Technical Committee 17 October 2018 Attachments

Minutes of a meeting of the Technical Committee held in the Council Chamber, Phillip Laing House, Dunedin on Wednesday 12 September commencing at 9:00am

Membership

Cr Andrew Noone	*(Chairperson)*
Cr Ella Lawton	*(Deputy Chairperson)*
Cr Graeme Bell	
Cr Doug Brown	
Cr Michael Deaker	
Cr Carmen Hope	
Cr Trevor Kempton	
Cr Michael Laws	
Cr Sam Neill	
Cr Gretchen Robertson	
Cr Bryan Scott	
Cr Stephen Woodhead	

Welcome

Cr Noone welcomed Councillors, members of the public and staff to the meeting.

1. APOLOGIES

Resolution

That the apologies for Cr Neill be accepted.

Moved: Cr Hope
Seconded: Cr Laws
CARRIED

2. LEAVE OF ABSENCE

No Leave of Absence was advised.

3. ATTENDANCE

Sarah Gardner	*(Chief Executive)*
Nick Donnelly	*(Director Corporate Services)*
Sian Sutton	*(Director Stakeholder Engagement)*
Gavin Palmer	*(Director Engineering, Hazards and Science)*
Scott MacLean	*(Director Environmental Monitoring and Operations)*
Lauren McDonald	*(Committee Secretary)*
Ben Mackey	*(Acting Manager Natural Hazards) - Item 11.1*
Rachel Ozanne	*(Acting Manager Resource Science) Item 11.1 and 11.2*
Sharon Hornblow	*(Natural Hazards Analyst) - Item 11.1*
Hugo Borges	*(Environmental Resource Scientist) - Item 11.1*
Alastair Logan	*(Council's Solicitor) - Item 11.1 (public excluded)*

4. CONFIRMATION OF AGENDA

The agenda was confirmed as a tabled.

5. CONFLICT OF INTEREST

No conflicts of interest were advised.

6. PUBLIC FORUM

No public forum was held.

7. PRESENTATIONS

A presentation from the Yellow-eyed Penguin Trust was tabled for councillor information.

A request was made for Dr Palmer to invite the Trust to attend the next committee round to present their quarterly report in person to speak to the report content, such as current population status and trends of the species.

8. CONFIRMATION OF MINUTES

Cr Noone noted the incorrect reference to Lower Waitaki Aquifer public forum speaker as John Borrie, should be Mr Peter Borrie.

Resolution

That the minutes of the meeting held on 1 August 2018 be received and confirmed as a true and accurate record, with the correction as noted above.

Moved: Cr Noone
Seconded: Cr Lawton
CARRIED

9. ACTIONS (Status report on the resolutions of the Technical Committee)

Action status noted as - 13/6/18 meeting:

- Leith Flood Protection Scheme Dundas Stage programme - (Closed), University of Otago has been informed.
- Assessment of the Clean Heat Clean Air programme's effectiveness to inform the review of financial incentives for Air Quality in 2018-19. (Open)

1/8/18 meeting:

- Lake Snow Experts Workshop - (Closed), Councillors invited to attend workshop as observers.
- Lake Hayes Restoration - (1) re-frame of the consultant Castalia Report (In progress) - Castalia have been briefed. (2) staff develop options for consideration (In progress)

10. MATTERS FOR COUNCIL DECISION

Nil

11. MATTERS FOR NOTING

11.1. Director's Report on Progress

The report provided an update on: Lake Snow Experts' Workshop held on 8 August; Otago Climate Change Adaptation; Rees-Dart River Delta Flood Hazard and Public Safety; Leith Flood Protection Scheme (engineering works on the Union to Leith Footbridge stage).

In attendance: Dr Ben Mackey; Dr Sharon Hornblow; Rachel Ozanne; Hugo Borges, Alastair Logan (Council's solicitor)

Lake Snow

Cr Noone summarised the report and advised that lake snow was recognised as an invasive species at a national level and that the Ministry for Primary Industries (MPI) was leading the response to the lake snow incursion in New Zealand.

A request was made for ORC to seek active collaboration with central government.

Dr Palmer responded to a question on international research reviews and data available. He advised that staff have looked at international research, reported this to Council and would continue to do so. He confirmed the sharing of research information both nationally and internationally.

Otago climate change adaptation

Dr Palmer advised that a report on the technical work programme in relation to climate change for South Dunedin would be provided to the October committee round,

A request was made for additional context to be provided on climate change adaptation overlay of Council work programmes and overall objectives.

Rees Dart River Delta

Dr Hornblow responded to questions from councillors on flow paths during a flood event. She advised that at high flow that had not been any issues of putting Kinloch township in flood as the flow was able to spread out over a wide area including the wetland and the Dart River Delta.

Resolution

That the public be excluded from the following parts of the proceedings of this meeting, namely:

Discussion of Section 3 - Rees-Dart River Delta flood hazard and public safety of Item 11.1 Director's report on Progress

Also move that Alastair Logan, Council solicitor and staff be permitted to remain at this meeting, after the public has been excluded, because of their knowledge of legal privilege. This knowledge, which will be of assistance in relation to the matter to be discussed.

Moved: Cr Laws
Seconded: Cr Deaker
CARRIED

The meeting moved into public excluded session at 9.57 am and adjourned at 10:50 am.

The meeting resumed in public session at 2:23 pm on the motion of Crs Noone and Lawton.

An apology from Cr Brown was adopted on the motion of Crs Noone and Lawton.

Resolution

That this report be received and noted.

Moved: Cr Robertson
Seconded: Cr Lawton
CARRIED

Resolution

That ORC formally invite central government through the Minister for Primary Industries to collaborate with the ORC to find a solution to the Lake Snow issue.

Moved: Cr Laws
Seconded: Cr Bell
CARRIED

Dr Palmer advised that currently there was no joined up work programme. An Implementation programme was intended to be brought to the next committee round to address how to best deliver as a sector. He confirmed work was ongoing and the need to write up a programme of action within the sector.

11.2. State of the Environment: Surface Water Quality in Otago (2006-2017)

The report outlined the State of the Environment (SoE) water quality monitoring network in lakes, rivers and stream throughout the Otago region. It also summarised water quality state and trends, and measurements against the objectives and policies of the National Policy Statement for Freshwater Management (NPSFM), for contaminants such as periphyton, nitrogen, phosphorus and E. coli.

Ms Rachel Ozanne, Environmental Resource Scientist in attendance.

Ms Ozanne confirmed the SOE: Surface Water Quality in Otago (2006-2017) report was very comprehensive, covering data collected over an 11 year period for the trends and five years for the SOE (including schedule 15 limits). She advised that NIWA had independently reviewed the report and that the trend analysis was completed in conjunction with a statistician.

It was noted the Long Term Plan (LTP) budget increase for additional monitoring sites and installation of new lake buoys.

A suggestion was made to workshop the report content with councillors after presentation of the report on water quality implementation to the October committee round.

Discussion was held, including:

- addressing the learning/recommendations from the SOE: Surface Water Quality in Otago (2006-2017) report,
- communicating the report details out and engaging with communities on the improvements required for water quality
- ongoing work programmes to address water quality degradation.
- impact of urban development on water quality
- better understanding of the 'drivers' to the state of water quality in the region and improvements for data capture

A request was made for the State of the Environment report to be referred to the Policy Committee for their consideration, review and recommendations for action. An amendment to the motion was tabled.

Resolution

1. *That the report be noted.*
2. *That this paper be referred to the Policy Committee for their consideration and review and policy recommendations related to this report*.

Moved: Cr Laws
Seconded: Cr Robertson
CARRIED

13. NOTICES OF MOTION
No Notices of Motion were advised.

14. CLOSURE
The meeting was declared closed at 2:55 pm.

Chairperson

July 2017

REPORT

REVIEW OF INTERNATIONAL CASE STUDIES

Protection Options for Managing Rising Groundwater in South Dunedin

Submitted to:
Dunedin City Council
Otago Regional Council

Report Number: 1671023_7410-004-R-Rev2

Deltares
Enabling Delta Life

Golder Associates

Executive Summary

South Dunedin has similarities with several other cities in the world with low lying areas and high groundwater levels that affect buildings and infrastructure through water ponding and drainage issues. Groundwater levels in South Dunedin are expected to rise as a consequence of sea level rise, exacerbating existing water ponding and drainage issues.

Dunedin City Council (DCC) and Otago Regional Council (ORC) are seeking to learn from overseas experiences of controlling groundwater levels and have engaged Golder Associates (NZ) Limited (Golder) and Deltares Ltd (Deltares) to identify and review overseas examples relevant to South Dunedin. This report presents fifteen case studies from throughout the world that provide useful information to inform the development of protection options in South Dunedin.

None of the case studies documented are exactly the same as the situation in South Dunedin. However, each offers clear similarities in the issues that authorities face in dealing with rising groundwater levels and they present multiple protection options that may also be feasible in South Dunedin.

In urban areas where groundwater levels are relatively close to the surface several issues may arise, such as surface water ponding, damage to infrastructure and buildings, and increased risks of liquefaction during earthquakes. These issues can be severe and widespread unless appropriate adaptive or management measures have been put in place. Factors such as sea level rise, increased weather extremes and land subsidence all influence the potential change in susceptibility.

The adverse effects of high and rising groundwater levels can be mitigated through careful planning, designing and maintaining adaptive mitigation measures. There are many different technical measures that can be implemented to control groundwater levels. The success of these systems depends heavily on the ability to install them in optimal locations, and the ongoing appropriate operation and maintenance of the systems.

Mitigation options include horizontal and vertical drainage, pumped open canals, ground improvement, seepage canals and cut-off walls. Horizontal subsurface drainage is the most widely used method for high groundwater level mitigation, as it can be retrofitted in existing urban areas. Subsurface drainage systems with infiltration capacities have been used to maintain a relatively flat groundwater table in some areas. The creation of open water bodies or canals with water levels managed through pumping can be an effective measure to control groundwater levels and provide added benefits in terms of stormwater management and amenity values.

A good understanding of local conditions (hydrology, hydrogeology and geology) and effective engagement of residents has been found to be critical in successful implementation and operation of technical measures. Successful case studies also have one or more key governmental authorities taking the initiative to drive the development of the mitigation approach.

To control rising groundwater levels in South Dunedin there are options to combine multiple protection measures. Protection options can be introduced slowly in a progressive manner rather than as a one-off operation and can be focussed initially to protect sensitive areas and buildings. There is potential to develop new recreational surface water bodies and features and look for windows of opportunity to maximise the benefits from constructional costs when retrofitting groundwater drainage systems. South Dunedin's stormwater and wastewater networks are up for renewal in the near future. This may provide opportunity for implementing some measures to manage groundwater levels.

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1.0 INTRODUCTION

1.1 The Project

Like many coastal cities around the world, Dunedin has low lying areas with high groundwater levels that affect buildings and infrastructure through water ponding and drainage issues. Of particular concern is the South Dunedin area, a low lying urban area bounded by both the ocean and the harbour (Figure 1).

Figure 1: South Dunedin, Dunedin Port and Otago Peninsula (source: Glassey et al 2002).

Groundwater levels are strongly influenced by the sea in South Dunedin and sea level rise over the past century has increased groundwater levels there (ORC 2012 and ORC 2016). With sea levels expected to further increase in response to climate change, groundwater levels in South Dunedin are projected to continue to rise. This rise will increase South Dunedin's susceptibility to water ponding and drainage issues.

These problems are not unique to South Dunedin. Cities throughout the world have built environments in low lying areas with high groundwater levels causing similar problems. Many of these cities have taken action to control groundwater levels or otherwise deal with the associated issues. Dunedin City Council (DCC) and Otago Regional Council (ORC) are seeking to learn from these overseas experiences.

DCC and ORC have requested Golder Associates (NZ) Limited (Golder) and Deltares Ltd (Deltares) to undertake an international review of case studies where protection options have been implemented, or are being implemented, to manage rising groundwater. This report describes fifteen case studies from throughout the world that can provide useful information for the development of solutions for South Dunedin's high groundwater levels.

1.2 Objectives

The objective of this study is to provide an overview of available techniques to control groundwater levels in different types of urban environment, by reviewing international case studies. The factors that made these techniques a potentially viable options for groundwater level management are also presented. These factors include technical arguments as well as governance issues such as scale (population), environmental and social setting, funding arrangements, precedent, public preferences, as well as the ability to retrofit these systems in an existing urban area. Not all case studies are about success. Failures have also been presented to show pitfalls in the implementation of mitigation measures.

These matters will help DCC and ORC to gain better understanding of possible protection options in the context of the particular social, economic and environmental setting of South Dunedin. The intended use of this study is to provide information to inform consultation with community and stakeholders on the range of potential options available for addressing the high groundwater level issues in South Dunedin. This study does not provide recommendations as to which protection options are viable for South Dunedin.

1.3 Approach

Fifteen towns and cities throughout the world were selected as useful case studies, based on their relevance to the South Dunedin situation and the availability of information. Their locations are shown in Figure 2. In a desktop study and through literature search, these case studies have been systematically reviewed and categorised in terms of environment, socio-economics and governance, for easy comparison with South Dunedin's circumstances. Where relevant and sufficient information is available, the following matters are described:

1) Characteristics, scale and size of the groundwater level rise issues.
2) Protection measures implemented or proposed (whether protection is part of a suite of measures).
3) Efficacy of the protection measures in achieving the intended goals (whether the protection component has provided the expected levels of service and whether residual risks have been created).
4) Limitations and constrains of implementing the protection measures imposed by technical factors or socio-economic factors (including the effectiveness of measures being limited to a finite period).
5) Community acceptance and the potential for 'windows of opportunity'.
6) Indication of whole life costs of protection measures, including cost to implement, operate and maintain during the expected life time of the measures.

There are many other towns and cities throughout the world that are affected by high and rising groundwater levels in the urban environment that are not presented in this report. The study case studies presented in this report have been selected based on the information available on the protection options utilised.

Some case studies have been studied for many years and mitigation measures have already been implemented. For others investigations are still underway. This means that the available information varies across the case studies and not all are described to the same level of detail. Many of the case studies are from the Netherlands, where a long and diverse track record of dealing with high groundwater levels has been established over decades.

Some case studies have similar issues or similar measures are implemented or considered. These case studies have been clustered to help provide a better overview of mitigation strategies and approaches.

The case studies presented in this report are all towns and cities with high groundwater level issues in existing urban areas. This means that mitigation measures, such as subsurface drainage, would have to be 'retrofitted' into an existing urban environment. There are constrains as to what mitigation measures can be implemented in existing urban areas. For example, options involving wholesale ground improvement and raising ground levels that are sometimes applied in new developments are often not feasible in existing urban areas. The focus in the selected case studies is on retrofitting systems in existing urban areas, which is most relevant to South Dunedin's circumstances.

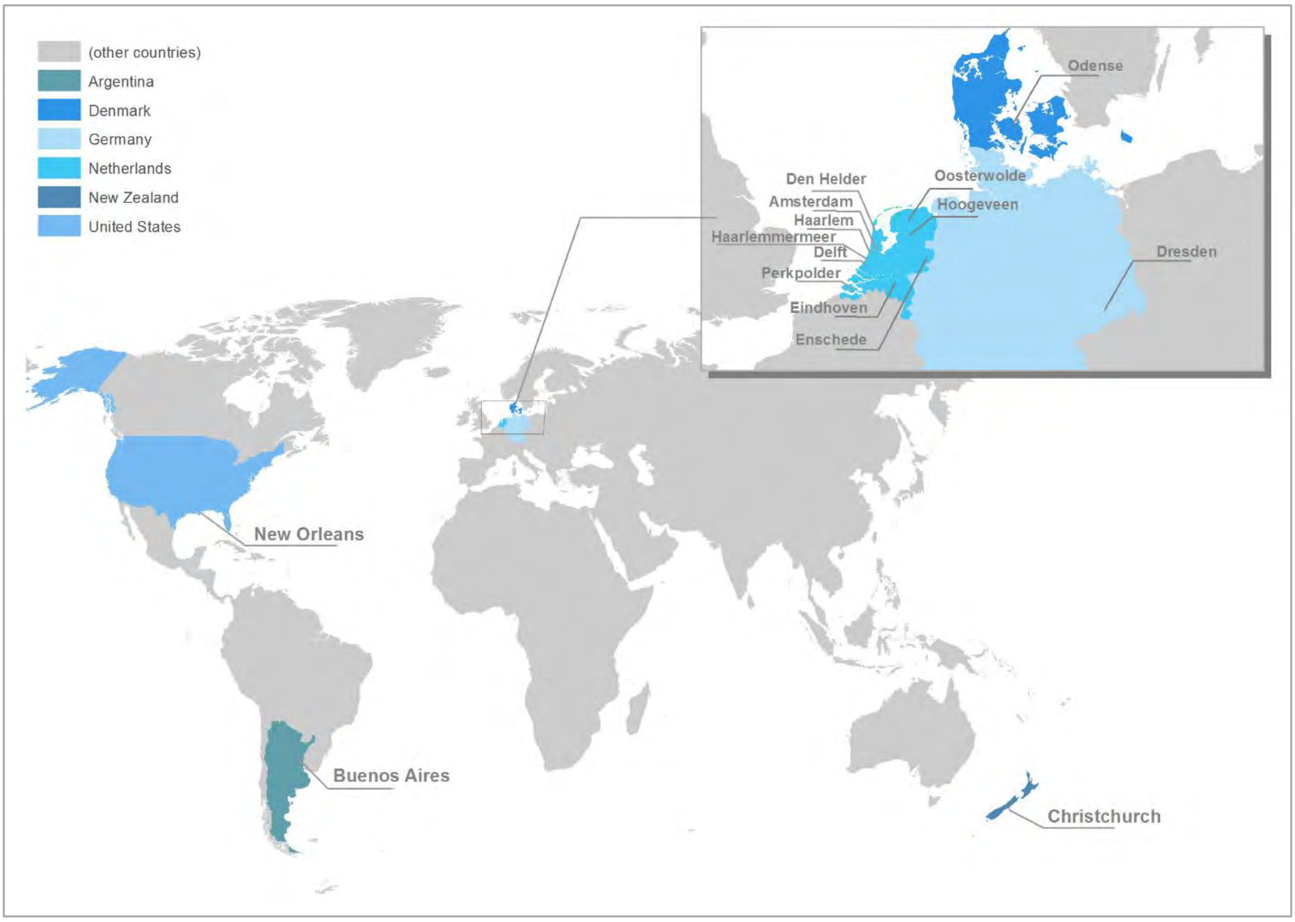

Figure 2: Overview map of international case studies used in this investigation.

1.4 South Dunedin Setting

For the purposes of this report, the area referred to as South Dunedin comprises a low-lying dense urban environment of 600 ha which is less than 3 m above mean sea level. South Dunedin is located south of the Dunedin city central business district, between the Otago Harbour Basin and the Pacific Ocean. It includes the suburbs of South Dunedin, Tainui, St Kilda, Forbury, St Clair and Kensington. South Dunedin is mainly a residential area with medium density housing (ORC 2012). Approximately 10,000 people live in about 4,800 dwellings in this area. The population is mainly older, has a lower income and the residents are less likely to own their homes than residents in average suburbs in New Zealand (ORC 2016 and ORC 2012).

Groundwater levels in South Dunedin are high and generally less than 1 m below ground level. Near Tonga Park in the centre of the area, groundwater levels are generally less than 0.5 m below ground level. Current high groundwater issues mainly affect the suburbs Forbury, St Kilda West and Tainui and, to lesser extent, the suburb of South Dunedin (Figure 3).

The area is an ancient river valley partly filled with alluvial gravels and sands that has been buried in soft sediments (sand, silts and clays) forming a land bridge between the surrounding hills as sea levels rose after the last ice age (ORC 2012, ORC 2016 and Fordyce 2013). In recent times before European settlement the area comprised salt marshes, lagoons, dunes and intertidal mudflats. South Dunedin was developed into a predominantly residential and commercial / retail area from the 1800's onward, following land reclamation and land filling. Land filling was often poorly compacted and some residual land settlement is still occurring (ORC 2016).

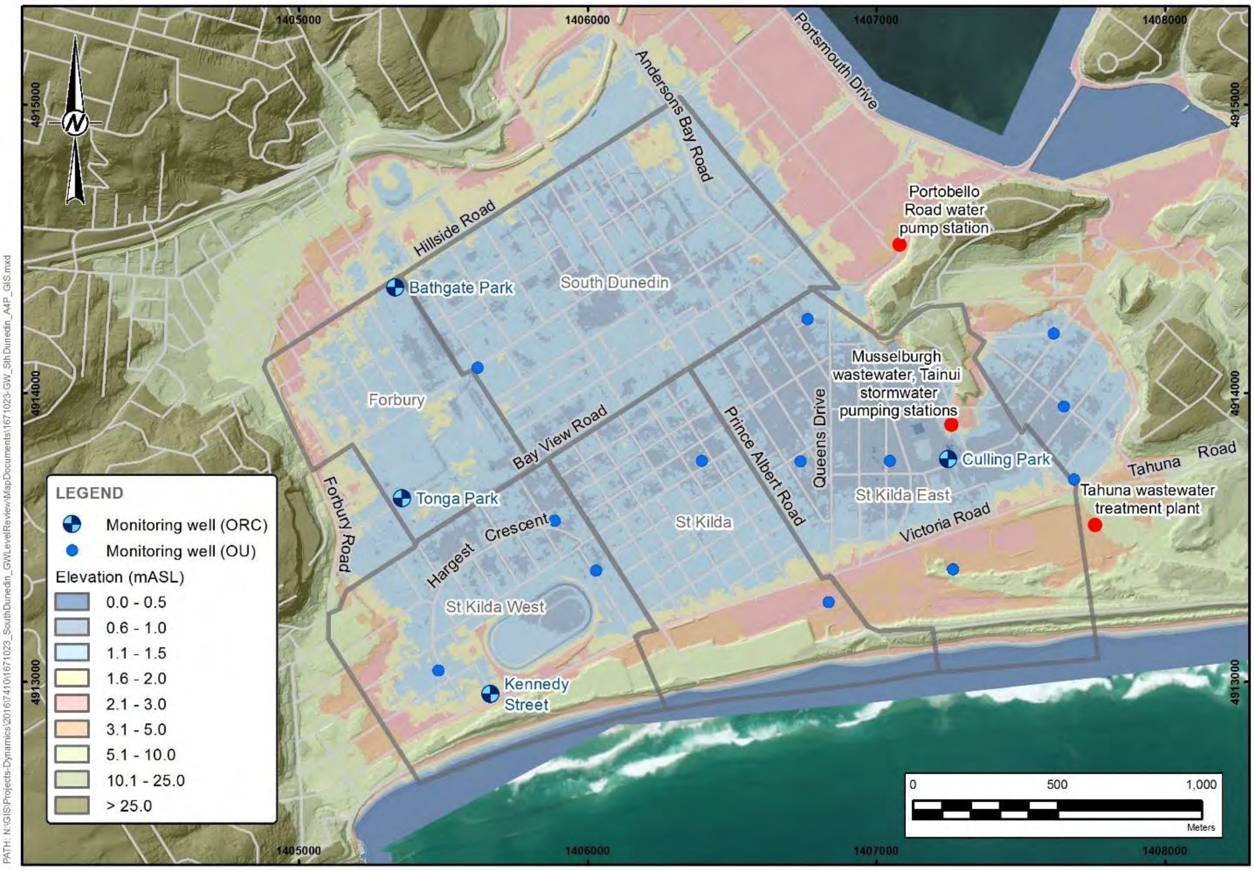

Figure 3: South Dunedin area.

Coastal protection from inundation for South Dunedin is provided by seawalls along the harbour side to the northeast, and by dunes to the south. The groundwater issues arise in part from the fact that there are limited locations for surface water in the area to naturally drain.

The annual mean rainfall is approximately 800 mm/year and is more or less evenly distributed throughout the year (ORC 2016). However, extended periods of moderate to heavy rainfall and concentrated heavy rainfall events occur and can lead to surface flooding. With impervious surfaces (hardstand, roads or roofs) covering 60 % of South Dunedin and locally up to 100 %, the stormwater network has to cope with a significant amount of runoff in a short timeframe. In addition to direct rainfall, the area receives runoff from the surrounding hills through direct flow and through the stormwater network. There are no natural outlets and open water courses on the South Dunedin plains. The lowest part of the area is in the southeast near Tainui. At Portobello Rd the collected stormwater is discharged to the harbour through a pump station. Wastewater is collected in the Musselburgh pump station and then pumped to the Tahuna wastewater treatment plant.

South Dunedin has long faced stormwater management challenges. The area is flat and the stormwater network is constrained by the small differences in elevation. The most recent wide spread flooding occurred in June 2015 (ORC 2016). During this event heavy rainfall and runoff, and the corresponding rise in groundwater levels, caused flooding especially in the central and western part of South Dunedin.

The current shallow groundwater levels are unintentionally mitigated to some extent by cracks and leaks in the existing aging sewage and stormwater networks. Replacement of these systems with non-leaking infrastructure may therefore lead to new groundwater issues in areas where they are currently not present.

There are also indications of locally higher groundwater levels resulting from infiltration at some locations, (ORC 2012, Fordyce 2013).

A study from ORC (2012) has confirmed the increased vulnerability of South Dunedin to high groundwater levels as a result of projected sea level rises. This study concluded that the area will be significantly impacted on an area-wide scale and extensive measures would be required to satisfactorily mitigate the adverse effects of rising groundwater levels. Capital costs and on-going operation and maintenance costs of measures to manage these effects have been estimated to be significant.

2.0 MITIGATION OPTIONS FOR HIGH GROUNDWATER IN URBAN AREAS

2.1 Introduction

In the case studies presented in the following sections several mitigation measures and strategies have been considered and in some cases successfully implemented. This section gives a high-level overview of some general high groundwater level mitigation measures for urban areas. The measures presented below can often be applied in combination, to solve multiple groundwater problems. It is noted that liquefaction may severely affect subsurface infrastructure including many of the systems described below.

2.2 Ground Improvement and Raising the Land

Low-lying areas prone to flooding and the effects of high groundwater levels can be raised using engineered fill to reduce their susceptibility (Figure 4). Ground improvement can be implemented to mitigate liquefaction risks and potential consolidation or heave.

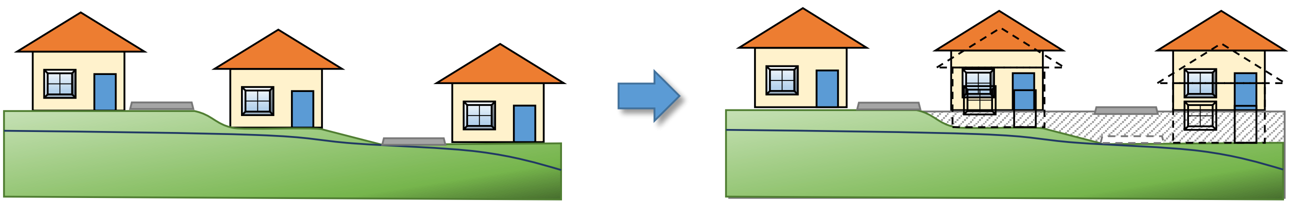

Figure 4: Ground improvement and raising the land.

These measures are usually considered when rural land is being developed into urban functions (often referred to as ‘greenfield development’). They are sometimes applied in existing urban areas, but typically require demolition and re-building. Alternatively, partial raising of existing levels or excavation filling may be applied to create a permeable layer or trench to enhance groundwater drainage (Figure 5). Excavation filling entails the excavation of clay soils under roads and building sites and backfilling with sand. A subsurface drain is installed in the sand to control the groundwater levels.

Figure 5: Excavation filling in progress for a new urban development The Netherlands, photograph supplied by Deltares.

2.3 Open Land Drain or Canal

An effective way to reduce groundwater levels is to install open drains or canals. This measure is often used in urban areas, either in combination with subsurface drainage or separately. The canals in Amsterdam, The Netherlands, are a well-known example. The Netherlands canals are often located below sea level and pumped to manage water levels to prevent flooding. Therefore canals and surface water features do not necessarily need a natural outflow.

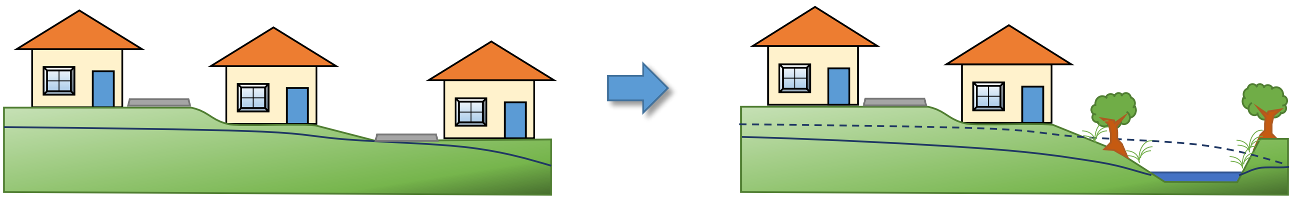

Figure 6: Open land drain or canal.

The loss of land for development can deter developers from introducing open surface water drainage features into new urban areas. However, surface water can provide added benefits for stormwater management and also form a recreational and ecological amenity to the community. In addition, the value of properties located next to water may be higher. Waterproofed buildings reduce the loss of land for development (e.g., floating houses or pile houses, see Figure 7). In existing urban areas the establishment of open land drains may require purchase of property and the removal of dwellings.

Buildings can be made less susceptible to the effects of high groundwater levels, for example by raising floor levels, waterproofing basements or installing pumped drainage systems around basements. The property owners are usually responsible for implementing these measures.

Infrastructural networks and objects can also be made less susceptible to the effects of high groundwater levels, for example by using alternative construction materials, elevated construction levels or alternative methods for construction and maintenance. Public authorities and utility companies are usually responsible for implementing mitigation measures for these networks.

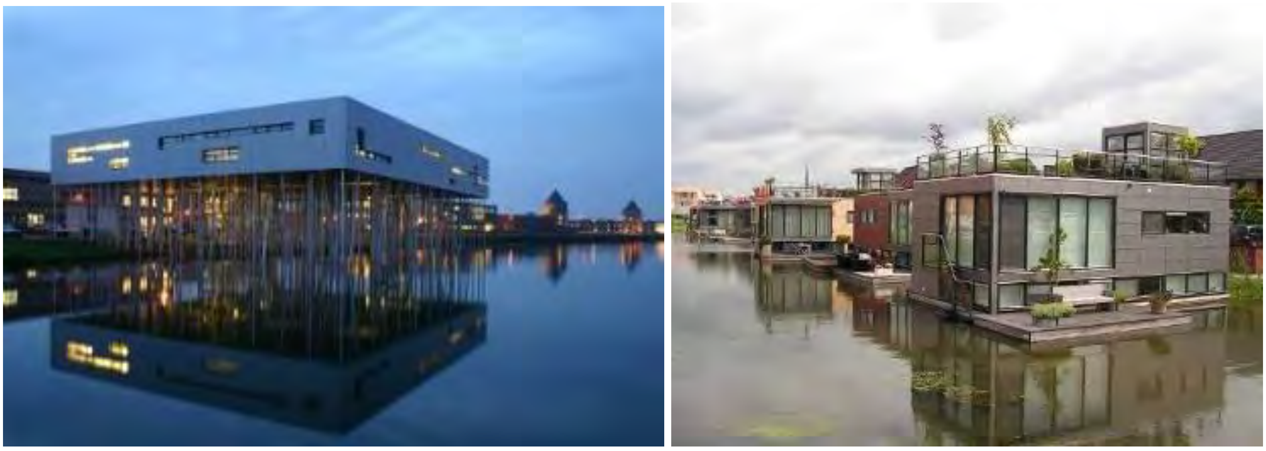

Figure 7: Examples of waterproof buildings (left: pile house; right: floating house).

2.4 Horizontal Subsurface Drainage

The best-known and widely applied measure to control groundwater levels is the installation of horizontal subsurface drains, typically known as “French drains” in New Zealand. These subsurface drains incorporate slotted pipes, either wrapped in a non-woven geotextile or placed in a gravel bed. These pipes are installed below the groundwater table to capture and divert the groundwater, thereby reducing nearby groundwater levels (Figure 8). If properly designed and installed, and soil permeability is favourable, subsurface drainage systems can be targeted and effective in controlling high groundwater levels.

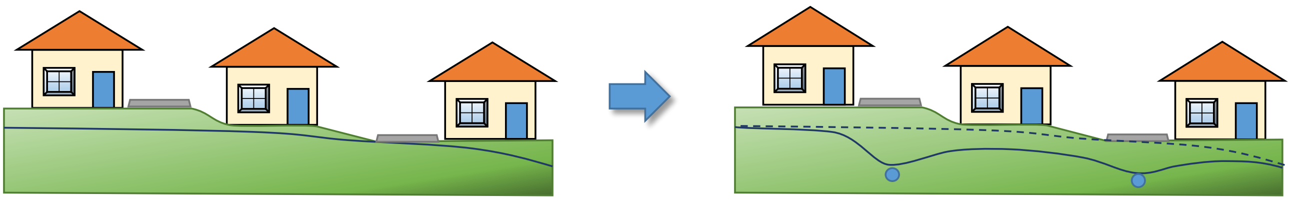

Figure 8: Horizontal subsurface drainage.

Subsurface drainage is often effectively applied in urban areas, if well designed, operated and maintained. Planned stormwater or wastewater network upgrades that involve trenching in roads can provide an opportunity to install horizontal subsurface drainage measures.

The potential for clogging is an important consideration when designing these systems. Iron-rich groundwater can lead to iron oxides precipitating, which clog the systems over time. Clogging risks are generally small if the drainage system remains permanently submerged in groundwater and the drainage material and native soil are geotechnically compatible. Tree roots are however also attracted to the presence of both water and air in a non-submerged subsurface drain. Provisions for discharging the drained groundwater are always required. Subsurface drainage systems can accelerate land subsidence if consolidation prone soils are present.

Subsurface drains can be installed on public land as well as on private land. Road maintenance authorities install subsurface drainage beneath roads to ensure sufficient drainage and this can help solve drainage problems on nearby properties. However, a low soil permeability may require additional subsurface drains to be installed on private land to avoid high groundwater levels under houses, buildings and gardens.

2.5 Vertical Drainage (Wells)

Wells can also be installed as mitigation against high groundwater levels. Pumping from the wells will lower the groundwater table in a radial area around the well (Figure 9). Multiple wells can be installed to drain a larger area.

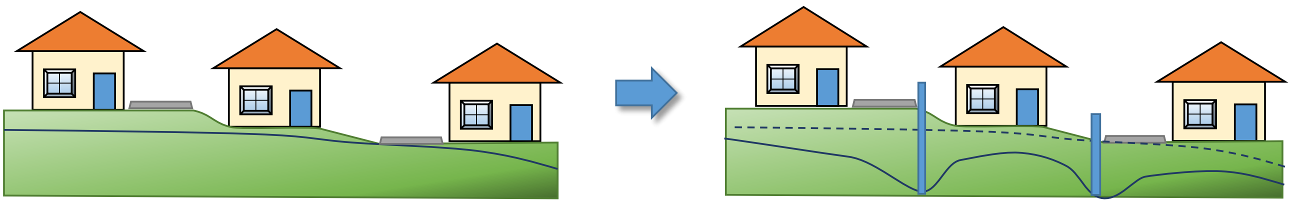

Figure 9: Vertical drainage (wells).

Vertical drainage through wells is less targeted than horizontal drainage as the largest groundwater drawdown occurs near the well. Land subsidence and in particular differential settlement can be significant if consolidation prone soils are present. A disproportionate amount of groundwater would need to be pumped to be as effective as horizontal drainage, although the installation and operation of multiple wells may enhance the efficacy. The advantage of vertical drainage through wells is that no trenching is required and they are easier to fit into an existing urban environment. This technique may also be more effective than horizontal drainage systems in areas with low permeability top soils.

2.6 Combined Stormwater and Groundwater Drainage Systems

In many cases low-lying areas with high groundwater levels are characterised by soils that are prone to consolidation, which causes land subsidence when groundwater levels are lowered. Lowered groundwater levels can accelerate land subsidence and affect urban functions as much as high groundwater levels. These areas benefit from a groundwater table that is kept “flat” or fluctuates within a narrow band. This can be achieved by systems that will infiltrate water when groundwater levels are too low and drain water when groundwater levels are too high. This twinned function can be achieved by combining a stormwater system with subsurface drainage (Figure 10).

In most cases only a portion of the locally collected stormwater can be infiltrated. Whilst this may be sufficient to raise the groundwater table to a desired level, most stormwater will still need to be diverted and discharged. The potential for clogging is an important consideration when designing these systems. The groundwater quality may be very different from the stormwater quality and physical, chemical or biological processes can lead to clogging of the systems over time. As with horizontal subsurface drainage, these combined systems need to be installed in trenches and the best opportunity for installation is when stormwater and wastewater network upgrades are planned.

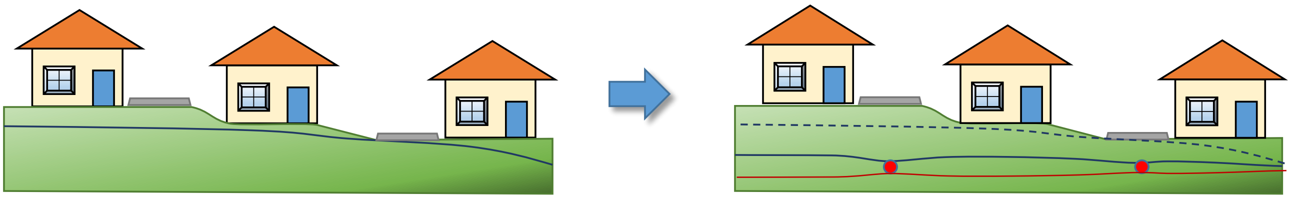

Figure 10: Combined stormwater and groundwater drainage systems.

2.7 Seepage Drain or Canal

This is a similar concept as an open land drain (see above), but is installed specifically near a water body (river, lake or sea) that may in part be the cause of the high groundwater levels Figure 11).

As with land drains, a seepage drain requires land to be surrendered that could otherwise be developed. However, seepage drains can have the same added benefits as open land drains for stormwater management and enhancing ecological, landscape and recreational values (see above). When installed near the sea, the water in the seepage drain will become saline over time.

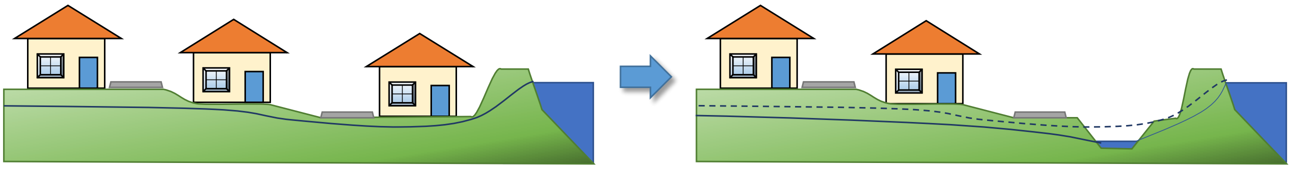

Figure 11: Seepage drain or canal.

2.8 Cut-Off Wall

A cut-off wall can be installed near a water body (river, lake or sea) that may in part be the cause of the high groundwater levels (Figure 12). Cut-off walls alone often have little value for mitigating high groundwater levels as installation to significant depth is often required to reduce the seepage beneath the wall satisfactorily. Additional measures such as subsurface drainage is usually required to make cut-off walls effective for groundwater management. There may be geotechnical constraints for installing cut off walls.

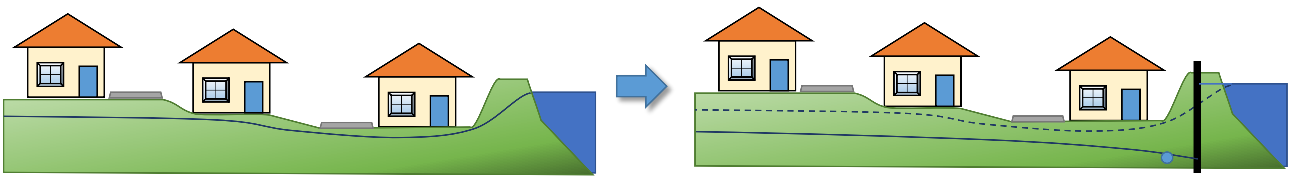

Figure 12: Cut-off wall, combined with subsurface drain.

2.9 Managed Retreat

In some cases communities may choose to retreat from a certain area, or a part of it. Managed retreat entails the rezoning of affected areas to a non-urban function, which means building consents will no longer be issued and services no longer maintained. Buildings are vacated and this is usually followed by demolition and site clearing (Figure 13). In the context of coastal protection, managed retreat may also include the removal of coastal protection and allowing an area to become flooded.

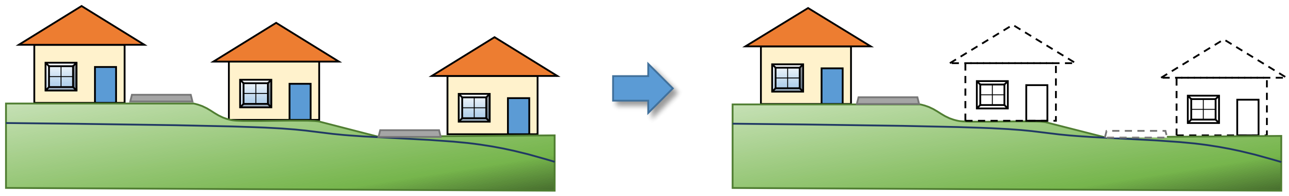

Figure 13: Managed retreat.

The red zoning of large parts of Christchurch, including buying out property owners following the Canterbury Earthquake Sequence (CES), is an example of managed retreat.

Examples of managed retreat from urban areas specifically caused by groundwater flooding were not encountered in this investigation (although their existence cannot be excluded). Managed retreat from a part of the urban area did occur in Odense, Denmark (Case Study 11), but this was only indirectly instigated by high groundwater issues.

3.0 CASE STUDIES

3.1 Overview

There are multiple reasons for rising groundwater levels and although the cause of rising groundwater levels in many of the case studies are different to South Dunedin the lessons learnt in developing protection options can potentially be applied.

Some of the main causes of high and rising groundwater levels are:

- Tidal fluctuations and sea level rise raising groundwater levels.
- High water levels in rivers and streams raising nearby groundwater levels.
- Cessation of pumping from large municipal or industrial groundwater abstractions.
- Land subsidence.
- Upgrading leaking stormwater and sewage pipes and connections.
- Urban development effects on groundwater recharge and drainage

Fifteen case studies from around the world are documented in this section. The case studies have been selected based on the amount of information available on the utilised protection options. Examples of various protection measures and suites of measures are presented.

Table 1 provides a ranking of the case studies and protection options with respect to their relevance to South Dunedin. None of the case studies is exactly the same as South Dunedin. Like all presented case studies, South Dunedin is unique in some ways. A good understanding of local circumstances is required for the successful implementation of protection strategies. Nonetheless, there are similarities between each of the case studies and South Dunedin. Protection options applied in the case studies are potentially viable in South Dunedin and lessons learnt from the case studies can be applied to South Dunedin.

South Dunedin has options to potentially combine multiple protection measures, as also documented in many of the case studies, in order to:

- Introduce measures in a progressive manner
- Combine stormwater and groundwater drainage measures
- Protect sensitive areas and buildings
- Develop new surface water recreational areas and features
- Identify windows of opportunity to minimise constructional costs of installing drainage.

As authorities and the community work through their preferred options for South Dunedin, the learnings from these case studies can be used to develop a solutions package of preferred measures.

The most comparable case study that has a similar coastal/urban setting to South Dunedin is Den Helder. It is a port town, surrounded by sea on three sides. It has high groundwater level issues and existing canals attracting saline groundwater. It has an on-going sewage replacement programme in which authorities are installing combined drainage/transportation stormwater sewage pipes (Gemeente Den Helder 2012). However, all case studies have relevance to South Dunedin and can be considered in the development of protection options.

Table 1: Case studies - relevance to South Dunedin.

Protection Options:	Case Studies:	Characteristics	Protection measures
Horizontal drainage	Haarlem Haarlemmermeer		
Mitigating Tidal Influence and Sea Level Rise	Den Helder Perkpolder		
Combined Horizontal Drainage and Infiltration	Amsterdam New Orleans		
Selective Groundwater Drainage	Hoogeveen Dresden		
Retrofitting Open Canals	Ooststellingwerf		
Vertical Drainage (wells)	Delft Eindhoven Buenos Aires Odense		
Risk-based Groundwater Management	Enschede		
Liquefaction and Managed Retreat	Christchurch		Not a protection measure

Ranking key for relevance to South Dunedin Table 1:

Most relevant			Least relevant

3.2 Horizontal Drainage

3.2.1 Introduction

Over several decades, the installation of horizontal drainage alongside sewage pipes has become widespread as part of building site preparation, sewer replacement and road (re)construction projects throughout The Netherlands. The efficacy of these systems is highly dependent on the quality of the design and subsequent implementation and maintenance. This section includes a 'good practice' example (Haarlem) and 'lessons learned' example (Haarlemmermeer).

3.2.2 Case Study 1: Haarlem (The Netherlands)

Characteristics

In the 1980s, the late 19th/early 20th century Leidsebuurt district (area of 34 ha) in Haarlem was one of the first locations in the Netherlands experiencing groundwater rise after sewer replacement.

Protection measures and mitigation approach

In response, the city of Haarlem financed and installed a horizontal subsurface drainage system in public land in 1989. To minimise clogging by iron oxides and damage by root growth, the system was installed in a gravel-filled trench below the (expected) lowest groundwater level. The drainage level can be changed with adjustable weirs in (dry) catch pits. Too low groundwater levels can affect foundations in this area and the ability to adjust drainage levels is important. The lowest groundwater level acceptable for these foundations may vary significantly over a short distance. The groundwater collected in the catch pits is discharged to nearby surface water through pumping, as the surface water level is higher than the drainage levels.

The drainage pipes are cleaned by medium pressure flushing every one or two years. After 26 years, the state of the subsurface drains was investigated. There was no clogging or root growth, and the coating material was hardly worn. As a result, the lifetime expectation of the drainage system was increased by another 60 years. Groundwater levels mostly remain within the imposed drainage levels and have not shown any upward trend since 2002, which often indicates clogging over time (Figure 14). The good performance of the system is considered largely to be owing to its permanent submergence in the groundwater.

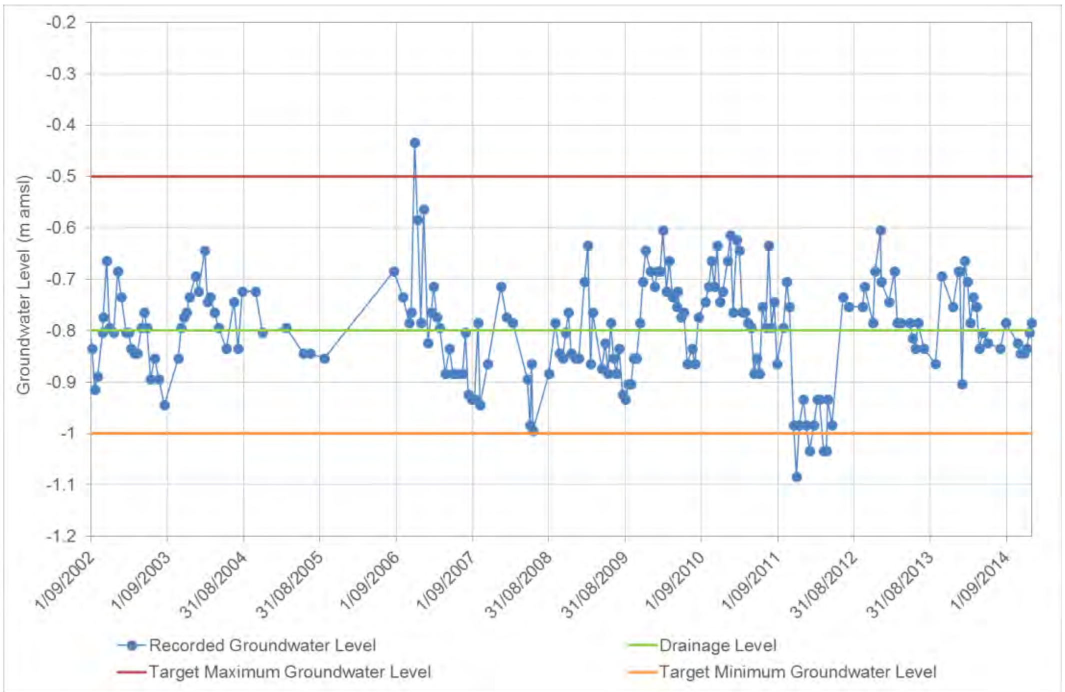

Figure 14: Groundwater levels in one of 12 observation wells near the subsurface drainage system in Haarlem. Source: Wareco / City of Haarlem.

3.2.3 Case Study 2: Haarlemmermeer (The Netherlands)

Characteristics

The Haarlemmermeer is a reclaimed former lake in between the cities of Amsterdam, Haarlem and Leiden, and hosts the Schiphol International Airport and urban areas like Hoofddorp and Nieuw Vennep. In the 1990s, the district/city council initiated several large urban development schemes to relieve the regional housing shortage.

Because of its low elevation (i.e., some 4 m below mean sea level), groundwater seepage is significant in this area. The area has no natural outlet and has to be pumped continuously for drainage. New urban developments are equipped with mandatory groundwater drainage systems. Nonetheless, the district/city council received many complaints about groundwater in crawl spaces beneath houses after the completion of the ‘Getsewoud’ development between 2000 and 2005 (approximately 200 ha).

Protection measures and mitigation approach

Investigations by the district/city council revealed the following causes of the high groundwater problems:

1) The drainage design was not optimal. There were too few discharge points to surface water, which made the system vulnerable to issues when some sections clogged.

2) The maintenance was insufficient. Many drainage pipes clogged over time by iron-oxides precipitation.

3) Building block drainage was initially installed on private property, but many property owners had not been made aware of the drainage location and maintenance requirements. Many systems were not maintained, became clogged and sometimes became inaccessible after paving.

The district/city council followed a ‘quick win’ approach by adding discharge points and resuming regular maintenance of systems to solve immediate problems. Furthermore, the district/city council commenced monitoring of groundwater levels and drainage performance, started a maintenance programme for the drains in public land and raised public awareness of the drainage systems on private land. The latter was carried out by means of an extensive communication programme, comprising public meetings, newsletters, a website, and appointing stakeholder representatives within the district/city council (Witteveen+Bos / Municipality of Haarlemmermeer 2012).

3.2.4 Summary and relevance to South Dunedin

A general overview and relevance of case studies 1 and 2 to South Dunedin is provided in Table 2.

Table 2: Horizontal drainage – summary and relevance.

Factors	Haarlem and Haarlemmermeer
Characteristics	■ Rising groundwater table after replacement of leaking sewage pipes which were acting as drainage.
Protection measures implemented or proposed *Part of suite of measures?*	■ Subsurface drainage installed during sewage replacement. ■ Not part of a suite of measures
Efficacy of the protection measures *Has protection provided expected level of service?* *Any residual risks?*	■ Haarlem- example of subsurface drainage operating successfully for 26 years, life expectancy up to 60 years. ■ Haarlemmermeer – example of drainage not performing as expected due to design errors and lack of maintenance (residual risk).
Limitations and constraints	■ Haarlemmermeer is in a 'polder' with no natural outlet. Continuous pumping for drainage is required.
Community acceptance and windows of opportunity	■ Subsurface drains were installed during sewage replacement projects.
Indication of whole life costs	■ Indicative costs for installing subsurface drainage in roads in The Netherlands ranges from € 30 per metre to € 250 per metre.
Relevance to South Dunedin	■ South Dunedin's sewage pipes are also leaking and the same may occur if replaced. ■ Subsurface drainage may provide a long-term solution for (parts of) South Dunedin. ■ Like the Haarlemmermeer, South Dunedin has no natural outlet. ■ Future sewage network replacement in South Dunedin could provide a window of opportunity.

3.3 Mitigating Tidal Influence and Sea Level Rise

3.3.1 Introduction

Groundwater levels in areas close to the sea can rise at high tide as a result of seepage beneath coastal protection measures such as sea walls, stop banks or dikes. A similar situation may occur near a river at high flows. Whilst sea walls or stop banks may protect against flooding, the seepage can cause high groundwater levels issues. Mitigation against this seepage is implemented in the case study presented in this section.

3.3.2 Case Study 3: Den Helder

Characteristics

Den Helder is a port city in the northwest of the Netherlands, which is bounded by the sea on three sides (Figure 15). The city has a population of some 56,000 and is protected from sea water inundation by dunes in the west and seawalls along the northern and eastern boundaries (Figure 16). A network of canals was constructed in historical times for transportation and defence purposes and serves as a discharge point for stormwater (Figure 17). The pumped canals are flushed with nutrient-enriched surface water from rural catchments south of the urban area, but also receive seepage of fresh groundwater from the western dune area and saline groundwater from the sea. Therefore, the water quality varies and some part of the canals are brackish.

Although the canals assist in managing groundwater levels, Den Helder has high groundwater level issues in the urban environment. The main causes are considered to be a lack of drainage systems and relatively high water levels in the canals (Gemeente Den Helder, HHNK and Grontmij 2005). Groundwater issues have reportedly increased following the replacement of leaking sewage pipes (Gemeente Den Helder 2012).

Figure 15: Overview map of Den Helder.

Figure 16: Photo of Den Helder and northern seawall near Koningsplein –taken facing west at high tide.

Figure 17: Canal near northern seawall at Koningsplein, Den Helder (source: Google Maps).

Protection measures and mitigation approach

Since 2008 all city and district councils in The Netherlands, including Den Helder, are responsible for investigating groundwater issues in urban areas and taking appropriate measures in public spaces where there are structural and persistent groundwater issues (Section 4.5). Den Helder City Council has acknowledged groundwater issues and has implemented some measures. However, further internal policy for managing urban groundwater issues has yet to be adopted (Gemeente Den Helder 2012).

As part of an on-going sewage and stormwater network upgrade programme, the stormwater pipes are being partially replaced with ‘drainage and transportation’ stormwater pipes (Gemeente Den Helder, HHNK and Grontmij 2005; Gemeente Den Helder 2012). These pipes provide sufficient storage and diversion capacity to manage stormwater, but also have a drainage and infiltration function to manage groundwater levels (Figure 18).

Costs and Finance

Costs for the implementation of high groundwater mitigation measures were projected to be €360,000 in the 2013 – 2017 management period.

Figure 18: Drainage and transportation stormwater pipes (source: WAVIN).

3.3.3 Case Study 4: Perkpolder (Netherlands)

Characteristics

Near the Perkpolder, in the southwest of the Netherlands, 75 ha of agricultural land was returned to the sea to restore tidal salt marshes and associated environmental values along the Westerschelde (estuary of the North Sea). As such, this case study represents a form of managed retreat (Section 4.5).

It also meant that the sea would come much closer to the adjacent farmland than was previously the case. This would cause saltwater seepage beneath the stop bank and the subsequent rise of groundwater levels as well as saline intrusion behind the stop bank. Agriculture in this area depends on a freshwater lens which is used for irrigation and would be adversely affected.

Protection measures and mitigation approach

To counteract an increase of hydraulic heads associated with high sea tides, a seepage collection system was installed on the land side behind the stop bank, under the supervision of and financed by the national water authority (‘Rijkswaterstaat’). The system consists of a seepage canal and 61 vertical seepage wells with 5 m to 10 m long screens (Figure 19). The wells were installed over a length of about 1 km at 12 m to 17 m depth, in an aquifer that mainly comprises fine sands. Monitoring results showed that the system would be effective even after the expected sea level rise has taken effect in this area (De Louw et al., 2016).

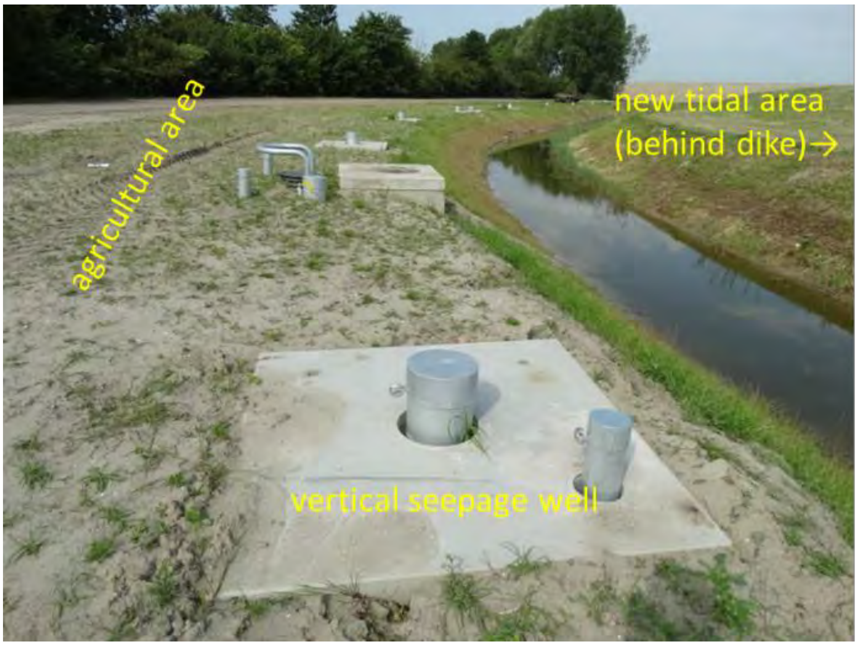

Figure 19: Seepage system Perkpolder.

Costs and finance

Installation costs of the system were an estimated € 800,000[1]. Returning fertile agricultural land to the sea remains controversial in this area, but the seepage system gives the farmers confidence that crops and freshwater resources for irrigation of the remaining farmland are safeguarded.

3.3.4 Summary and relevance to South Dunedin

A general overview and relevance of case studies 3 and 4 to South Dunedin is provided in Table 3.

[1] www.volkskrant.nl/economie/ingenieus-kwelscherm-houdt-water-op-akkers-zoet~a4209218/. Visited 20 Apr 2017.

Table 3: Mitigating tidal influence and sea level rise - summary and relevance.

Factors	Den Helder and Perkpolder
Characteristics	■ Saltwater intrusion and high groundwater levels affect nearby farmland (in the Perkpolder case) or urban areas (in the Den Helder case).
Protection measures implemented or proposed *Part of suite of measures?*	■ For Perkpolder a seepage canal and wells are installed along coastal protection to capture saltwater intrusion and control groundwater levels. ■ In Den Helder, canals for water management and seepage control were historically constructed when the city was built. Recent groundwater issues are mitigated by drainage / transportation stormwater pipes. ■ Both cases involve a combination of measures.
Efficacy of the protection measures *Has protection provided expected level of service?* *Any residual risks?*	■ Initial results show the system in Perkpolder would be effective even after the expected sea level rise takes effect. Therefore, it has provided the expected level of service. Residual risks are not documented. ■ Den Helder involves installing new protection measures and results are not yet documented.
Limitations and constraints	■ Neither Den Helder nor Perkpolder has a natural outlet.
Community acceptance and windows of opportunity	■ Use of drainage / transportation stormwater pipes, to be installed with sewage network upgrades in Den Helder. For Perkpolder, the solution ensured productivity of the adjacent farmland.
Indication of whole life costs	■ In Den Helder costs were projected to be € 360,000 ■ Estimated installation costs of the system in Perkpolder were € 800,000
Relevance to South Dunedin	■ The groundwater level issues have occurred due to similar processes as in South Dunedin. ■ South Dunedin has no natural surface water outlet either. ■ A seepage canal with horizontal drainage like that used in Perkpolder may be applicable to South Dunedin. ■ Combined drainage / transportation stormwater pipes may be of use in South Dunedin.

3.4 Combined Horizontal Drainage and Infiltration

3.4.1 Introduction

Horizontal subsurface drainage can also be used for infiltration of (a portion of the) collected stormwater, or of surface water. This combined function can be used to draw the groundwater table almost flat, ensuring groundwater levels are neither too high nor too low. In areas with poorly permeable soils or high groundwater levels, the portion of collected stormwater that can be infiltrated through such system will be relatively small and has only limited relevance for stormwater disposal.

3.4.2 Case Study 5: Amsterdam (The Netherlands)

Characteristics

In the Vondelpark in Amsterdam, a combined drainage-infiltration system was designed to buffer groundwater fluctuation. The Vondelpark is lower than the surrounding residential properties and groundwater levels in the park were close to the surface (Figure 20). This posed a risk to fully-matured monumental trees in the park, which could degrade and even tumble. Wooden foundation piles of nearby historic residential buildings were originally installed below the groundwater table, which was common practice in historic times. These piles will rot if exposed to air after lowering the groundwater table, which potentially severely affects the buildings. Land subsidence as a result of groundwater drainage, could also affect nearby buildings.

Protection measures and mitigation approach

A combined subsurface drainage and infiltration system was installed to manage groundwater levels in an area of approximately 3 ha. The subsurface drainage system is connected to nearby surface water at 'boezem level'[2] which allows infiltration from the surface water. Before infiltration, suspended sediment is trapped and the water is further filtered by passage through a lavastone bedding (i.e., a form of stormwater treatment facility). The activation of the surface water inlet is controlled by the groundwater level. A subsurface sheet pile wall prevents the residential area from excessive drainage into the park. The system performs as designed and ensures groundwater levels remain within acceptable levels, as shown in Figure 21.

Costs and Finance

After the first maintenance round in 2015, the system appeared to show no decline in performance. The drainage-infiltration system was part of an integrated renovation of the park, including also restoration of buildings, gates and statues. The total cost of the renovation was 29 million euros, largely due to the complexity of construction activities in narrow, historic streets in the centre of the city, and were financed by the Amsterdam metropolitan council, the district/city council, and several other governmental bodies[3]. The district/city council took initiatives to acquire additional funding by selling 'Vondelpark' merchandise to the public, such as T-shirts, balloons, caps and umbrellas, and facilitating adoption of patches of the Vondelpark by companies[4].

[2] Many drainage systems in the Netherlands are divided in 'polders' and the 'boezem'. Most boezem levels are within 1 m below sea level, while polder levels can be down to 6 m below sea level. Polders discharge their water to the boezem using pumps, through which the water is diverted via sluices to the sea or a nearby river.

[3] https://www.trouw.nl/home/vondelpark-wordt-weer-romantisch~aaea62e7/ , visited 25 Apr 2017.

[4] https://www.nrc.nl/nieuws/2004/04/08/t-shirts-en-petjes-voor-renovatie-vondelpark-7681394-a1183310, visited 25 April 2017.

Figure 20: Canals and restoration construction being undertaken, Vondel Park (Amsterdam).

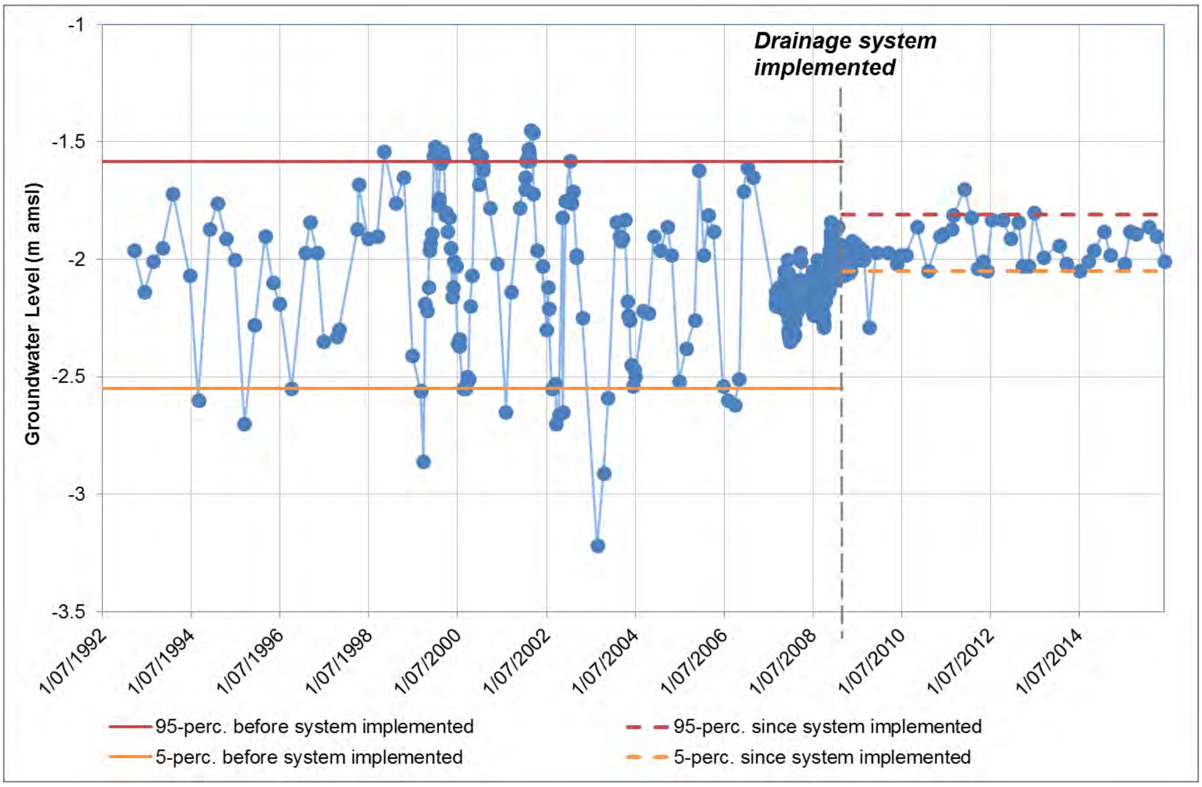

Figure 21: Groundwater levels observed in a residential area near Vondelpark, Amsterdam, before and after implementation of a combined subsurface drainage and infiltration system in Vondelpark. Source: Waternet.

3.4.3 Case Study 6: New Orleans (USA)

Characteristics

Groundwater levels in Greater New Orleans have declined over the years, causing substantial land subsidence in an area possibly as large as 200 km^2.[5] Land subsidence causes differential settlement, damages structures and infrastructure, and increases vulnerability to floods originating from the sea, river or Lake Pontchartrain. A major cause of declining groundwater levels and subsequent land subsidence is the abstraction of deep groundwater, but the drainage of shallow groundwater by leaky stormwater drainage and wastewater pipes and deep (freeboards in the) drainage canals has exacerbated the land subsidence (Figure 22).

Protection measures and mitigation approach

The repair or replacement of the stormwater drainage system is now considered, including installing a combined drainage –infiltration system to minimise land subsidence, as was implemented in the Vondelpark in Amsterdam (see above). This would raise average groundwater levels, and buffer large fluctuations caused by excessive rainfall events and prolonged drought (Figure 23).

Figure 22: Land subsidence in New Orleans - land has subsided but not the floor level.

1.1 [5] Based on a map of subsidence in Dixon et al., 2006. Space geodesy: Subsidence and flooding in New Orleans. *Nature* **441**, 587-588.

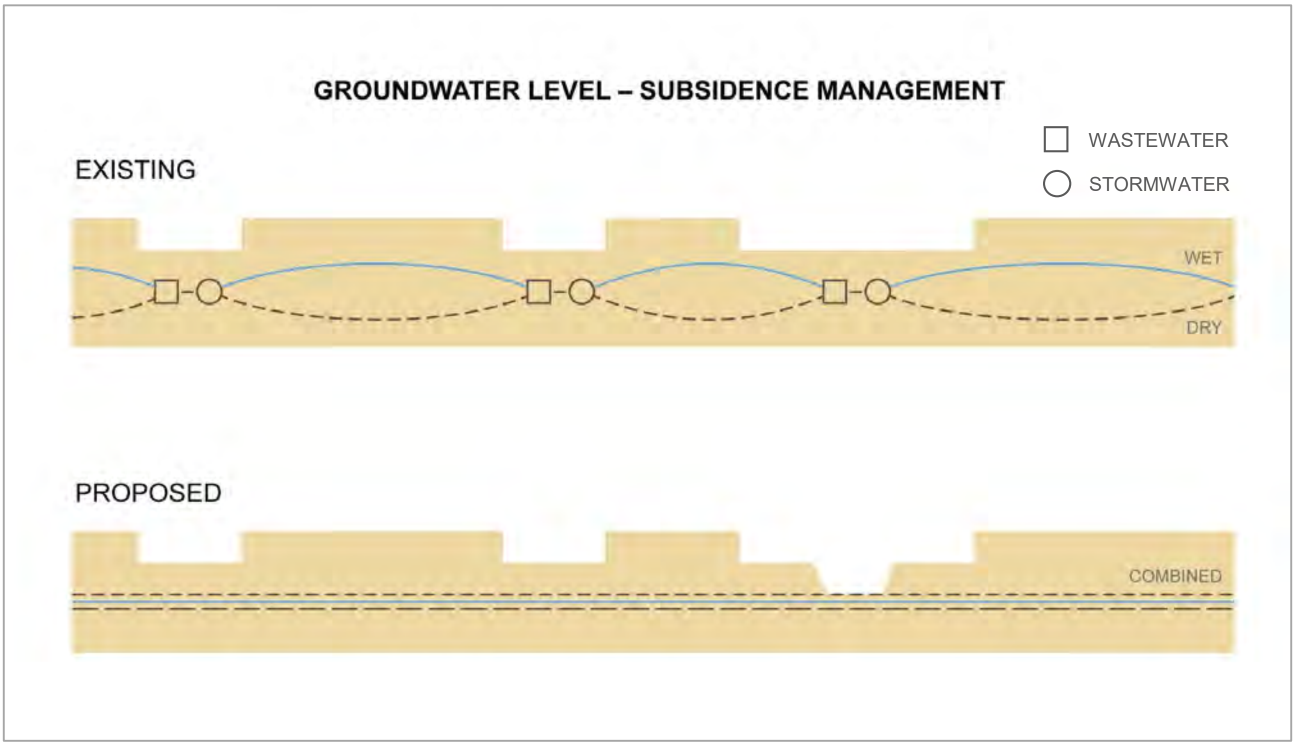

Figure 23: Schematic representation of a groundwater table managed by a combined drainage - infiltration system.

Costs and Finance

New Orleans lacks complete information on the groundwater system which limits the ability to design efficient and effective measures tuned to local conditions. In addition, little is known about the propagation of water level fluctuations of the Mississippi River and Lake Pontchartrain into the groundwater system (Deltares, 2013). Groundwater level and land subsidence issues have only recently gained attention in the city's first Urban Water Plan, and currently no entity is responsible for groundwater management (Waggonner and Ball, 2013).

Managing groundwater and land subsidence, is only a fraction of the integrated Greater New Orleans Urban Water Plan. Total implementation of the plan would cost an estimated $US 6.2 billion but generate a total economic benefit of an estimated $US 22.3 billion over a 50-year period. Despite the allocated budgets, the proposed large-scale (ground) water management will require a creative approach and multiple avenues of funding (Waggonner & Ball, 2013). Likewise, integrated water management will increase the number of stakeholders involved, including a multitude of public bodies but possibly also new collaborations between the public and private sector (Waggonner & Ball, 2013).

3.4.4 Summary and Relevance to South Dunedin

A general overview and relevance of case studies 5 and 6 to South Dunedin is provided in Table 4.

Table 4: Combined horizontal drainage and infiltration – summary and relevance.

Factors	Amsterdam and New Orleans
Characteristics	■ Both high and low groundwater levels can have adverse effects in these areas.
Protection measures implemented or proposed *Part of suite of measures?*	■ A combined horizontal drainage and infiltration system ensures the groundwater level is optimal. ■ If groundwater levels decline too much it can accelerate land subsidence and affect wooden pile foundations (exposure to air). Therefore levels are controlled and stabilised. ■ The Amsterdam case study involves a suite of measures; subsurface drainage, sheet piling, groundwater treatment and discharge to a surface water body.
Efficacy of the protection measures *Has protection provided expected level of service?* *Any residual risks?*	■ System in operation in Amsterdam since 2015 and is reported as functioning well without residual risks. ■ New Orleans system is still in proposal phase.
Limitations and constraints	■ System design, operation and maintenance can be complex.
Community acceptance and windows of opportunity	■ Systems implementation forms part of urban renewal project.
Indication of whole life costs	■ $US 6.2 billion for full plan, however, much larger area than South Dunedin and costs reflect this.
Relevance to South Dunedin	■ High groundwater levels are the concern in South Dunedin. ■ Some areas may be prone to land settlement. Saline intrusion may be accelerated if drainage levels are set too low. ■ Urban renewal projects could also provide a window of opportunity for implementing protection options in South Dunedin.

3.5 Selective Groundwater Drainage

3.5.1 Introduction

The response of the authorities in these case studies was to progressively improve groundwater drainage under public buildings/spaces and communicate responsibility of private property owners to improve drainage within their own properties. Priority areas for protection measures have been determined through planning mechanisms.

The Hoogeveen case study serves as an example of the implementation of the legal framework for managing groundwater issues in urban areas in The Netherlands (Section 4.5). The city council has implemented drainage in public spaces and facilitated measures taken by private property owners, for example by offering connections for groundwater discharge from private properties to the public stormwater system. The Dresden case study describes a situation in which a large urban area is affected by high groundwater levels following significant flows in a major river nearby. The dynamics of high river flows and subsequent groundwater level rise are different from sea level fluctuation effects on nearby groundwater levels but the adverse effects can be similar.

3.5.2 Case Study 7: Hoogeveen (The Netherlands)

Characteristics

Hoogeveen is a city in the north of The Netherlands that has widespread and locally persistent high groundwater issues, despite being located at relatively high ground. The main cause is the presence of a (nearly) impermeable glacial clay layer at shallow depth, and a loamy topsoil, both of which restrict proper drainage and cause high groundwater levels. The city has a population of 40,000 and the urban area covers approximately 20 km^2.

Protection measures and mitigation approach

Until 2008, little action was taken to tackle the problem, much to the frustration to the residents who did not know whom to address their issues. The establishment of the Dutch national legal framework on managing groundwater in urban areas (Section 4.5), prompted the district/city council to develop internal policy catered to local conditions. Three closely related key elements of this policy are as follows:

1) Establishment of an extensive groundwater monitoring network;
2) Development of a groundwater plan (Gemeente Hoogeveen & Wareco Ingenieurs 2012); and
3) Development of a communication strategy including an on-line water portal.

Initially, past experiences and monitoring data were used to delineate priority areas. Residents in those areas were interviewed in 2012 about their experiences with high groundwater on or near their property. The outcomes were then used to refine the district management plan. The district management plan states where the district/city council will take action, what type of action, and when. It combines several of district/city council's responsibilities and by including groundwater management the potential for windows of opportunities (Section 4.5) were identified.

The groundwater plan states that when high groundwater level issues are regarded 'structurally and persistently', the district council has responsibility to implement mitigation measures, provided that they are cost effective. In this case the number of specific high groundwater complaints and the length of period that the depth to groundwater is less 0.8 m below ground level in the public space are used as criteria. A clear division of responsibilities between the public and private sector for addressing urban groundwater issues is formalised in the groundwater plan.

Hoogeveen city council aims to reduce present and future structural and persistent high groundwater issues, by taking cost-efficient measures on public land. The district/city council will also facilitate measures taken by private property owners, for example by offering connections for groundwater discharge from private properties to the public stormwater system.

Based on an evaluation of a pilot drainage project, it is expected that measures on private property are in many cases necessary, given the generally low permeability of the loamy topsoil. The following ranking in preferred measures to be taken by the district/city council in both new and existing urban areas applies:

1) Raise ground level (with sufficient addition of sand)
2) Ground improvement of the top soil
3) Create (additional) surface water
4) Install groundwater measures such as subsurface drainage

Furthermore, it was decided that design and construction standards are adopted or developed, so as to ensure sufficient and constant quality, and durability of all measures taken.

All relevant plans, projects and monitoring results are communicated through the water portal in a way that is understandable for the general public. The district/city council's motto is 'communicate what you do and do what you communicate'.

Costs and finance

For the period 2012-2014, the total costs of groundwater management were budgeted at circa € 835,000. Of this total € 725,000 are one-off costs (groundwater plan, district-scale groundwater plans, drainage projects), and € 110,000 are annual costs for groundwater monitoring, operation of the water portal, and maintenance of existing drainage.

The annual time investment for the responsible council officer amounts to 0.2 of a full time equivalent. All costs are financed from the sewage tax, which forms part of the council rates. Since the introduction of the national legal framework for managing groundwater issues in urban areas in 2008, many municipalities have extended the existing sewage tax to encompass groundwater management.

3.5.3 Case Study 8: Dresden (Germany)

Characteristics

Dresden is a city in the southeast of Germany and has a population of approximately 540,000. The Elbe River flows through the city centre. In 2002, unprecedented high flows in the river Elbe not only caused direct flooding of parts of the city of, but also raised groundwater levels in other parts of the city. This caused widespread damage to structures throughout the city.

Protection measures and mitigation approach

After the 2002 flooding Dresden City Council took initiative to mitigate the effects of future high river flows and subsequent groundwater level rise. This was done in cooperation with other authorities among others the Saxony Regional Council.

The city council developed a flood protection plan (Landeshauptstadt Dresden, 2011) in which a clear distinction between responsibilities was made:

- Mitigation measures aimed at controlling Elbe river stages, such as flood protection walls and upstream retention basins, are the responsibility of public authorities. These measures are not explicitly related to groundwater, but indirectly contribute to mitigating of groundwater rise.
- Local groundwater drainage systems dedicated to public buildings were installed (and financed) by the city council.
- The city council also implemented an extensive groundwater monitoring system (Figure 24), covering an estimated 20 % of the total city area.
- Private property owners are in principle responsible for taking measures against high groundwater levels. This means that private property owners are responsible for implementing groundwater mitigation measures (on their property), which may be required in those areas not benefiting from the measures related to Elbe river stages.

In 2013 another significant flood event occurred in the Elbe River, ranked second in history after the 2002 event. In a subsequent evaluation, it was concluded that Dresden coped well with the consequences of the 2013 event because of the efforts made since 2002 (Landeshauptstadt Dresden, 2013). This includes the effectiveness of technical measures taken, a better flood protection organisation, and a better organised self-reliance of residents in flood-prone areas. The self-reliance is seen as an important part of the mitigation strategy, because technical measures may not be sufficient to fully avoid flooding.

The groundwater monitoring network from the city council was upgraded into a real-time municipal groundwater monitoring network with web based access since 2013. The real-time data presented on the website enables residents to take timely measures against the effects of high groundwater levels.

Figure 24: On-line portal to groundwater monitoring network in Dresden with real-time display of measurements. Source: Landeshauptstadt Dresden, Umweltamt.

Costs and finance

The cost of local groundwater drainage systems dedicated to public buildings had mounted to €2.86 million by 2011. The costs of the groundwater monitoring system were €450,000 installation and an additional €30,000 per year for operation and maintenance[6].

3.5.4 Summary and relevance to South Dunedin

A general overview and relevance of case studies 7 and 8 to South Dunedin is provided in Table 5.

[6] http://stadtplan.dresden.de/(S(wu2pdprbovzkfseijhcpi3ji))/spdd.aspx?TH=UWA_GRUWA_MESS, visited 21 Apr 2017.

Table 5: Selective Groundwater Drainage - summary and relevance.

Factors	Dresden and Hoogeveen
Characteristics	■ In Hoogeveen, poor drainage capacity of the soils result in high groundwater issues. Initially, property owners considered they had nowhere to turn to resolve these. ■ In Dresden, increase in river flows as a result of more extreme weather has made the city more flood prone and increased urban groundwater issues.
Protection measures implemented or proposed *Part of suite of measures?*	■ Authorities developed policies and management plans with clear division of responsibilities of the council and those of property owners. ■ Local groundwater drainage systems installed near council buildings and structures. However, private property owners remain responsible for drainage issues on their properties. ■ Part of a suite of measures.
Efficacy of the protection measures *Has protection provided expected level of service?* *Any residual risks?*	■ In Dresden, protection has provided the expected level of service as significant high river flow events occurred after implementation and effects of high groundwater levels were significantly less. Residual risks are communicated to the property owners. ■ Hoogeveen involves the progressive installation of protection measures as individual sites are deemed to be affected through planning mechanisms.
Limitations and constraints	■ Protection measures installed by authorities under public buildings and public spaces.
Community acceptance and windows of opportunity	■ The division of responsibilities and information sharing is formally outlined in policies and plans to provide transparency.
Indication of whole life costs	■ Dresden installation costs: Groundwater drainage system: €2.86 M. Groundwater monitoring network: €450,000 and O&M €30,000/y. ■ Hoogeveen costs for plan changes and installation were € 725,000, ongoing monitoring and management € 110,000 per year.
Relevance to South Dunedin	■ A gradual increase of urban groundwater level issues as a result of climate change is also expected in South Dunedin. ■ The separation of protection measures between authorities and property owners could be a relevant consideration for the South Dunedin situation.

3.6 Retrofitting Open Canals

3.6.1 Introduction

Planned development or re-development in or near urban areas affected by high groundwater levels can provide a window of opportunity to cost-effectively implement large-scale and robust mitigation measures against the effects of high groundwater levels. The case study Ooststellingwerf in The Netherlands provides an example of the benefits of retrofitting open canals.

3.6.2 Case Study 9: Ooststellingwerf (The Netherlands)

Characteristics

The town of Oosterwolde in the municipality of Ooststellingwerf is located in the north of The Netherlands close to Hoogeveen (Section 3.5.2). It is set in a similar geological environment, with (nearly) impermeable glacial clays and loamy top soils characterising the subsurface. The town has a population of approximately 10,000. Stormwater flooding and high groundwater issues were persistent in the low-lying neighbourhood of Oosterwolde-Zuid in the south of the town, which covers an area of some 1 km^2.

This neighbourhood was developed during the post-WWII rapid urbanisation period, prompted by huge demand for housing. The quality of houses, roads and amenities of the neighbourhood deteriorated over time exacerbated by the stormwater and groundwater issues.

Protection measures and mitigation approach

In 2000, the district/city council, the water board (i.e., a local water management authority), two housing corporations and a residential interest group agreed on an integrated renovation of the housing stock, the public space, and the water system (STOWA / Deltares / Rijkswaterstaat, 2009; www.oosterwoldezuid.nl).

A major feature of the renovation was the creation of a central open canal in the neighbourhood, enabling storage for rain water and drainage of groundwater (Figure 25). A new stormwater network was installed as well as a subsurface drainage system that both discharged to the canal. The canal discharges into a nearby regional water course. A number of houses had to be demolished to develop the canal, but the canal provided clear added benefits to the overall quality of the neighbourhood by providing a recreational amenity. In addition, water houses were built partially into the water, as such utilising the apparent loss of land surface for the creation of open water.

The district/city council clearly communicated to stakeholders that the council would only install drainage systems on public land. Private property owners would have to implement measures on their own land if still required. However, the council made provisions so property owners could discharge the drained groundwater from their property. This division of responsibilities is an example of the implementation of the Dutch national legal framework on managing groundwater issues in urban areas, operative since 2008 (Section 4.5).

The district/city council played a crucial role in handling delicate issues such as the demolition of existing houses to make way for the open canal. The early and continuous involvement of the district/city council is considered a major success factor.

Figure 25: New open canal dug during the district renovation of Oosterwolde-Zuid: water storage, drainage, improved water quality and overall quality of the public space.

Costs and Finance

The renovation was financed by the housing corporation (€ 25 million) and the municipality (€ 7.5 million)[7] and completed in 2007. Overall, the subsurface drainage system installed on public land still performs well after 10 years. Technical matters requiring attention are as follows:

1) Management of the inflow of iron-rich compounds, which may cause clogging, and

2) Informing newcomers about existing drainages and about their responsibilities with respect to managing groundwater on their properties (pers. comm., Municipality of Ooststellingwerf).

[7] http://www.oosterwoldezuid.nl/?page_id=150

3.6.3 Summary and relevance to South Dunedin

A general overview and relevance of case study 9 to South Dunedin is provided in Table 6.

Table 6: Retrofitting open canals - summary and relevance.

Factors	Ooststellingwerf
Characteristics	■ Rapidly developed suburb in low-lying area. Groundwater issues arise from poor drainage. ■ Deterioration of houses, roads and amenities was exacerbated by stormwater and groundwater issues.
Protection measures implemented or proposed *Part of suite of measures?*	■ Urban renewal project involved the construction of open water (canal) as well as stormwater network renewal and groundwater drainage systems. ■ Part of a suite of measures.
Efficacy of the protection measures *Has protection provided expected level of service?* *Any residual risks?*	■ Open water in combination with subsurface drainage provides both groundwater (drainage) and stormwater (storage) benefits. The system still works well after 10 years and is considered to be providing the expected level of service. ■ Open water provides amenity values to the community. ■ Residual risks not documented.
Limitations and constraints	■ The implementation required removal of houses.
Community acceptance and windows of opportunity	■ Early community engagement and council involvement was crucial. ■ The urban renewal project provided multiple benefits and the outcome is widely accepted.
Indication of whole life costs	■ Housing corporation € 25 million. ■ Municipality € 7.5 million.
Relevance to South Dunedin	■ Similar shallow groundwater in low lying area. ■ South Dunedin currently has no open water courses. ■ Creating open water may have similar constraints and benefits in South Dunedin. ■ Urban renewal projects could also provide a window of opportunity for implementing protection options.

3.7 Vertical Drainage (wells)

3.7.1 Introduction

The effects of reducing pumping from production wells can cause rising groundwater levels under urban areas. The slow rise in groundwater level can be related to South Dunedin's situation, even though the cause of rising groundwater level is different. Lessons learnt regarding pumping from deep wells to protect urban areas can be used to assess potential issues with vertical pumping as a protection measure. Some case studies found that pumping costs can be significant without a beneficial use for the abstracted water.

Many cities across the globe face the effects of abandoned large-scale groundwater abstractions, the cities of Delft and Eindhoven have taken initiative to take over the groundwater abstractions before they were closed, in an effort to mitigate against the effects of rising groundwater levels.

3.7.2 Case Study 10: Delft

General

The city of Delft is located in the west of the Netherlands and has a population of approximately 100,000. The city is located in an area with peat meadows, characteristic of the western and northern part of The Netherlands. Peat soils are prone to shrinkage which can cause land subsidence.

In Delft, the industrial groundwater abstraction 'Delft Noord' significantly reduced groundwater levels across the city (Figure 26), which also caused land subsidence over time. Cessation of pumping would raise groundwater levels in areas that had subsided and would cause widespread high groundwater issues.

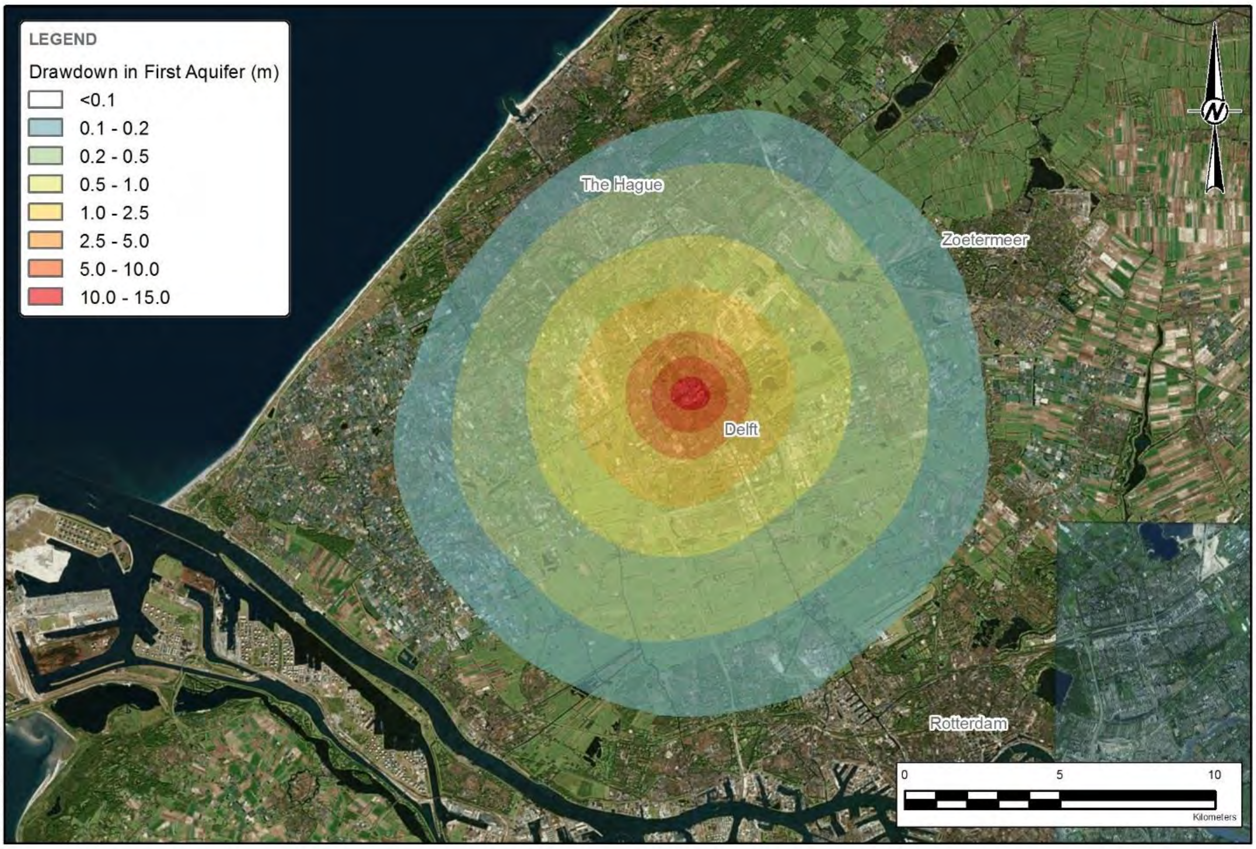

Figure 26: Current drawdown of hydraulic head below Delft exceeds 10 meters, conditioned by pumping station Delft-Noord.

Protection measures and mitigation approach

The city council therefore decided to take over the groundwater abstraction, initially in cooperation with the regional council. The groundwater abstraction was maintained and the associated investments and annual operational costs amount to several million of euros. The city council would prefer to transfer the groundwater abstraction to a new user, but has so far not been able to find one, partly because the pumped groundwater is brackish and of little use to potential users.

Meanwhile, the city council proposed a stepwise reduction of pumping, in combination with close monitoring of groundwater level responses and implementation of additional horizontal subsurface drainage where needed. Priority areas for this subsurface drainage have been identified following a risk-based approach on the basis of monitoring results of an extensive groundwater monitoring network (160 shallow observation wells distributed over circa 24 km^2 municipality area), groundwater modelling of various future scenarios, and an assessment of objects that are vulnerable to groundwater rise.

High groundwater level issues are already common throughout the city, but are unrelated to the reduction of the large-scale groundwater abstraction. This often complicates communication with residents about the issue.

3.7.3 Case Study 11: Eindhoven

General

The city of Eindhoven is located in the south of the Netherlands and has a population of 200,000. The area has a sandy soil and subsurface and is less prone to land subsidence than Delft. In this case two large-scale groundwater abstractions were encroached by expanding urban areas. The cessation of pumping would cause groundwater levels to rise and local buildings and other urban functions do not have sufficient groundwater drainage provisions. The groundwater abstractions comprise of an industrial abstraction that became redundant, and a drinking water supply abstraction affected by groundwater contamination.

Protection measures and mitigation approach

The city of Eindhoven managed to establish a sustainable coalition with regional partners to continue pumping. This coalition maintains the industrial abstraction to avoid widespread groundwater flooding issues. The contaminated drinking water well was abandoned and the abstraction moved to a nearby area unaffected by the groundwater contamination. Furthermore, a reconfiguration of pumping regimes across three drinking water abstractions in the area was established, which had multiple benefits, such as drought relieve to environmental conservation areas, a reduction of salinization risks, and the prevention of high groundwater issues in the city of Eindhoven. Whilst groundwater levels did rise, this was maintained within acceptable limits for the local buildings and urban features in the area.

Cost and Finance

The costs of the described operations are jointly carried by the city of Eindhoven, the water authority, and the drinking water company. The city council's contribution was € 750,000 (Gemeente Eindhoven, 2003).

3.7.4 Case Study 12: Buenos Aires

General

Buenos Aires is the capital and most populous city of Argentina, with a population of approximately 2.9 million. The city is located in the north east of Argentina near the coast.

Following growing concern about groundwater pollution, the main water supply authority was required to improve the quality of the supplied water to WHO potable standards. With groundwater no longer an option large volumes of treated surface water were imported to the city. However, widespread and persistent groundwater drainage problems occurred in the city as a consequence of the reduction in groundwater abstraction from the underlying aquifer.

Protection measures and mitigation approach

It was recognised that the generally low permeability of the shallow subsurface would render horizontal subsurface drainage inefficient. The most effective solution was to (partly) restore pumping from the underlying aquifer, preferably combined with some form of utilisation of the abstracted groundwater. In 2002, it was recognised that establishing an alliance of public authorities and representatives of the urban population would be crucial. A ‘revolving fund’ was proposed to finance the required efforts, which was to be recovered from urban rates and water charges (World Bank / GW MATE, 2002).

By 2007, several projects to control the groundwater table in specific areas of Buenos Aires were in the design phase. The plan proposed that pumped water was to be discharged into the stormwater drainage system (HIDROAR / Ciudad de Buenos Aires, 2007). The discharge of the pumped groundwater was a constraint on the system as leakage from the stormwater drainage network could lead to renewed recharge of the aquifer. The limited capacity of the stormwater drainage network during high rainfall was an additional concern. The cost of installing 37 wells with pumping equipment in the Puelche and Paraná aquifers was estimated at $US 3.2 million (HIDROAR, 2009). The installation of the wells was implemented in the framework of an integrated water management project in the Matanza – Riachuelo basin (2,240 km^2).

No information was found on the actual implementation of the proposed measures, and their efficacy.

3.7.5 Case Study 13: Odense

General

Odense is located on the middle of Denmark on the island of Funen. The city’s groundwater abstraction history is similar to that of Buenos Aires (Laursen & Mielby, 2016). Groundwater abstraction gradually increased from 1870 onwards and reached its peak after 1950. Due to deterioration in water quality and a desire for a more sustainable abstraction, pumping has been reduced dramatically in the last decade. Pumping is now almost back at the same rate as during the first half of the 20th century.

During the same period the city has grown considerably from 11,000 inhabitants in an area of 2.5 km^2 in the 1850’s to more than 172,000 inhabitants living across 78 km^2 in 2014. Urban areas that were developed in the period of maximum groundwater drawdown are becoming increasingly waterlogged, as groundwater abstraction is reduced. This is a concern for the inhabitants. In addition, annual mean precipitation has increased by around 100 mm since measurements started in 1876, which exacerbates the groundwater issues.

Protection measures and mitigation approach

The local water / waste water service company (VCS) prefers to minimize the amount of groundwater entering the sewage system and would rather groundwater is discharged on site. In addition, the city of Odense has the ambition to manage stormwater locally as much as possible. Therefore, attempts are by the authorities to persuade private property owners to establish seepage systems and swales on their property. Those who do can get a reduction in council rates paid for sewage connection.

High groundwater levels interfere with the stormwater infiltration initiatives and localised managed retreat was implemented by VCS, to cope with reoccurring flooding in an Odense suburb. Seven property owners were bought out, their houses were removed and the resulting area was turned into a local park which included a rain water storage area (Figure 27). This measure was not designed to solve high groundwater issues, but rather to address stormwater issues that in part were the result of high groundwater levels.

Danish law rules that a party that abstracts groundwater is liable for any damages caused on buildings or structures by lowering the groundwater table. However, parties hold no liability for damages if groundwater levels are returned to the original level (i.e., after pumping is stopped). No measures have yet been implemented against the effects of high groundwater level and no major groundwater monitoring program or detailed groundwater modelling has been undertaken.

Figure 27: Managed retreat: former residential area turned into park and stormwater storage, Odense. Source: COST-Suburban (2016).

3.7.6 Summary and relevance to South Dunedin

A general overview and relevance of case studies 10 to 13 to South Dunedin is provided in Table 7.

Table 7: Vertical Drainage (Wells) - summary and relevance.

Factors	Delft, Eindhoven, Buenos Aires and Odense
Characteristics	■ Cessation of large groundwater abstractions can cause a significant rise in groundwater levels on a large scale, affecting extensive urban areas that do not have (sufficient) groundwater drainage infrastructure.
Protection measures implemented or proposed *Part of suite of measures?*	■ Implementation of an area-wide solution would be too costly. Prioritisation of drainage issues has been made based on monitoring and scenario modelling. ■ Continuation of well abstractions and new use of abstracted water has been explored. ■ Alliances between authorities and stakeholders have been formed to address the issues (Delft, Eindhoven). ■ Suites of measures such as selective removal of properties, raising ground level and creation of storage for stormwater management, have been combined with groundwater level control (Odense).
Efficacy of the protection measures *Has protection provided expected level of service?* *Any residual risks?*	■ Large scale abstraction from wells was effective in lowering groundwater levels. ■ Continued large scale abstractions from wells can be expensive if there is no beneficial use for the abstracted water. ■ Drainage and stormwater storage solutions are being instigated to deal with the risks of rising groundwater level.
Limitations and constraints	■ Drainage water may be of poor quality and limits the possibilities for discharge (Buenos Aires).
Community acceptance and windows of opportunity	■ Authorities are looking at uses and disposal locations for the abstracted water.
Indication of whole life costs	■ Eindhoven involved split cost between city authorities, water authority, and drinking water company. City council's contribution € 750,000. ■ Buenos Aires: Cost of installing 37 wells with pumping equipment in the Puelche and Paraná aquifers was estimated at $US 3.2 million.
Relevance to South Dunedin	■ The groundwater level rise in South Dunedin has a different cause, but the wide-spread effects and potential protection options are similar. ■ Any vertical pumping protection measure for South Dunedin would require careful consideration of discharge options and costs of pumping.

3.8 Risk-Based Groundwater Management

3.8.1 Introduction

This section includes a case study in which the authorities determined the responsibilities for managing high groundwater levels in urban areas by following a risk-based approach.

3.8.2 Case Study 14: Enschede (Netherlands)

Characteristics

The municipality of Enschede (approx. 158,000 inhabitants in 140 km^2) faces groundwater level rise after reduction and closure of pumping stations, in this case mainly conditioned by the rise and fall of the textile industry during the 20th century.

Protection measures and mitigation approach

In response to groundwater level rises occurring throughout the city, the city council developed internal policy in recognition of the Dutch legal framework on managing urban groundwater issues (Section 4.5).

The city's groundwater management policy comprises a risk-based approach to groundwater problems on private properties. Different categories of adverse effects of high groundwater are ranked according to their severity (health and safety issues ranking highest) and assigned a maximum acceptable risk threshold, based on frequency of occurrence (Figure 28). If the risk threshold is exceeded, action by the city is required provided that measures are cost-effective.

Severity category (of adverse effect s)	(almost) impossible	unlikely	possible	likely	regularly	frequently
	<1/1000	≥ 1/1.000 <1/100 year	≥1/100 year < 1/10 year	≥ 1/10 year <1 year	≥1 year < 1/month	≥1/month
very high	M	H	VH	EH	EH	EH
High	L	M	H	VH	EH	EH
Significant	VL	L	M	H	VH	EH
Medium	VL	VL	L	M	H	VH
Low	VL	VL	VL	L	M	H
negligible	VL	VL	VL	VL	L	M

risk threshold

Figure 28: Risk matrix as guidance for deciding upon measures against high groundwater. VL=very low to EH = extremely high. Note: risk threshold may vary for different municipalities (policy choice). Adjusted after original by City of Enschede.

In the absence of a clear definition of cost-effectiveness in the national legal framework, the city council has adopted the (provisional) rule that the cost of measures in the public space should not exceed 80 % of the cost of measures on private grounds. The city does not take responsibility for groundwater leakage or flooding in basements as this is considered to be a responsibility of the property owner. Buildings younger than 1992 are excluded from this approach, as laws require them to have a damp-proof ground floor. Therefore, groundwater flooding in the crawl space under the new houses should not cause problems in the living spaces of the houses if installed correctly.

So far, the risk-based approach has been implemented in one case in Enschede. The outcome was that the city was considered responsible to take measures, which was welcomed by the residents. The city expects less positive reception in cases were no measures by the city council are required (i.e., when none of the risk thresholds are exceeded), even if the community has been made fully aware of the approach. Conversely, risk thresholds are expected to be exceeded in areas with large-scale effects on health, prompting measures by the city (pers. comm., City of Enschede). Currently, seven areas are prioritised for additional investigations, with areas estimated at 5 to 20 ha each (Gemeente Enschede, 2016).

3.8.3 Summary and relevance to South Dunedin

A general overview and relevance of case study 14 to South Dunedin is provided in Table 7.

Table 8: Risk-based groundwater management - summary and relevance.

Factors	Enschede
Characteristics	■ Cessation of large groundwater abstractions caused a significant rise in groundwater levels on a large scale, affecting extensive urban areas without sufficient groundwater drainage infrastructure.
Protection measures implemented or proposed *Part of suite of measures?*	■ Groundwater management policy comprises a risk-based approach (ranking according to effects severity, based on frequency of occurrence) to groundwater problems on private properties. ■ Part of a suite of measures
Efficacy of the protection measures *Has protection provided expected level of service?* *Any residual risks?*	■ Implemented in one area so far where the authorities carried out protection measures. ■ Has allowed prioritisation of resources by the city council. ■ Residual risks to those considered low priority.
Limitations and constraints	■ In some cases the risk matrix may lead to the authorities deeming the responsibility for protection measures is the responsibility of the property owners.
Community acceptance and windows of opportunity	■ Accepted by those who gain from the results of the risk assessment.
Indication of whole life costs	■ No detail available for costs to determine the risk matrix. Costs to city will depend on extent of areas requiring protection measures.
Relevance to South Dunedin	■ The groundwater level rise in South Dunedin has a different cause, but the wide-spread effects and potential protection options are similar. ■ A risk-based approach provides a practical and transparent method to separate responsibilities between authorities and property owners.

3.9 Liquefaction and Managed Retreat

3.9.1 Introduction

Liquefaction of soils occurs when saturated or partially saturated cohesion-less soil substantially loses strength and stiffness in response to earthquake shaking, causing it to behave like a liquid. This can result in substantial damage to buildings and infrastructure. Liquefaction after a significant earthquake can be widespread in areas with a shallow groundwater table in combination with susceptible silty or sandy soils. The Christchurch case study presented in this section is an example of the widespread damaging effects of liquefaction following significant earthquakes.

3.9.2 Case Study 15: Christchurch (New Zealand)

Characteristics

Christchurch is located on the east coast of New Zealand's South Island and has a population of approximately 350,000. Most of the city resides upon late Quaternary alluvial sediments, with alluvial gravels dominating the west of the city and coastal dunes and estuarine/tidal wetland sediments dominating the east. There are finer alluvial overbank deposits from the Avon and Heathcote Rivers superimposed on these accumulations (Brown and Weeber 1992). Groundwater is more than 5 m below the surface west of Christchurch City, but less than 2 m deep beneath much of the city (GNS 2014).

Urban expansion in the late 1800's included widespread drainage works to allow for the development of the land. Separate stormwater and wastewater networks were installed, which over time developed leaks and consequently drains groundwater. Drainage into both the stormwater and wastewater networks has contributed to land subsidence (Hughes *et al* 2015).

Christchurch was struck by four major earthquakes on 4 September 2010, 22 February 2011, 13 June 2011 and 23 December 2011 and a large number of significant aftershocks, which severely damaged much of the central business district and surrounding residential areas. Widespread soil liquefaction occurred predominantly in saturated, unconsolidated alluvial and marine fine sediments in east Christchurch, affecting roads, subsurface infrastructure and buildings (Figure 29). High groundwater levels in susceptible soils significantly increases the vulnerability to liquefaction. Urban rivers and streams were affected by liquefaction induced lateral spreading of the river banks, and sedimentation, which narrowed and shallowed the streams. The liquefaction and tectonic movement caused land subsidence in excess of 0.5 to 1 m along tidal stretches of the two main urban rivers (i.e. Avon and Heathcote). This greatly enhancing the spatial extent and severity of inundation hazards posed by 100-year floods, storm surges, and sea-level rise (Hughes *et al* 2015).

The land subsidence from drainage works, leaking sewage systems and, more recently, earthquakes have caused groundwater levels to be closer to the ground surface, which increased the areas susceptibility to high groundwater issues. However, reports of high groundwater level effects such as water ponding and damp or wet basements, being widespread and perceived as a significant issue throughout Christchurch could not be found. Christchurch has a long history in dealing with drainage issues and between 1875 and 1989 the now defunct Christchurch Drainage Board installed and maintained a network of open channels and drains to manage groundwater. That a separate body, with sole responsibility for drainage, was thought necessary for Christchurch from an early date is an indication of the difficulties the city's site posed for drainage and sewage (CDB, 1989). CDB's responsibilities and assets were transferred to Christchurch City Council in 1989. Currently, high groundwater level concerns from the Christchurch City Council (CCC) and Canterbury Regional Council (CRC) are more related to the increased susceptibility to liquefaction of certain urban areas.

Figure 29: Effects of liquefaction on Kilmore St (Asher Trafford), Christchurch, following the Canterbury earthquakes (source: https://keithwoodford.wordpress.com/2011/02/27/understanding-the-christchurch-earthquake-building-damage/).

Protection measures and mitigation approach

A large part of Christchurch's eastern suburbs has been 'Red Zoned' following the 2011 earthquakes. The Red Zone is an area defined by the Government as unsuitable for continued residential occupation at the present time. Generally this area encompasses the most severely damaged land in Canterbury (GNS 2014). This includes areas that were severely affected by liquefaction and for which the susceptibility for flooding increased. This can be considered a form of managed retreat.

Structural solutions to building foundations and ground improvement solutions are usually considered for reducing the susceptibility of a property to liquefaction. Although the relationship between high groundwater levels and liquefaction is acknowledged (GNS 2014, Hughes 2015), measures to control groundwater levels are not usually part of the design philosophy.

Drainage measures are considered for dealing with water ponding and wet/damp conditions in existing urban areas. CCC has issued drainage guidelines (CCC 2006) to be used during development or re-development of urban areas. It includes a description of design consideration for open drainage channels and subsurface drainage systems. These guidelines recommend that subsurface drainage should only be used to remedy surface water ponding in existing urban areas. The guideline also recommends that subsurface drainage is installed so that it is submerged at all times to avoid clogging. Furthermore, sufficient access points for maintenance are recommended. Ground levels should be appropriately raised in new developments and locally low-lying (wet) area should not be developed, but included as wetlands or open water within the development.

Private property owners are responsible for stormwater that falls on their own property and to install and maintain groundwater drainage measures on their property. CCC will provide a point of discharge for the property.

CCC does not have a communication strategy in relation to high groundwater level issues or a designated groundwater monitoring network for the shallow groundwater table to assess these issues. However, many shallow groundwater monitoring wells have been installed for geotechnical investigations. Shallow groundwater investigations are mainly undertaken in the context of geotechnical investigations in relation to liquefaction susceptibility (GNS 2014).

3.9.3 Summary and relevance to South Dunedin

A general overview and relevance to South Dunedin is provided in Table 9.

Table 9: Liquefaction and managed retreat as adaption to seismic hazard - summary and relevance.

Factors	**Christchurch**
Characteristics	■ Soil conditions and high groundwater levels in Christchurch's eastern suburbs makes the area prone to the effects of liquefaction during earth quakes, as occurred in the 2011 Canterbury Earthquake Sequence.
Protection measures implemented or proposed *Part of suite of measures?*	■ Christchurch Residential Red Zone represents a form of managed retreat. ■ Ground improvement is usually applied when properties are (re)developed to reduce the liquefaction susceptibility. ■ Suite of measures includes retreat and land improvement.
Efficacy of the protection measures *Has protection provided expected level of service?* *Any residual risks?*	■ Managed retreat rather than a protection measure against the effects of high groundwater levels.
Limitations and constraints	■ Not a protection measure.
Community acceptance and windows of opportunity	■ High impact on communities.
Indication of whole life costs	■ Not a protection measure. Significant costs for loss of property.
Relevance to South Dunedin	■ South Dunedin has similar soil conditions and high groundwater levels. ■ The effects of liquefaction and the relationship with high groundwater levels could be taken into consideration when developing protection strategies for South Dunedin.

4.0 DISCUSSION

4.1 Introduction

This section provides a description of causes and effects of high groundwater issues in urban areas derived from the selected case studies and other relevant examples. Many of the case studies are from The Netherlands which is very low lying and has relied on protection measures such as pumped open canals for groundwater level and flood protection for many years (Figure 30).

The success of protection options depends heavily on the ability to install them in optimal locations, and the ability to properly operate and maintain the systems. The case studies highlight that other matters to consider when protection options are considered are ownership of land, financial means for installation, and clearly defined responsibilities for operation and maintenance. High groundwater levels are often only one of the issues that low-lying urban areas face, as these areas typically also have stormwater management challenges and can be prone to inundation from the sea.

4.2 Causes of High Groundwater in Urban Areas

High groundwater levels typically occur in flat, low lying areas with low permeability soils after periods of prolonged rainfall. These are usually areas close to rivers, lakes or the sea. If natural drainage is poor and urban water management systems are not sufficient to cope with these conditions, groundwater levels can rise significantly. Several different causes for groundwater level rise are identified within the case studies. The learnings from how authorities decided to respond to the situation and the protection options used can be considered when investigating potential options for South Dunedin.

Figure 30: Pumped open canal in Hoorn, The Netherlands.

4.3 Consequences of High Urban Groundwater Levels

In urban areas where groundwater levels are relatively close to the surface (less than 1 m on average) several issues may arise, including surface water ponding, damage to infrastructure and buildings, and increased risks of liquefaction during earthquakes (MFE 2015). There are several ways that these issues affect urban areas:

- Flooding involving stormwater ponding on the surface associated with high groundwater levels. The high groundwater levels mean flooding can persist for a long time after significant rainfall events. Flooding generates a wide range of secondary effects, with the severity of many of these effects linked to the duration of the flooding.
- Buildings can be affected by wet conditions in basements and crawl spaces. Continually damp conditions are ideal for growth of fungus, affecting building materials such as timber framing and cladding, and causing respiratory diseases in humans.
- Fluctuations in groundwater levels can result in differential deformation of structures such as roads and houses due to soil swelling and shrinkage. Building floors can bulge as a result of buoyancy. Some soils may swell when wet or saturated, causing surface heave. Other soils are prone to collapse, resulting in subsidence and settlement. Problems may also arise for the installation and maintenance of subsurface infrastructure.
- In combination with certain types of soil and earthquake ground motions, high groundwater levels contribute to vulnerability of the built environment to damage caused by liquefaction and lateral spreading, affecting buildings, roads, subsurface infrastructure and waterways.
- The infiltration and storage capacity of soils for stormwater can be reduced affecting the soils stormwater detention potential.

High groundwater levels in urban areas can affect the whole community, including private property owners, businesses and district/city councils.

Authorities in The Netherlands use minimum drainage depth guideline values for various urban functions as listed in Table 10 (SBR 2007) to evaluate if urban areas are potentially affected by the consequences of high groundwater levels. Issues described above often arise when the required drainage depth cannot be longer maintained.

Table 10: Minimum drainage depth guideline values in The Netherlands for various urban functions under design rainfall conditions (5 mm/day) (after SBR 2007).

Land use type	Drainage depth (depth the groundwater in m below surface level)
Houses, buildings, structures	0.70
Primary roads	1.00
Secondary roads	0.70
Cables and pipes	0.60 – 1.20
Gardens and parks	0.50
Sports fields	0.50
Graveyards	0.30 below coffin

As a consequence of pumping to manage groundwater levels, saline intrusion can occur. Saline intrusion is the movement of saline water (e.g., sea water) into an aquifer formerly occupied by fresh water as a result of human activity (Fetter 1994). Fresh groundwater, which is of lower density than seawater, will float on top of the saline groundwater. Saline intrusion risk needs to be considered when designing protection options for

South Dunedin. Saline water can affect water quality of coastal streams and wetlands, but also buildings and infrastructure (salinity can affect concrete piles and riprap).

4.4 High urban groundwater in New Zealand

Most major urban centres in New Zealand are located close to the sea and include areas that are low-lying and potentially affected by inundation from the sea. These areas typically also have high groundwater levels. MFE (2015) has assessed which coastal urban areas in New Zealand lie close to the average spring tide sea levels. Christchurch and Dunedin are the cities with the largest urban areas and the most buildings and infrastructure in areas less than 1 m above the spring tide levels (Table 11).

Table 11: Low-lying homes, businesses and roads in the four major cities of New Zealand (after MFE 2015)

	0 – 0.5 m	0.5 – 1 m	Total (0 – 1 m)
Dunedin			
Homes (number)	2,683	604	3,287
Businesses (number)	116	29	145
Roads (km)	35	17	52
Christchurch			
Homes (number)	901	3,629	4,530
Businesses (number)	5	58	63
Roads (km)	40	77	117
Wellington			
Homes (number)	103	1,920	2,023
Businesses (number)	1	20	21
Roads (km)	2	21	23
Auckland			
Homes (number)	108	457	565
Businesses (number)	4	13	17
Roads (km)	9	18	27

4.5 Management and Governance Considerations

Experience in The Netherlands has shown that the development and implementation of mitigation measures against the effects of high groundwater levels in urban areas can be cumbersome and costly. The nature of the issues may change over time with an increasingly larger area being affected. It may be unclear to what extent the land or property owner is responsible for addressing the issues or whether authorities are best placed to take the initiative. There may be uncertainty about the ways to finance mitigation approaches.

In this section several management considerations arising from the collective case studies are described that have been found to be critical as part of investigations and discussions during the development of mitigation strategies. This section also provides background information with respect to some of the case studies that can support an understanding of how the protection measures were implemented.

Formalising responsibilities

High groundwater levels affect privately owned properties, businesses and council land. This leads to multiple stakeholders dealing with the consequences of high groundwater levels. In many cases the issues cannot be effectively addressed on a single property and collaboration between stakeholders and proper coordination is essential.

A starting point could be to formally define the responsibilities of different stakeholders. An example of this is the way high groundwater issues in urban areas have been embedded within a legal framework in the Netherlands since 2008. The law in the Netherlands now requires municipalities (i.e., district or city councils) to take measures on public land to minimise structural and persistent adverse effects of high groundwater levels on council land and land adjacent to it. Measures are only required when they can be implemented cost-effectively and provided that they do not fall under another authorities' jurisdictions. Property owners are responsible for installing measures themselves on their own property if needed, such as a subsurface drainage system. However, the district/city council is required to provide a means to discharge the drainage water. This could be a connection point to the nearby stormwater system. The district/city councils are the 'first port of call' for stakeholders to raise issues and concerns. The councils are required to carry out monitoring, investigate issues and are responsible for appropriate communication and stakeholder engagement.

Communication strategy

Communication and stakeholder engagement is a key element of any mitigation strategy, as its success often depends on stakeholder 'buy in'. On-line media can help provide timely, transparent and targeted communication to stakeholders.

Communication can include the provision of information about the groundwater issues, their causes and results from monitoring. On-line publications and web-based presentation of real-time groundwater monitoring data may inform residents and businesses about short-term and long-term risks of rising groundwater levels, as described in the Hoogeveen case study (Section 3.5.2).

Monitoring

Continuous monitoring of groundwater levels helps to create awareness for groundwater amongst residents and public authorities. The monitoring results allow for evaluation of the groundwater conditions and of the performance of any groundwater management system. Clogging, blockages and other problems can be signalled from the monitoring. Groundwater levels can be visualised for residents and for educational purposes by making observation wells visible.

Financial arrangements

The case studies show that embedding the district/city council's responsibility for urban groundwater management into a legal framework works best if sufficient funding is available for the responsible authority to inform stakeholders and implement measures. This means the district/city council needs sufficient staff resources and funding for implementing, operating and maintaining measures. In the Netherlands the broadening of the district/city council's water management responsibilities to include urban groundwater management, allowed district/city councils to increase rates within reason. Rates increases can potentially be offset for landowners as property values increase while the urban environment improves (Figure 31).

Stakeholder alliances

In the case studies, alliances between different authorities were often established or expanded to jointly undertake necessary investigations or the development and implementation of effective mitigation measures. This collaborative approach has led to financial benefits to authorities and stakeholders.

Utilising windows of opportunities

Windows of opportunities arise when certain large-scale developments occur in or near an urban area that is susceptible to the effects of high groundwater levels. If utilised, these windows of opportunity have provided significant financial benefit to communities in their endeavour to tackle urban groundwater issues. The following windows of opportunity are worth considering:

- Planned road or sewage network maintenance programmes: one of the best opportunities to implement high groundwater mitigation measures is when roads are excavated in their entirety for stormwater, wastewater or water main renewal or upgrade. Similar opportunities occur when parts of the water supply network or the power network are being replaced.
- Building permitting processes: specific requirements for groundwater management measures can be included on building permits or consents when new urban areas are being developed or existing urban areas are re-developed.

Figure 31: Urban open canal in Hoorn, The Netherlands

Integrated solution packages

Low lying urban areas are usually subject to multiple hazards such as severe weather, flooding, earthquakes and tsunamis, together with geotechnical issues that exacerbate the effects of those hazards. Experience indicates that an integrated approach to resolving these collective issues is important because:

- Considering approaches and solutions collectively may enable multiple hazards to be mitigated at the same time, improving the cost effectiveness of the measures instigated.
- The risk of mitigation measures resolving one issue but simultaneously exacerbating other issues is reduced (e.g., groundwater drainage can also lead to acceleration of on-going land settlement).

The Miami region in the USA serves as an example how multiple hazards can expose urban assets and populations on a large scale. This region is susceptible to inundation from the sea, which has increased as a result of sea level rise (Anderson *et al* 2016). Saltwater seepage underneath sea walls through porous limestone also affects groundwater quality through saline intrusion (WRI 2014). The Miami stormwater system is locally designed to drain to the sea and experiences reduced effectiveness as sea levels rise or during extreme high tide periods, increasing flood risks.

5.0 SYNTHESIS FROM CASE STUDIES

5.1 Introduction

This section summarises the findings from the case studies in relation to South Dunedin, based on the six factors listed in Section 1.3. It gives a synthesis of the commonalities between case studies but also their uniqueness in relation the urban high groundwater issues. The different characteristics of the case studies are compared to the South Dunedin situation.

5.2 Characteristics, Scale and Size

The most common effects of high groundwater levels in urban areas are damp or even wet basements and crawl spaces beneath buildings, and the associated adverse effects on the building's climate and construction as well as the occupant's health. Also reported was damage to trees, bulging floors as a result of buoyancy or heave, and saline intrusion affecting groundwater quality, foundations and septic tanks.

The issue of liquefaction presented in the Christchurch case study is an issue specific to earthquake prone areas with silty and sandy soil types, which is relevant to South Dunedin's situation.

South Dunedin's issues cover multiple neighbourhoods. All but one of the presented case studies are on the scale of a neighbourhood, multiple neighbourhoods, a whole city, or a full metropolitan region. Several case studies of the successful implementation of mitigation strategies relate to an area of a similar size to South Dunedin. The scale of South Dunedin's groundwater issue is therefore not considered to fundamentally restrict the development and implementation of a successful mitigation approach.

5.3 Protection Measures and their Efficacy

The successful application of technical measures is often more dependent on proper design, implementation and on-going maintenance than the nature of the measures. Often a suite of methods have been applied in the case studies rather than one protection measure alone.

Successful systems are designed to be robust and allow for sufficient options for maintenance and repair. Adequate supervision during installation and testing has been shown to be crucial. A proper understanding of local conditions (mainly hydrology, hydrogeology and geology) and effective engagement of residents is always required.

Relevant insights from the case studies include:

- Horizontal subsurface drainage is the most widely used method for high groundwater level mitigation as it can be retrofitted in existing urban areas. In most cases these systems better target the problem areas and require less water to be abstracted than vertical drainage systems.
- Vertical drainage through pumping wells is more feasible if the abstracted water can be used or other benefits can be achieved (case study Eindhoven).
- Horizontal subsurface drainage is best installed below the expected lowest groundwater level to ensure it is always saturated. This minimizes the risk of clogging and excessive maintenance (case studies Haarlemmermeer and Haarlem).
- Measures taken on private property should be properly documented and new property owners need to be made aware of their responsibilities. If not, systems may gradually degrade because of poor maintenance and lack of repair (case studies Haarlemmermeer and Oosterwolde).
- The use of subsurface drainage systems with infiltration capacities is feasible, if designed properly. They can be effective in maintaining a relatively flat groundwater table, which minimises land subsidence as well as high groundwater issues (case studies Haarlem and Amsterdam). The infiltration capacity can be obtained by linking the subsurface drainage with stormwater systems or nearby open water.

- The creation of open water through the problem area or an open seepage canal along the water body that is contributing to the problem (i.e., a major river such as in the Dresden case study or the sea in the Den Helder and Perkpolder case studies), can be an effective measure that provides added benefits in terms of stormwater management and amenity values.

Successful case studies generally have one or more key authorities taking the initiative to drive the development of a mitigation approach. A key element for the successful implementation is the separation of responsibilities between authorities and private property owners. The risk-based approach to provide practical guidance to defining responsibilities in groundwater management as implemented in the Enschede case study can make decisions more transparent to the community.

Prioritising problem areas may also be an important consideration to accommodate budget constraints. This requires a good understanding of current and future issues through surveys, field investigations, on-going monitoring and modelling studies.

Planned large-scale developments or renovation programmes provide good opportunities to install technical measures at lower costs. Financial means for implementing mitigation strategies and their on-going costs are often gained from increasing sewage rates.

5.4 Limitations and Constraints

In the development of mitigation strategies for high groundwater issues in urban areas the following limitations and constraints will often arise and need consideration:

- The abstracted groundwater will need to be discharged and measures will need to be designed in view of the stormwater management and hydrology of the area. The capacity of existing pump stations may need to be increased, although the abstracted groundwater volumes are generally less than stormwater runoff generated during a peak storm event. The water quality of the pumped water potentially may limit the possibilities for discharging to open water. It is better not to discharge the abstracted groundwater into a combined sewer system (i.e., stormwater and wastewater) as that will dilute the wastewater and reduces wastewater treatment efficiency.
- The range and effectiveness of mitigation measures is heavily dependent on the hydrogeological characteristics of the area. Low permeability top soils and large distances between drainage measures restrict their effectiveness. The ability to implement measures at optimal distance may be limited in densely built urban areas. In many cases the implementation of measures on public land is not sufficient and additional measures on private properties is required.
- Technical measures against high groundwater levels require maintenance and residents need to be aware of systems on their properties and their responsibilities. It may be challenging to get buy in from tenants of rental properties and issues may arise sooner in areas with substantial numbers of rental properties.
- Certain groundwater drainage measures may inadvertently accelerate land subsidence processes increasing the areas susceptibility to the effects of high groundwater levels. This should be taken into consideration in the design of urban drainage systems.

5.5 Community Acceptance and Windows of Opportunity

Most of the successful case studies have implemented a proper groundwater monitoring programme and a well-developed communication strategy. On-line access to information about the reasons of the groundwater issues, how certain technical measures operate, the separation of responsibilities, and real-time groundwater level data, all help to create buy in from the community. Real-time groundwater monitoring accessible on-line, can provide added value as an early warning to residents who can take precautionary measures on their properties. The groundwater monitoring network requires sufficient coverage to achieve this (see case studies Dresden and Hoogeveen).

Large-scale urban development or renovation programmes (of roads or stormwater and wastewater networks) provide good windows of opportunity for also mitigating high groundwater level issues. Mitigation measures taken in a large-scale development or renovation context may have a much broader scope and hence larger impact (e.g. added benefits to the community with the establishment of open water, such as in the case study Oosterwolde). Multi-purpose mitigation strategies can have added benefits over measures that only address the groundwater rise issue. This may also reduce the actual costs for mitigating high groundwater issues.

5.6 Costs and Finance

The programmes of measures identified in the case studies range in costs from approximately 1 million to tens of millions of euros. The scale of implementation and the complexity of the projects seem to have the most influence on the costs.

6.0 CONCLUSIONS

There are many case studies throughout the world that have similar causes and effects of high groundwater levels in urban areas such as South Dunedin. Whilst there are differences and each case is in some way unique, much can be learned from case studies that are well developed and where measures have been successfully implemented. South Dunedin’s issues cover multiple neighbourhoods and several case studies with successful implementation of mitigation strategies have issues affecting an area of a similar size.

The causes of high groundwater levels in urban areas vary considerably throughout the presented case studies. The effects are more similar, with damp or even wet basements and crawl spaces beneath buildings, the associated adverse effects on the building as well as the occupant’s health, and stability issues affecting roads and subsurface infrastructure being the most common. The issue of liquefaction presented in the Christchurch case study is an issue specific to earthquake prone areas with silty and sandy soil types, which are also present in South Dunedin.

Horizontal subsurface drainage is the most widely used method for high groundwater level mitigation as it can be retrofitted in existing urban areas. In most cases, these systems better target the problem areas and require less water to be abstracted than vertical drainage systems. Vertical drainage through pumping wells is more feasible if the abstracted water can be used or other benefits can be achieved. Horizontal subsurface drainage is best installed below the expected lowest groundwater level to ensure it is always saturated.

The use of subsurface drainage systems with infiltration capacities is feasible, if designed properly. They can be effective in maintaining a relatively flat groundwater table, which minimises land subsidence as well as high groundwater issues. The infiltration capacity can be obtained by linking the subsurface drainage with stormwater systems or nearby open water. The creation of pumped open water bodies or open seepage canals can be effective measures that provide added benefits in terms of stormwater management and amenity values.

Whether certain technical measures will be successful depends on proper design, implementation and on-going maintenance. A proper understanding of local conditions (mainly hydrology, hydrogeology and geology) and effective engagement of residents is needed. Successful case studies would appear to have one or more key authorities taking the initiative to drive the development of a mitigation approach. A key element for the successful implementation is the separation of responsibilities between authorities and private property owners. Financial means for implementing mitigation strategies and their on-going costs are often gained from increasing council rates for storm drainage and sewage services.

Large-scale urban development or renovation programmes (of roads or stormwater and wastewater networks) provide good windows of opportunity for also mitigating high groundwater issues at lower costs. Mitigation measures taken in a large-scale development or renovation context may have a much broader scope and hence larger impact.

To control rising groundwater levels in South Dunedin there are options to combine multiple protection measures. Protection options can be introduced slowly in a progressive manner rather than as a one off operation and can be focussed initially to protect sensitive areas and building. There is potential to develop new recreational surface water bodies and features and look for windows of opportunity to maximise the benefits from constructional costs when retrofitting groundwater drainage systems.

7.0 REPORT LIMITATIONS

Your attention is drawn to the document, “Report Limitations”, as attached in Appendix A. The statements presented in that document are intended to advise you of what your realistic expectations of this report should be, and to present you with recommendations on how to minimise the risks to which this report relates which are associated with this project. The document is not intended to exclude or otherwise limit the obligations necessarily imposed by law on Golder Associates (NZ) Limited, but rather to ensure that all parties who may rely on this report are aware of the responsibilities each assumes in so doing.

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APPENDIX A

Report Limitations

Report Limitations

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Golder Associates

Deltares
Enabling Delta Life

KINGSTON

Community Response Plan

ACCIDENT

GET READY GET THRU

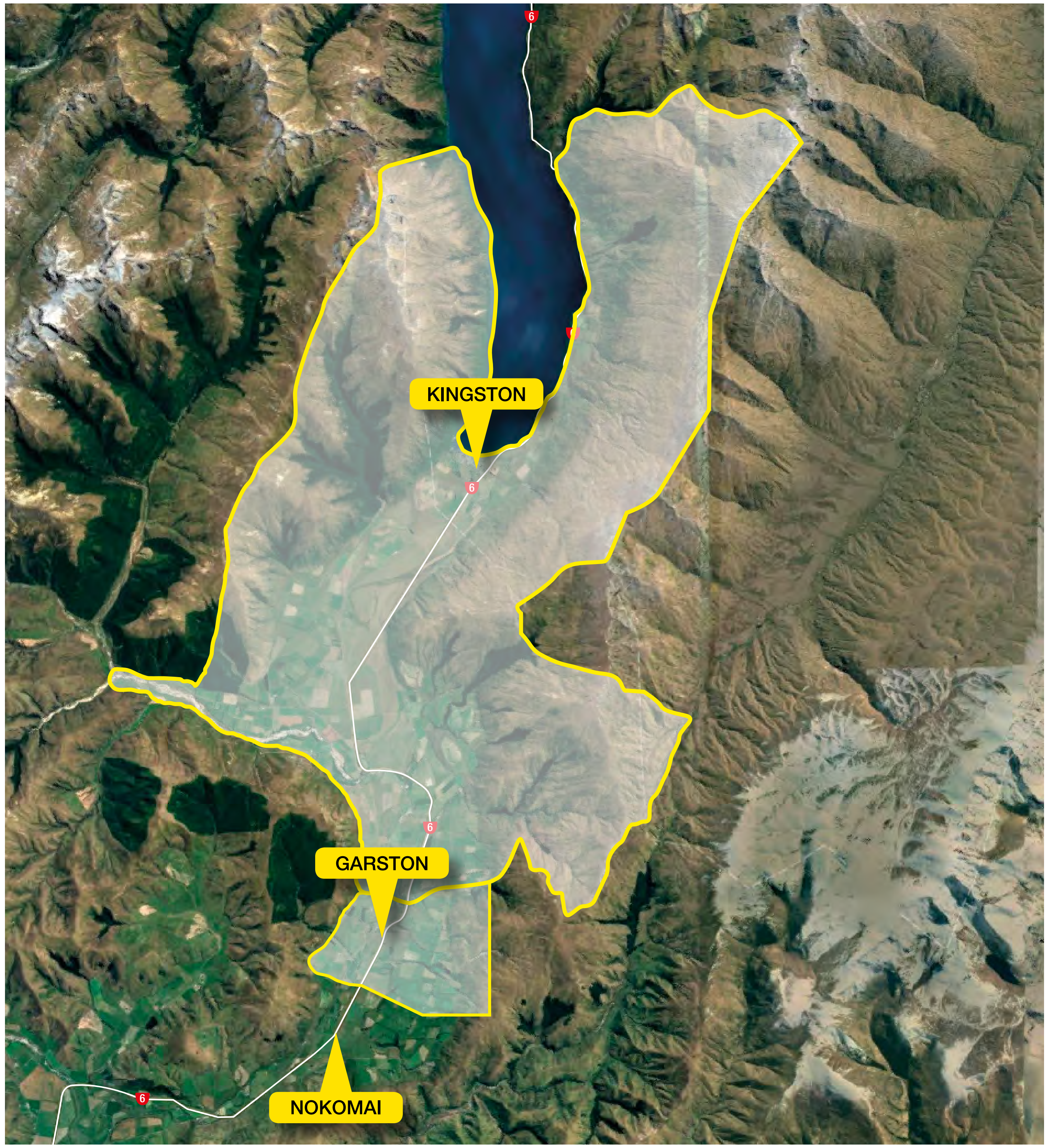
CIVIL DEFENCE

QUEENSTOWN LAKES DISTRICT COUNCIL

contents...

get ready...

KINGSTON
Area Map



get ready...

THE KEY HAZARDS IN KINGSTON

Earthquake // Major Storms // Snowstorms
Flooding // Wildfire // Landslide // Accident

Earthquake

New Zealand lies on the boundary of the Pacific and Australian tectonic plates. Most earthquakes occur at faults, which are breaks extending deep within the earth, caused by movements of these plates.

There are thousands of earthquakes in New Zealand every year, but most of them are not felt because they are either small, or very deep within the earth. Each year there are about 150 – 200 quakes that are big enough to be felt. A large, damaging earthquake could occur at any time, and can be followed by aftershocks that continue for days, weeks or months. **www.geonet.org.nz**

Major storms / Snowstorms

Major storms affect wide areas and can be accompanied by strong winds, heavy rain, thunder, lightning, tornadoes and snow. They can cause damage to property, infrastructure, affect crops and livestock and disrupt essential services.

Severe weather warnings are issued by the MetService and available through the broadcast media, by email alerts, and online at **www.metservice.com**

get ready...

Flooding

Floods can cause injury and loss of life, damage to property and infrastructure, loss of stock, and contamination of water and land.

Floods are usually caused by continuous heavy rain or thunderstorms. A flood becomes dangerous if:

- the water is very deep or travelling very fast
- the floods have risen very quickly
- the floodwater contains debris, such as trees and sheets of corrugated iron.

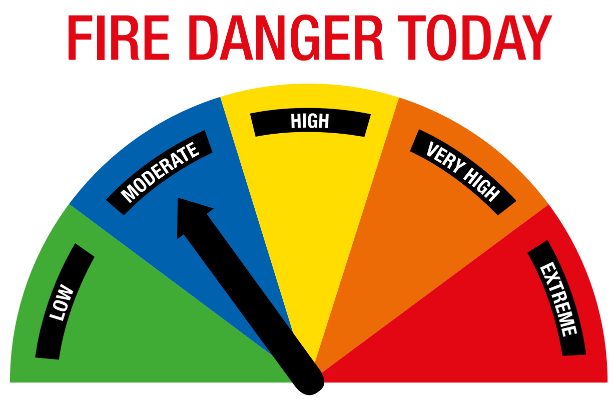
Getting ready before a flood strikes will help reduce damage to your home and business and help you survive. **water.orc.govt.nz** **envdata.es.govt.nz**

Wildfire

Although there are many benefits to living in the country, rural property owners face a higher risk of fire than city dwellers.

If a fire starts it may not be detected as quickly and emergency services take longer to respond because of greater travel distances.

For information on fire danger, fire season status and requirements for fire permits visit **fireandemergency.nz**



Landslide

Landslides are vertical and horizontal land movement down a slope and most are triggered by heavy rain, snowmelt, earthquake shaking, volcanic eruptions and gravity.
www.geonet.org.nz
www.eqc.govt.nz

Road Transport Crashes

Queenstown Lakes' topography is varied, ranging from rolling flats to mountain passes, with many winding roads. Add in ice and snow, visitors unfamiliar with our conditions, and congested roads, managing transport in this area is challenging. The New Zealand Transport Agency operates the state highways and Queenstown Lakes District council manages the local roads. **www.nzta.govt.nz** and **www.qldc.govt.nz**

CREATE AND PRACTICE

Household Emergency Plan

YOUR HOUSEHOLD

Address

Name	Phone numbers
Name	Phone numbers
Name	Phone numbers
Name	Phone numbers
Name	Phone numbers
Name	Phone numbers

1. If we can't get home or contact each other we will meet or leave a message at:

Name

Contact details

Name (back-up)

Contact details

Name (out of town)

Contact details

2. The person responsible for collecting the children from school is:

Name

Contact details

3. Emergency Survival Items and Getaway Kit

Person responsible for checking water and food

Items will be checked and replenished on:

(check and replenish at least once a year)

The Getaway Kits are stored in the

4. The radio station (inc AM/FM frequency) we will tune in to for local civil defence information during an emergency

5. Friends/neighbours who may need our help or who can help us

Name

Address

Phone

Name

Address

Phone

6. On a separate sheet of paper draw a plan of the house showing places to shelter in an earthquake or storm, exits and safe assembly areas and where to turn off water, electricity and gas.

IMPORTANT PHONE NUMBERS

FOR POLICE, FIRE OR AMBULANCE CALL 111

Local Police station	Water Supplier
Medical Centre	Gas Supplier
Insurance Company	Electrician
Vet/Kennel/Cattery	Plumber
Electricity Supplier	Builder
Council Emergency Helpline	

get ready...

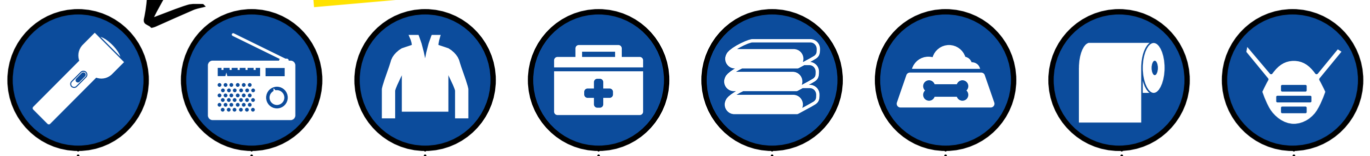
CREATE

Emergency Survival Kit

In most emergencies you should be able to stay in your home. Plan to be able to look after yourself and your household for at least three days or more.

Assemble and maintain your emergency survival items for your home as well as a portable getaway kit in case you have to leave in a hurry. You should also have essential emergency items in your workplace and in your car.

EMERGENCY SURVIVAL ITEMS



- Torch with spare batteries or a self-charging torch
- Radio with spare batteries
- Wind and waterproof clothing, sun hats and strong outdoor shoes
- First aid kit and essential medicines
- Blankets or sleeping bags
- Pet supplies
- Toilet paper and large rubbish bags for your emergency toilet
- Face and dust masks

GETAWAY KIT

Everyone should have a packed getaway kit in an easily accessible place at home and at work which includes:

- Torch and radio with spare batteries
- Any special needs such as hearing aids and spare batteries, glasses or mobility aids
- Emergency water and easy-to-carry food rations such as energy bars and dried foods.
- First aid kit and essential medicines
- Essential items for infants or young children such as formula and food, nappies and a favourite toy
- Change of clothes (wind/waterproof clothing and strong outdoor shoes)
- Toiletries – towel, soap, toothbrush, sanitary items, toilet paper
- Blankets or sleeping bags
- Face and dust masks
- Pet supplies.

HOW TO

Stay in touch

In a power outage, only analogue phones on a copper wire network will continue to operate (fibre optic networks will fail).

Cell phone communications can become easily overloaded in a crisis. **Texting** is a better way to communicate with friends and family.

Use your car radio to listen to instructions and information if you don't have a battery operated radio.

Use your car for charging your cell phone/computer. A 12v charger is required for this. Make it part of your kit or keep in the car.

LOCAL RADIO STATIONS

Radio NZ // 101.6FM
NewsTalk ZB // 89.6FM
The Hits // 90.4FM
More FM // 90.0FM

WEBSITES

Log on to one of the following websites for more information.
www.otagocdem.govt.nz
www.qldc.govt.nz
www.facebook.com/QLDCinfo
www.facebook.com/otagocdem

TELEPHONE TREE

A phone tree is a network of people organized in such a way that they can quickly and easily spread information amongst each other.

get thru..

EARTHQUAKE

Before an earthquake

- Getting ready before an earthquake strikes will help reduce damage to your home and business and help you survive.
- Develop a Household Emergency Plan. Assemble and maintain your Emergency Survival Items for your home and workplace, as well as a portable getaway kit.
- Practice Drop, Cover and Hold.

- Identify safe places within your home, school or workplace.
- Check your household insurance policy for cover and amount.
- Seek qualified advice to make sure your house is secured to its foundations and ensure any renovations comply with the New Zealand Building Code.
- Secure heavy items of furniture to the floor or wall.
- Visit **www.eqc.govt.nz** to find out how to quake-safe your home.

During an earthquake

IF YOU ARE INSIDE A BUILDING, move no more than a few steps, drop, cover and hold. Stay indoors till the shaking stops and you are sure it is safe to exit. In most buildings in New Zealand you are safer if you stay where you are until the shaking stops.

IF YOU ARE IN AN ELEVATOR, drop, cover and hold. When the shaking stops, try and get out at the nearest floor if you can safely do so.

IF YOU ARE OUTDOORS when the shaking starts, move no more than a few steps away from buildings, trees, streetlights, and power lines, then Drop, Cover and Hold.

IF YOU ARE DRIVING, pull over to a clear location, stop and stay there with your seatbelt fastened until the shaking stops. Once the shaking stops, proceed with caution and avoid bridges or ramps that might have been damaged.

IF YOU ARE IN A MOUNTAINOUS AREA or near unstable slopes or cliffs, be alert for falling debris or landslides.

IF YOU ARE NEAR A LAKE, BAY OR RIVER MOUTH consider evacuating to higher ground immediately as a seiche (inland tsunami) may be generated with the potential to rapidly flood or inundate low lying areas to a depth of 5 metres or greater.

After an earthquake

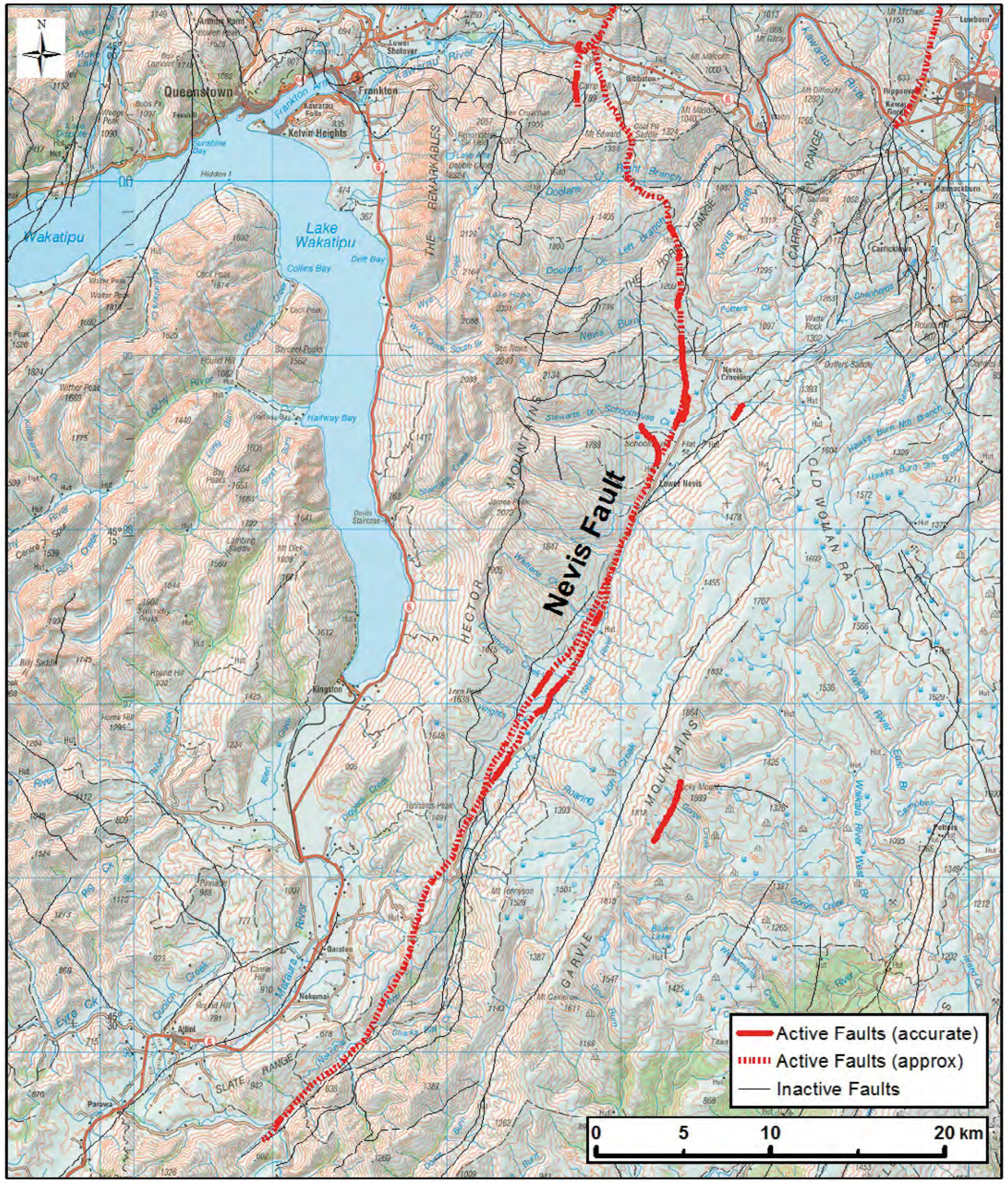
- Monitor social media and listen to your local radio stations as emergency management officials will be broadcasting the most appropriate advice for your community and situation.
- Expect to feel aftershocks.
- Check yourself for injuries and get first aid if necessary. Help others if you can.
- Be aware that electricity supply could be cut, and fire alarms and sprinkler systems can go off in buildings during an earthquake even if there is no fire. Check for, and extinguish, small fires.
- If you are in a damaged building, try to get outside and find a safe, open place. Use the stairs, not the elevators.
- Watch out for fallen power lines or broken gas lines, and stay out of damaged areas.
- Only use the phone for short essential calls to keep the lines clear for emergency calls.
- If you smell gas or hear a blowing or hissing noise, open a window, get everyone out quickly and turn off the gas if you can. If you see sparks, broken wires or evidence of electrical system damage, turn off the electricity at the main fuse box if it is safe to do so.
- Keep your animals under your direct control as they can become disorientated. Take measures to protect your animals from hazards, and to protect other people from your animals.
- If your property is damaged, take notes and photographs for insurance purposes. If you rent your property, contact your landlord and your contents insurance company as soon as possible.

POST DISASTER

Building management

Following the 2011 Canterbury earthquake, changes were made to how rapid building safety evaluations are carried out after earthquakes or floods. The Ministry of Building, Innovation & Employment (MBIE) has developed a number of documents to reflect these changes.

These documents are available on **www.building.govt.nz/post-disaster-building-management** for your information and are designed to be used by trained professionals during a State of Emergency.



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SNOWSTORMS / MAJOR STORMS

Before a storm

- Develop a Household Emergency Plan. Assemble and maintain your Emergency Survival Items for your home as well as a portable getaway kit.
- Prepare your property for high winds. Secure large heavy objects or remove any item which can become a deadly or damaging missile. Get your roof checked regularly to make sure it is secure. List items that may need to be secured or moved indoors when strong winds are forecast.
- Keep materials at hand for repairing windows, such as tarpaulins, boards and duct tape.
- If you are renovating or building, make sure all work complies with the New Zealand Building Code which has specific standards to minimise storm damage.
- If farming, know which paddocks are safe to move livestock away from floodwaters, landslides and power lines.

WHEN A WARNING IS ISSUED AND

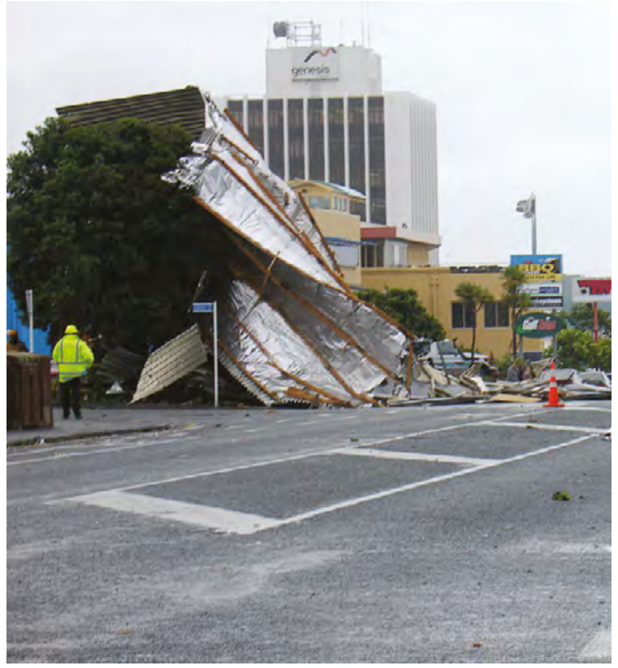
During a storm

- Stay informed on weather updates. Monitor social media and listen to your local radio stations as civil defence authorities will be broadcasting the most appropriate advice for your community and situation. **www.metservice.com**
- Put your household emergency plan into action and check your getaway kit in case you have to leave in a hurry.
- Secure, or move indoors, all items that could get blown about and cause harm in strong winds.
- Close windows, external and internal doors. Pull curtains and drapes over unprotected glass areas to prevent injury from shattered or flying glass.
- If the wind becomes destructive, stay away from doors and windows and shelter further inside the house.
- Water supplies can be affected so it is a good idea to store drinking water in containers and fill bathtubs and sinks with water.

- Don’t walk around outside and avoid driving unless absolutely necessary.
- Power cuts are possible in severe weather. Unplug small appliances which may be affected by electrical power surges. If power is lost unplug major appliances to reduce the power surge and possible damage when power is restored.
- Bring pets inside. Move stock to shelter. If you have to evacuate, take your pets with you.

After a storm

- Monitor social media and listen to your local radio stations as emergency management officials will be broadcasting the most appropriate advice for your community and situation.
- Check for injuries and help others if you can, especially people who require special assistance.
- Look for and report broken utility lines to appropriate authorities.
- Contact your local council if your house or building has been severely damaged.
- If your property or contents are damaged take notes and photographs and contact your insurance company. Inform your landlord if there is damage to the rental property.
- Ask your council for advice on how to clean up debris safely.



Snowstorms

In a snowstorm, the primary concerns are the potential loss of heat, power and telephone service, and a shortage of supplies if storm conditions continue for more than a day. It is important for people living in areas at risk from snowstorms to consider the need for alternative forms of heating and power generation.

- Avoid leaving home unless absolutely necessary when a snow warning is issued.
- If you have to travel make sure you are well prepared with snow chains, sleeping bags, warm clothing and essential emergency items.
- At home, check fuel supplies for woodburners, gas heaters, barbeques and generators.
- Bring pets inside. Move domestic animals and stock to shelter.
- If you are caught in your car or truck in a snowstorm, stay in your vehicle. Run the engine every ten minutes to keep warm. Drink fluids to avoid dehydration. Open the window a little to avoid carbon monoxide poisoning. Make yourself visible to rescuers by tying a brightcoloured cloth to your radio aerial or door and keeping the inside light on.

Before a flood

- Find out from your local council if your home or business is at risk from flooding. Ask about evacuation plans and local public alerting systems; how you can reduce the risk of future flooding to your home or business; and what to do with your pets and livestock if you have to evacuate.
- Know where the closest high ground is and how to get there.
- Develop a Household Emergency Plan. Assemble and maintain your Emergency Survival Items for your home as well as a portable getaway kit.
- Check your insurance policy to ensure you have sufficient cover.

During a flood

OR IF A FLOOD IS IMMINENT

- Monitor social media and listen to your local radio stations as emergency management officials will be broadcasting the most appropriate advice for your community and situation.
- If you have a disability or need support, make contact with your support network.
- Put your household emergency plan into action and check your getaway kit. Be prepared to evacuate quickly if it becomes necessary.
- Where possible, move pets inside or to a safe place, and move stock to higher ground.
- Consider using sandbags to keep water away from your home.
- Lift valuable household items and chemicals as high above the floor as possible.
- Fill bathtubs, sinks and storage containers with clean water in case water becomes contaminated.
- Turn off utilities if told to do so by authorities as it can help prevent damage to your home or community. Unplug small appliances to avoid damage from power surges.
- Do not attempt to drive or walk through floodwater unless it is your only escape route.

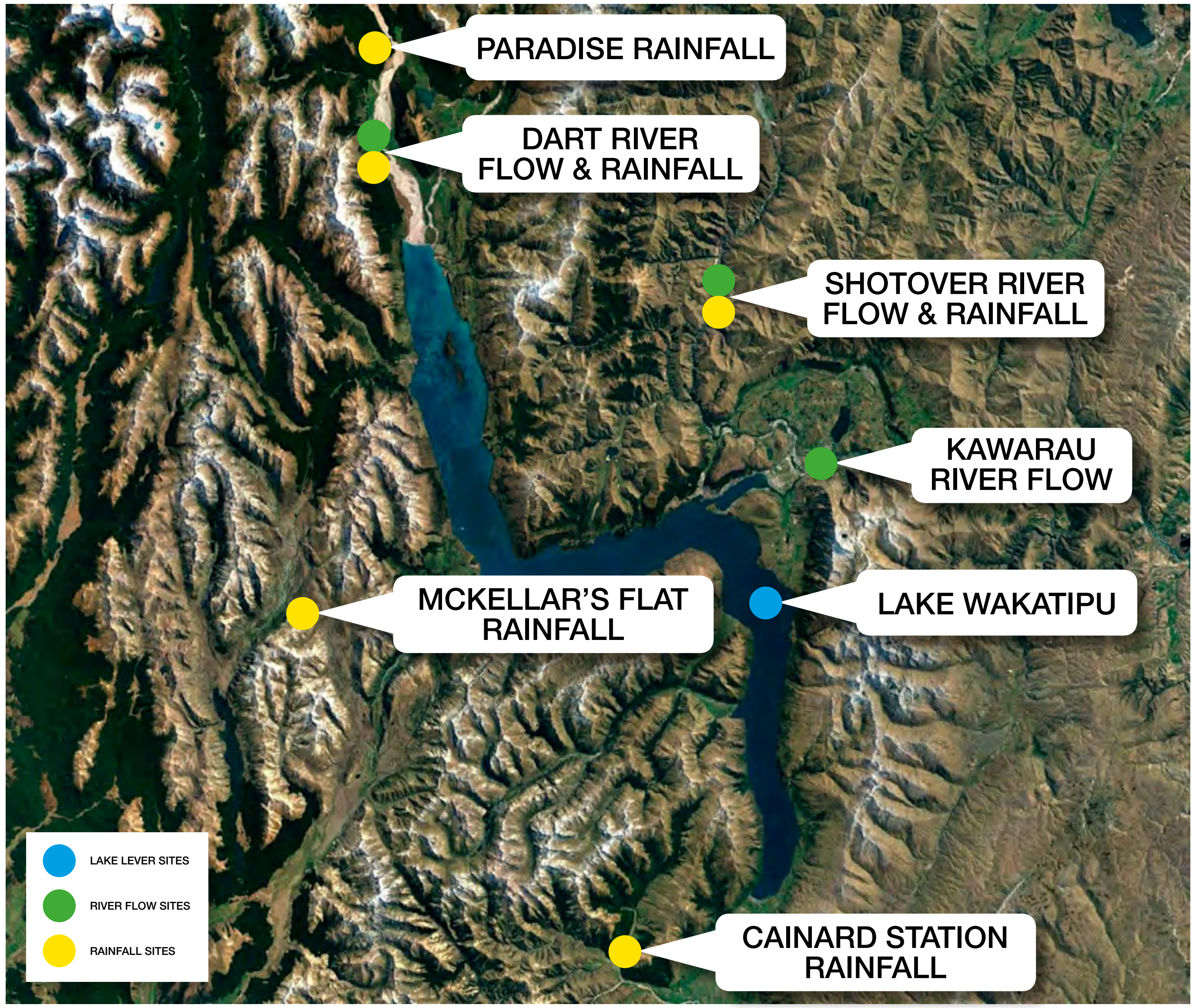
After a flood

- It may not be safe to return home even when the floodwaters have receded. Continue to monitor social media and listen to your local radio station for civil defence instructions.
- Help others if you can, especially people who may require special assistance.
- Throw away food including canned goods and water that has been contaminated by floodwater.
- Avoid drinking or preparing food with tap water until you are certain it is not contaminated. If in doubt, check with your local council or public health authority.
- Look for and report broken utility lines to appropriate authorities.
- If your property is damaged, take notes and photographs for insurance purposes. If you rent your property, contact your landlord and your contents insurance company as soon as possible.

get thru...

KINGSTON

Lake & River Levels



Online at www.orc.govt.nz/managing-our-environment/water/water-monitoring-and-alerts
Source - Otago Regional Council

KINGSTON

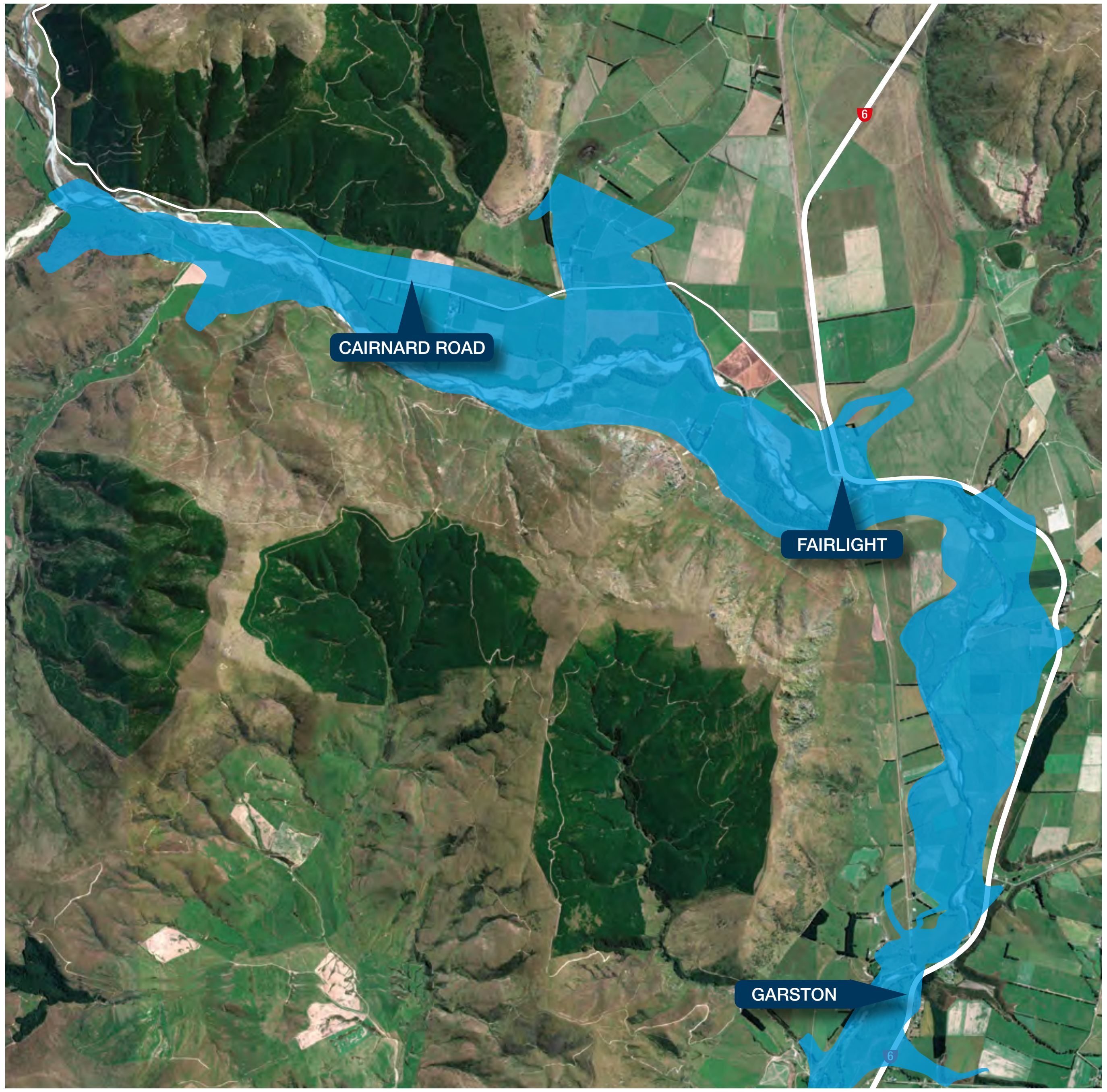
Lake Wakatipu Flood Zone

Source - ORC Natural Hazards Database

get thru...

GARSTON

Upper Mataura River Flood Hazard Zone



Source - Environment Southland Beacon, Significant Floodplains

WILDFIRE

Before a fire

To protect your rural property from fire, we recommend:

- Installing smoke alarms and testing them regularly.
- Designing an escape plan and practicing it.
- Keeping the grass green and mown or grazed around your home.
- Creating a safety zone around your home of at least 10m by clearing any dead or dry material and replacing flammable plants and trees with low flammable species.
- Making sure your property is clearly signposted with your RAPID rural property identification number.
- Installing multipurpose dry powder extinguishers in your house and out buildings.
- Keeping a garden hose connected and make sure it is long enough to reach around the house.
- Ensuring your driveway has a minimum clearance of 4m wide and 4m high and adequate turning space for large vehicles.
- Easy access to water supplies and making sure they are signposted.
- Storing firewood and other flammable material away from your house.
- Safe handling and storage of gas or liquid fuels.
- Maintaining machinery and equipment in working order.
- Disposing of ash safely in a metal container and using approved incinerators.

During a fire

- Crawl low and fast to escape smoke. **'Get Down, Get Low, Get Out.'**
- Shut doors behind you to slow the spread of fire.
- Meet at the planned meeting place.
- Once out, stay out - never go back inside.
- Phone 111 from a safe phone.

TELL FIRE AND EMERGENCY NEW ZEALAND

- House number
- Street
- Nearest intersection
- Suburb and City
- RAPID number if you have one

After a fire

Nothing can really prepare you for the impact of a fire or other emergency on your family and property. Even a small fire or flood can make you feel helpless and unsure of what to do next. This is entirely understandable. Fire and Emergency New Zealand (FENZ) regularly sees home owners faced with the same distressing situation. Here's some guidance on the important things you need to do now that the unimaginable has happened.

Do not enter your damaged house unless you have to and have been advised it is safe to do so. Fire and Emergency NZ will check the water, electricity and gas supplies and either arrange to have them disconnected or advise you what action to take.

If you can't enter your home, you'll need to arrange accommodation. You may need to stay with family, friends or in a motel for at least one night, and longer if the house has been seriously damaged.

When your house is safe and you are allowed back:

- Try to find your identification, insurance information, medication information, eye glasses, hearing aid, wallet and valuables
- If the house is too badly damaged to live in, board up openings to discourage trespassers
- You may need to arrange security patrols to protect it from burglary
- Keep receipts for expenses resulting from the fire, such as accommodation or clothes
- Get supplies of medicine or eye glasses.

Fire Seasons

There are three fire seasons you should be aware of:

OPEN FIRE SEASON
A fire permit is not required to light a fire in the open air as long as certain conditions are met.

RESTRICTED FIRE SEASON
In this season a fire permit from Fire and Emergency NZ Authority is required before you can light a fire in the open air.

PROHIBITED FIRE SEASON
Means a total fire ban is in place. Lighting fires in the open air is not permitted.

For the current fire season and to apply for fire permits contact Fire and Emergency NZ or visit **fireandemergency.nz**

HAVE YOU CONSIDERED INSTALLING FIRE SPRINKLERS?

Home sprinklers will protect your family, home and contents from the threat of fire - 24 hours a day.

Sprinkler technology has come a long way in a short space of time. The cost of including home sprinklers into a new house or adding them as part of major renovations is probably a lot cheaper than you think.

Home sprinklers use the same domestic plumbing as your kitchen taps and can be installed by a qualified plumber in less than two days.

More importantly though, sprinklers provide the fastest possible means of extinguishing fires in rural homes.

For more information visit **fireandemergency.nz**

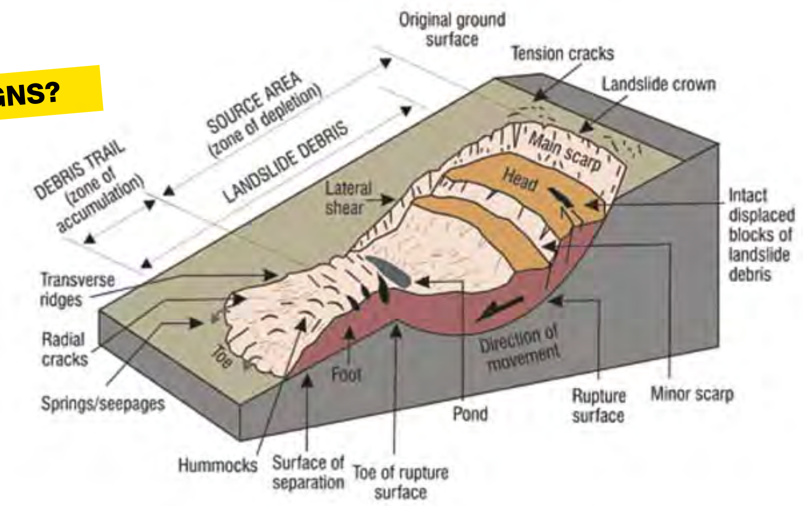
Before a landslide

- Develop an evacuation plan. Familiarise yourself with the land around you and regularly inspect your property watching for the patterns of storm water drainage on slopes near your home especially the places where runoff water converges. Watch the hillsides around your home for any signs of land movement, such as small landslides, debris flows or progressively tilting trees.
- Ensure livestock are in safe paddocks if there is heavy rain. Consider precautionary evacuation of livestock if you believe there is a risk of landslide. Bring your pets indoors and maintain direct control of them. Should you need to evacuate take your pets with you – if it is not safe for you, it is not safe for them.
- If you are near a stream or channel, be alert for any sudden increase or decrease in water flow and for a change from clear to muddy water. Such changes may indicate landslide activity upstream, so be prepared to move quickly. Act quickly. Save yourself, not your belongings.
- Listen for any unusual sounds that might indicate moving debris, such as trees cracking or boulders knocking together. A trickle of flowing or falling mud or debris may precede a large landslide. Moving debris can flow quickly and sometimes without warning.

During a landslide

- If you learn or suspect that a landslide is occurring or is about to occur in your area evacuate immediately. Getting out of the path of a landslide or debris flow path is your best protection. Consider evacuating across slopes and not downhill below potential debris paths.
- Inform neighbours, they may not be aware of the potential hazard. Help neighbours who need assistance to evacuate. Check for injured and trapped persons and animals near the slide, without entering the slide area. Direct rescuers to their locations.
- Contact your local council or regional council. Local officials are the people best able to assess the potential danger.
- Help people who require special assistance – infants, elderly people, those without transportation, families who may need additional help, people with disabilities, visitors and tourists who don't know the area.

WHAT ARE THE DANGER SIGNS?



After a landslide

- Stay away from the slide area. Further landslides may occur.
- Landslides can occur progressively, often hours or days after a triggering event e.g. rainstorm or earthquake. Be aware of any changes to your property following a landslide or major rainstorm or earthquake, noting any cracks or ground bulging.
- Watch for flooding which may occur after a landslide or debris flow.
- Look for and report broken utility lines to appropriate authorities. Reporting potential hazards will get the utilities turned off as quickly as possible, preventing further hazard and injury.
- Check your home's foundation, chimney, and surrounding land for damage.
- Re-plant damaged ground as soon as possible because erosion caused by the loss of ground cover can lead to flash flooding.
- If your property has been damaged contact EQC and your insurance company. Be aware that in general, landslide insurance is not available. However, the Earthquake Commission may pay out on claims lodged by residential property owners for damage caused by landslides to residential properties and their contents, outbuildings, land within eight metres of buildings and outbuildings, access way land and a range of other structures and facilities. **www.eqc.govt.nz**

KINGSTON

Debris Flow (Mudslide) Hazard Zones

Debris flow zones

get thru...

ROAD TRANSPORT CRASHES

Before a road transport crash

Heavy vehicles pose a particular challenge to road safety because the consequences of their crashes are more severe, particularly if they are transporting flammable or toxic substances. Toxic or industrial chemicals are widely used, stored and transported for industrial use throughout the Otago area. These chemicals have the potential to cause mass casualties and would require large scale evacuation of buildings and residents.

During a road transport crash

Definition of Evacuation Zones

HOT ZONE

This is the contaminated area where the initial release occurs or disperses to. It will be the area likely to pose an immediate threat to the health and safety of all those located within it and it is the area of greatest risk. The need to remove persons from this area is paramount. The Incident Commander will carry out a Dynamic Risk Assessment prior to anyone entering it and is an area that must be strictly controlled.

WARM ZONE

This is the area uncontaminated by the initial release of a substance, which becomes contaminated by the movement of people or vehicles. It is imperative that no victims leave this zone/cordon without appropriate decontamination.

COLD ZONE

This is the uncontaminated area where no exposure or risk is expected. Decontaminated persons will be taken to this area and given medical advice, medication and assessment by medical staff.

After a road transport crash

Decontamination is the process of cleansing the human body to remove contamination by hazardous materials and infectious substances. People who have been contaminated are usually separated by gender and led into a decontamination tent where they privately shed their contaminated clothes and are then showered and issued clean clothing or plastic overalls. Fire and Emergency New Zealand, St John and Health personnel will then provide medical attention if required. Civil Defence, Red Cross, Salvation Army and Government support agency personnel will then provide temporary shelter, assistance and support at civil defence centres.

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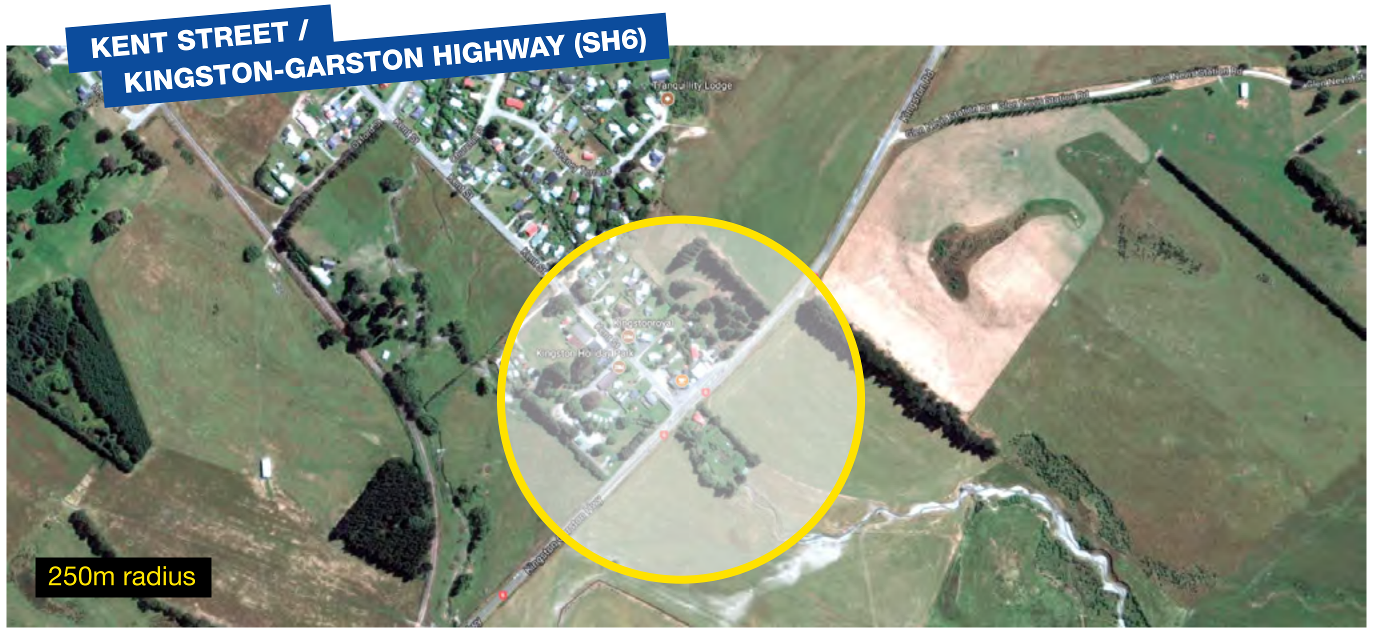
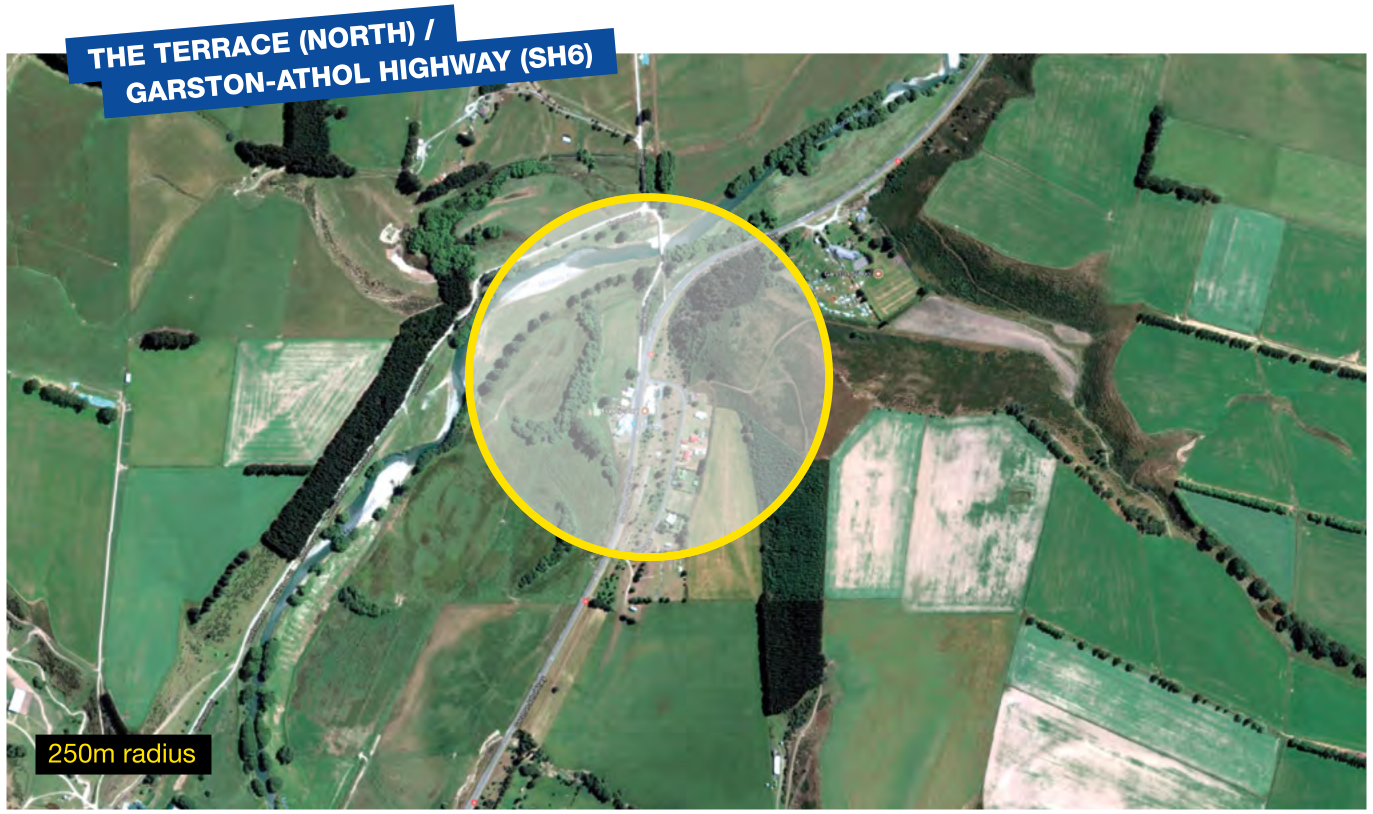
KINGSTON

Truck crash zones



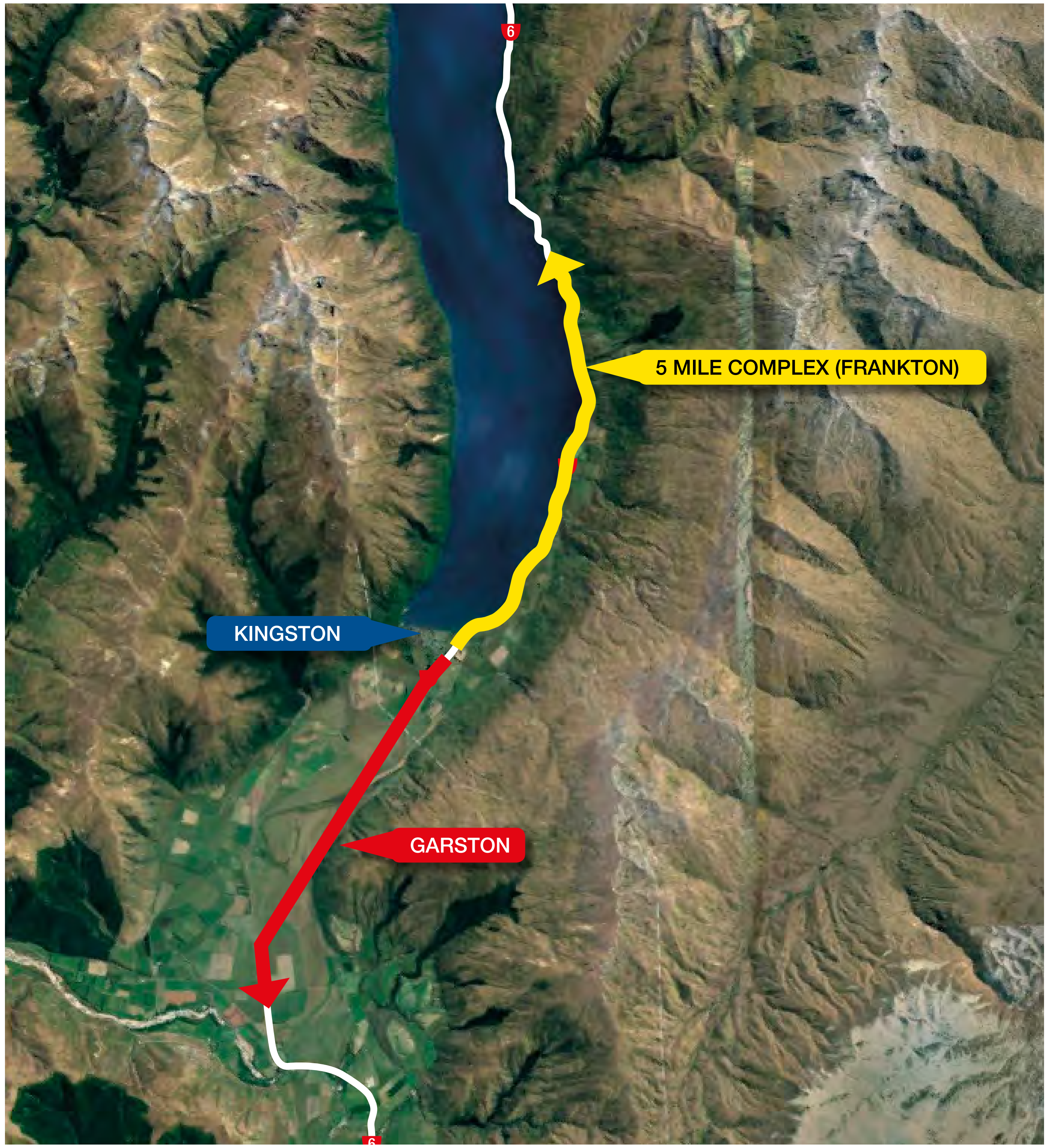


KINGSTON TOWNSHIP

Evacuation routes

KINGSTON

Evacuation routes



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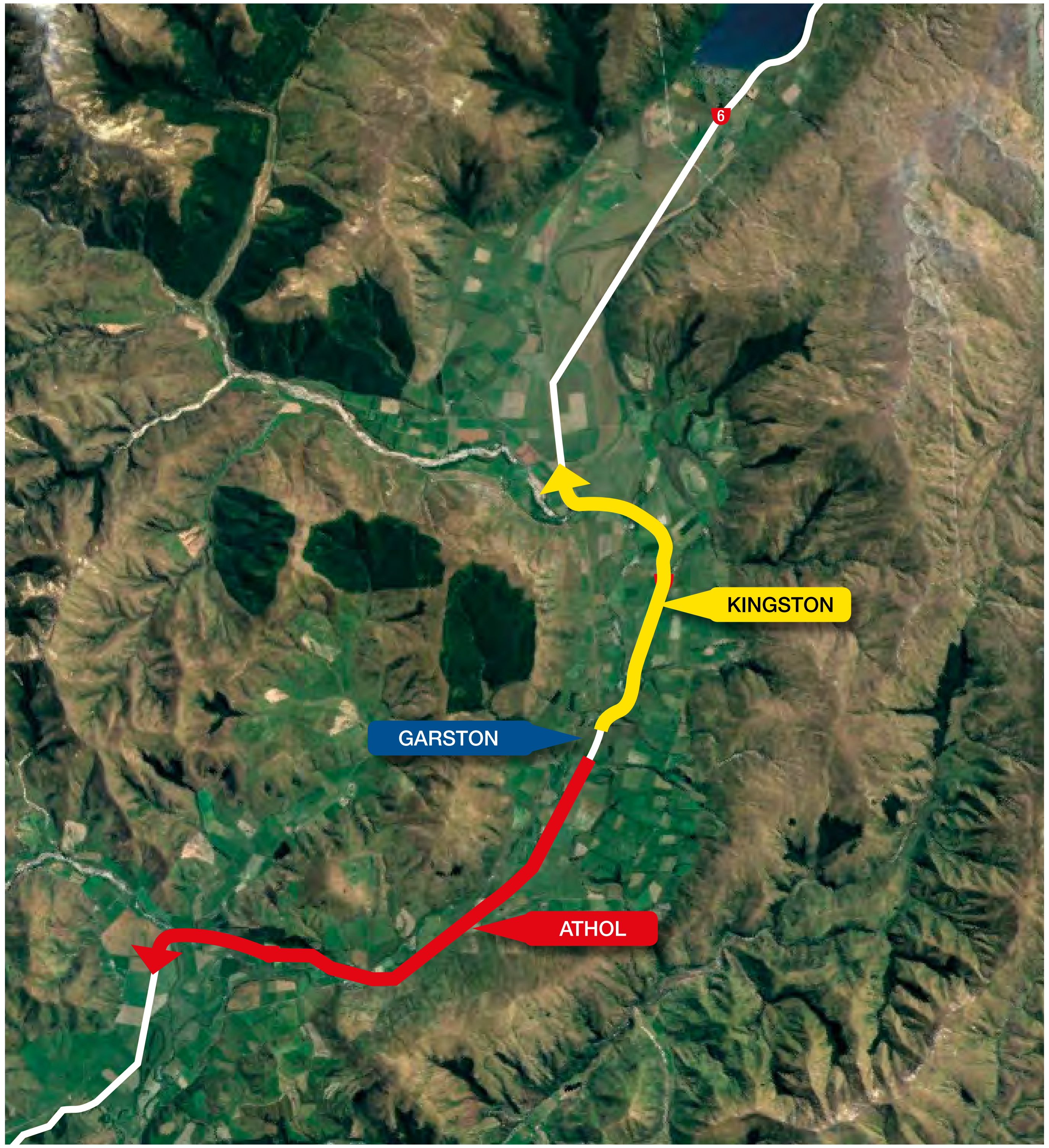
GARSTON

Evacuation routes

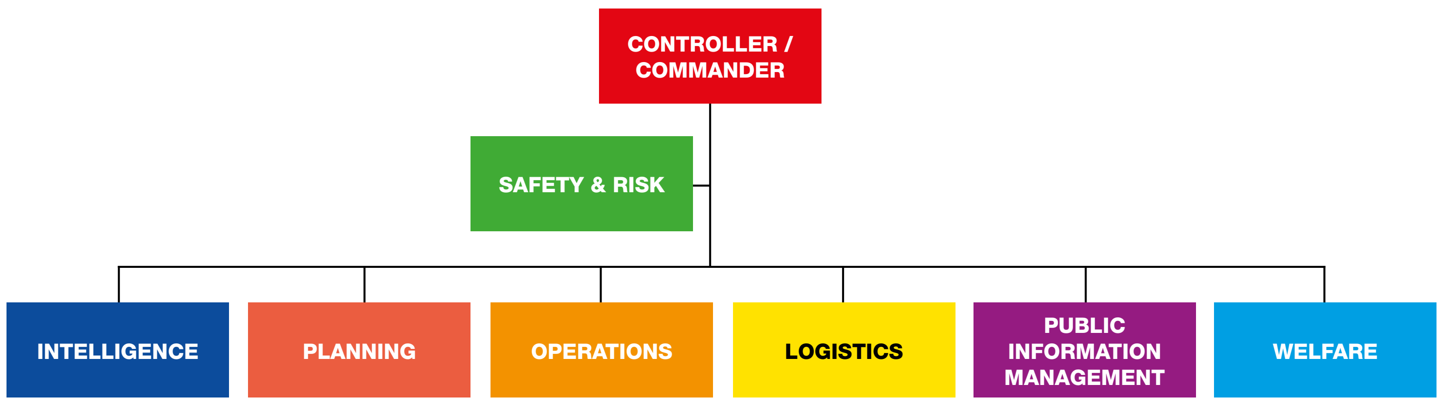


Roles and responsibilities

The roles and responsibilities of the emergency services and civil defence is defined by legislation. In the event of a "State of Emergency" being declared all activities are coordinated by civil defence.

Organisation	Responsibilities
Civil Defence	Liaise with police and emergency services to initiate and assist in a response to a civil emergency, disseminate warnings and identify and make arrangements for civil defence centres if required.
New Zealand Police	Maintain law and order Protect life and property Assisting the coroner Search and rescue Evacuations
Fire Emergency New Zealand	Rural and Urban firefighting Containment of releases and spillages of hazardous substances Urban search and rescue Redistribution of water for specific needs Reducing fire risk in rural areas
KINGSTON HOLIDAY PARK	Visitor, tourist and foreign national registration and coordination Liaison with the QLDC Queenstown Emergency Operations Centre (EOC) on visitors, tourists and foreign nationals issues Providing logistical support
St John	Provision of emergency medical care

All services and organisations will work together under the Coordinated Incident Management System (C.I.M.S.)



Plan activation process

These instructions are for members of the Kingston community response group and emergency services for initiating their pre-planned roles.

DO THIS

- Arrange to meet at the Kingston Fire Station (Incident Control Point - ICP)
- Liaise to determine what actions should be taken
- Consider who will be affected and where
- Assess vulnerable population sites. See map on page 28.
- Activate community warning systems i.e. door knocking, phone tree, mobile phone emergency alert, texting, social media, local radio stations, emergency vehicles sirens and PA's
- Reassess the location of the Incident Control Point
- Consider the establishment of Civil Defence Centres.
- Geographically sectorise the area to aid damage assessment
- Send a situation report (Sitrep) to the Queenstown emergency operations centre (EOC). Ring 03 441 0499 or email eoc@qldc.govt.nz (Refer to the Kingston civil defence communications plan for other options)

Civil Defence Centres

The opening of these centres will vary depending on the type of civil defence emergency.

KINGSTON SECTOR

KINGSTON CORNER CAFÉ
1 Kent Street
South 45° 20' 17.59" East 168° 43' 26.09"

KINGSTON HOLIDAY PARK
16 Kent Street
South 45° 20' 17.88" East 168° 43' 21.21"

KINGSTON COMMUNITY CENTRE & GOLF CLUB
32 Gloucester Street
South 45° 19' 59.24" East 168° 42' 44.27"

GLEN NEVIS STATION WOOLSHED & SHEARERS QUARTERS
59 Glen Nevis Station Road
South 45° 20' 05.97" East 168° 44' 09.15"

KINGSTON STATION WOOLSHED
87 Kingston – Garson Highway
South 45° 20' 45.45" East 168° 43' 15.29"

GARSTON SECTOR

GARSTON SCHOOL
1705 Kingston-Athol Highway
South 45° 27' 49.87" East 168° 41' 17.59"

GARSTON COMMUNITY HALL
11 The Terrace
South 45° 28' 00.55" East 168° 41' 06.06"

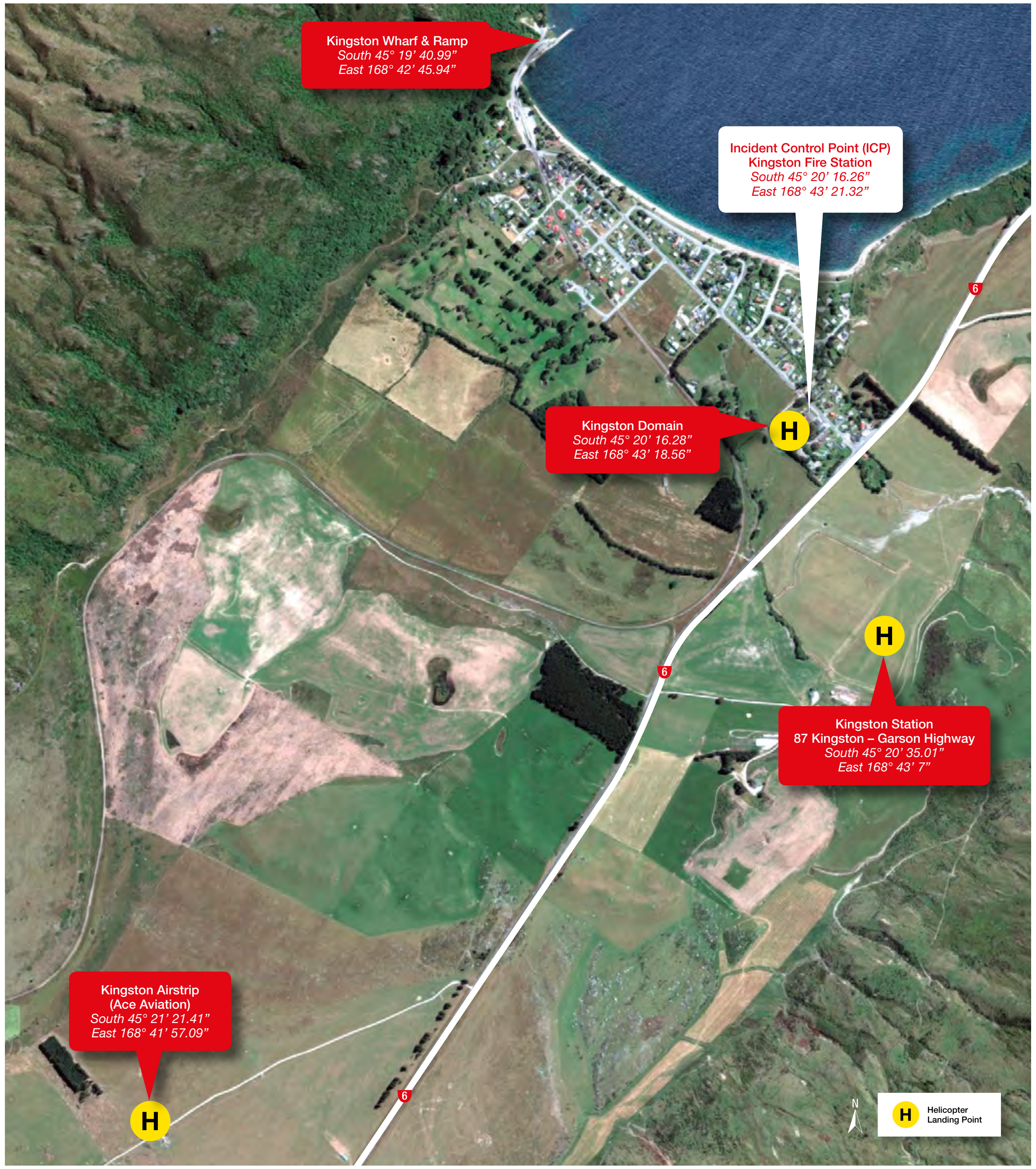
THE GARSTON HOTEL & CAFÉ
SH6 / 8 Garston-Athol Highway
South 45° 28' 00.97" East 168° 40' 59.58"

get thru...

Vulnerable Population Sites

KINGSTON

Tactical Sites Map

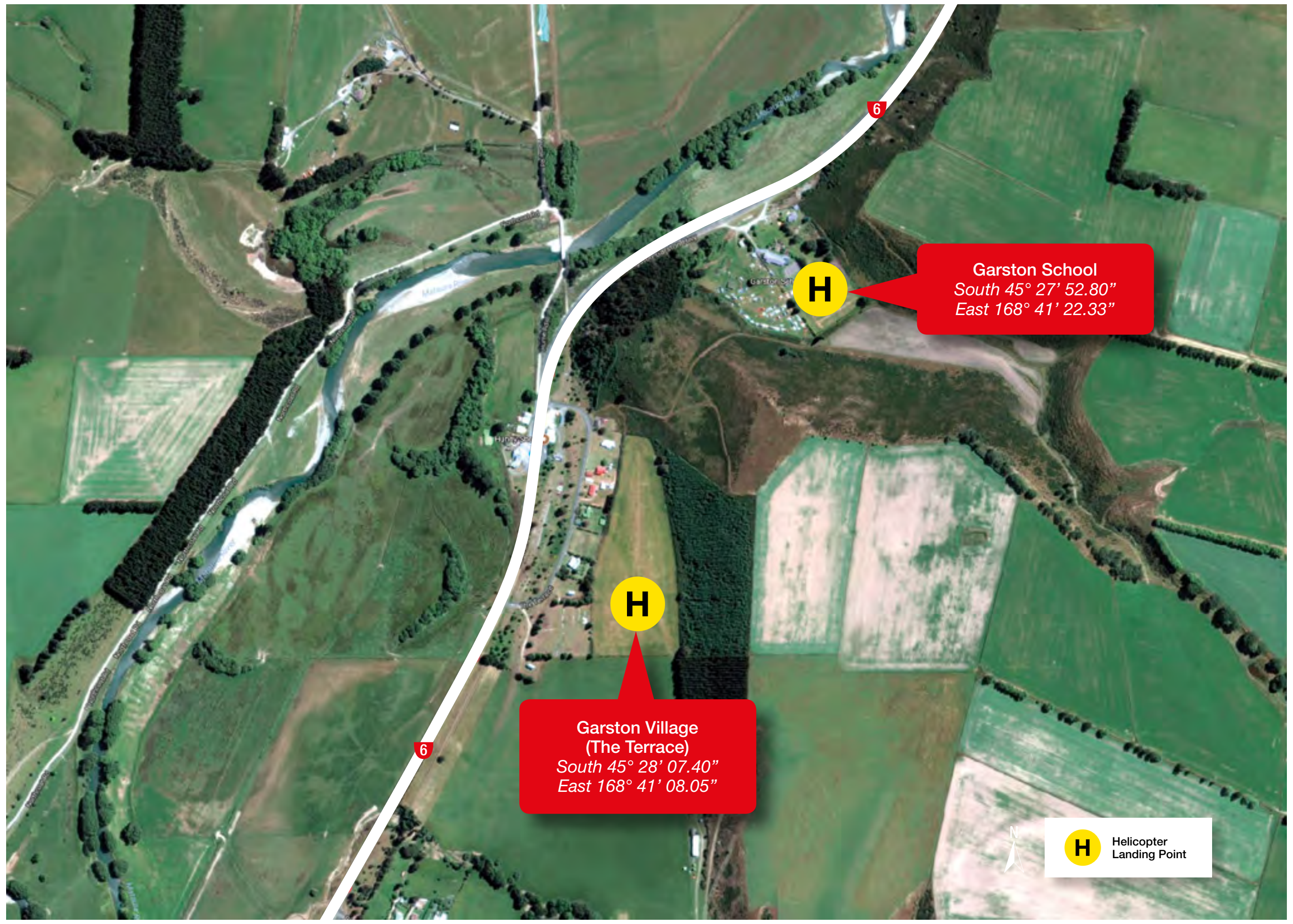


KINGSTON

Tactical Sites Map

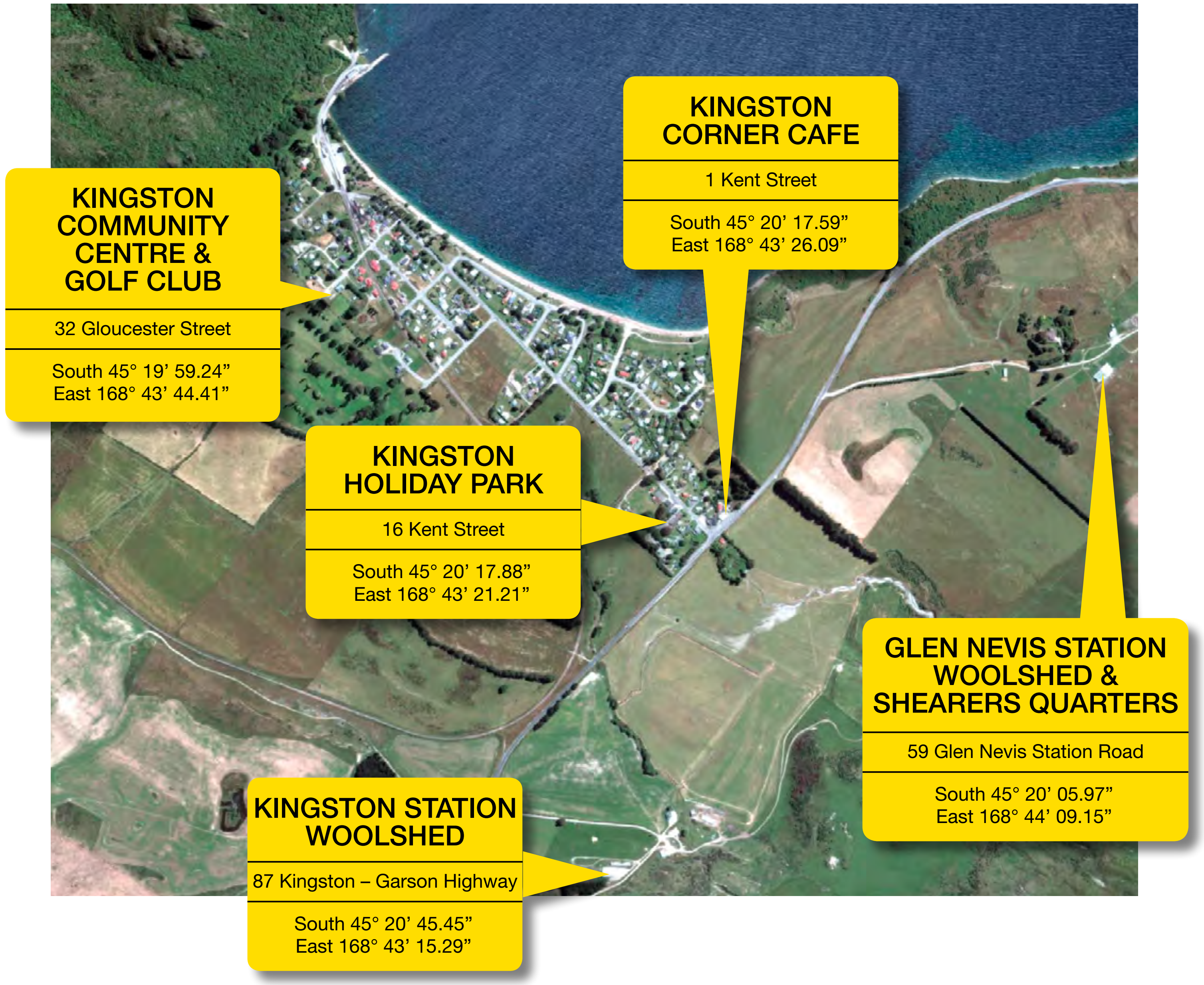
GARSTON

Tactical Sites Map



KINGSTON

Civil Defence Centres Map



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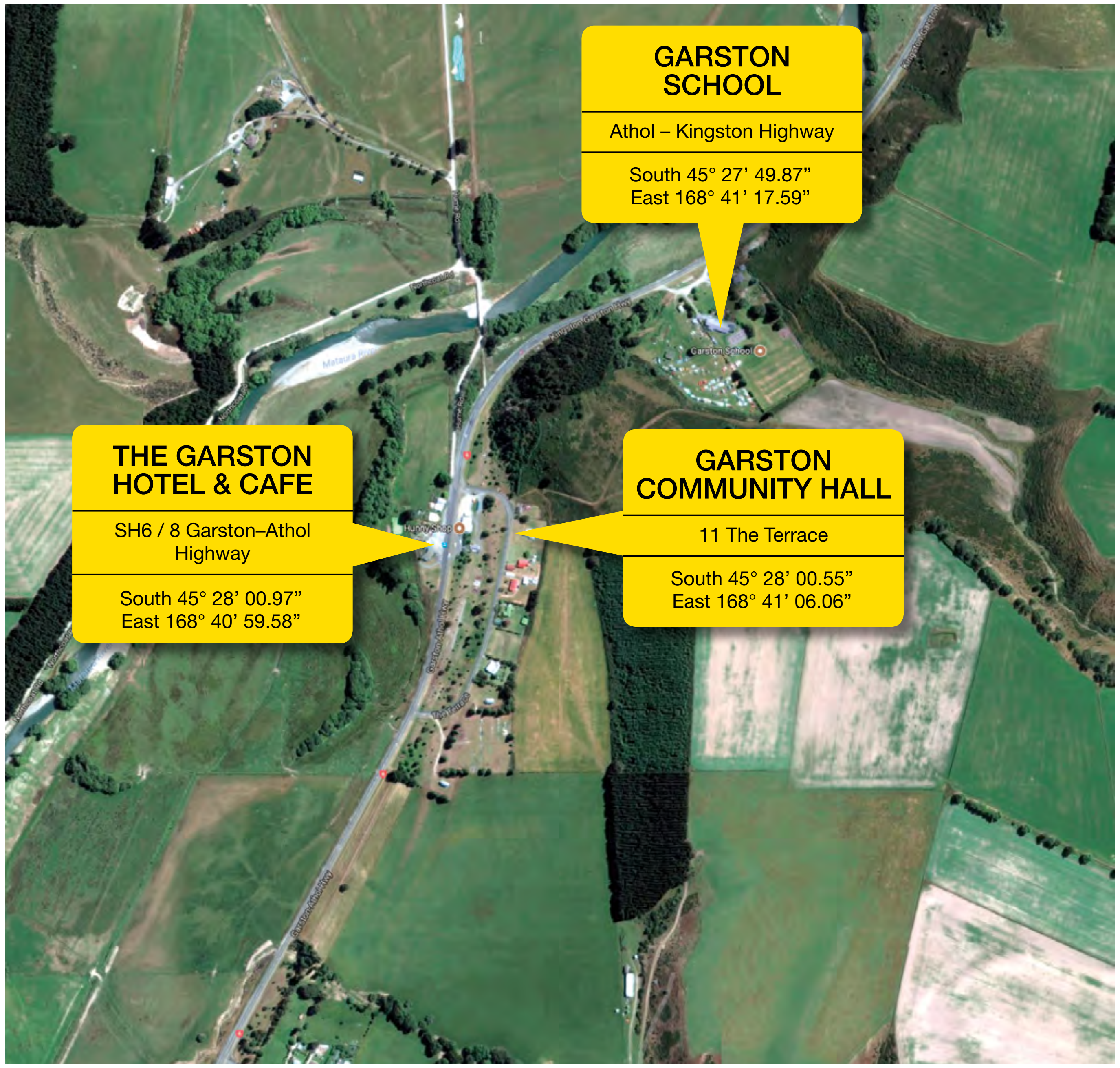
GARSTON

Civil Defence Centres Map



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KINGSTON

Visitor, Tourist and Foreign Nationals Welfare

Contact Information

Only call 111 in an emergency. Do not call 111 for information and advice. Calling 111 unnecessarily may put others who are in a genuine emergency situation at risk.

Emergency Management Otago
Te Rākau Whakamarumaru Ōtākou
otagocdem.govt.nz
0800 474 082

New Zealand Police
Dial 111 (Emergencies Only)
Queenstown Police Station
03 441 1600
www.police.govt.nz

Fire Emergency New Zealand
Dial 111 (Emergencies Only)
Kingston Fire Station
03 248 8807 0800 673 473
www.fireandemergency.nz

St John
Dial 111 (Emergencies Only)
Kingston
0800 785 646
www.stjohn.org.nz

Coastguard
Dial 111 (Emergencies Only)
www.coastguard.nz

New Zealand Red Cross
0800 REDCROSS
www.redcross.org.nz

Queenstown Lakes District Council
03 443 0024
www.qldc.govt.nz

Otago Regional Council
0800 474 082
www.orc.govt.nz

Department of Conservation Te Papa Atawhai
0800 362 468
www.doc.govt.nz

Ministry of Civil Defence & Emergency Management
www.civildefence.govt.nz

AA
www.aaroadwatch.co.nz

NZ Transport Agency
www.nzta.govt.nz

PowerNet
0800 808 587

MetService
www.metservice.com

Aurora Energy
0800 220 005
www.auroraenergy.co.nz

For further information:

LOCAL COUNCIL

Queenstown Lakes District Council
03 441 0499
www.qldc.govt.nz

Otago Regional Council
0800 474 082
www.orc.govt.nz

CIVIL DEFENCE SITES

Otago Civil Defence
www.otagocdem.govt.nz

Ministry of Civil Defence
www.civildefence.govt.nz

Be prepared
www.whatstheplanstan.govt.nz
www.getthru.govt.nz

EMERGENCY SERVICES

Fire & Emergency NZ
www.fireandemergency.nz

New Zealand Police
www.police.govt.nz

St John Ambulance
www.stjohn.org.nz

Emergency Management Otago
Te Rākau Whakamarumaru Ōtākou

QUEENSTOWN LAKES DISTRICT COUNCIL

Summary report: Lake snow technical workshop

8 August 2018

Prepared for Otago Regional Council

October 2018

Prepared by:
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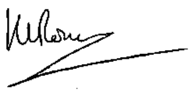	Approved for release by:	Helen Rouse

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Executive summary

A technical workshop to discuss the lake snow phenomenon that is affecting Lakes Wanaka and Wakatipu in the Queenstown-Lakes District was held in Dunedin on 8 August 2018. The workshop was convened at the request of the Otago Regional Council (ORC) to revisit the state of knowledge around lake snow in light of research projects that had been undertaken since the inaugural workshop in December 2016. The 2018 workshop included presentations from four scientists leading different components of the research projects, and a discussion. Three staff from the Ministry of Primary Industries (MPI) also attended the workshop, along with a range of staff and two councillors from the ORC, an engineer from Queenstown Lakes District Council, and scientists from Environment Canterbury and Waikato Regional Council.

Key findings from the workshop are:

- *Lindavia intermedia*, the centric diatom responsible for lake snow (slime), is an invasive species.
- An assessment of archived lake and lake outlet diatom samples confirmed that *L. intermedia* has been present in New Zealand since at least 2002 and indicated it was present in multiple North and South Island lakes by 2005. As of June 2018, *L. intermedia* had been recorded in 26 lakes in the Otago, Southland, Canterbury, Hawke's Bay, Waikato and Manawatu-Wanganui regions.
- Methods are now available for the effective sampling, identification and quantification of *L. intermedia*. These methods are being refined through existing Ministry for Business, Innovation and Employment (MBIE)-funded research. Some methods to quantify lake snow production are still in development.
- A review of the literature indicates that climate warming is likely to be a key driver behind observed shifts in lake phytoplankton communities towards centric diatoms. However, the relevance of climatic drivers in lake snow production is unknown. Other hypotheses for the shift in phytoplankton communities include increasing nutrient inputs and a change in grazing pressure due to the arrival of the invasive water flea *Daphnia pulex*.
- Initial trials indicate that freezing is the only treatment that is 100% effective at killing *L. intermedia* cells. Detergent, bleach and drying were at least 90% effective but an extended treatment time was recommended from the 1-minute used in the trial.
- There might be parasites specifically associated with *L. intermedia* that could be used for a biological control. In theory, such a control could reduce the abundance of *L. intermedia* without modifying a lake's trophic or toxicological status.
- The Touchstone and Wanaka Lake Swimmers Club's lake snow study and wider citizen science-based water quality project have raised awareness about freshwater biosecurity issues and current and potential future water quality challenges facing Lake Wanaka.

Two high priority areas identified as part of a revised future research programme are investigating the drivers for 'excessive' slime production by *L. intermedia* in New Zealand and assessing the potential use of a parasitic biological control agent.

The wide distribution of *L. intermedia* across New Zealand, and potential for lake snow issues to arise in lakes outside of Otago, suggest that a national lake snow working group should be established to scope and source funding for priority research and management initiatives. The basis for such a group already exists as part of the current MBIE-funded lake snow toolbox research project led by Landcare Research.

1 Introduction and background

In December 2016, Otago Regional Council (ORC) hosted a technical workshop to discuss the lake snow phenomenon[1] that had developed in Lakes Wanaka and Wakatipu. The participants represented a mix of New Zealand-based algae and lake experts, regional council science and biosecurity staff, and representatives from ORC management and water infrastructure services at Queenstown Lakes District Council (QLDC). The workshop sought to bring participants up to speed on current knowledge of the lake snow phenomenon and the level of understanding in the New Zealand context, before focusing on the development and prioritisation of research questions relevant to identifying potentially feasible methods of managing the effects of lake snow (Ryder 2017).

In July 2018, the ORC contracted NIWA to facilitate a second technical workshop to revisit the state of knowledge of the lake snow phenomenon, in light of research projects that had been undertaken since the inaugural workshop. The primary purpose of this workshop was to revisit the ORC research programme prepared following the December 2016 workshop and confirm or adjust the programme in light of the more recent findings. The ORC has a particular interest in research that will inform their decisions around managing the effects of lake snow.

The second technical workshop was held at the Otago Museum on 8 August 2018. This report summarises the information presented at the workshop and the subsequent discussion on future research priorities. The workshop agenda and a list of workshop participants are provided in Appendix A.

[1] Lake snow is a sticky, biological material created by excretion of a type of polysaccharide mucilage that form aggregates known as transparent exopolymer particles (or TEPs). Lake snow reported in New Zealand is related to polysaccharides produced by the centric diatom *Lindavia intermedia*. Lake snow is often a nuisance to swimmers, coats fishing lines and clogs water filters.

2 Science and research update

Four scientists presented updates on selected components of the research programme developed from the December 2016 technical workshop. Key findings from those presentations are summarised here, along with responses to some questions raised by workshop attendees. The research programme, documented in Ryder (2017), is reproduced in full in Appendix B.

2.1 Presentation by Marc Schallenberg

Dr Marc Schallenberg (Research Fellow at University of Otago) provided an update on four research components:

1. Historical dynamics of *Lindavia intermedia* in New Zealand lakes – paleolimnological diatom analysis of dated sediment cores *[Research component 1(iii)].*
2. Literature review of shifts in lake phytoplankton to increased dominance by (*Lindavia*-like) centric diatoms *[Research component 2A(i)].*
3. Correlation of historical *L. intermedia* dynamics with environmental drivers in our lakes *[Research component 2A(ii)].*
4. Development of cost-effective and efficient methods for quantitatively sampling lake snow in lakes (at different depths) *[Research component 3(ii)].*

There has been no funding to date for work on two further research components:

- Whether proliferations of didymo[2] and *L. intermedia* in South Island waters are related to a common driver or species incursion *[Research component 2A(iii)].*
- Study of the relationships between diatom polysaccharide overproduction and (1) nutrient availability, (2) climate warming, and (3) grazing pressure *[Research component 2B(ii)].*

2.1.1 Historical dynamics of *L. intermedia* in New Zealand lakes

The results of paleolimnological diatom analyses performed on dated sediment cores from Lakes Wanaka, Wakatipu and Coleridge indicate that *L. intermedia* has been in these lakes since the early 2000s. Paleolimnological diatom analysis has since been performed on dated sediment cores from four further lakes in Otago: Hayes, Johnson, Hawea and Moke. Diatom counting is now underway. A report on the core analysis is due with the ORC in December.

Coring of Lakes Aviemore and Benmore in Canterbury had been delayed. Environment Canterbury have now contracted this work and results will be reported at the end of March 2019. There is an approximate turn-around of eight months between core collection and completion of analyses.

2.1.2 Literature review of shifts in lake phytoplankton to increased dominance by (*Lindavia*-like) centric diatoms

A number of large oligotrophic lakes in New Zealand, including Lakes Wanaka, Wakatipu and Coleridge, have undergone shifts in phytoplankton community structure from pico-cyanobacterial

[2] Didymo is the non-native diatom *Didymosphenia geminata*. Didymo is responsible for large "blooms" in rivers, which comprise mainly polysaccharide stalks excreted from the cells. Didymo and *L. intermedia* are similar in that they both cause a nuisance through excretion of polysaccharide material.

dominance to dominance by *Lindavia*-like centric diatoms. This has also occurred in some overseas lakes, including Lake Youngs in the U.S. where lake snow also exists. A shift in phytoplankton community can be a sensitive indicator of stress, although the invasive status of *L. intermedia* in some lakes complicates the picture.

2.1.3 Correlations of *L. intermedia* dynamics with environmental drivers

A literature review indicates that decadal-scale climate warming appears to be a key driver of shifts in lake phytoplankton communities towards centric diatoms. In Otago, there is a lack of long term data to assess trends in lake water temperature, although a preliminary examination of air temperature records from Manapouri, Queenstown and Wanaka airports showed that some aspects of air temperature have increased at these airports over the past 25 years.

Other hypotheses for the shift in phytoplankton communities include increasing nutrient availability and a change in grazing pressure on phytoplankton due to the arrival of the invasive water flea *Daphnia pulex*. While the link between dominance of cyclotelloid diatoms and climate warming has strong support from previous studies, changes in nutrient availability and grazing pressure in Otago lakes may have benefitted *L. intermedia* and, therefore, further investigation into these potential drivers may be warranted.

As of June 2018, *L. intermedia* had been recorded in 26 lakes in New Zealand (Table 2-1). However, lake snow, or similar mucilage events, have only been reported from nine of the 26 lakes. Not all of the 26 lakes have been assessed for the presence of lake snow.

Table 2-1: A list of lakes known to contain *Lindavia intermedia* in New Zealand as of June 2018. Data from Kilroy et al. (2018) and Novis et al. (2017a, 2017b). Lake snow events are only regarded as absent (="No") when appropriate testing is known to have taken place. Trophic status is based on LAWA ratings (www.lawa.org.nz) in which 0-2 is microtrophic, 2-3 is oligotrophic, 3-4 is mesotrophic, 4-5 is eutrophic, and >5 is supertrophic; N/A = not available.

Lake	Trophic status	Year *L. intermedia* first collected	Lake snow events known from lake?	Nature of event
Hayes	4	2002-3	No	N/A
Waitaki/Aviemore/Benmore	1	2002-3	Yes	Transient
Wanaka	2	2005	Yes	Persistent
Moawhango	N/A	2005	Unknown	N/A
Tennyson	N/A	2005	Unknown	N/A
Gunn	N/A	2005	Unknown	N/A
Opuha	N/A	2005	Unknown	N/A
Heron	2	2005	Unknown	N/A
Ohau	1	2005	Unknown	N/A
Mason	N/A	2005	Unknown	N/A
Moke	N/A	2008	Yes	Unknown
Waikaremoana	1	2008	Yes	Transient
South Mavora	N/A	2009	Unknown	N/A
Coleridge	1	2015	Yes	Persistent
Wakatipu	1	2015	Yes	Transient
Hawea	1	2015	Yes	Transient
Sumner	1	2017	Yes	Unknown
McGregor	N/A	2017	Unknown	N/A
Tekapo	1	2017	Yes	Transient
Kellands	N/A	2017	Unknown	N/A
Alexandrina	3	2017	Unknown	N/A
Ruataniwha	N/A	2017	Unknown	N/A
Lyndon	3	2018	Unknown	N/A
Rotoaira	N/A	2018	Unknown	N/A
Johnson	5	2018	Unknown	N/A
Taupo	2	2018	Unknown	N/A

2.1.4 Cost-effective and efficient methods for quantitatively sampling lake snow

A lake snow sampling method has been developed for use on a boat whereby a length (e.g., 90 m) of weighted fishing line, marked at 10 m intervals, is trolled behind the boat for a distance of 1 km. A 1.2 kg torpedo-shaped steel weight is attached to the end of the line. Calibration has shown that at a tow velocity of 4 km/hr, the line descends at a 45-degree angle behind the boat into the lake, such that each 10 m segment of the line is towed through 5 m of vertical depth.

The sampling method is being used in both Lakes Wanaka and Wakatipu to identify the depths at which lake snow is present and quantify its abundance. Results from October 2017 demonstrated that lake snow abundance was highest in the top 20 m of Lake Wanaka. In contrast, very little lake snow was found in the top 10 m of the water column in Lake Wakatipu (Figure 2-1).

Further analysis could compare these depth distributions to vertical profiles of water temperature (density) and light penetration in the lakes to determine whether temperature and light constrain the vertical distributions in some way.

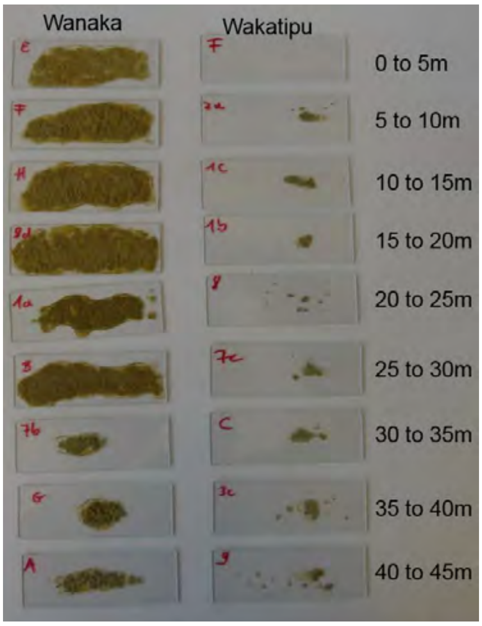

Figure 2-1: Quantities of lake snow collected from lakes Wanaka and Wakatipu during snow tows in October 2017. Reproduced with permission of Dr Marc Schallenberg.

Two short videos were played to demonstrate the clumpy and sticky nature of lake snow, and also the different sized aggregates found on the tow line. The size distribution of aggregates could provide useful information. Aggregates (at least at the macro-scale) were actually quite rare in the lakes – at times even a 1 km tow hardly collected any macro-aggregates. However, there was variation across the lakes (e.g., Stevenson Arm in Lake Wanaka can be a hotspot). In addition, at times it was observed that the aggregates in the surface layers were stickier than aggregates collected from deeper depths.

Measurement of settling velocities of the macroaggregates in the lab suggests that the aggregates rely on turbulent conditions in the lake (especially at the thermocline[3]) to maintain their position within the mixed layer. It was unclear whether there was an advantage in forming increasingly large macro-aggregates because the larger they are, the faster they sink (in the absence of turbulence). Dr Novis suggested this clumping could be useful when surface waters were depleted of nutrients – cells entering a dormant phase could benefit from aggregation which could facilitate sinking to the lake bed. Subsequently, reanimation and flux into the water column could occur, once conditions became more favourable.

Mr Glasner (Chief Engineer, QLDC) noted that layering of lake snow aggregates had been observed in the two water reservoirs in late 2016 – higher abundance of lake snow was present at the bottom of the reservoir.

The viability of the aggregates at different lake depths is unknown. Dr Novis stated that cells do deteriorate or change within macro-aggregates at depth. Composition and colour also change with

[3] The thermocline is the transition layer between warmer mixed water at the lake's surface and cooler deep water below.

depth, the latter probably reflecting a lack of photosynthesis and bacterial degradation of the pigments and polysaccharides.

To help understand the enrichment factors within macroaggregates, it was suggested that the density of single *L. intermedia* cells in free open water should be compared with the density within the aggregates.

2.2 Presentation by Cathy Kilroy

Dr Cathy Kilroy (Freshwater Ecologist at NIWA) provided an update on two aspects:

1. Decontamination using "Check, Clean, Dry" methods developed for didymo (*Research component 4(i)]*
2. Search for *L. intermedia* in historical samples *[Research component 1(ii)].*

2.2.1 Decontamination methods

As part of a wider contract for the Ministry of Primary Industries (MPI), a trial had been carried out to investigate the effectiveness of current Check, Clean, Dry methods[4] for decontamination of *L. intermedia*. The methods were originally developed for decontamination of didymo and include exposure to detergent (5% solution), bleach (2% solution), hot water (> 60°C and > 45°C) and freezing (until solid). Three further treatments were trialled; drying and salt at 4% and 10% w/v concentrations. The trials were conducted on samples of *L. intermedia* in lake snow collected from both Lakes Wanaka and Wakatipu.

The trial found that the decontamination methods effective for didymo were a little less effective on *L. intermedia*. Freezing was the only treatment that was 100% effective, while other treatments were partly effective. Detergent, bleach and drying were at least 90% effective using the 1 minute exposure time recommended in the current Check, Clean, Dry methods. An extended treatment time was recommended. For bleach, a quality product (containing at least 40 mg/L sodium hypochlorite) should be used. The hot water treatments gave ambiguous results in that it was not clear whether cells were non-viable from their appearance. Longer treatment times than the recommended 1 minute at 60°C and 20 min at 45°C may give clearer results, but this needs to be tested. The salt treatments similarly gave ambiguous results and require further testing.

The trials were performed only on algal cells in samples of lake snow slime, and not on swimwear or other fabrics.

2.2.2 Presence of *L. intermedia* in historical lake samples

The ORC commissioned a study to determine the length of time *L. intermedia* has been present in New Zealand by examining archived diatom samples from lakes and lake outlet rivers. Because *L. intermedia* had previously been named as a species in a related genus (*Cyclotella*) it was possible that identifications of *Cyclotella* in archived samples were in fact *L. intermedia*. Therefore the study included examining old samples in which *Cyclotella* had been recorded.

[4] The currently recommended Check, Clean, Dry methods aimed at slowing or preventing the spread of freshwater pests can be found at: http://www.mpi.govt.nz/travel-and-recreation/outdoor-activities/check-clean-dry/

No *L. intermedia* was found in a check of slides and samples from Landcare Research and other collections for the period 1970 to 1991. From this it was concluded that *L. intermedia* had not been identified as *Cyclotella* in the past.

A check of available lake and lake outlet diatom samples (primarily 144 samples from NIWA's diatom collection dating back to ~1998), did not add any further information to what was already known about the length of time *L. intermedia* has been present in New Zealand. The earliest identifications date back to Lakes Hayes and Aviemore in 2002 and 2003, respectively. However, the exercise identified that, by 2005, *L. intermedia* was well dispersed over both the North and South Island (i.e., much wider distribution than previously known) (Figure 2-2). A significant finding was that *L. intermedia* was present in the Moawhango River (and therefore Lake Moawhango) in 2005. Lake Moawhango is directly connected to Lake Taupo via a water diversion scheme. Following the study, there have been new identifications of *L. intermedia* in Lake Taupo and downstream lakes (in low abundance).

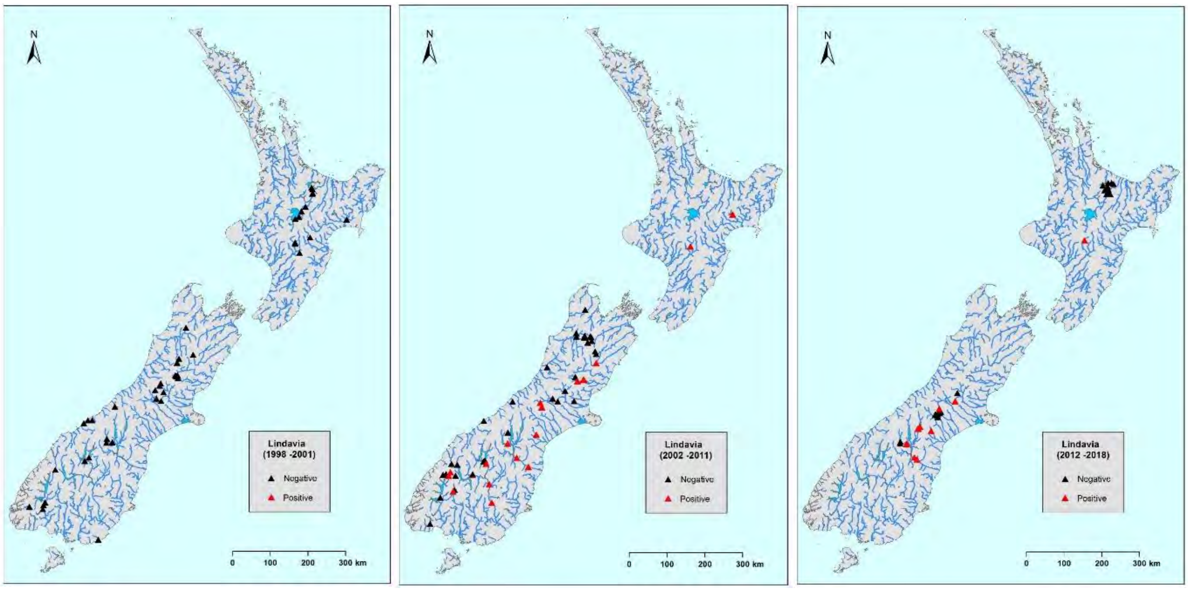

Figure 2-2: Summary of search for *L. intermedia* in archived diatom samples collected from New Zealand lakes or lake outlets. *L. intermedia* was not found in any samples collected pre-2001. Reproduced with permission of Dr Cathy Kilroy.

2.3 Presentation by Phil Novis

Dr Phil Novis (Phycology Researcher at Manaaki Whenua-Landcare Research) provided an update on four research components:

1. Investigation of cell genetics of New Zealand and overseas *L. intermedia* populations *[Research component 1(i)].*
2. Literature review on 'excessive' diatom polysaccharide from similar situations overseas *[Research component 2B(i)].*
3. The development of new sensor technology to monitor in situ polysaccharide concentrations in lakes *[Research component 3(i)]*.
4. The possibility of developing DNA methods for sensitive detection of *L. intermedia* in lakes *[Research component 3(iii)].*

2.3.1 Cell genetics

Microsatellite analysis demonstrated that all New Zealand samples were genetically identical. The New Zealand samples were also identical to samples from Youngs Lake in the U.S., which also has lake snow issues, and there was a wider genetic diversity within the species in the Northern Hemisphere. These observations are most consistent with a dispersal from the Northern Hemisphere to New Zealand; coupling these with the spreading nature of *L. intermedia* in New Zealand and the undesirable consequences of its spread means that the species should be regarded as invasive. The fact that it is invasive has other implications, namely that the drivers of *L. intermedia* productivity in New Zealand are more complex than straight environmental change (since the species was recently introduced into a new environment).

2.3.2 Literature review on diatom polysaccharide

The lake snow or slime produced in lakes very likely contains β-chitin as its structural unit. Molecules associated with the chitin influence its behaviour. Some or all of these (including the chitin) likely contribute to the transparent exopolymer (TEP) fraction extruded by *L. intermedia* cells.

The literature review identified that the production of TEP material, its aggregation, and its effects are likely promoted by:

- Light (i.e., oxygenic photosynthesis).
- Higher concentrations of cations.
- Lower concentrations of silicon, nitrogen and (especially) phosphorus.
- Turbulent mixing in the surface layer of a stratified water column.
- Higher water temperatures.
- The presence of specific diatom-associated bacteria.

Disaggregation is probably promoted by lower water temperatures, bacterial degradation, zooplankton and fish feeding, deep mixing and strong shear forces, pesticides (e.g., DCMU and polyoxin-D), nutrient or metal contamination, infection of the diatom population by parasites, and the incorporation of inorganic particles.

Lake snow particles can transform the microbial ecosystem, with consequences for other trophic levels, by:

- Increasing carbon availability to heterotrophs that release carbon dioxide and become prey for grazers.
- Creating a low oxygen (hypoxic) environment inside large aggregates leading to methane production and nitrate storage and recycling.
- Providing a carbonaceous substrate that attracts terrestrial bacteria, potentially including pathogens.

An extreme example of food web impacts – that also demonstrates the possibility for public health consequences in drinking water drawn from Lakes Wanaka and Wakatipu[5] – was pathogenic poisoning of sea otters associated with exopolysaccharides off the coast of New York. The TEP material floating in the water offshore and attaching to kelp was colonised by *E. coli* bacteria/pathogens that were eaten by snails and then by sea otters.

A large methane flux (70 tonnes/year) measured from Lake Constance was attributed to lake snow; the lake was a source of methane in summer and a sink in winter. As methane is a potent greenhouse gas, methane production by lake snow may warrant further investigation.

The final part of the presentation turned to the use of parasites as a possible biological control. This option is attractive in part because other species of *Lindavia* have been very seldom reported in New Zealand, so the by-kill of close relatives of *L. intermedia* would be of minimal consequence. Certain (oomycete and chytrid) parasites of centric diatoms are known to be species (or even strain) specific, lending themselves to potential application as a biocontrol that does not involve modifying the trophic or toxicological status of a lake (e.g., from chemical dosing). These parasites spread between host cells by swimming zoospores. In one study, parasites reduced the diatom cells present by 25% per day.

Further investigation is needed into a possible biological control for *Lindavia*. Some expertise in the study, isolation, culturing and archiving of oomycetes and chytrids, as well as implementation of biological control, exists in New Zealand within Landcare Research and University of Otago, but there will be a steep learning curve in combining these in the proposed application. Dr Novis was not aware of any reports of native parasites of centric diatoms and believed that overseas samples would need to be obtained (under strict quarantine procedures) and a lab culture developed in order to target *Lindavia*. A first step would be to undertake metagenomics on samples from overseas (this would involve no risk, as the samples could be ethanol preserved on collection).

2.3.3 New sensor technology to monitor in situ polysaccharide concentrations

As part of the MBIE-funded Smart Ideas "Lake snow tool box" research project[6], spectrometry has been trialled as a potential tool to monitor polysaccharide concentrations in lakes. Spectrometry was found to be a very sensitive technique for the material that can discriminate between lakes and depths within lakes. The spectrometer unit initially looked at is about 16 cm long and requires both a laser source and power supply. Due to cost of off the shelf models, a dedicated spectrometer unit is now being built as part of the project.

2.3.4 DNA methods for sensitive detection of *L. intermedia* in lakes

Initial work under the "Lake snow tool box" research project has demonstrated a DNA method that can quantify *Lindavia* abundance in lake water samples without specialist knowledge. While the method offers high potential as monitoring tool it still requires specificity testing.

A common means of obtaining phytoplankton for quantitative analysis is to use nets ("plankton tows"). Due to the inaccuracy of estimating water flow through a net, a filter-based method is more

[5] The municipal water supplies for Wanaka and Queenstown are supplied from Lakes Wanaka and Queenstown, respectively. Both lakes receive urban stormwater inputs and, at times (e.g., very heavy rain events), wastewater inputs.

[6] This trial forms part of the MBIE-funded Smart Ideas "Lake snow toolbox" research project led by Landcare Research. It was noted that a Special Session on this research will be held at the NZ Freshwater Sciences Society in December 2018.

quantitatively accurate than other methods. In the first instance, the method might simply be used for presence/absence screening to confirm if *Lindavia* is in a lake.

In response to questions about the volume of water to be filtered given *Lindavia's* patchy distribution, Dr Novis noted that the method could be tailored to user needs, including use with a snow tow. The sensitivity of the method was such that probably a single cell could be detected.

The cost per sample was yet to be determined but was unlikely to be cheap. Processing samples in bulk could reduce costs.

2.4 Presentation by Chris Arbuckle

Chris Arbuckle (Environmental Consultant, Aspiring Environmental and Touchstone) provided an overview of a citizen science initiative involving members of the Wanaka Lake Swimmers Club. This project is additional to the citizen science-based web reporting initiative set out in Appendix B.

2.4.1 Wanaka Lake Swimmers' lake snow study

The Wanaka Lake Swimmers' lake snow study is contributing to a larger Touchstone community-based water project designed to connect people in the community with their lake. It is also aimed at building an understanding about current and potential future water quality challenges facing Lake Wanaka. The project involves members of the community collecting environmental measurements and observations, including: changes in lake visual water clarity and colour through time; lake water samples for laboratory determination of nitrogen, *E. coli* and algal biomass to supplement monthly sampling by the ORC; and lake snow/algal biomass estimates from "baby wipes" used in cleaning down after swimming and other methods (Figure 2-3).

A key aim of the study is to raise awareness of biosecurity issues at large swim events such as the annual Ruby Island swim. Over 400 swimmers participated in the January 2018 swim, highlighting the significance of such events. Drying wetsuits and swimwear is being emphasised as the key treatment to stop the spread of lake snow after swim events because most other decontamination methods were not favoured (e.g., washing gear in bins with bleach or detergent).

From October, swimmers undertake Sunday morning swims around Ruby Island, providing opportunities to collect several environmental measurements and provide access to another source of data on the extent and effects of lake snow. During method trials and swim events, lake snow has proven to be particularly irritable to female swimmers after longer swims, where it has attached to their finer body hair and acted as an abrasive layer between their skin and wetsuit.

The project has been successful in raising awareness in the local community and building 'local champions'.

Figure 2-3: Examples of algal biomass captured on "body wipes" following swimming in Lake Wanaka. Photos supplied courtesy of Chris Arbuckle.

3 MPI comments and discussion

Samuel Beaumont (Adviser, Long-term Planning and Transition) provided some brief comments on behalf of MPI in response to the science updates. It was acknowledged that *L. intermedia* is very likely invasive[7] and that there is a lack of tools to manage it.

The MPI Freshwater Biosecurity Partnership focusses on the spread of invasive organisms rather than on managing sites where species like *L. intermedia* are already present. Most of the funding is allocated to the Clean, Check, Dry programme, with only a small amount available for research such as the trial Dr Kilroy carried out. The Clean, Check, Dry programme is currently under review to assess whether the focus is on the right pathways and user groups.

MPI is keen to keep up with the research. There is an Annual Governance meeting for the Freshwater Biosecurity Partnership in September/October. The workshop findings will be taken back to the governance meeting.

Dr Palmer from the ORC noted that control at source, if effective, would reduce spread.

Mr Glasner from QLDC stated that the lake water supply intakes from both Lakes Wanaka and Wakatipu are chlorinated, but not filtered. Could the water supply system be a potential source of distribution for *L. intermedia*? In response, it was suggested that some tap water samples be sent to Dr Kilroy for assessment. Staining of samples for viability is needed.

Ms Velvin from MPI enquired about the ability for QLDC to manipulate the lake water intake level. Mr Glasner noted that tests done in the past had indicated that it wasn't possible to go deep enough to avoid lake snow. The council will need to plan for water treatment upgrade requirements across the entire district over the next 10 years – filtering could cost millions more than the current operation.

[7] An "invasive species" is defined by the National Invasive Species Information Center as a species that is:
1) non-native (or alien) to the ecosystem under consideration, and
2) whose introduction causes, or is likely to cause, economic or environmental harm, or harm to human health.
https://www.invasivespeciesinfo.gov/whatis.shtml

4 Discussion on research needs

This section captures the key points of discussion following the research updates on projects that formed part of the original research programme (Appendix B). Appendix C presents a revised research priorities table developed with input from Dr Novis and Dr Schallenberg following the workshop.

Note: The research discussion was shorter than originally intended. The workshop was late starting because fog disrupted flights landing at Dunedin Airport; three participants had to return to Christchurch and were only able to join the meeting by Skype. It was difficult for these participants, which included Dr Novis and Dr Kilroy, to hear all of the round-table discussion.

4.1 Drivers

4.1.1 Climate change

The literature review has indicated a need to look further at climatic drivers. While there was lack of long-term water temperature data for Otago's lakes, there were likely records for some other New Zealand lakes that could be examined to determine whether there have been significant trends in lake temperatures over time.

Dr Palmer noted that from a climate change perspective, the ORC needs to weigh up competing funding demands, such as for investigating flooding in South Dunedin. He suggested that a few of the researchers scope up what a possible investigation into the effects of climate change could look like. It was felt that the focus needed to be on very small changes in temperature. Dr Bayer suggested that climate data (e.g., air temperature) could be used to hindcast historical lake water temperatures.

Dr Bayer supported the development of a tool that could predict temperatures / conditions in which lake snow will be a problem. Dr Novis noted that climate change is often phrased in averages, but it might be extremes that are important.

Dr Palmer said Otago lacks certain data and it will take time to get better information. He asked if a wider (national) set of study lakes could be identified. It was agreed that lake snow was a national interest/problem and there was a need to bring North Island regional councils on board. Mr Tulagi (Waikato Regional Council, WRC) said WRC would be happy to supply data/samples and there may be potential to support research. He had attended today given the recent positive identifications of *Lindavia* in some Waikato lakes – including Lake Taupo – and wanting to get up to speed with lake snow.

Dr Kilroy noted that there was a modelling component coming up in Dr Novis's MBIE research project to build a spatial model of where *Lindavia* is and isn't – similar to that done for didymo.

Dr Novis was keen to get fresh or preserved samples from across New Zealand to develop a method to quantify the gene that produces the mucilage. Brian Quinn (MPI) advised that the MPI diagnostics lab has some funding to detect new spread of organisms – it was best to approach MPI at the start of the financial year.

Dr Schallenberg said a culture of *Lindavia* would be good to have to help study: (1) the factors favouring the dominance of *L intermedia* in phytoplankton communities and (2) the factors favouring polysaccharide production by *L intermedia*.

4.1.2 Daphnia

Dr Schallenberg felt it was important to understand environmental interactions, noting that the increasing grazing pressure by invasive *Daphnia* could plausibly affect the phytoplankton, warranting some investigation as to potential effects of grazing pressure on polysaccharide production in *L. intemedia* and on aggregate formation. It was suggested that this could be progressed via an MSc thesis.

4.1.3 Nutrients

With limited long-term records on lake nutrient concentrations, data from lake outlet river sites could provide a proxy for the nutrient status of their upstream lakes. This information could be useful in the spatial modelling of *Lindavia* presence.

Dr Schallenberg wondered if the latest updates to the CLUES[8] model and Landcover Database could be utilised to assess land use change and potential changes in nutrient losses through time. Mr Arbuckle suggested that this approach was too coarse to be useful; the changes were more subtle and at the farm scale – stocking rates, farming practices, etc. It is difficult getting this information. Farm diaries can be useful. An AgResearch paper on the Overseer model has information on nutrient losses.

Dr Schallenberg thought an experimental approach might be useful to see if the addition of nitrogen and phosphorus stimulates more production of lake snow.

Dr Novis said resolution was needed as to why there is no lake snow in Lake Hayes when *L. intermedia* was in the lake. Lake Hayes is the only eutrophic lake which is known to contain *L. intermedia* and is also a lake with *L. intermedia* in which macroaggregates have not been found. This interesting lack of aggregate formation may have something to do with the lake's eutrophic state or it might be related to something else such as residues from pesticides (e.g., if applied at the golf course).

Dr Schallenberg said a habitat template should be created for the various lakes where *Lindavia* has been detected. Only a small proportion of these lakes have produced lake snow – but all need to be tested for lake snow. Dr Kilroy noted there were a lot of lakes that we have no information on.

4.2 Spread and control

Mr Beaumont commented that the Clean, Check, Dry campaign has been running for 10 years (for all freshwater pests). Dr Kilroy's research had validated the methods reasonably well and the current review would determine if existing messages or delivery need to change.

Mr Arbuckle felt there was apathy amongst the public. Most people associated the Clean, Check, Dry campaign with didymo, not lake snow. There was a need to tailor messages to different user groups. For example, swimmers don't want to put wetsuits in 'chemical' solutions.

[8] Catchment Land Use for Environmental Sustainability (CLUES) is a GIS-based modelling system developed by NIWA to assess the effects of land use change on water quality and other indicators.

Dr Schallenberg didn’t think it was possible to stop the spread from lake-to lake – lake snow is sticky and many potential vectors exist other than human transfer via recreation exist (e.g., fish, ducks, wind, water transfers, etc.). The key biosecurity message is that more effort should be put in at the border to stop such nuisance micro-organisms from entering New Zealand.

The discussion returned to the potential for a parasite control and it was agreed that the necessary work to investigate this should be scoped out. Dr Novis acknowledged that it was a long shot but he suspected the algae are parasitized by a variety of organisms, some of which are highly specific and could therefore become safe biological controls. None are known from *Lindavia* specifically, but it would be unsurprising if they existed. If such parasites are absent in New Zealand it would help to explain why lake snow is common here but not overseas.

Dr Palmer asked what opportunities existed to link up with research occurring on Lake Youngs in the U.S. Dr Schallenberg noted that the focus there is on trying to understand it, rather than controlling it. Dr Novis added that the U.S. only has one lake affected so spread is less of an issue.

Mr Manning asked how quickly lab-cultured *Lindavia* would reproduce and spread in a lake. Dr Novis said work in the U.S. suggests slow reproduction at low temperature and light conditions. He wasn’t sure how quickly it would spread – this was dependent on vectors, currents, etc.

4.3 Other

Dr Schallenberg asked if there was any possibility that Lake Youngs had a New Zealand *Lindavia* species? Dr Novis thought that this was highly unlikely – the U.S. had a broader genotypic diversity of *L. intermedia* compared with New Zealand. *L. intermedia* was definitely present in Lake Youngs in 2008 – originally identified as *Cyclotella*.

5 Concluding comments and next steps

A significant amount of the highest priority research identified from the December 2016 technical workshop has been carried out. The revised future research programme (Appendix C) centres on two 'high priority' areas:

- Investigating the drivers for 'excessive' polysaccharide mucilage by *L. intermedia* in New Zealand, including climate factors, changes in nutrient availability and grazing pressure from *Daphnia*, and
- A new research component to assess the potential use of a parasitic biological control agent.

These two areas for investigation need to be scoped and funding opportunities explored. Given that the distribution of *L. intermedia* across New Zealand is much wider than originally realised – and there is potential for lake snow issues to arise in lakes outside of Otago – a national lake snow working group should be established. The basis for such a group already exists as part of the current MBIE-funded 'Lake snow toolbox' research project led by Landcare Research.

Further assessment of affected lakes' potable water supplies was also suggested, including checks that *L. intermedia* is not potentially being spread by the transfer of tap water.

6 Acknowledgements

Dr Marc Schallenberg, Dr Cathy Kilroy, Dr Phil Novis and Chris Arbuckle provided valuable contributions at the workshop and in the review and finalisation of this report.

Thank you to Jasmine Weaver (ORC) for organising the workshop venue and catering.

7 References

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Appendix A Workshop agenda and participants

Lake Snow technical workshop

Date & time: 8 August 2018, 10:00 – 3:30 pm

Venue: Theomin Balcony Room, Otago Museum

Facilitator: Juliet Milne (NIWA)

Agenda

9:30 am	Arrival (tea & coffee, light snack)
10:00	Introductions & housekeeping (Juliet Milne and Cr Ella Lawton)
10:05	Workshop purpose
10:10	Recap: Our understanding at December 2016 – science, issues & research priorities (Juliet Milne)
10:30	Research updates – what have we learnt in the last 18 months?
	• Dr Marc Schallenberg (University of Otago) • Dr Cathy Kilroy (NIWA) • Dr Phil Novis (Landcare Research) • Chris Arbuckle (Aspiring Environmental)
12:00	Council & MPI comments
12:30	Lunch
1:00 pm	Discussion (in light of updated current state of knowledge) • Research gaps and priorities – confirm/adjust the original research work programme • Progressing priority research – funding/co-funding opportunities
3:30 pm	Close and next steps

Attendee list

Name	Position	Organisation
Rachel Ozanne	Environmental Scientist	Otago Regional Council
Nathan Manning	Environmental Officer	Otago Regional Council
Stephanie Dwyer	Compliance Officer	Otago Regional Council
Gavin Palmer	Director Engineering, Hazards and Science	Otago Regional Council
Jean-Luc Payan	Acting Resource Science Manager	Otago Regional Council
Ella Lawton	Councillor	Otago Regional Council
Michael Deaker	Councillor	Otago Regional Council
Ulrich Glasner	Chief Engineer - Property & Infrastructure	Queenstown Lakes District Council
Juliet Milne	Resource Management Scientist	NIWA
Cathy Kilroy	Freshwater Ecologist	NIWA
Anika Kuczynski	Freshwater Ecologist/Water Quality Modeller	NIWA
Phil Novis	Phycology Researcher	Landcare Research
Marc Schallenberg	Research Fellow	University of Otago
Chris Arbuckle	Environmental Scientist/Consultant	Aspiring Environmental
Tina Bayer	Environmental Scientist	Environment Canterbury
Asaeli Tulagi	Senior Environmental Scientist	Waikato Regional Council
Brian Quinn	Senior Scientist - Botany	MPI
Sam Beaumont	Adviser, Long-term Planning & Transition	MPI
Frances Velvin	National Interest Pest Responses (NIPR) Programme Manager	MPI
Apologies		
Carolyn Burns	Emeritus Professor	University of Otago
Gerry Closs	Professor	University of Otago
David Kelly	Senior Scientist	Cawthron Institute
Janine Kamke	Scientist – Water Quality	Horizons Regional Council
Keryn Roberts	Environmental Scientist – Estuaries and Lakes	Environment Southland
Nick Ward	Team Leader – Ecosystem Response	Environment Southland
Randall Milne	Senior Biosecurity Officer	Environment Southland

Appendix B Research programme

Reproduced from Ryder (2017)

Priority Ranking	Code
High - Immediate	[dark red]
High - Medium term	[orange]
Medium - Medium term	[light orange]

RESEARCH GROUP	COMPONENT	PRIORITY RANKING	INDICATIVE TIMING
Is *Lindavia intermedia* a native or non-native species? How long has it been here for?	(i) Investigation of cell genetics (microsatellite analysis) that is underway, but won't be completed until the middle of 2017.	High - Immediate	mid 2017
	(ii) Comprehensive examination of NZ diatom samples, collections and reports.	High - Immediate	3-6 months from starting
	(iii) Historical dynamics of *L. intermedia* in NZ lakes from which it has been reported using palaeolimnological diatom analysis of dated sediment cores.	High - Immediate	
What are the drivers of: *L. intermedia* dominance in lakes; and polysaccharide overproduction by *L. intermedia*?	A. *L. intermedia* – drivers behind distribution		
	(i) Literature review of shifts in lake phytoplankton to increased dominance by centric diatoms.	High - Immediate	3-6 months from starting
	(ii) Are historical *L. intermedia* dynamics correlated to environmental drivers in our lakes? [Note: This work is covered in the University of Otago MBIE bid.]	Medium - Medium term	
	(iii) Are proliferations of *D. geminata* (Didymo) and *L. intermedia* in South Island waters related to a common driver?	Medium - Medium term	hard to estimate
	B. Polysaccharide overproduction		
	(i) Comprehensive literature review on diatom polysaccharide overproduction.	High - Immediate	3-6 months from starting
	(i) Study of the relationships between diatom polysaccharide overproduction in NZ and; (1) nutrient availability, (2) climate warming, (3) wave action and (4) grazing pressure. [Note: This work is covered in the University of Otago MBIE bid.]	High - Medium term	possibly 2-3 years from starting

RESEARCH GROUP	COMPONENT	PRIORITY RANKING	INDICATIVE TIMING
Can we develop technologies for effective sampling and monitoring of *L. intermedia* and lake snow? [Note: All of these points are covered by the University of Otago MBIE.]	(i) The development of new sensor technology to monitor *in situ* polysaccharide concentrations in lakes.		possibly 2-3 years from starting
	(ii) The development of cost-effective and efficient methods for quantitatively sampling lake snow in lakes (at different depths).		1-1.5 years from starting
	(iii) Can environmental DNA methods be developed for the sensitive detection of *L. intermedia* in lakes?		6 months from starting
How might the spread of *L. intermedia* between lakes be stopped or slowed? [Note: assumes implementing a containment program is worthwhile]	(i) Are the BNZ Didymo sanitation methods adequate for the disinfection of *L. intermedia*?		Currently underway
	(ii) Are additional scrubbing methods needed to remove *L. intermedia* from boats and recreational equipment?		
	(iii) Does lake snow contain viable *L. intermedia* cells when dry?		6 months from starting
Other priority research/work areas discussed during the December lake snow technical workshop.	(i) Support for citizen science – web reporting of lake snow encounters.		Otago Regional Council already have established an online reporting system
	(ii) Working with the professional trout guide community to document lake snow dynamics around the lakes.		

Appendix C Revised research programme

The following table represents initial thoughts on a revised research programme into the future addressing research that is not currently underway. Further discussion is needed to develop the scope, and to confirm costings and research providers.

Sub-programme	Priority ranking	Indicative associated costs	Justification/comments	Likely lead agency
1) What are the drivers of (A) *L. intermedia* dominance in lakes?				
a) Are historical *L. intermedia* dynamics correlated to environmental drivers in our lakes?	Medium - Medium term	Will be funded via the existing MBIE Endeavour "Lakes380" Research Programme, jointly led by GNS Science and the Cawthron Institute	This work is extensive and best delivered through university postgraduate and post-doctoral research programmes.	Univ. of Otago
b) Are proliferations of *Didymo* and *L. intermedia* in South Island waters related to a common driver or species incursion?	Low-medium - Medium term	Costing and delivery difficult to estimate until study design developed (originally estimated in 2017 at a minimum of $19K)	If the timing and spread of these two incursions are coherent, then that would provide evidence of a common incursion (both place and time) and support management of future incursions and responses.	Univ. of Otago / CRIs
2) What are the drivers of (B) polysaccharide overproduction by *L. intermedia*?				
2a) Investigation into climatic drivers[9]: ▪ Assessment of historic lake water temperature and other climatic records in NZ ▪ Experiment-based investigations (e.g., water temperature changes) 2b) Nutrient-related investigations: ▪ Assessment of historic data from affected lake catchments ▪ Experiment-based investigations of the effects of changes in nutrient availability 2c) Investigation into changes in grazing pressure from *Daphnia pulex*	High – Medium-term	~$200K spread over 3 years as a PhD project	High priority given the actual and potential impacts of lake snow – Part 2b) has potential implications for the rural community if nutrients are a key driver. Various options exist to structure this research which require scoping (e.g., delivery could be shortened to 1-2 years using research staff at ~$250K, part 2)c could be a separate MSc thesis, etc.) but cost efficiencies are greatest in progressing all 3 components together.	Univ. of Otago with CRI and RC support

[9] The potential for methane generation from lake snow could also be investigated (medium-high priority) – needs costing.

Sub-programme	Priority Ranking	Indicative associated costs	Justification/comments	Lead agency
3) Are there biocontrol agents that could be used on *L. intermedia*?				
3a) Study to investigate the possibility of using natural parasites of *L. intermedia* as a form of biological control via reducing abundance and therefore mucilage production	High – Short-medium term	Year 1: $28K Year 2: $67K Year 3: $66K Delivery 3 years	3-year project with associated stage-gates ▪ Year 1 (Feb-Jun 2019): National and international sample collection, DNA extraction and assembling of metabarcoding results. Results determine if work proceeds to year 2 ▪ Year 2: Culture-related work. Work ceases here if unable to get anything to grow ▪ Year 3: Culture-testing under quarantine conditions	Landcare Research

The following table outlines existing medium to high priority research from Appendix B that is continuing.

Sub-programme	Associated costs	Justification	Lead agency
Can we develop technologies for effective sampling and monitoring of *L. intermedia* and lake snow?			
i) The development of new sensor technology to monitor in situ polysaccharide concentrations in lakes.	Funded via current MBIE Endeavour Smart Ideas project and in progress	Capacity to monitor the abundance and spatial variability of lake snow is critical to understanding the environmental drivers that lead to lake snow production	Landcare Research / Univ. Of Otago
ii) The development of cost-effective and efficient methods for quantitatively sampling lake snow in lakes (at different depths).			
iii) Can DNA methods be developed for the sensitive detection of *L. intermedia* in lakes?			Landcare Research / Cawthron