right bank.

In the Union St to Leith St reach the left bank has two regions of scouring approximately 5m long to approximately 4m above the bed. Scouring on the right bank of the bend immediately downstream of the ITS building has been reported, water levels have now receded to allow a survey of the extent of this damage. A survey is underway and initial visual assessments indicate the scour could be to a depth of 1.8m and extend approximately 1m under the existing wall. On the left bank material has been deposited on the beach. The existing channel confinement walls and banks performed as expected. Remedial works are required as soon as practicable to stabilise the suspected under scoured wall.

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

The Water of Leith debris traps performed as intended. The Woodhaugh Street boulder trap collected the bulk of the Leith debris (Figure 26) 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 27). Numerous sections of Lindsay Creek experienced significant bank erosion, as shown in Figure 28 to Figure 30.

Figure 26. Water of Leith debris trap at Malvern Street (left) and Woodhaugh Street boulder trap (right) during the event, 3 June 2015

Figure 27. Lindsay Creek debris trap at Bethunes Gully during the event, 3 June 2015

Figure 28. Bank erosion undermining a shed alongside Lindsay Creek at Kelvin Road, 4 June 2015

Figure 29. Bank erosion alongside Lindsay Creek at Kelvin Road, 4 June 2015

Figure 30. Bank erosion alongside Lindsay Creek at Norwood Street, 4 June 2015

9. 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 SH1 underpass),
- The intersection of Kaikorai Valley Road and Stone Street, as well as much of Kaikorai Valley Road below this point (Figure 31),
- SH1 at Green Island (Figure 32) 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.[21]

Figure 31. Examples of surface flooding on Kaikorai Valley Road, midday on 3 June 2015

Figure 32. 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.

At 12:30pm, a car and tree were reported in Kaikorai Stream, wedged in an NZTA box culvert under SH1 at Burnside (Figure 33), with a tree and other debris further upstream, caught up under a bridge (Figure 34). NZTA's contractor was contacted by ORC operations staff but was unable to remove the blockage in a timely manner because of other priorities. All blockages were removed by ORC staff by 4:35pm.

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

Figure 33. Car and tree lodged in culvert beneath SH1 at Burnside, 3 June 2015

Figure 34. 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 that had been sited on top of the creek bank that 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 adjacent to Abbots Creek which appears to have caused some localised flooding to those properties. Fulton Hogan is assessing the situation at the request of the affected landowners.

10. Flooding effects – Taieri Plain

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

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 35) but no overtopping of the main floodbanks was recorded. The Henley spillway downstream of Otokia operated between approximately 10am on 4 June and 2am on 5 June (Figure 36) resulting in extensive ponding in the Henley floodway as 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 37). 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 38). However, water from other sources resulted in a maximum water depth of approximately 1.2m in the Upper Pond, with a total stored volume of 1.5 million cubic meters (4% of the Upper Pond 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 approximately 4pm and 10pm on 3 June. Figure 39 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 40). 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.[22] The extent of ponding behind the Cutoff Bank was less than 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.

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 causing localised flooding in the area (Figure 41).

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 42).

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[22] *'Update to Taieri Plain flood hazard mapping for Dunedin City District Plan'* Report No. 2015/0960. '. Report to ORC Technical Committee, 22 May 2015.

Figure 35. Taieri River berms and floodway looking southwest, downstream of Allanton – 4 June 2015

Figure 36. Henley Spillway (downstream of Otokia) operating – 4 June 2015 11.45am

Extensive ponding was also recorded in the Lower Pond (Figure 43 and Figure 44) 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 44).

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 45) 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 approximately. 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 north-western end of Lake Waihola were overtopped causing localised ponding.

Figure 37. Aerial view towards the south of floodwater at Henley – 4 June 2015

Figure 38. Ponding in the Upper Pond, view is towards the southwest – 4 June 2015

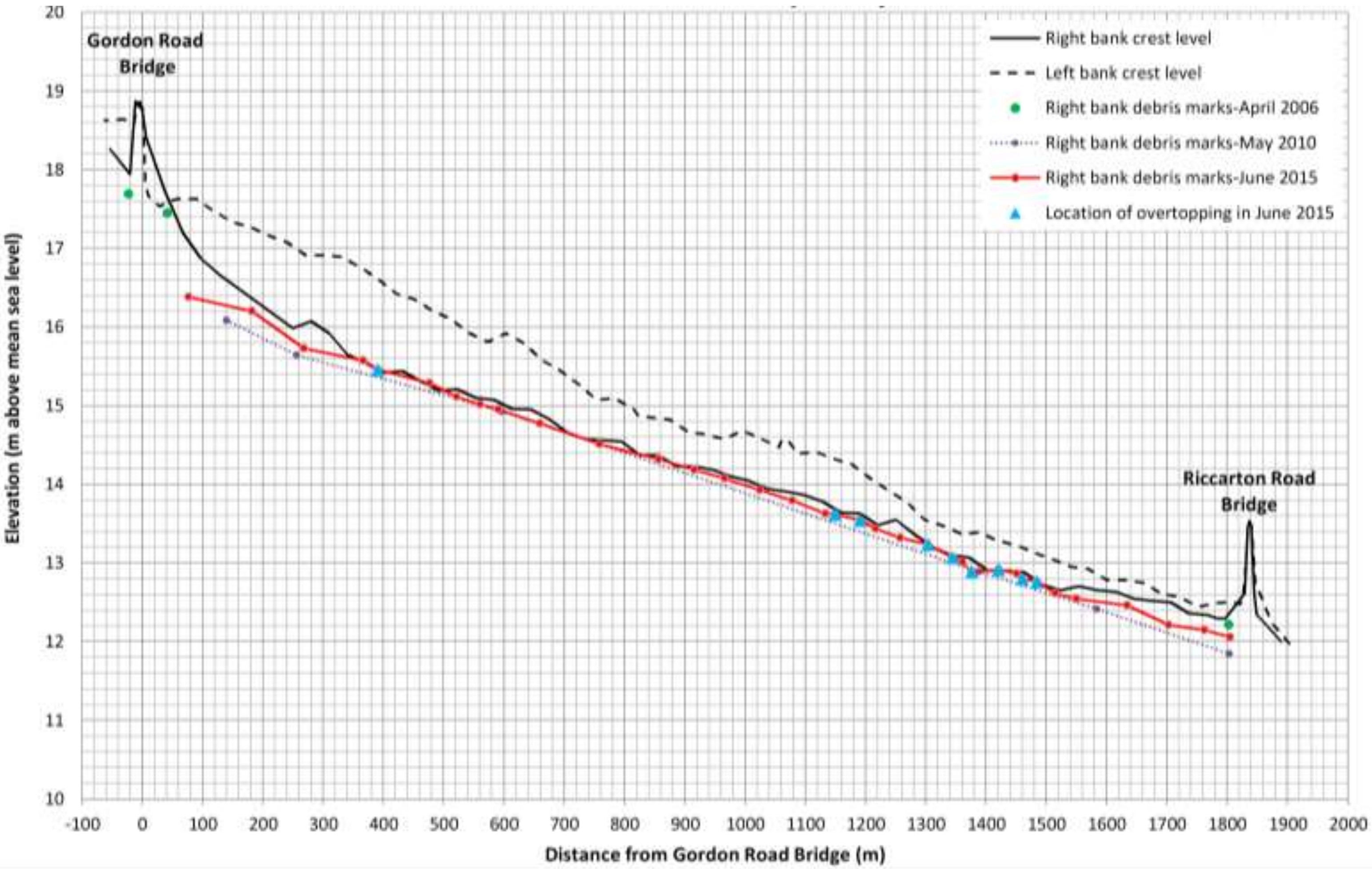

Figure 39. June 2015 maximum water level in the Silver Stream in relation to the top of the left and right floodbanks, between Gordon and Riccarton roads. Flood debris marks collected after the April 2006 flood event are also plotted.

Figure 40. Ponding behind the Cutoff Bank, view is towards the south – 4 June 2015

Figure 41. Debris marks indicative of overland flow and ponding in the vicinity of Wyllies Crossing – 4 June 2015

Figure 42. 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 43. Ponding in the Lower Pond, view is towards the southwest – 4 June 2015

Figure 44. 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 45. Flooding in Gow (left) and McGlashan (right) Streets, Mosgiel – 3 June 2015 (photos courtesy of PW Engineering and Payne Aluminium)

Taieri Land Drainage Pumping Stations

The *Waipori pump station* achieved the necessary pumping capacity to maintain drain levels and convey floodwater (Figure 46).

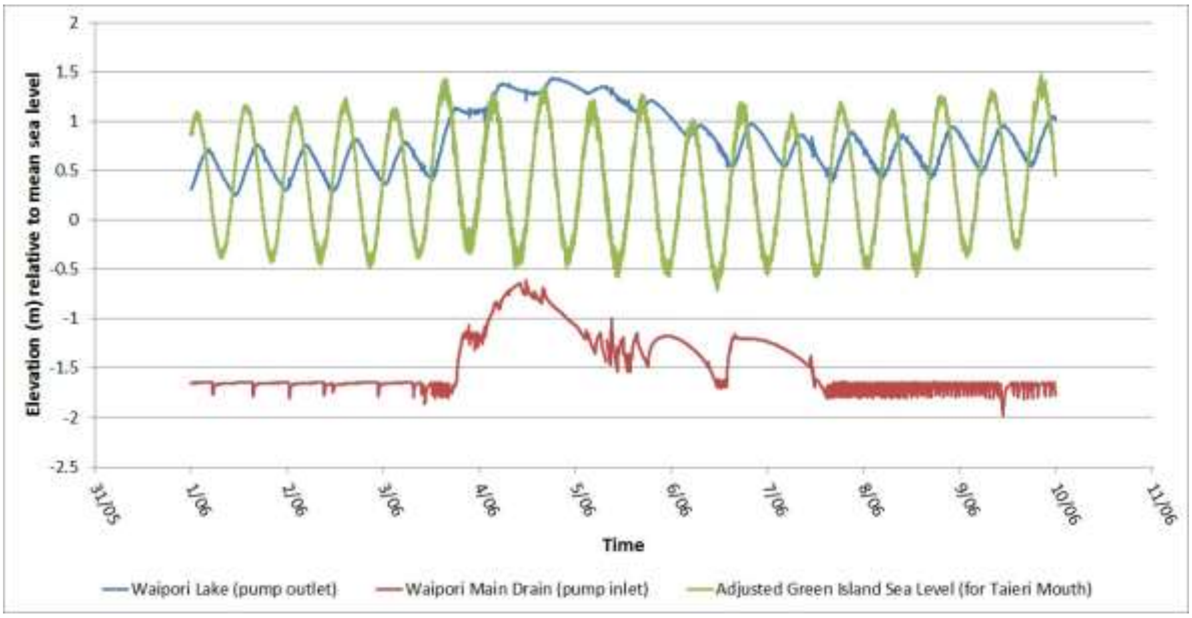

Figure 46. Main drain level at Waipori pump station, level of Lake Waipori and sea level, 1 to 9 June 2015

Landholders indicated their satisfaction that the event had been contained. The flood conditions provided valuable learnings, and an opportunity to refine the control system. It had not been previously possible to commission the pump station with all pumps running simultaneously with a high discharge head. 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 was diagnosed and corrected by adjustments to the motor control parameters over the two days succeeding the event. The learning 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. This 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, hence there was no point running the pump further, 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 via 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 2 pumps; it required one pump to handle the event in the catchment.

Mill Creek pumping station comprises of 2 pumps. Dead poplar trees overhanging the power supply lines to the pump station were scheduled to be removed by Delta at the start of the flood event, resulting in a temporary power outage to the pump station. The consequence of the dead trees being downed into the drains was that a number of branches hampered the pump station 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, all 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 truck loads. At this time of the year the grass dies and drains have been mowed. A significant amount of the material that blocked screens and culverts resulted from drain mowing.

11. 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 Clutha District Council (CDC) floodbank downstream of SH1 prevented the Tokomairiro River from affecting low-lying properties in the Mill Street area, with some freeboard (Figure 47), and the CDC pump appeared to be assisting in the removal of surface runoff from Milton.

Figure 47. 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[23], and Figure 48 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 49), 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 did not evacuate.

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

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

Figure 48. 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 49. Aerial view of floodwater on Ajax Street (centre) Milton, with Union Street (SH1) to the right, 4 June 2015

12. 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 which formed at the Koau mouth of the Clutha River, impeding gravity drainage from the catchments.

Over this month, a total of 156mm 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 (10mm) 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 50). 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.

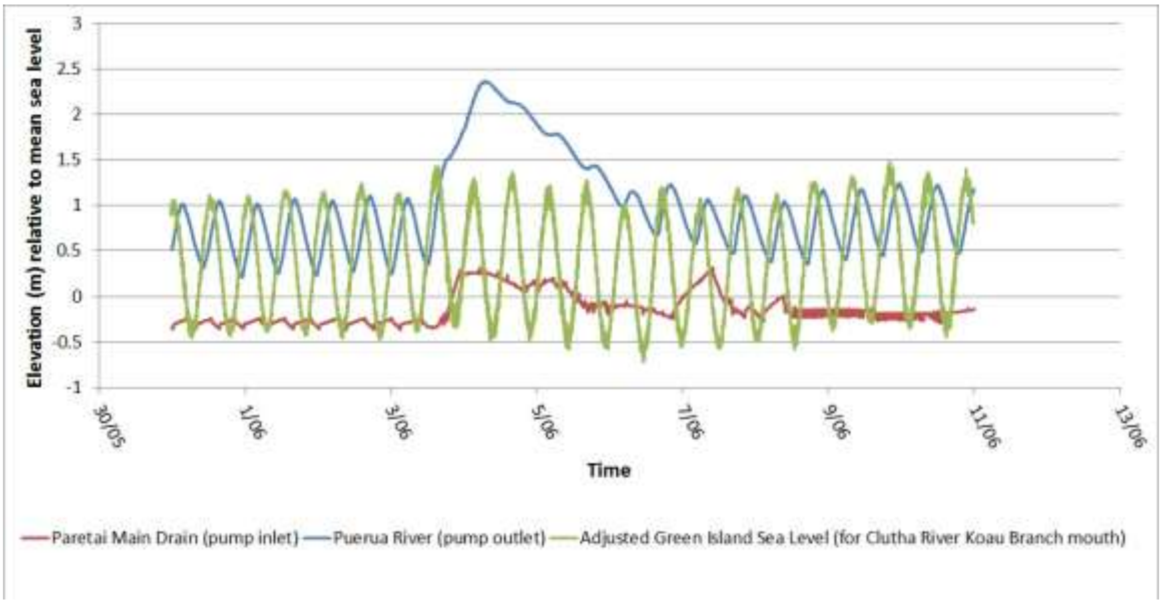

Figure 50. Paretai Pump Station inlet water level, outlet water level (Puerua River) and sea level, 1 to 10 June 2015

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.

Inch Clutha pump station performed well.

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

13. Flooding effects – Inland Otago

Rainfall intensities further inland were generally less significant than those in and around Dunedin City (Figure 3), and the Central Otago District Council did not observe any major flooding related issues.[24] One exception was at Blackjacks Creek, 3km south of Roxburgh, where a culvert under SH8 was washed out by flash flooding, closing the road for 2 days (Figure 51). The nearest rain gauge is Moa Flat (17km to the south) where the 56mm of rain recorded was the 10th highest 1-day rainfall on record. This suggests that the flooding in Blackjacks Creek resulted from localised heavy rainfall within the catchment.

Figure 51. Flooding at Blackjacks Creek at SH8, 3 June 2015

14. Landslides

Numerous landslides on hillslopes in the Dunedin City district occurred as a result of the 3 June rainfall event, and an example of one small area on the Otago Peninsula is shown in Figure 52. Staff from ORC and GNS Science completed a program of observations and assessment of landslide activity following 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 program of work instigated by ORC in 2012 to improve the understanding of landslide hazard within the Dunedin City district.[25]

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

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

Figure 52. Aerial view of Harbour Cone, with landslide locations marked with red arrows, 16 June 2015

15. Discussion

Generally speaking, the rainfall and its effects had precedent and verified existing knowledge and information to do with flood hazard for Otago. Notwithstanding that, the event enabled the body of knowledge to be extended and information to be refined. For example, 9 flow gaugings were completed over the peak of this relatively brief high-flow event. This included 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 meter 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 53).

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 53. 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 Dunedin City's 2GP District Plan 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 benefited 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:

1. Completing the Leith Flood Protection Scheme;
2. Continuing to work with Otago's territorial authorities to integrate natural hazard information into District Plans;
3. With Dunedin City Council, developing a natural hazard risk management strategy for South Dunedin;[26]

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

4. 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;

5. Investigating options to improve drainage of the upper pond (Lower Taieri Flood Protection Scheme and East Taieri Drainage Scheme);

6. Providing real-time public access to operational information for the Paretai, Kaitangata and Barnego pump stations (Lower Clutha Flood Protection and Drainage Scheme).

16. Recommendations

That this report be received and noted.

Gavin Palmer
Director Engineering, Hazards and Science