50 The Octagon, PO Box 5045, Moray Place
Dunedin 9058, New Zealand
Telephone: 03 477 4000, Fax: 03 474 3488
Email: dcc@dcc.govt.nz
www.dunedin.govt.nz

15 June 2018

[redacted]

Dear [redacted]

Local Government Official Information and Meetings Act 1987 (LGOIMA) request for a copy of the 2006 Waitati flood report

I am writing in response to your official information request for a copy of the 2006 Waitati flood report received 17 May 2018.

Please find attached the 2006 Waitati Flood Report as requested. I advise that no report has been prepared for the 2017 flood event.

Yours sincerely

Rebecca Murray
Governance Support Officer

MWH

Meeting the challenge

Dunedin City Council
Civil Defence and Rural Fires

Waitati Flood Reporting

August 2006

This document has been prepared for the benefit of Dunedin City Council. No liability is accepted by this company or any employee or sub-consultant of this company with respect to its use by any other person.

This disclaimer shall apply notwithstanding that the report may be made available to other persons for an application for permission or approval to fulfil a legal requirement.

Quality Assurance Statement	
MWH New Zealand Ltd 265 Princes Street, Level 3 John Wickliffe House P O Box 4 Dunedin Tel: 64-3-477 0885 Fax: 64-3-477 0616	**Project Manager:** David Whittington
	Prepared by: David Whittington
	Reviewed by: Roger Oakley ....
	Approved for issue by: David Whittington ....

Dunedin City Council

Waitati Flood Reporting

Contents

1 Introduction

Following a long dry spell, on 25 and 26 April 2006 a prolonged period of heavy rain fell on the City of Dunedin.

This rainfall, the severity of which varied widely across the greater Dunedin area, affected a number of areas. Amongst the worst affected areas was the village of Waitati, 15km to the north of the City centre.

The purpose of this report is to develop a record of the storm event and the flooding that resulted for the Dunedin City Council's hazard register.

This report describes the nature of the rainfall event including intensity and duration, how the catchment area collected the rainfall and runoff to affected areas, and to identify where the worst of the flooding occurred and the flowpaths taken by the floodwater.

2 Rainfall Records

Raineffects Ltd were commissioned to provide hydrological data and report: their report is included as Appendix A. Raineffects also produced isohyet (rainfall contour) maps which are included at the back of their report.

This event was a relatively long duration and high intensity storm. The equivalent return period for this storm can be assessed as a 24 hour storm (to identify the greatest intensity rainfall), or in order to assess the long duration, as 48 or 72 hour storms.

There are many rain gauges around Dunedin; the ones most applicable to this event are those at Sullivans Dam, Powder Creek and at Mosgiel Town at the Sewage Treatment Plant.

Sullivans Dam Rain gauge recorded the following:

24 hour storm	207.5mm	1 in 186 year return period
48 hour storm	240mm	1 in 36 year return period
72 hour storm	250mm	1 in 25 year return period

This identifies the highest intensity focus of the storm over the Mount Cargill area.

The Powder Creek rain gauge should only be used with caution and has less certainty of derived intensity assessments because there are only limited records available. However, by combining the Powder Creek rain gauge information with the one at Whare Flat, it is possible to greatly increase the confidence in the assessment and also gives better correlation to the other records for this storm:

24 hour storm	219mm	1 in 280 year return period (Powder Creek only)
		1 in 143 year return period (Combined Powder Creek & Whare Flat)
48 hour storm	251mm	1 in 106 year return period (Powder Creek only)
72 hour storm	257mm	1 in 68 year return period (Powder Creek only)

As described in Section 3 below, part of the cause of the problems at Mosgiel were due to the high river flows in the Silverstream at the same time as local stormwater run off being unable to drain into the river.

The rainfall in Mosgiel Town at this time was recorded at the Sewage Treatment Works.

24 hour storm	147mm	1 in 197 year return period
48 hour storm	170mm	1 in 86 year return period
72 hour storm	175mm	1 in 66 year return period

The short term intensity of the rainfall over Mosgiel was clearly as great an event as that in the headwaters of the Silverstream, the Waitati River and the Water of Leith, the combination of these events had a compounding effect.

The resultant flow in the receiving rivers is an important factor in the analysis of this storm event.

In the Water of Leith a flow of 95 cubic metres per second was measured. This has a 1 in 10-15 year return period. Raineffects Ltd have advised that based on the nature and location of the storm, it is reasonable to assume that the flow in the Waitati River would be of the same magnitude. Flow recorders in the Waitati River are not present to confirm this.

For comparison, previous storms have been measured in the Water of Leith as:

1980 storm	= 97 cubic metres per second (cumecs).
1991	= 114 cumecs
1929	= 220 cumecs
1923	= 200 cumecs

The Silverstream was assessed as having a flow of 223 cumecs which has a 1 in 80 year return period.

3 Description of Event

The catchment area for the Waitati Valley was subjected to some of the heaviest rainfall of the whole of the storm period of the 25 and 26 April 2006. The catchment area is bounded to the south by the ridge through Leith Saddle between Mount Cargill and Swampy Summit.

Details of the event have been collated from eye witness accounts, photographs and physical evidence on site.

Waitati Valley catchment Area

The period leading up to the storm had been drier than normal. This may have affected the resulting floods in two ways:

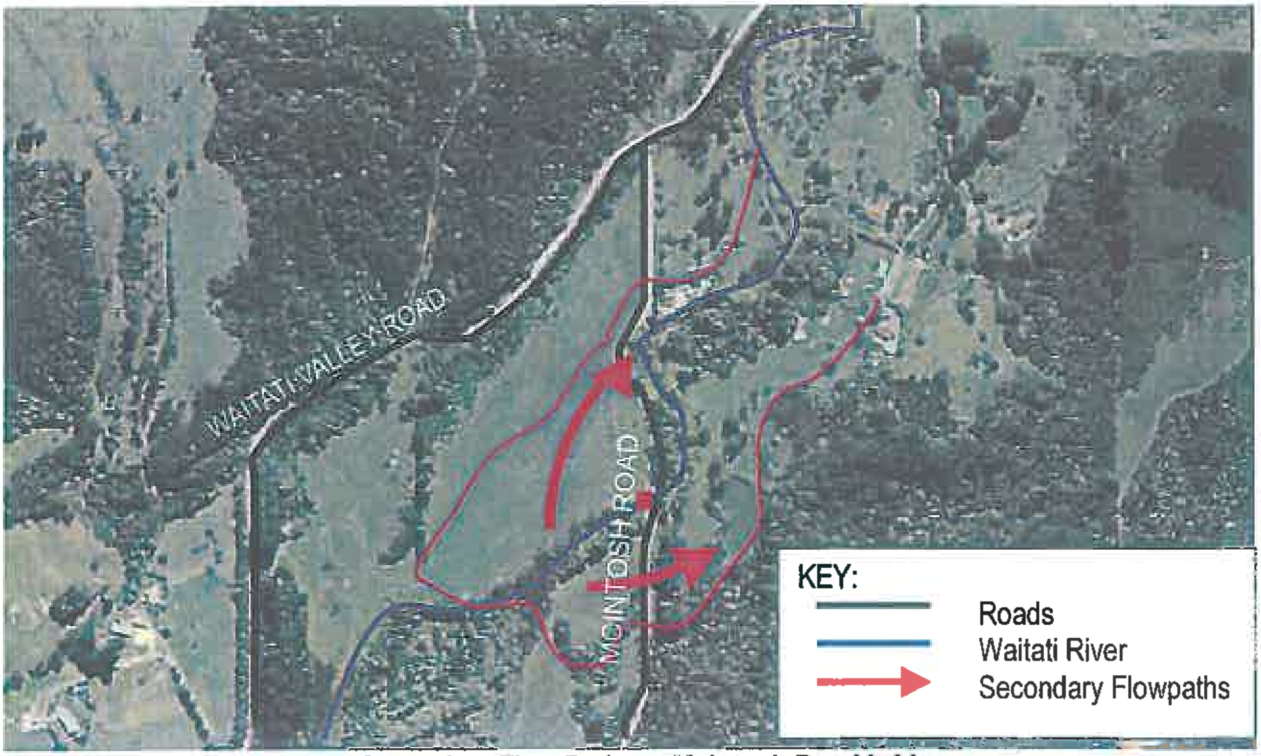
- Firstly the lack of significant rainfall meant that a flow rate in the river sufficient to flush away any build up of material such as dead trees and fallen branches had not been achieved for some time, possibly as much as two years.
- Secondly the ground surface will have been hard and impermeable at the onset of the storm resulting in increased run-off.

As the rainfall period progressed, the ground surface became waterlogged before any significant absorption could occur.

As rain fell on the northern slopes of Mount Cargill, down through Pigeon Flat, on the east side of the State Highway (SH1), the run off followed the same route. A storm drainage channel at the eastern side of SH1 was washed out and run-off from the eastern part of the catchment crossed SH1 and joined the upper reaches of Wetherstons Creek and the Waitati River.

The heavy rainfall developed sufficient flow in the Waitati River and its tributaries to flush the river channel. Unfortunately the volume of debris being carried reached such proportions that some became trapped against bridges and other structures in and around the river channel. This was most notable at the small single track bridge in McIntosh Road. Debris became trapped on the upstream side of the bridge which reduced the clear opening and caused even more debris to build up, creating a sizeable dam and reservoir.

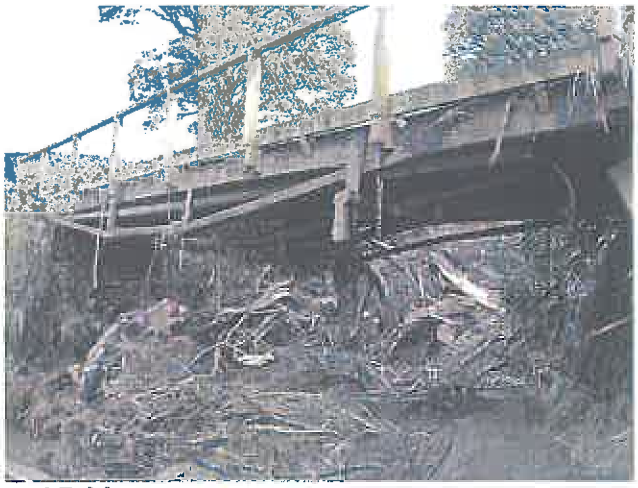
As the depth of water behind the dam increased, secondary flow paths were developed across adjacent paddocks.



Secondary Flow Paths at McIntosh Road bridge

When the weight of water on the bridge reached a critical level, the bridge gave way releasing a surge wave down through the lower Waitati Valley.

The bridge settled back onto its abutments, possibly through being anchored in place by the service ducts passing across the bridge. The services themselves were severed.



McIntosh Road Bridge

As the surge wave passed onwards down the Waitati Valley, further problems were to develop.

Approximately 300m downstream of the McIntosh Road Bridge a meander in the old riverbed was totally washed out by the surge wave, taking with it a section of Waitati Valley Road some 350m long.

350m Washout in Waitati Valley Road

The surge wave progressively passed down the Waitati Valley, taking with it three footbridges in its path down through to Miller Road.

In the area around Miller Road, the topography of the Waitati Valley levels out into flood plain. This reduced the velocity of the surge and the destructive force it carried.

A high volume of water, albeit at lower velocity than had been the case, continued on towards Waitati, joining with the flows from Wetherstons Creek, Cedar Creek and Dons Creek. All of these streams were also flowing at, or near to flood rates, carrying with them the same type of debris described above.

The high flows running in the river adjacent to SH1 approximately 1km south of Waitati eroded the true left bank of the river right up to the edge of the sealed road. It is impossible to determine how much more flow could have been accommodated before SH1 would have been washed away. Reinforcing the riverbank with something more substantial would be recommended.

A dead tree, carried by the high river flows, became lodged under the main road bridge in Waitati on Harvey Street beside the Waitati Hall/Library/Community Centre. This obstruction caused the river to back up and burst the true right bank.

Full river flow under the Harvey Street road bridge shortly before the tree became stuck

The paddocks identified as 42 and 44 Harvey Street were flooded to a maximum depth of approximately 3m. Parts of these paddocks had been set to grazing sheep, a number of which perished.

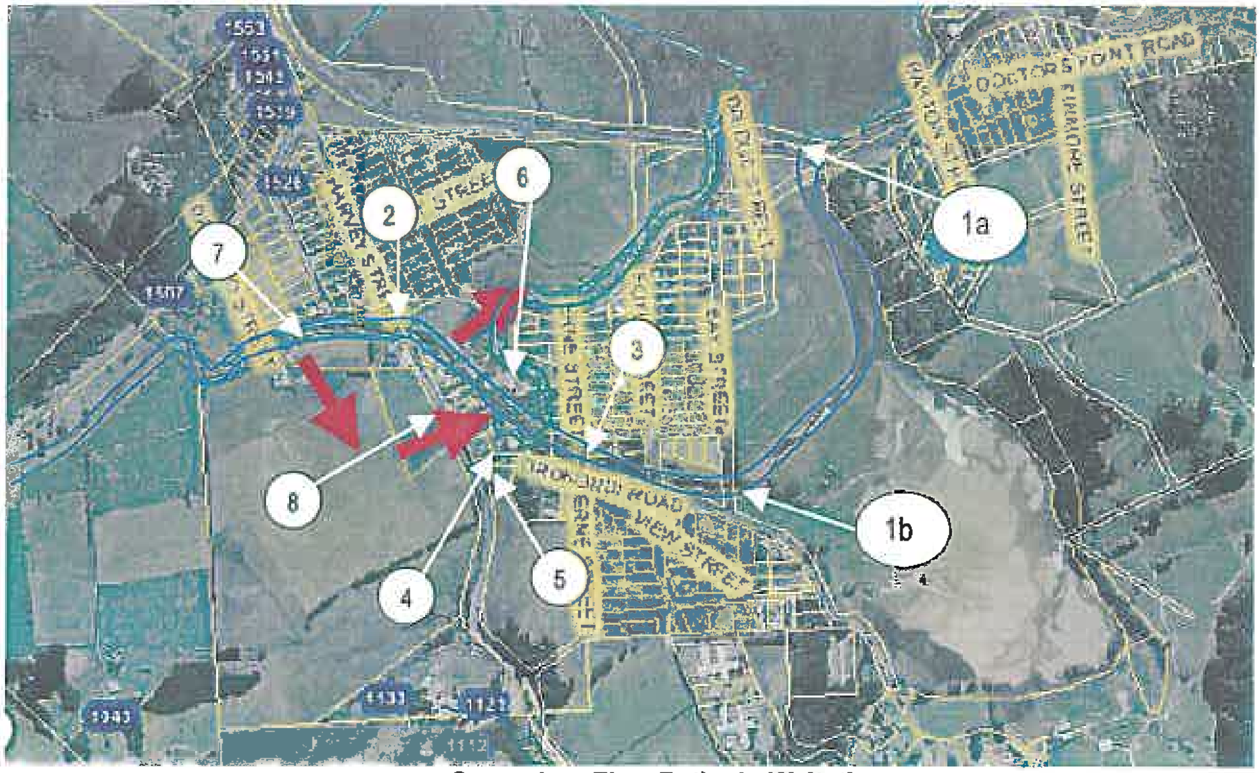
Sheep were forced against this fence by the flood water. Debris can be seen indicating the depth of the flood

Two secondary flow paths developed. The principal secondary flow path draining the flooded area was across Harvey Street and along Orokonui Road (including passing through #57 Harvey Street and the section behind), rejoining the Waitati River approximately opposite Erne Street. The lesser secondary flow path took a north-westerly direction, almost following the old river alignment.

Secondary Flow Path Developed through Blueskin Nursery

Footbridge Connecting Erne Street to Orokonui Road

NOTE: the pale blue line on the map below shows the route taken by the Waitati River through the township. The pale green line shows an historic route of the river as shown on Cadastral records.



Secondary Flow Paths in Waitati

4 Definition of Flooded Areas

By analysing photographs taken at the height of the storm to determine known top water levels against a 0.5m contour map of Waitati, and assuming hydraulic gradients between these known points, it is possible to derive an area affected by flooding. The datum points used are as follows (levels are above mean sea level):

1. The flooded section of Doctors Point Road correlates to the 2.0m contour line (1a). The wide estuarine area to the south of Doctors point Road towards Orokonui Creek would have experienced low velocity flow and therefore a shallow hydraulic gradient has been assumed across this area. Where the Waitati River discharges into the estuarine area, a top water level of 2.5m has been assumed (1b).
2. Flood water in the Waitati River reached the soffit of the Harvey Street overbridge at approximately 8.0m.
3. The water level in the river reached the Erne Street/Orokonui Road footbridge as shown in the photograph above. Straight hydraulic grade has been assumed from 2.5m at the downstream end (1b) to the footbridge (3) where an allowance of 0.5m headloss has been assumed. Then straight hydraulic grade to 8.0m at the upstream end (2).
4. This hydraulic grade concurs with eye witness accounts of the flood water level at the Harvey Street/Orokonui Road intersection. At this intersection, the flood water reached the house at #57 Harvey Street at 5.0m.
5. The bus stop on the opposite corner of Orokonui Road is also at 5.0m which also agrees with eye witness accounts.

6. The flood water flowed through Blueskin Nursery at a depth of approximately 100mm. This has been assumed to be a secondary flow path through the Nursery to the line of the old river.
7. Upstream of the Harvey Street bridge, the water level in the river has been assumed to be constant at around 8.0m adjacent to Quayle Street. This concurs with eye witness accounts of where the river burst its southern bank into the paddock behind #36 Harvey Street.
8. The wire fence along the west side of Harvey Street through #42 and #44 trapped an amount of debris as the flood water passed through it. From the 5.0m top water level at the Orokonui Road intersection described above, 0.3m head loss through the wire fence has been assumed, followed by a straight hydraulic grade up to 8.0m at Quayle Street.

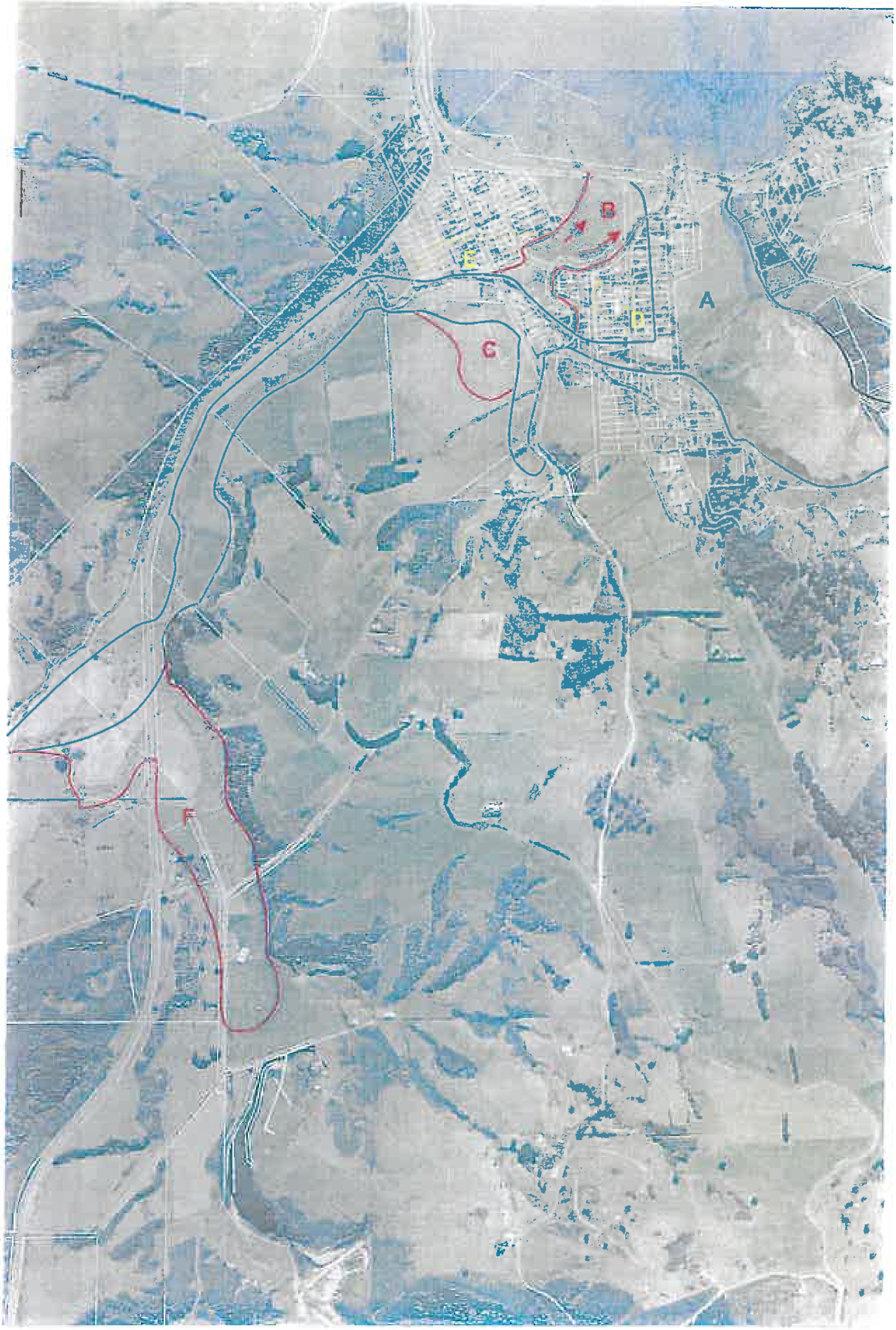
The levels quoted above have been derived using DCC's aerial photographs of the city and their contours derived by GIS. The accuracy of these levels therefore is determined by the accuracy of the base data from DCC.

In addition to the flooding that occurred in the Waitati township a large area to the south of the town was also affected. From DCC ratings information, the properties affected were #24 and #40 Donalds Hill Road; #1011 Mount Cargill Road; and #671 and 693 Waitati Valley Road. However, this area is rural and only farm outbuildings were flooded, the only residential property is elevated and was unaffected. Few photographs of this area were taken. There are a number of wire fences through this area which did trap debris carried by the stormwater, and was evident for some time after the storm had ceased. The height of this debris was 200 to 300mm.

5 Flood Risk Areas Defined in Dunedin City Council Lifelines Project

The areas affected by flooding in Waitati on 26 April 2006 have been compared to the flood risk areas defined in the Dunedin City Council Lifelines Project.

The area enclosed by the blue lines on the map below show the area defined in the Lifelines Project, this has been manually transferred from the 1:50,000 scale Map 3 from the Lifelines Project Report; as such, the boundaries of this area are an approximation. The red lines show the approximate boundaries of how the April 06 floods extended beyond this limit. The red arrows depict where the flood water formed a secondary flow path. The area bounded by the yellow line may be at risk from flooding in future events.


B
E
A
D
C
F

6 Conclusion

Any flood event is an ephemeral occurrence, with constantly rising, then falling water levels. Without monitoring exact limits of the floodwater throughout the event, it is not possible to state categorically where those limits were. Currents, streamlines and eddies create a water surface that is dynamic; standing waves appear and disappear.

It is difficult to draw definitive conclusions based on the results of a single storm. The main contributory factors are described above, however there are a number of other considerations that may affect flooded areas and secondary flow paths. The volume of debris will be affected by the time of year in which any future storm occurs, in autumn there will be greater volumes of leaf litter: in summer the runoff coefficient of the soil will be at its greatest. Developers may build houses, residents and property owners may build garden walls, out houses and other structures, all of which might change the route of secondary flow paths. In low lying, flood plain geography such as at Waitati, small changes in surface features can have a big impact on flows.

Waitati was affected by the April 2006 storm as a result of a combination of three main contributory factors:

1. The highest intensity rainfall, over a 24 hour duration, had a 1 in 186 year intensity return period and was focused over Mount Cargill. The instantaneous rate of rainfall was not unusual; in this case it was the sustained duration of the storm that caused the problems.
2. The derived flow in the Waitati River of approximately 95 cubic metres per second has a 1 in 10 to 15 year return period.
3. The storm came after a long dry spell and flushed large volume of debris out of the riverbed.

The combination of these factors culminated in large amounts of debris being carried in the storm flow, which became trapped against the McIntosh Road bridge and causing the water to back up until the bridge gave way and a large surge wave descended the Waitati Valley. Most of the damage caused was as a result of the erosive power of the surge of water and the debris and sediment it contained. A lot of the destructive energy was dissipated as the surge wave entered the flood plain and lost velocity, however storm flows that might normally be contained within the riverbanks through the Waitati township, were not.

It is quite possible for future storms of different intensities and durations to combine and develop similar flow in the Waitati River. For example, a storm with higher intensity instantaneous rate of rainfall over a shorter period: could have similar outcome. Due to the rural and inaccessible nature of a high proportion of the catchment, it is likely that future storms will also flush out large volumes of debris.

The bridge at McIntosh Road has been reinstated.

Waitati is located at the bottom of the catchments of the Waitati River and Orokonui Creek. The geography of the town is typical of a river flood plain; this extends to the south for approximately 3km in the Waitati Valley. In the town the river historically took a meandering route through what is now the Blueskin Nursery and along a similar route to Doctors Point Road, discharging to Blueskin Bay to the west of Bridge Street. The Waitati River has latterly been straightened to follow a path to the south of Killarney Street to the estuarine area at the bottom of Orokonui Creek. During the storm, flood water from the river burst the north bank and reverted back to the old route.

Due to the low lying nature of a large section of Waitati, had the storm event occurred at the same time as a high tide in Blueskin Bay, flood water could have backed up and a significantly wider area might have been affected. As it was, the surge of flood water occurred at approximately mean tide and the outlet to Blueskin Bay was discharging freely.

The effects of climate change are causing sea levels to rise as the polar icecaps melt. Numerous reports into climate change suggest both that the east coastal areas of Otago might see more, and less rainfall in the future, so no conclusions can be made on the generic trends. What does seem to be agreed is that the incidents of extreme weather patterns will become more frequent, so heavy storms after dry spells will occur more often.

Waitati is not identified in the Lifelines Report as being at risk of tsunami which is not considered in this report.

For a rainfall with 24 hour intensity of 1 in 186 year return period coupled with flow in the Waitati River of 1 in 10-15 year return period, the probability and magnitude of repeat events can be assessed. Unfortunately the background data relating to the Waitati River is not available as records are not kept and values used in this report have been derived [by Raineffects Ltd] from data relating to the Water of Leith.

Storms of greater magnitude are possible, however the likelihood will be with higher return periods than the April event. As the hydrological analysis is based on a statistical process, it should be noted that it is possible for another storm of similar severity to occur at any time.

The vulnerability of Waitati to repeat events would be a subjective analysis. The relative importance, how prone to damage, the length of time before damage could be repaired and the economic impact of a repeat event at Waitati is dependent on the nature of the storm event at the time. Waitati is a small community separated from Dunedin, where most of the rescue and recovery services would be based.

Based on the above, it is reasonable to expect that a repeat of such flooding will occur within the next 50 year period based the following statistics:

- Flow in the Waitati River had a 1 in 10 to 15 year return period. Therefore, over a period of 50 years, this flow would be expected 3 to 5 times.
- Rainfall of similar or equivalent intensity or duration would be expected approximately 0.25 times over a period of 50 years.
- An equivalent storm with peak instantaneous intensity occurring at the same time as high tide in Blueskin Bay could result in more properties being affected.
- Debris caused problems at defined locations (for example at McIntosh Road bridge). In future flood events debris capture might not recur at the same places, but debris in floods is always a problem. It is our opinion that debris would be likely to cause a similar level of problems. In general, without better evidence, the extent of flooding experienced on 26 April can be expected to recur in similar circumstances.

7 Recommendations

Development on the line of the Waitati River's historical meanders is not recommended without suitable provision of flood protection measures. This area, through Blueskin Nursery and along the north side of Doctors Point Road is at risk of future floods.

The areas marked inside the blue lines marked A on the map in section 5 of this report are the areas included in the DCC Lifelines report (note this has been manually reproduced from the Dunedin City Lifelines Project: Map 3 at 1:50,000). The April '06 storm was substantially within this area, it is therefore recommended that any planning restrictions associated with this area continue.

The areas marked B, C and F inside the red lines on the map in section 5 of this report show where the April '06 storm affected areas outside the risk area identified in the DCC Lifelines Report. These areas were identified by the methods described in Section 4 of this Report. Extending the Lifelines Report risk areas to include the areas inside the red lines should be considered. We believe that the risk of flooding within a 50 year period is likely. Any development inside the red lines should be considered carefully before being granted any building consent.

The area marked E inside the yellow lines on the map in section 5 of this report were not directly affected by the April '06 storm. These areas have been identified as being in close proximity and at similar level to the low lying areas that suffered damage and inconvenience. This suggests that it may at risk in a slightly more severe storm.

The low lying area marked D on the map in section 5 of this report (between the yellow dashed line and the areas that were flooded), around Foyle Street and Erne Street is surrounded by areas that were flooded during the April '06 storm. This area may be at risk from flooding during a slightly more severe storm. Detailed analysis of the topography and storm drainage system may prove that the whole of the enclosed area shown is at similar level of risk of floods.

In order to increase the confidence in the areas that have been identified as possibly being at risk of flooding in is future storm event it is recommended that a topographical level survey of Waitati is conducted to confirm the GIS contour information used for the purposes of this report. This survey should be extended to include all existing storm water management infrastructure such as mud tanks, swayles and storm drains. This information could then be used to develop a hydrological network model of the township. This would confirm the current hydraulic capacity, to identify any bottlenecks, and facilitate investigating options for any remedial physical works that may be required. The model could be run at a number of tide levels to assess the back flow curve and hydraulic gradient through various flow paths through the township which could then determine if minimum floor levels for future developments and subdivisions could be recommended.

Please see Table 7 below.

Table 7: Summary of Flood Risk Areas

Area A	Identified at-risk area from Lifelines Project. Recommended that it remain in that classification.
Area B	Secondary flow path for floodwater in April 2006 Storm event. Includes the old river alignment and likely to be subject to repeated flooding in the future. Frequency of flooding, potentially 1:10 to 1:15 years. Recommended to be added to Lifelines Project at-risk classification.
Area C	Flooded in April 2006 Storm event. Likely to be subject to repeated flooding in the future. Frequency of flooding, potentially 1:10 to 1:15 years. Recommended to be added to Lifelines Project at-risk classification.
Area D	Potentially at risk from flooding during higher intensity storm than April 2006 event. Frequency of flooding, potentially 1:50 years [subject to confirmation by further investigation]. Recommended to be fully assessed for level of risk by topographical survey and network modelling.
Area E	Potentially at risk from flooding during higher intensity storm than April 2006 event. Frequency of flooding, potentially 1:50 years [subject to confirmation by further investigation]. Recommended to be fully assessed for level of risk by topographical survey and network modelling.
Area F	Flooded in April 2006 Storm event. Likely to be subject to repeated flooding in the future. Frequency of flooding, potentially 1:10 to 1:15 years. Recommended to be added to Lifelines Project at-risk classification.

Appendix A – Report by Raineffects Ltd

Review of 24/25 April 2006 Rainstorm

1. Introduction

On 25/26 April 2006, a prolonged heavy rainfall event in the Dunedin area resulted in flooding of local streams and rivers, the flooding of many properties, the overflowing of many stormwater systems causing water to pond in flat areas, damage to roads through slips and the accompanying gale-force wind also caused damage to trees and roofs. This rainfall event was a significant event in that most of the City and environs received in excess of 100mm of rain in about 36 hours and some areas recorded in excess of 150mm.

Unlike thunderstorms, which often exceed the design criteria of stormwater systems, this rainstorm was not a heavy enough event at its peak to exceed the 10-year return period criteria which is the fundamental design criteria for stormwater systems. Stormwater did collect in some areas and cause problems due mainly to leaves and other debris blocking mud tanks and gutters, and in the case of the people beside the Silver Stream, the Silver Stream being too high to allow the stormwater to drain by gravity into it.

However, prolonged rainstorms combined with windy conditions such as that on 25/26 April bring other problems not usually experienced from thunderstorms such as leaking roofs, hillside slumping, and flooding of the large rivers and streams in the region.

The purpose if this report is to identify the areas of heaviest rain in the Dunedin area from this storm, analyse the storm to identify the patterns of rainfall and determine if there was any sequential pattern to the rainfall from a north to south perspective, and to assign return periods to the rainfalls.

2. Antecedent Conditions

The rainstorm occurred after a significantly dry spell in the Dunedin area. Rainfalls in February had been between 30% and 50% below average; in March they were between 10% and 50% below average; and in April, very little rain fell anywhere before the rainstorm arrived on 25 April. In the 40 days prior to the April rainstorm, Musselburgh recorded only 20mm while Dunedin Airport recorded only 16mm. The ground had dried out and grass growth was limited by lack of moisture.

It is often said that heavy rain on top of dry ground normally results in very high runoff rates because the rain cannot soak into the ground because the ground is too dry. In this case, the ground was dry when the rain began but the gentle rain that occurred for the first 10 hours of this rainstorm was light enough to mostly soak into the ground. The problem in this particular event was mostly the rainfall rates which well exceeded soil infiltration rates for about 24 hours. In Dunedin soils, infiltration rates are likely to be around 1-2mm/hour. When rainfall rates exceed infiltration rates, runoff occurs. Irrespective of how dry the ground was before the rainstorm this rainstorm was large enough that significant flooding was always going to happen.

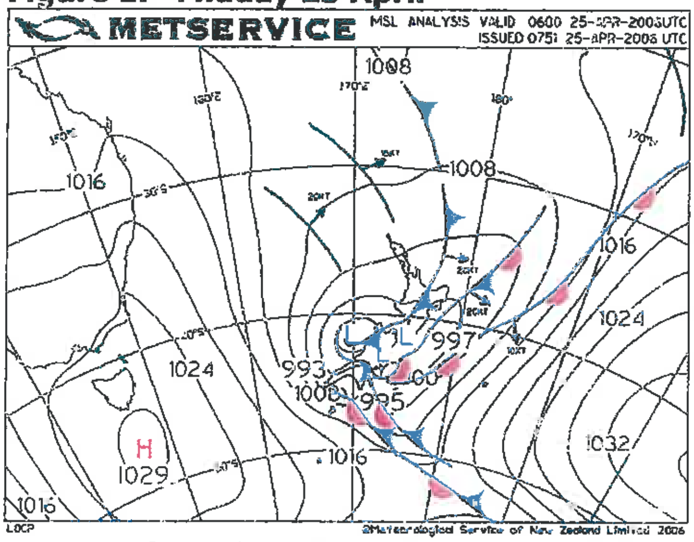
In this case, rainfall rates were generally around 10-12mm/hour at times and at some sites, rates of up to 18mm/hour were reported. If rainfalls persist at these high rates for significant periods of time as they did in this case, large volumes of runoff result and small streams such as the Water of Leith, Waitati Stream and the Silver Stream rise rapidly.

3. Meteorological Situation

MetService has provided a succinct description of the meteorological situation which resulted in the rainstorm. They have also provided a series of five sequential synoptic maps (actual weather maps drawn to actual measured air pressure) at 6-hourly intervals from midday on 25 April to midday on 26 April. They state:

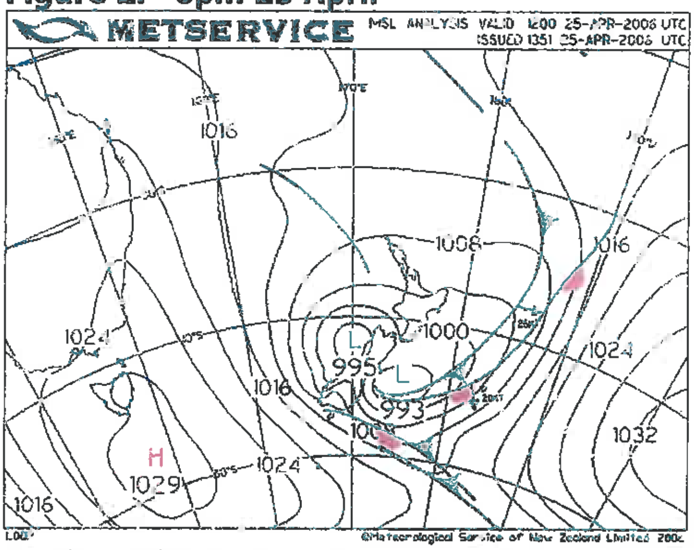
"On 25 April 2006 a depression formed just west of the South Island from a stationary trough of low pressure which was lying over New Zealand. An intense anticyclone lay to the east of New Zealand and another anticyclone lay over Tasmania (Figure 1).

Figure 1. Midday 25 April



A warm front formed in the northeast flow between the depression and the anticyclone and a warm moist air stream was directed on to the east coast of the South Island (Figure 2).

Figure 2. 6pm 25 April



On the night of 25 April and morning of the 26 April, a slow moving low pressure centre was located just off the South Canterbury coast. Lowering pressure east of the South Island had turned the moist air stream more easterly, and this directed a band of heavy rain onto the eastern Otago coast until late morning on 26 April (Figures 3 – 5)."

Figure 3. Midnight 25/26 April

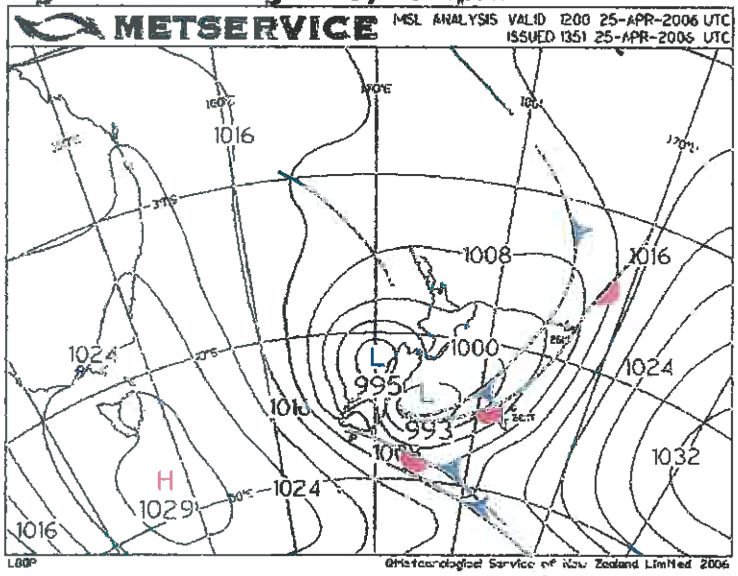


Figure 4. 6am 26 April

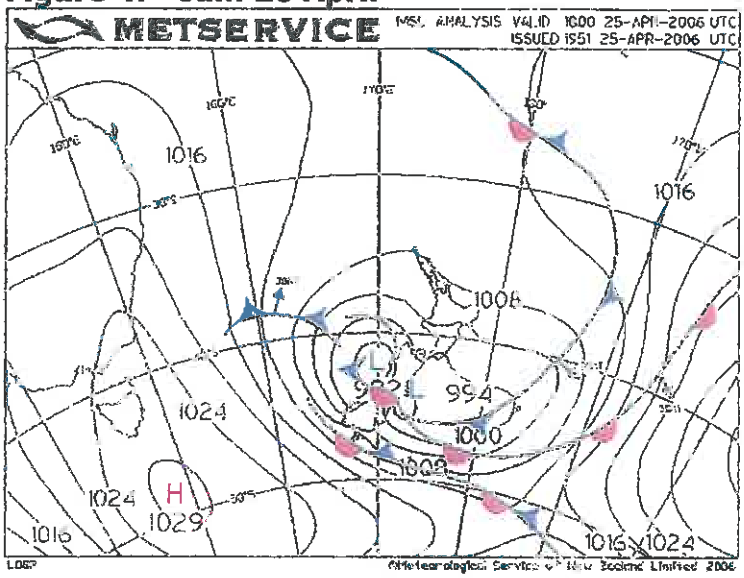
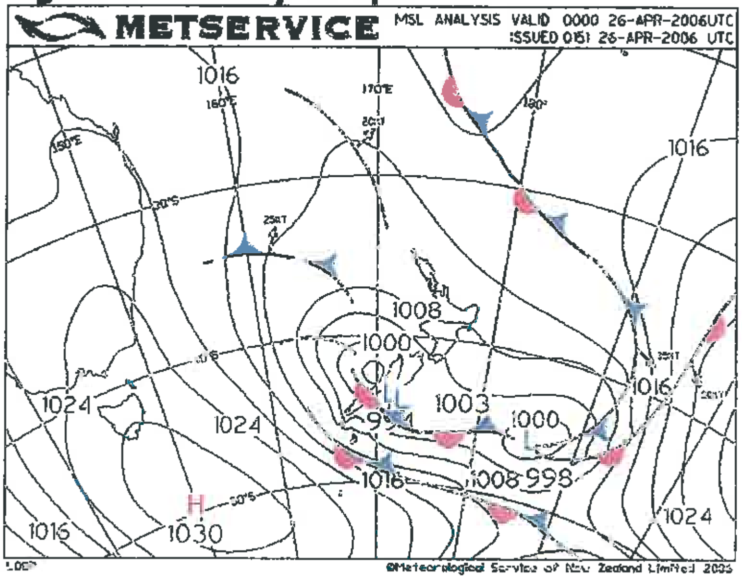


Figure 5. Midday 26 April



The weather system brought winds from the southeasterly direction which is not a common wind direction for this area of the east coast. The storm itself was unusual in that it began as a cold front which brought heavy rain to the West Coast on 21/22 April. This front stalled over Nelson and then came back down the South Island forming itself into a deep and vigorous depression as it did so. As it headed south it brought heavy rain to east coast areas eventually reaching Dunedin. After dumping its rain around Dunedin on 25/26 April, it headed westwards back into the Tasman Sea and then moved northwards over the next few days eventually crossing the North Island early in the next week and creating havoc in the form of heavy rain and strong winds as it did so.

4. Rainfall

4(a) Available Raingauges

There are about 15 official raingauges between Dunedin Airport and Sullivans Dam that are operated either by New Zealand Meteorological Service (MetService), the National Institute of Water and Atmospheric Research (NIWA), the Otago Regional Council (ORC), and the Dunedin City Council (DCC). Given the area that this report was to cover, the 15 official raingauges were insufficient to provide the detailed picture of rainfall distribution required.

To gain more information, a call was made through the news media for people with private raingauges to provide their rainfall measurements. A further 36 raingauge totals were provided through this request and many of these rainfall totals were very useful to this report.

The raingauges used by the official organisations are usually standard 5-inch manually-read daily raingauges or automatic tipping-bucket raingauges, which record in quarter-hourly intervals or both. They are normally sited under strict criteria with regards to location and distance to the nearest high object that could affect the raingauge catch.

The private raingauges varied from sophisticated automatic raingauges with non-standard collector systems to daily-read plastic raingauges with diameters from 100mm down to 25mm and also wedge-shaped raingauges. None of these raingauges meet the national standards for raingauge size and many will not be sited according to the strict criteria. While it is recognised that these non-standard raingauges are not likely to have the accuracy of the official raingauges, if they were likely to read to within a few millimetres of what a standard raingauge would read, then they are quite usable in a rainstorm as large as that of 25/26 April.

The storm not only contained heavy rain but it also brought gale-force winds and such winds can affect raingauge catch. As a result, some rainfall measurements were obviously lower due to wind effects than what actually occurred. Some sites on ridges obviously under-caught rainfall and these anomalies showed when the rainfall totals were plotted on a map and isohyetal lines were drawn. Rainfall totals that were obviously anomalies were discarded.

4(b) Daily Rainfalls

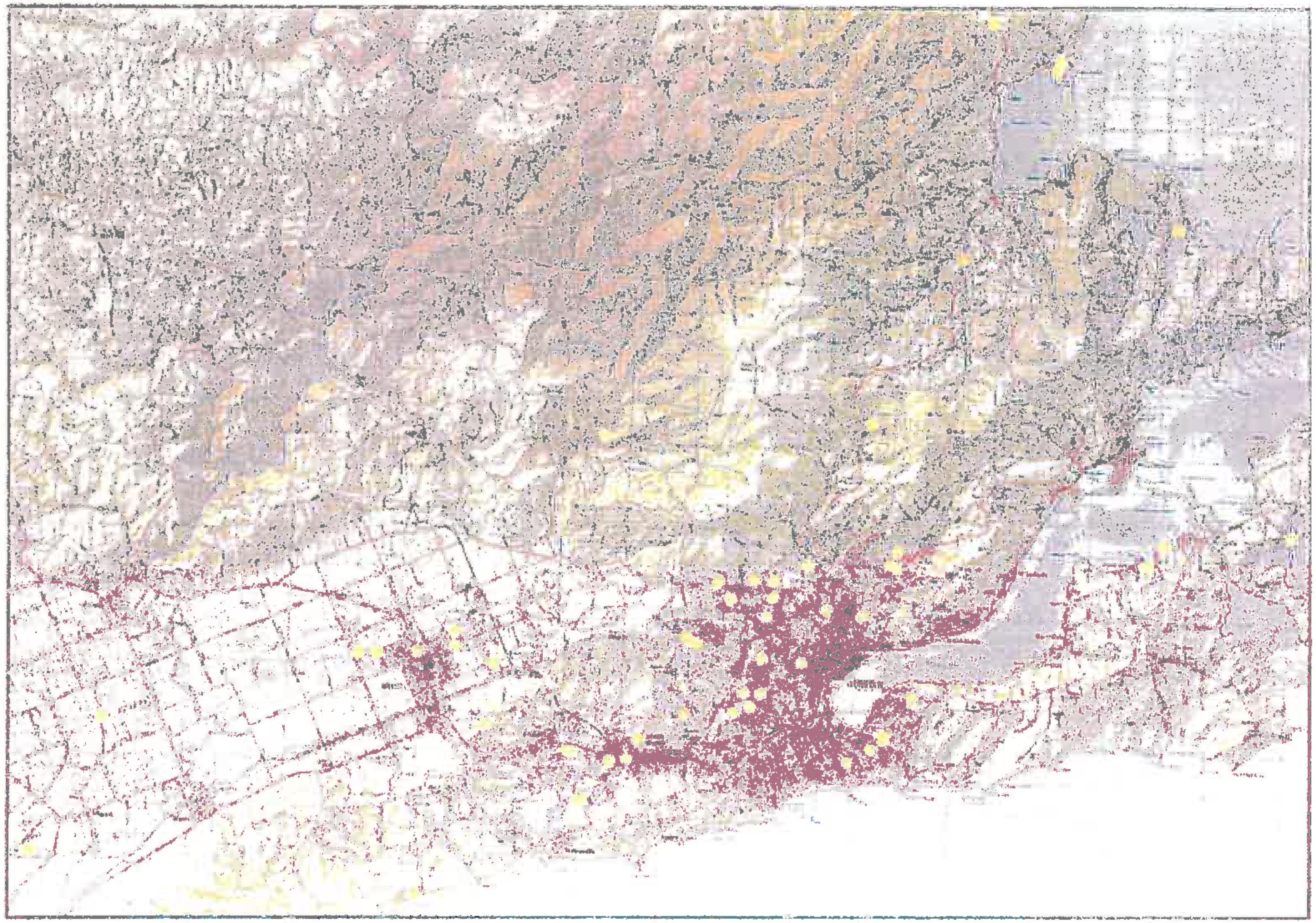
Table 1 lists the daily rainfalls provided for this report. Note that although rain did not start falling until after midnight on 24 April, the convention for reading daily rainfalls is that they are read at 9.00am each day and the rainfall is credited to the previous day's date and that is why 24 April is included. The main rain period was in the 36-hour period from about 1am on 25 April through to about 1pm on 26 April. The table lists daily rainfalls where these were available. Some raingauge readers provided only a total for the whole rainstorm. The table also provides the grid reference and locality of the raingauge. Figure 6 shows the location of each raingauge.

Table 1. Daily Rainfalls for Various Sites

Grid Reference	Locality	Rainfall (mm) 24 Apr	25 Apr	26 Apr	Total
I43:955104	Nenthorn	2	64	8	74
I44:713028	DCC Rocklands	1	25	3	29
I44:683996	DCC Deep Stm	1	61	8	70
H44:809969	ORC Deep Stm	1	77	13	91
H44:787877	Lee Flat	1.5	77.5	25	104
H44:887739	Maungatua	2.4	122	60.6	185
I44:925719	Airport	1.2	123.2	26.4	150.8
I44:945761	Outram	3.2	157.7	37.6	198.5
I44:020783	Taieri Depot	3.5	157.5	16	177
I44:059762	Mosgiel (1)		107	28.3	135.3
I44:049786	Mosgiel (2)		122	18	140
I44:049790	Mosgiel (3)		113		113
I44:026783	Mosgiel Town	4.8	147.2	23.2	175.2
I44:038784	Mosgiel (4)	4.1	140.4	23.3	167.8
I44:061781	Wingatui	5.5	123	39	167.5
I44:084755	Fairfield	6	150	3	159
I44:040710	Brighton	10.2	43.7	3	56.9
I44:088740	DCC Green Island STP	3.4	99.5	9.8	112.7
I44:097752	Green Island		109.6	11.4	121
I44:102753	Southern Motorway	5	135	8	148
I44:105759	Abbotsford		124.9	12.7	137.6
I44:119767	Southern Reservoir	5.7	117.4	15.5	138.6
I44:134768	Balaclava	3.9	115.1	13.9	132.9
I44:137774	Kenmure	6	106	13	125
I44:142774	Mornington	11	110	14	135
I44:139770	Mornington	4.5	107	11	122.5
I44:142785	Belleknowes		130	8	138
I44:119791	Mt Grand Brockville	6	144	21.2	171.2
I44:122789	Brockville		132		132

Grid Reference	Locality	Rainfall (mm) 24 Apr	25 Apr	26 Apr	Total
			70	135	205
I44:132809	Halfway Bush	7.5	157	33	197.5
I44:092852	DCC Powder Creek	6	219	32	257
I44:145804	Wakari		158		158
I44:139809	Helensburgh		150		150
I44:145809	Helensburgh	12	142	20.4	174.4
I44:143798	Kaikorai		119	14	133
I44:154784	City Rise	4	106	11	121
I44:161801	Maori Hill	10	140	14	164
I44:155814	DCC Ross Creek	5.4	141.4	24.4	171.2
I44:169754	Musselburgh (1)	3.2	82	6	91.2
I44:176758	Musselburgh (2)		112		112
I44:180761	Musselburgh (3)	3	69	6	78
I44:180762	Andersons Bay		91	16	107
I44:188774	Waverley		149		149
I44:263823	Broad Bay	5	128	10	143
I44:258817	Broad Bay	9.5	117	6.5	133
I44:301827	Papanui Inlet	7	82	10	99
I44:172799	North Dunedin	10	94	5	109
I44:179827	Pine Hill	7.5	151.5	22.5	181.5
I44:180815	North East Valley	36	140	6	182
I44:182814	North East Valley	7.5	179.5	19	206
I44:173858	Sullivans Dam	10	207.5	32.5	250
I44:199909	Upper Waitati	6.5	162	36	204.5
I44:264920	Long Beach	6.5	120.5	10	137
I44:227970	Warrington		125		125
I44:226967	Warrington		125		125
I44:206981	Kilmog Hill	15	108	17	140

Figure 6. Raingauge Locations



There are some raingauges included in the table which are not used in this analysis except that for the isohyetal maps, these sites give an indication of what occurred at more inland sites. These sites include: Nenthorn, DCC Rocklands, DCC Deep Stream, ORC Deep Stream and Lee Flat.

5(c) Automatic Raingauges

These raingauges normally measure totals every 15 minutes but for this review, hourly totals were used. The automatic sites included: Dunedin Airport, Taieri Depot, Mosgiel (4), Southern Motorway, Mt. Grand, Silver Stream, Ross Creek, Musselburgh (1), Pine Hill and Sullivans Dam.

These sites were used in two ways. Firstly, they were used to analyse the distribution of rainfall over time. Figures 7 and 8 show the distributions. Figure 7 shows the hourly rainfalls for each site plotted against time and Figure 8 shows the cumulative total rainfall for each site.

Figure 7. Hourly rainfalls for Various Sites

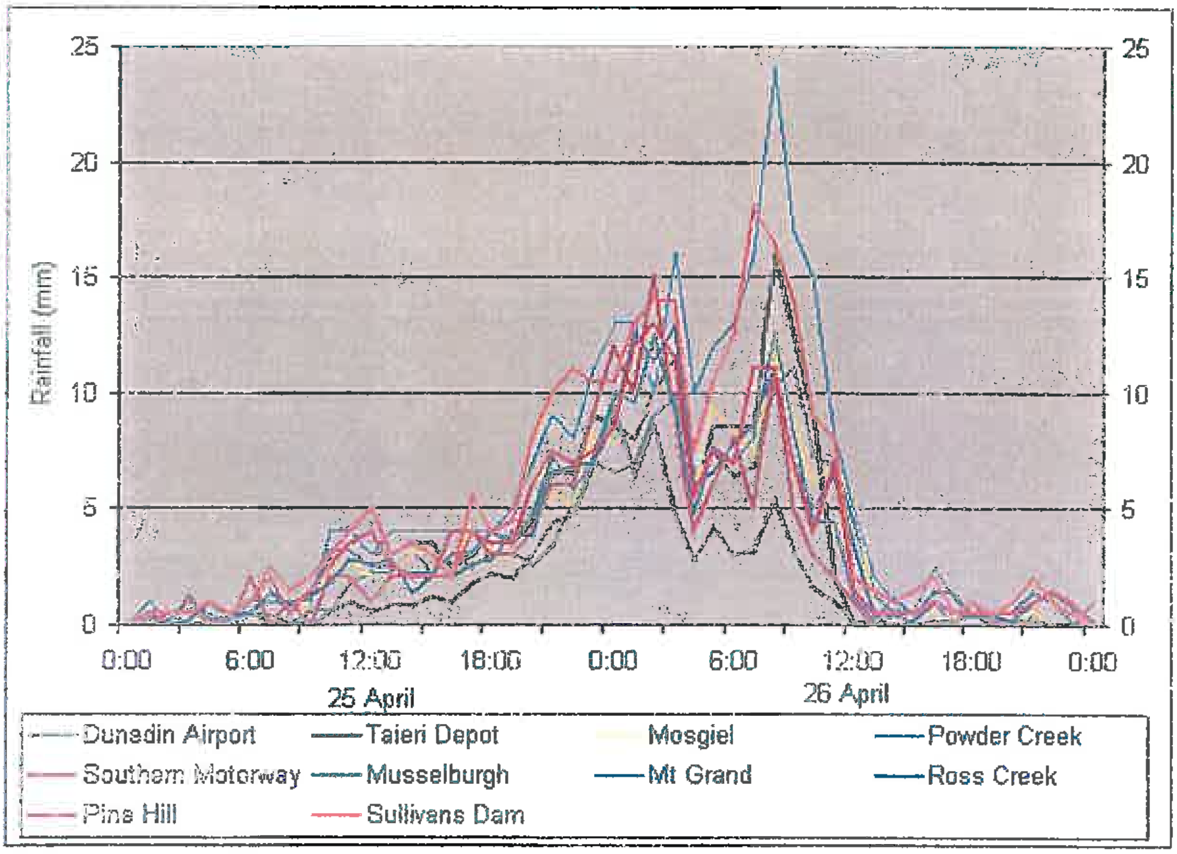


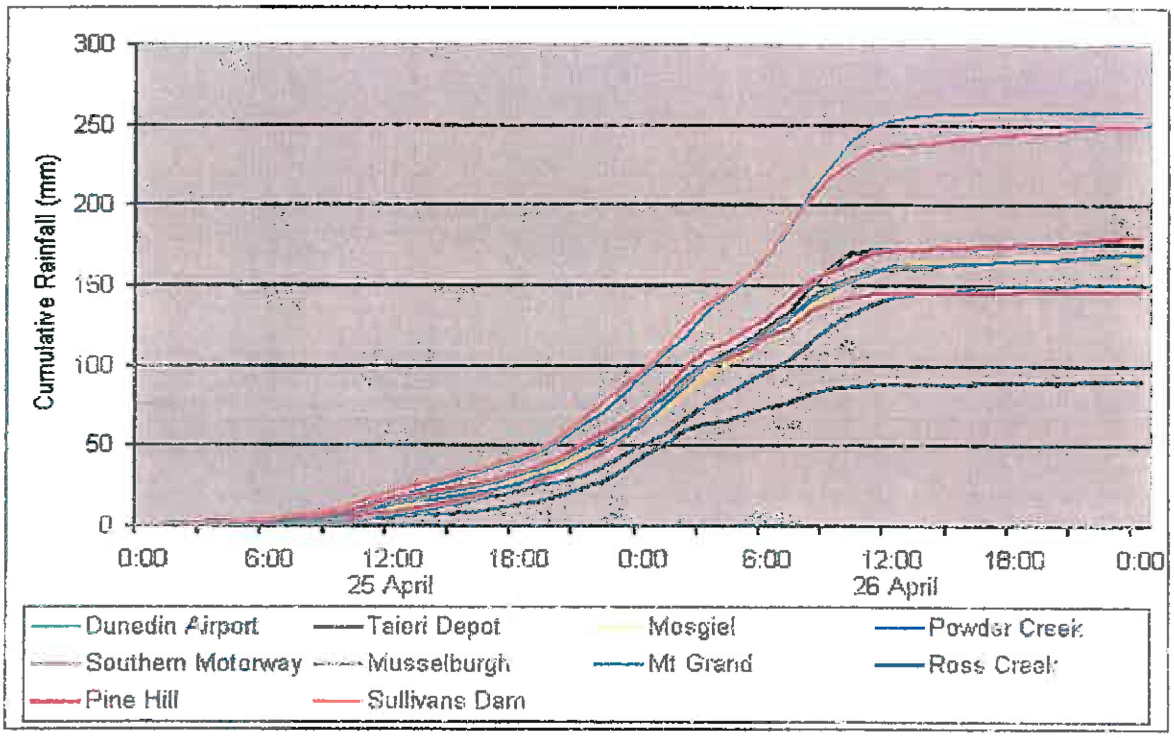
Figure 7 shows that in general, the rainfall pattern through the storm was essentially the same at all sites. The rainfalls started quite lightly but gradually increased in intensity through to about 6pm (1800 hours) on 25 April. Rainfall intensities increased quite rapidly between 5pm on 25 April and 2am on 26 April. Over the next 2 hours intensities fell but by 4am they were increasing again to peak at around

8am. Intensities then fell quite rapidly after that and generally by midday, rainfall intensities had dropped to about 1mm/hour.

Figure 7 suggests that there is about a one hour lag between peak rainfall intensities at Sullivans Dam and all other raingauges except Dunedin Airport and that there is a two hour lag between Sullivans Dam and Dunedin Airport.

Figure 8 is a hyetograph and clearly shows the increasing intensity of rain with time. In fact this hyetograph is typical of most major rainstorms in New Zealand. A notable feature of this rainstorm is the rapidity that rainfalls generally went from peak intensity around 7-8am to virtually nil by 11am. This abrupt end in rainfall is usually associated with the passage of a front, in this case an occluded front as shown on Figure 5.

Figure 8. Cumulative Rainfalls for Various Sites



Secondly the automatic rainfalls were used to distribute the daily rainfall totals for sites that were read on a daily basis. The purpose of this daily rainfall distribution was to be able to use more raingauges than just the automatics when drawing up isohyetal maps. The isohyetal maps, which are discussed in the next section of this report, were drawn for midday 25 April, midnight 25 April, 6am 26 April and midnight 26 April. The only way all rainfalls could be used to help draw these maps was to distribute them all on an hourly basis. The way this was done was as follows:

> The hourly rainfalls at each automatic site were calculated as a proportion of the total rainfall from 0000 hours on 25 April to 2400 hours on 26 April (48 hours).

These hourly proportions were then assigned to the total rainfall at each daily rainfall site and an hourly distribution was then determined for the daily rainfalls. The daily rainfall totals were allocated to the nearest automatic raingauge for distribution. In some cases where the daily raingauges were located between 2 automatic raingauges, then the automatic raingauge hourly proportions were averaged and these averages applied to the daily rainfalls.

5(d) Isohyetal Maps

These are maps with lines joining points of equal rainfall total. As discussed in Section 5(c), all the raingauge totals listed in Table 1 were distributed in hourly totals throughout the storm period. The rainfalls at all sites were then totalled from midnight on 24/25 April to 6pm on 25 April, then from midnight on 24/25 April to midnight on 25/26 April, from midnight on 24/25 April to 6am on 26 April and finally from midnight on 24/25 April to midnight on 26/27 April. The first totals were the first 18 hours of the storm, the second totals were for the first 24 hours of the storm, the third totals were for the first 30 hours of the storm and the final totals for the entire 48-hour period of the storm.

Figure 9 shows the 18-hour totals plotted on the map. It shows that already, the rainfall in the headwaters of the Silver Stream, Water of Leith and Waitati Stream were significantly heavier than over the rest of the area.

Figure 10 shows the 24-hour totals plotted. Within 6 hours the rainfall totals had increased by up to 150% on the 18-hour totals. Average rainfall rates at higher elevations are likely to have been around 13 mm/hour. Heavy rain continued to fall in the headwaters of the above-mentioned streams and heavy falls were also accumulating on the Mt. Cargill side as well. In addition, significant rainfalls had occurred over most of Dunedin especially with distance inland.

Figure 11 shows that in the 6-hour period from midnight on 25/26 April to 6am on 26 April, a further 25mm at lower elevations and up to 100mm at higher elevations had fallen. In the headwaters of the above-mentioned streams, average rainfall rates over the 6-hour period were about 17mm/hour.

In the 6-hour period 6am to midday, rainfall rates were very heavy for about 4 hours and then rapidly dropped to light rain by midday. Most automatic raingauges recorded less in this last 6 hours compared with the previous 6 hours. There were two exceptions with Dunedin Airport recording the same amount in each 6-hour period and Powder Creek recorded about 10mm more in the second 6-hour period.

Figure 12 shows the 48-hour total rainfall from midnight 24/25 April to midnight 26/27 April. Upwards of 300mm are likely to have fallen in the headwaters of Silver Stream, Water of Leith and Waitati Stream resulting in significant flooding in all three streams. The rainfall distribution pattern on Figure 11 shows the heaviest falls occurred in these 3 streams headwaters, rainfalls were lightest along the southern coast and the Otago Peninsula and significant heavy falls occurred on the Taieri Plains from Dunedin Airport through Mosgiel and Wingatui to the hill suburbs of Dunedin. The flatter areas of the City (South Dunedin, City Centre and North Dunedin) received the lightest falls. With any easterly quarter storm experienced in Dunedin and surrounds, there is always a significant orographic (increasing rainfall with altitude) component to them and the storm of 25/26 April was no exception.

5(e) Rainfall Return Periods

There are 9 sites for which it is possible to calculate rainfall return periods. These sites included Dunedin Airport, Maungatua, Balmoral Outram, Mosgiel Town, Powder Creek, Southern Reservoir, Balaclava, Musselburgh and Sullivans Dam. These sites with the exception of Powder Creek, have in excess of 20 years of daily records available for use in the analysis and the 1-day record of 13 years for Powder Creek can be extended a further 21 years by adding the maximum 1-day rainfalls for the Whare Flat site which is close to Powder Creek. A 17-year record exists for the ORC site Taieri Depot but it is close to the Mosgiel Town site which has a 42-year record and is preferred for this analysis.

Table 2 shows the calculated rainfalls and their return periods for 1-day, 2-day and 3-day total rainfalls.

Table 2. Rainfall Return Periods for Various Sites and Various Durations

Return Period (yrs)	Sullivans Dam (mm)			Powder Creek (mm)			Musselburgh (mm)		
	1-Day	2-Day	3-Day	1-Day*	2-Day	3-Day	1-Day	2-Day	3-Day
2	73	101	112	72	80	90	50	61	67
5	105	150	167	108	125	139	68	86	96
10	125	183	204	132	155	172	79	103	116
20	145	214	239	155	184	203	90	119	134
50	171	255	285	185	221	244	105	139	159
100	190	285	319	207	249	274	115	155	177
500	235	355	398	259	313	344	140	190	219
Return Period (yrs)	Balaclava			Southern Reservoir			Mosgiel Town		
	1-Day	2-Day	3-Day	1-Day	2-Day	3-Day	1-Day	2-Day	3-Day
2	54	73	83	53	73	80	47	62	68
5	74	101	115	73	101	112	70	92	100
10	87	119	136	86	119	133	85	112	121
20	99	136	157	98	137	154	100	131	141
50	116	159	183	114	160	181	119	156	167
100	128	176	203	127	177	201	133	174	187
500	156	215	248	154	217	247	166	217	232
Return Period (yrs)	Balmoral Outram			Maungatua			Dunedin Airport		
	1-Day	2-Day	3-Day	1-Day	2-Day	3-Day	1-Day	2-Day	3-Day
2	43	61	67	42	61	68	51	63	68
5	64	89	97	59	86	93	75	93	99
10	78	108	116	70	103	111	91	113	120
20	91	126	135	81	119	127	107	133	140
50	108	150	159	94	139	148	126	158	165
100	121	167	177	105	155	164	141	176	184
500	151	208	219	129	190	201	176	220	228

* This is Powder Creek plus Whare Flat record

Table 3 shows the actual measured 1-, 2-, and 3-day rainfalls at each of the sites and their calculated return periods.

Table 3. April 2006 1-, 2-, and 3-day Rainfall Return Periods

Raingauge	1-Day Total (mm)	Return Period (yrs)	2-Day Total (mm)	Return Period (yrs)	3-Day Total (mm)	Return Period (yrs)	Record Length (yrs)
Sullivans Dam	207.5	186	240	36	250	25	39
Powder Creek	219	143	251	106	257	68	34-13*
Musselburgh	82	12	88	5	91.2	4	55
Balaclava	115.1	49	129	15	132.9	9	31
Southern Reservoir	117.4	59	132.9	17	138.6	12	37
Mosgiel Town	147.2	197	170.4	86	175.2	66	46
Balmoral Outram	157.7	722	195.6	306	198.5	230	37
Maungatua	122	322	182.6	355	185	251	32
Dunedin Airport	123.2	43	149.6	37	150.1	30	43

* 1-day totals had 34 years of record, 2- and 3-day totals only 13 years of record.

It should be noted that return periods greater than about 50 years for record lengths in excess of 30 years and return periods greater than about 25 years for record lengths less than 15 years must be used with caution. The validity of these values is questionable given the short record length with the likelihood that the record length may not be a completely representative sample of the actual record if all of it had been measured.

The results of the return period analyses on the maximum 1-day rainfalls during the storm show that in most of the area being considered here (Warrington to Dunedin Airport), the 1-day rainfall totals would be considered rare events. The exception was Musselburgh where the 1-day rainfall had a return period of 12 years. The Musselburgh total was confirmed by nearby private raingauges. Elsewhere, return periods for the 1-day fall varied from 43 years (Dunedin Airport) to in excess of 200 years (Balmoral Outram, Maungatua) with others being close to 200 years (Sullivans Dam, Mosgiel Town).

The results of the maximum 2-day rainfall return period analyses show that in most instances, this was not as rare as the 1-day rainfalls. For Musselburgh, the 88mm recorded in 2 days had a return period of only 5 years. Sullivans Dam and Mosgiel Town reduced to less than 100-year return periods (36 years and 86 years respectively), Outram reduced significantly but was still in excess of 200 years and Maungatua remained about the same. The short record for the 2-day event for Powder Creek mean that the return periods calculated may be questionable but it is likely that the 2-day event was still a relatively rare event.

Return period calculations for the 3-day rainfall totals show that Balmoral Outram and Maungatua still had quite high return periods but elsewhere the return periods dropped again from the 2-day events. The 3-day event at Sullivans Dam was down to a 25-year return period, at Mosgiel Town it was 66 years, Powder Creek 68 years and Dunedin Airport 30 years.

5. Areas For Closer Review

There were two main areas within the greater Dunedin City area where significant stormwater problems occurred. These areas were the area in and around Mosgiel and the Waitati catchment especially the Waitati township.

In both areas, the issues related to two of the three main catchments draining the Flagstaff/Swampy Summit/Mt. Cargill area. The three catchments are the Silver Stream, Water of Leith and Waitati Steam. While there was a significant flood in the Water of Leith, no major issues arose from the flooding. By contrast, in Mosgiel there were stormwater issues related to the prevention of stormwater being able to discharge into the Silver Stream by gravity as it normally does. The major flood event that occurred in Silver Stream caused the water level in the Silver Stream to be too high and prevented the gravity drainage of stormwater into it.

The problems in the Waitati catchment did relate to flooding in Waitati Stream but it is unlikely that the flood was as large as the major event that occurred in the Silver Stream. The problem seemed to be more related to debris damming the stream generally at bridges causing water to back up until the force of the water caused the debris to give way resulting in significant flood waves flowing down the river.

Figure 12 shows the rainfalls that occurred in the headwaters of both catchments. Inspection of this isohyetal map shows that heavy rainfall occurred over a wider area of the Silver Stream catchment than it did over the Water of Leith and Waitati Stream catchments and this resulted in a larger flood in the Silver Stream. Problems of flooding in the Silver Stream were compounded by the very heavy rainfall that occurred in Mosgiel with the 1-day rainfall return period at the Mosgiel Town raingauge which would be fairly representative of the general Mosgiel area, showing that the event had a return period of almost 200 years.

There are peak flow records available for the Silver Stream for the period 1970 to 2006 and are a composite record from 3 separate sites. Initial records were collected at Riccarton Road. This closed and a site at Wingatui Road was set up. In 1975, the site was transferred to Gordon Road, but since 1987 they have been collected at the Riccarton Road site again. If the peak flow records for each site are added together, it gives a record of 37 years.

Analysis of this 37-year record shows that the flood event in the Silver Stream at Riccarton Road had a return period of about 80 years. However, prediction of return periods beyond 50 years should be used with caution. The Otago Regional Council believe this latest flood was larger than that of the major storm and flood event of June 1980.

Figure 13 is a graph showing hourly rainfall totals (vertical bars) at the Powder Creek raingauge plotted on the same time scale as the measured flood level (metres in Otago datum which is 100m below mean sea level) in the Silver Stream at Riccarton Road as measured by the ORC recorder. This graph shows that the river level responded quickly to rainfall and that the peak water level occurred at Riccarton Road about 2 hours after the maximum rainfall was recorded at Powder Creek.

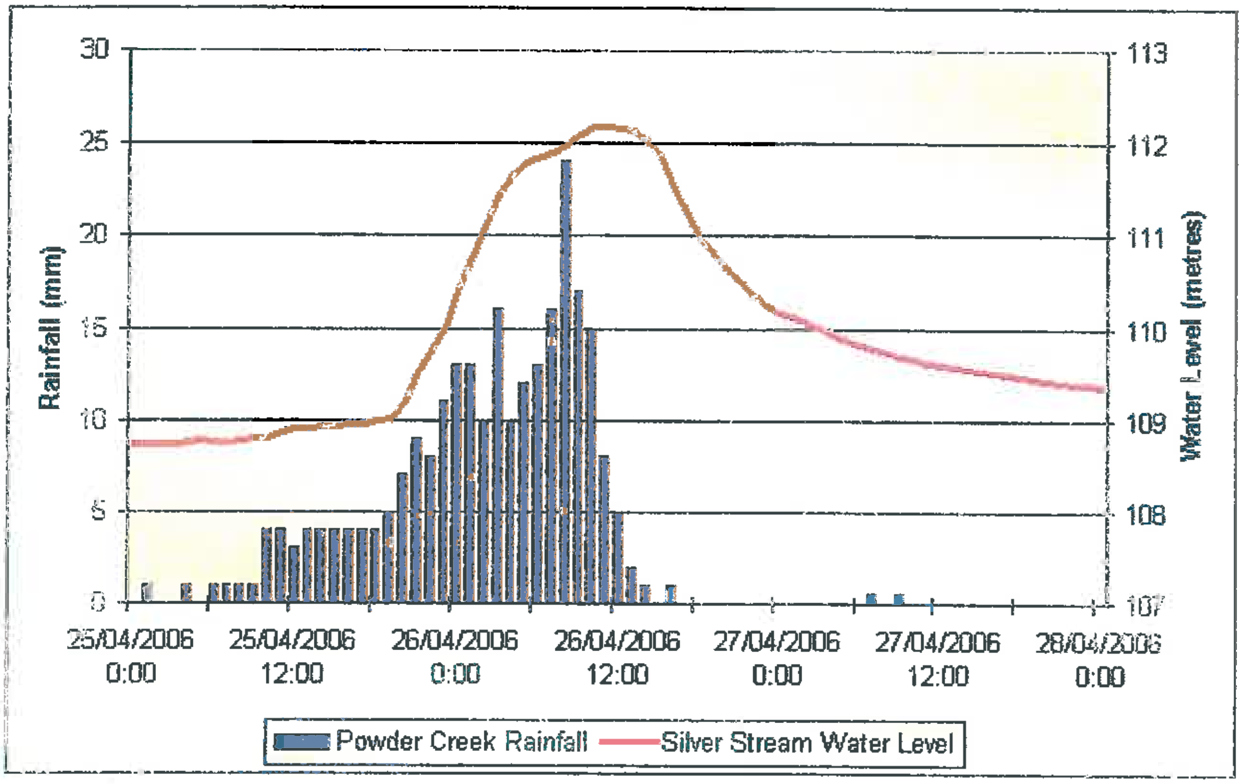
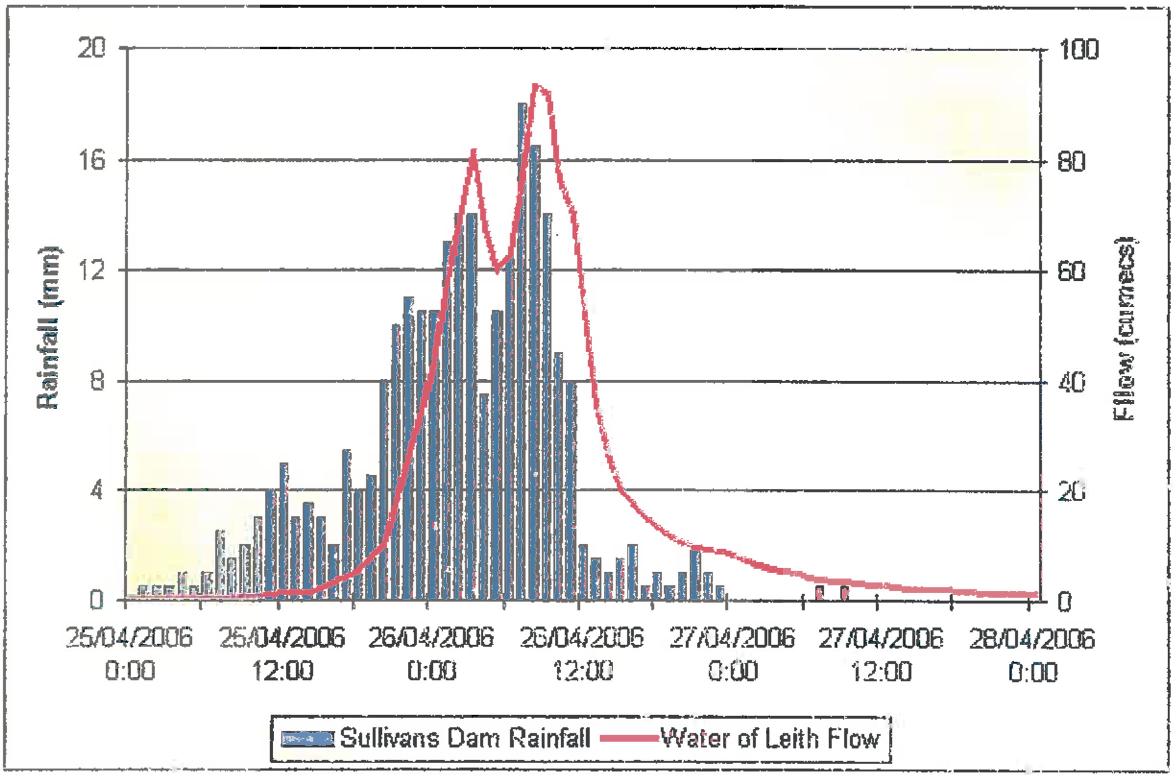


Figure 13. Silver Stream Water Level and Powder Creek Rainfall

There are peak flow records available for the Water of Leith at University Footbridge for the period 1963 to 2006 and there are some historic floods that can be used in a peak flood return period analysis. Analysis of this entire record shows that the flood event in the Water of Leith at University Footbridge had a return period of about 10 years. A similar sized event is likely to have occurred in Waitati Stream.

It would be possible to derive a record of the flood flows in the Waitati Stream from the Water of Leith measured at the University Footbridge record if the Waitati Stream had not had the blockages caused by debris. These blockages will have caused the water level to rise much more rapidly at times and more slowly at other times at the Waitati township compared with the flood flow record for the Water of Leith. Figure 14 shows the Water of Leith flood flow at the University footbridge plotted with the Sullivans Dam hourly rainfalls. These two graphs are on the same time scale and they show that the Water of Leith is very responsive to rainfall in the catchment. The Waitati Stream would respond similarly if debris had not caused blockages from time to time.

Figure 14. Water of Leith Flow and Sullivans Dam Rainfall



6. Summary

The April 25/26 2006 rainstorm was a significant rainfall event. The rain persisted for at least 36 hours and resulted in flooding of local streams and rivers, flooding of properties, and many flat areas had considerable water lying on them due to overflowing of stormwater systems. The event was large in that generally in excess of 100mm occurred with much of the Dunedin area receiving in excess of 150mm.

The storm occurred following a reasonably dry spell in the region but the rain event was such that significant flooding would have occurred whether or not the antecedent conditions had been dry. The storm itself was a large, deep, and vigorous depression which dragged very moist southeasterly winds onto the Dunedin area causing some of the largest 1-, 2-, and 3-day rainfalls ever measured in some areas.

A set of official and private raingauges was identified in the local area and data from these raingauges were used to analyse the rainstorm. The automatic raingauges showed that the pattern of rainfall was similar from Sullivans Dam to Dunedin Airport although a lag of 2 hours can be detected between these two raingauges for the peak hourly rainfall during the event.

A series of isohyetal maps for the Dunedin area show that the headwaters of the Silver Stream, Water of Leith and Waitati Stream which includes the Flagstaff/Swampy Summit/Mt Cargill areas, received the most rain. These are the highest areas around the City and during an easterly storm, rainfall totals are enhanced at higher elevations due to the orographic effect. These maps show that very heavy rain fell in the headwaters of these streams with totals in excess of 300mm at the highest points. While these figures are inferred, they are justified since two raingauges (Sullivans Dam at 300m high and Powder Creek at 100m high) recorded in excess of 250mm during the 3-day period.

Very heavy rain fell on the Taieri Plains and in the hill suburbs of Dunedin. Some of the rainfalls on the Taieri Plains were the highest ever recorded in their 30-40 year record periods.

Analysis of the return periods of some of the raingauges showed that the 1-day rainfall total in most areas except the flat areas of Dunedin were rare with return periods around and in excess of 200 years for many of the Taieri Plains sites while around the hill suburbs of Dunedin, they were in the range of 50-100 years. The 2- and 3-day rainfall totals generally had lesser return periods but on the Taieri Plains, in excess of 200 year return periods were still estimated.

A brief review of the Silver Stream and Water of Leith flow records compared with automatic raingauge records show that these small streams are very responsive to rainfall and for the Silver Stream, the flood had a return period of around 80 years while that for the Water of Leith and probably Waitati Stream was around 10 years.

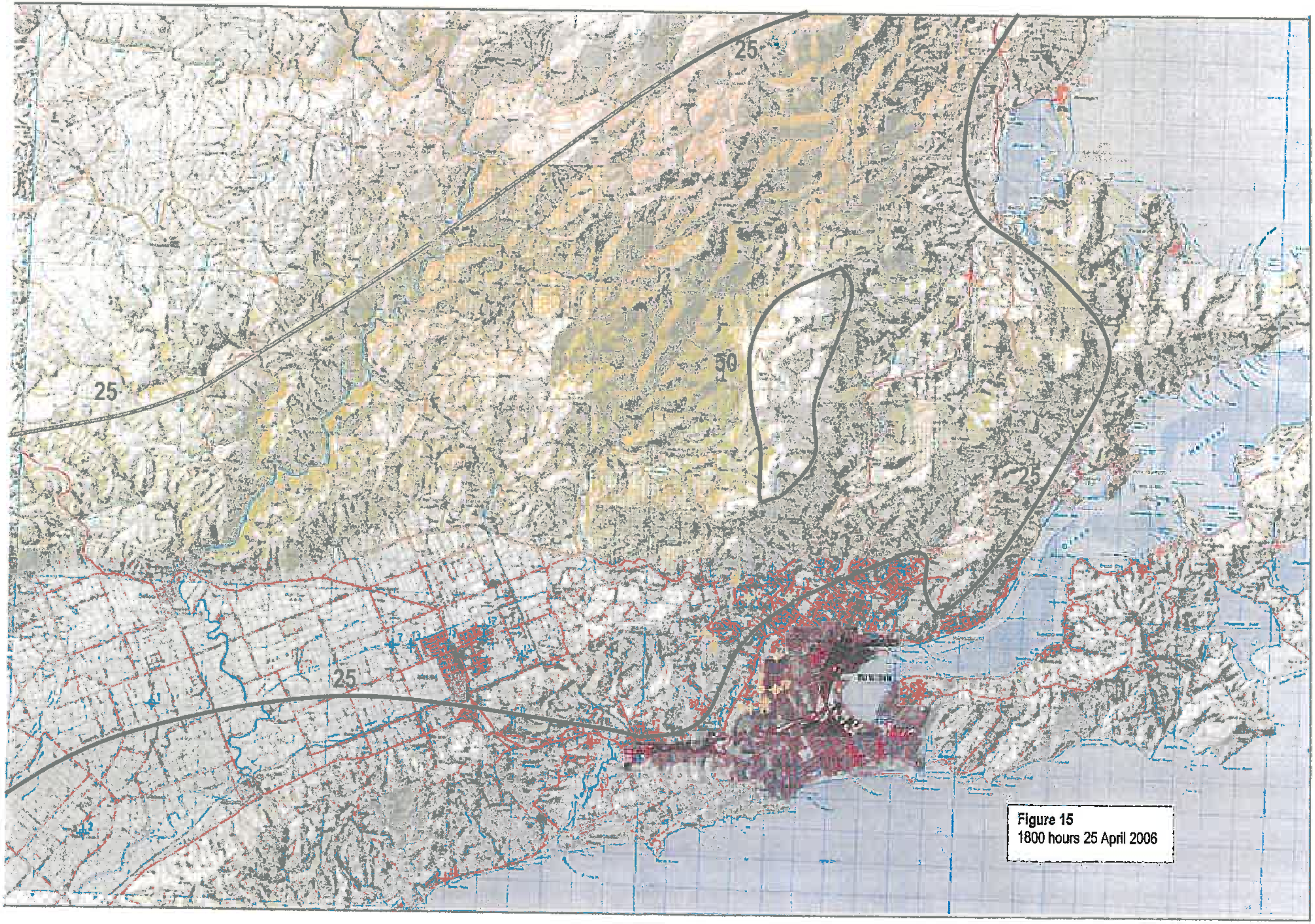


Figure 15
1800 hours 25 April 2006

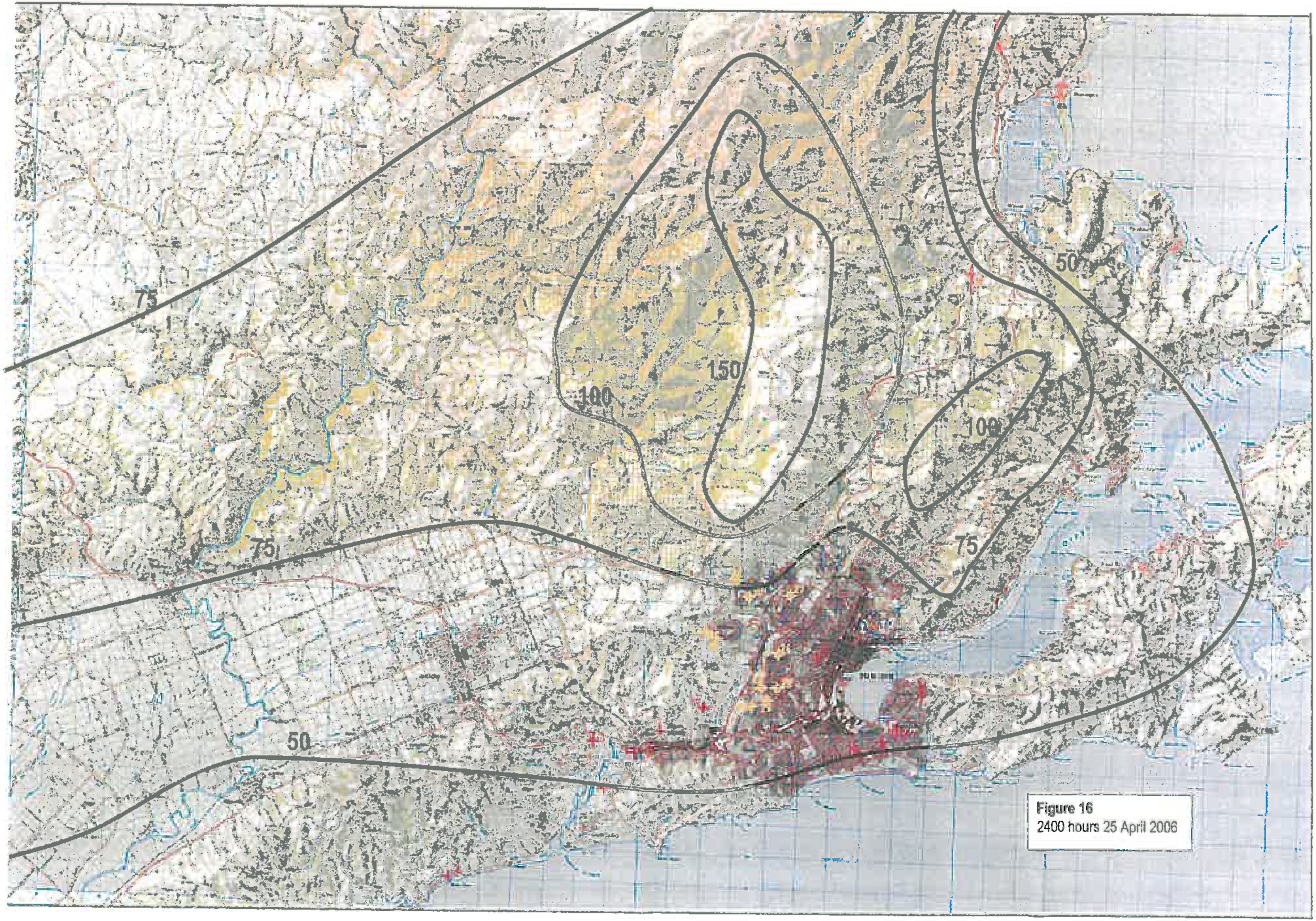


Figure 16
2400 hours 25 April 2006

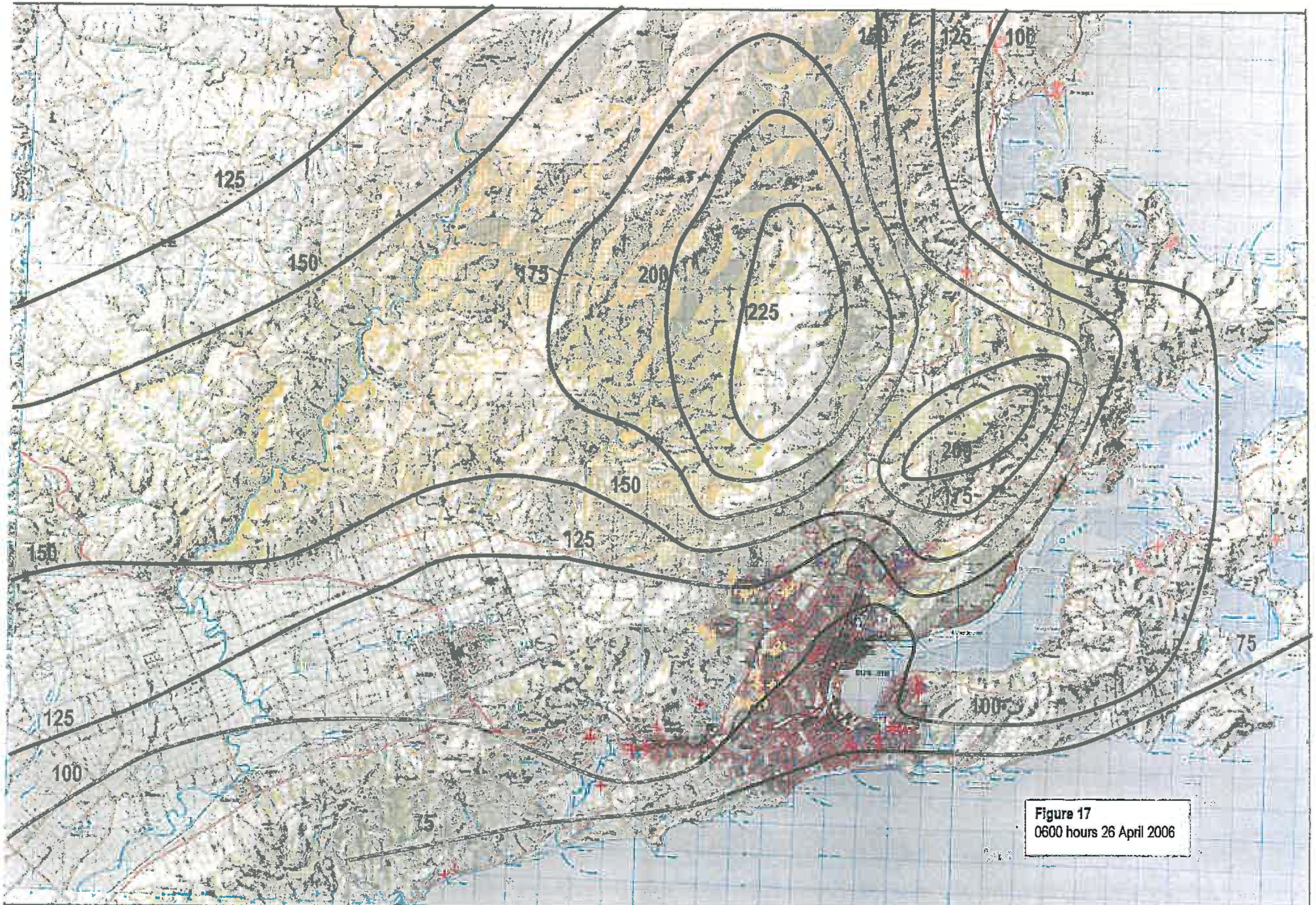


Figure 17
0600 hours 26 April 2006

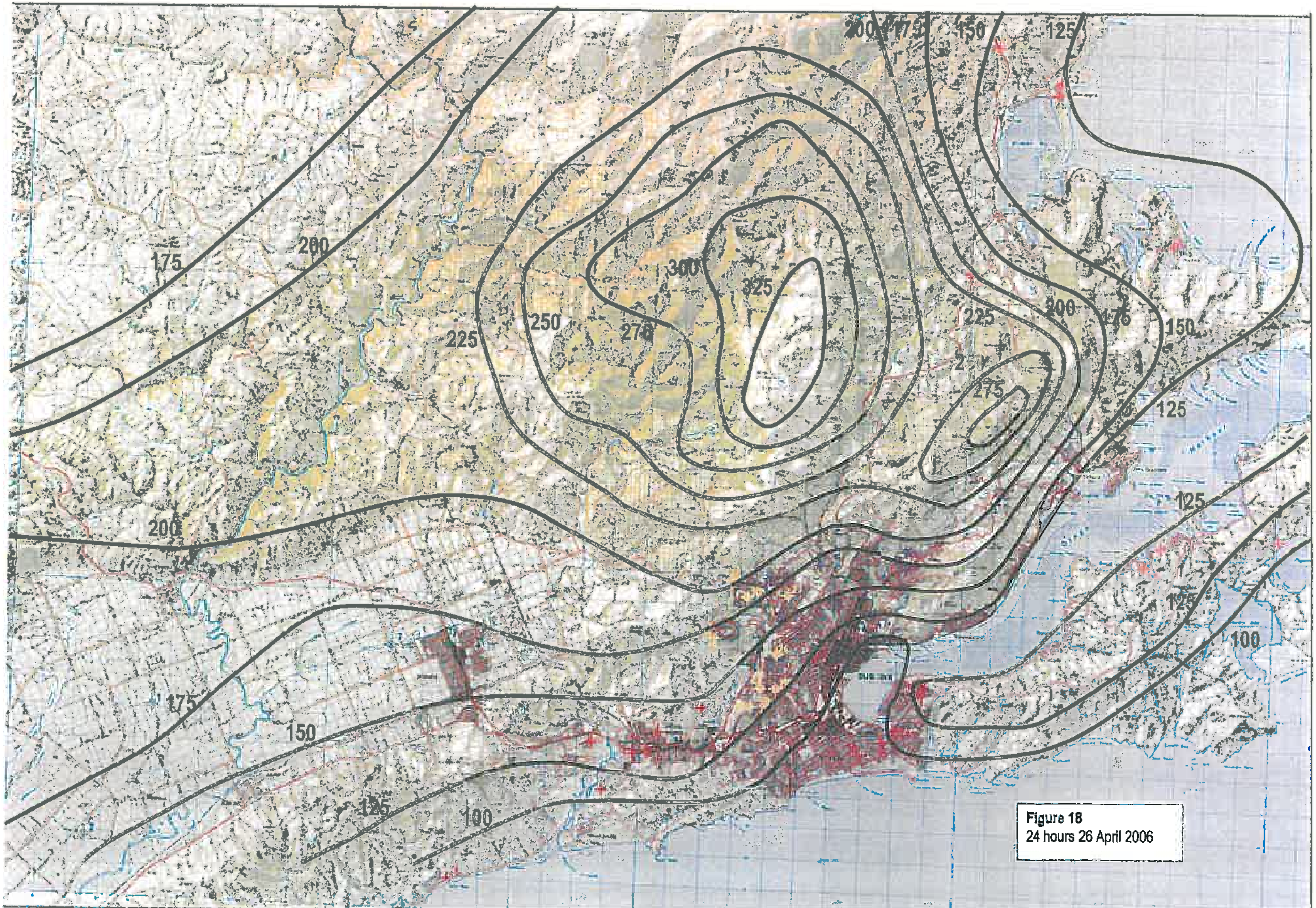


Figure 18
24 hours 26 April 2006