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OVERVIEW OF HAZARDS

Introduction

The Hazards Group was the first group to commence detailed work for the Lifelines Project as this provided the scenarios and basic mapping of hazard areas for the other groups. A hazards seminar was held on 19 November 1996 to present information to all participants in the Lifelines Project and papers presented have formed the core of this section. Authors were asked to review their contributions and update them if further information become available. Maps have been redrafted for inclusion in this report. More detailed maps are held by the Dunedin City Council.

Earthquake

Seismic hazard to Dunedin lifelines is evaluated within the context of a more frequent and less intense *Design Event* and a less frequent *Maximum Credible Event*. The *Design Event* is capable of producing bedrock intensities (Modified Mercalli Scale) in Dunedin of MM VII and could be generated by failure along any of the Otago faults, the Alpine Fault or by small earthquakes within 20km of Dunedin similar to the 1974 Dunedin earthquake. We estimate a 100-year frequency of a *Design Event* derived from combining estimates of the three different types of source. The source of the *Maximum Credible Event* is a single continuous rupture of 40km on the Akatore Fault to within 20km of Dunedin centre. The *Maximum Credible Event* is capable of producing MM IX bedrock intensity in Dunedin and has an estimated frequency of approximately 7,000 years based upon radiometric dating of fault scarps. Our estimates of shaking intensity are generalised for bedrock and do not consider the effects of directionality or frequency content of shaking. Shaking for both *Design* and *Maximum Credible* events is likely to be intensified by one level on the Modified Mercalli Scale in regions of unconsolidated sediment and topographic focusing. Preliminary studies show that extensive, low lying parts of the greater Dunedin area are susceptible to liquefaction damage. In the event of strong earthquake shaking of MM Intensity VII or greater, generated by a local or more distant large magnitude earthquake, liquefaction-related damage to these parts of Dunedin could be severe, increasing with higher intensity of shaking. Such damage might rupture buried pipelines, especially those made of brittle materials, disrupt water and gas supplies, sewer and stormwater disposal, power and telephone cables, transport routes such as road and rail, port facilities, and tear apart shallow founded buildings. Depending on its severity, this damage might take weeks to months to repair. Potential regions of enhanced shaking are indicated on accompanying maps.

Flooding

Flooding and river and stream control within the greater Dunedin City has always been an issue with the Taieri River, Silverstream, Owhiro Creek, Water of Leith and Lindsay Creek posing the greater threats. The lower lying parts of Dunedin and the Taieri Plains have been subject to extensive flooding damage over the last 150 years and works have been constructed in an attempt to reduce the frequency and severity of flooding. Such works are constructed to a standard (normally a 1% or 2% probability of exceedance in any one year) but from time to time events may occur which will exceed the capacity of such works. Associated with flooding are stream bank erosion and high velocity water flow, which can cause localised damage to structures. Stormwater systems are normally constructed to a lesser standard than those for rivers and streams and localised flooding due to high intensity rainfalls, often associated with cyclonic weather patterns or thunderstorms, may impact on lifelines but is not covered by the mapping associated with this section.

Landslide

Landslides are defined as masses of rock and soil, which have moved downhill under the influence of gravity. They occur wherever combinations of rock or soil type, slope, and water content are unfavourable, and are triggered by heavy rain, earthquakes, or by oversteepening of slopes. In the Dunedin region, large landslides are concentrated in the Silverpeaks area (steep slopes); around southwest Dunedin (including Abbotsford), and on the Kilmog (weak rock types). Smaller landslides, concentrated in soils rather than in bedrock, occur on the Otago Peninsula and on volcanic rocks around the city hills. Landslide mapping combined with geology and topography can identify where future landslides may occur, but not when; that factor is controlled by seismic shaking or the weather.

Meteorological
The major meteorological hazards likely to affect lifelines are windstorms, heavy snow and persistent ice, and subtropical cyclones. There is good knowledge about past events from over 130 years of climate data and newspaper accounts. Design events are as follows:

- Wind, gusts of 130 knots on high exposed ground and over 80 knots in city hill suburbs.
- Snow, depths of over 30 cm at sea level and 50-200 cm in hill suburbs lasting three days.
- Subtropical cyclone, winds of 50-100 knots, rainfall in excess of 220mm in 24 hours, and storm surges of 1-2 m along the coast and of 0.5m in the harbour.

By their very nature, meteorological hazards affect the whole of the city simultaneously and will disrupt many lifelines, including main access roads, the rail link, the airport, electricity supplies and telecommunications.

Tsunami and Storm Surge
The Dunedin coastline is approximately 280km in length and is generally exposed to the east or south. Tsunamis are seismically generated sea waves capable of inflicting considerable damage at sites remote from their source areas. The maximum credible tsunami event (with an estimated return period of about 350 years) would result in water levels estimated as 3.9m, 2.8m, and 1.7m above MSL for open coast oriented to the south, oriented to the north, and at Dunedin wharfs respectively. Tsunamis from Hawaii or South America would take over nine hours to arrive and hence warning should be available, but those generated from an earthquake close offshore would arrive within minutes and effective warning is unlikely. Storm surges arise from low atmospheric pressure accompanied by wind stress on the water surface with the maximum credible storm surge event calculated to be in the range 0.7-0.8m above the tide level. Wave run-up from either storm surge or tsunami depends on local coastline features and further work to identify the areas that could be affected is progressing. Areas with ground elevations less than 3m above MSL are at high potential risk from both tsunami and storm surge.

Technological
Technological hazards arise from the human introduction of substances and practices which have potential to cause harm or damage by accident or as a result of malicious or negligent acts. Damage to lifelines could be caused by explosion, spillage of hazardous substances, fire, transportation accidents, failure of built structures and terrorism or sabotage. While safety standards and security systems may reduce the probability of these hazards, they cannot be eliminated altogether. Because of the random nature of many technological hazards, lifeline owners need to investigate the risk from these on a site-by-site basis.

EARTHQUAKE HAZARD
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Introduction
In assessing the earthquake hazard to lifelines, the seismic hazard has been considered as arising from two different classes of earthquake; the “Design event” and the “Maximum credible event”. The accompanying maps pertain to the maximum credible event. In this report, we do not differentiate the distribution of bedrock intensity within Dunedin for the design event, although any individual event will be likely to produce an uneven distribution of bedrock intensities within the city.

Definitions
Felt intensities are measured on the Modified Mercalli Scale - usually written MM VII (for example). Engineering has widely adopted the use of Arabic characters in substitution for the Roman letters i.e. (MM7) and the reader should be aware of this equivalence (See the appendix to this section of the report on earthquake hazard).

Earthquake magnitudes are measured on the Richter Scale - usually written M5.5 (for example).

Design Event

Working definition
Capable of producing bedrock intensities in the Dunedin region of MM VII.

Potential Sources of the Design Earthquake
The design earthquake can be generated by:

- Rupture along any one of the longer fault segments that bound the range fronts throughout central and eastern Otago (see map Earthquake Hazard - Faultlines) not including the Akatore Fault discussed below. Each of at least 10 faults within a 100km radius of Dunedin could move in M6 events. In addition, larger events on any of the western Otago fault zones or eastern Fiordland bounding faults could generate similar intensities in Dunedin.
  Frequency: No single fault segment is highly active within this group, each having poorly constrained recurrence intervals in the order of 5000 years. Assuming even distribution of events in time, a likely recurrence interval of an M6 quake on at least one of the structures is 300- 500 years.

- Great earthquakes along the Alpine Fault (M>7.5) including the Fiordland onshore and offshore segments. (NB. The Fiordland section of the Alpine Fault is not included in the Alpine Fault source area used by McCahon, Yetton and Cook, 1993).
  Frequency: 200-400 years

- Small to moderate (M4.5-M5.5) earthquakes within 20km radius of Dunedin centre. The 1974 Dunedin earthquake (M4.9) produced maximum intensities of MM VII in a limited area. Fault segments capable of generating these smaller earthquakes are difficult or impossible to recognise in surface geology.
  Frequency: Uncertain; probably 150 years at the top of the range.

Return Period of Design Event
About 100 years. This estimate is similar to that made by McCahon et al (1993) for an MM VII event based on calculated frequency of earthquakes in all contributing areas of the southern South Island.

Distribution of Isoseismals
Because the specific source of the next design event is unknown, we take a conservative view and assume the whole city area is subject to MM VII intensity. In the case of small to moderate earthquakes within 20km of Dunedin this is clearly unlikely and strong gradients in intensity will be present. In the case of rupture along one of the longer fault segments in Otago, variations in intensity, due to distance from the source, will also occur, whereas for Alpine Fault movements, a more uniform intensity distribution for the city is likely, due to the distance from the epicentre. Amplification of shaking due to ground conditions also needs to be considered and best estimates of these areas are shown on the earthquake hazard mapping.

Maximum Credible Event

Working Definition
A surface breaking event on a fault of the Akatore system producing a probable maximum bedrock intensity in the city area of MM IX.

Source
A single continuous rupture along 40km of the Akatore Fault, with rupture extending to within 20km from the centre of Dunedin. The epicentre is taken to be offshore just north of Taieri Mouth with the earthquake magnitude estimated as M 7.0.

Return Period
Approximately 7000 years (5000-10,000 years)

Distribution of Isoseismals
Bedrock intensity will be strongly localised and have steep gradients within the city area. General bedrock isoseismals have been calculated using general attenuation relationships determined for southern New Zealand. Local amplification effects will be strong.

Earthquake-Generated Landslides

Much of Dunedin is sited on relatively steep topography, with areas of known instability (after McCahon et al 1993). Large earthquakes could trigger movement on existing landslides, where the movement would probably be limited, or generate new landslides, which would occur only if the slope was already at marginal stability. Areas vulnerable to new earthquake-triggered movement are difficult to determine, and the best indication is the distribution of known mass movement features.

Existing landslides would probably move with only small displacements with damage confined to the slide perimeters. New landslides may be initiated if other conditions such as slope angle, soil strength, and groundwater pressures already result in the slope being at or near equilibrium. Such areas are difficult to determine, and the best guide is provided by the distribution of static mass movement features. A significant area of South Dunedin is potentially vulnerable to deep-seated, seismically triggered landsliding, but probably only during earthquakes with return periods in excess of 150-200 years (i.e. longer than the Design Event). The absence of large landslides developing or reactivating in the 1974 earthquake suggests the triggering event must be of greater intensity, duration or frequency.

Pre-existing groundwater conditions are less important in the moderate to high risk areas of Dunedin than they are, for example, in Christchurch. However, there would be a significantly greater chance of major failures developing if the earthquake were to occur in the late winter or early spring when groundwater levels are generally highest.

Earthquake Hazard Maps

Maps of the city area portraying potential levels of seismic hazard are based on several sources (see bibliography); the areas of potential intensification within the metropolitan area are largely based on the EQC report by Soils Foundations Ltd. (McCahon et al, 1993).

Earthquake Hazard- Faultlines

This map shows quaternary faulting, maximum credible intensity, and amplification areas.
The faults shown on this map are all those known and for which some evidence exists of Quaternary movement (movement in the last 2 million years). They are further subdivided into two categories:

- Faults with evidence of Late Quaternary (last 500,000 years) movement are coloured red (these would rank as Active Faults - Class 1, 2 or 3 on the NZ classification system).
- Faults with evidence of Quaternary movement, but with no evidence for Late Quaternary displacement (although this is still possible) are coloured blue. We have not tried to subdivide faults any further (e.g. into Active Faults, Classes 1, 2 & 3) as there is little detailed information available on the various faults so that classification would be based more on lack of data than on positive information. The exception is the Akatore Fault, for which sufficient evidence exists to classify it as a Class 1 Active Fault (Norris et al 1994).

The map shows areas of likely enhancement of intensity colour coded into two levels:

- Areas of >20m of unconsolidated sediment; we estimate here a probable intensification by 1 level on the MM scale.
- Areas of <20m, or unknown thickness, of unconsolidated sediment; here we indicate the probability of some degree of intensification between 0-1 division on the MM scale.
  Note that areas of intensification due to factors other than sediment thicknesses (e.g. topographic focussing) are not shown.

Earthquake Hazard-Areas of Intensification of Shaking

This map showing urban area quaternary faulting, maximum credible intensity and amplification areas.
The Maximum Credible Event is modelled as a magnitude M7 event on the northern section of the Akatore (or parallel) fault. Isoseismals for intensities MM IX and VIII are shown together with areas of likely intensification.

The position of each isoseismal is calculated from the intensity/magnitude/distance relationships presented by McCahon et al (1993, p.35, partly based on Smith, 1978). It should be stressed that the isoseismals are only approximate and in any case merely represent arbitrary divisions of a continuum.

This is a more detailed map of the metropolitan area where more specific information exists, based on site investigations reported by McCahon et al (1993), and on the effects of the 1974 event. The map shows areas of likely enhancement of intensity - areas are colour coded into two levels:

- Areas of >20m of unconsolidated sediment; we estimate here a probable intensification by 1 level on the MM scale.
- Areas of <20m, or unknown thickness, of unconsolidated sediment; here we indicate the probability of some degree of intensification between 0-1 division on the MM scale.

It should be stressed that boundaries between areas of background (bedrock) intensity and those of potentially enhanced intensity should be viewed as generalisations and not accurate to the precision of the line on the map.

Also shown are areas where probable topographic focussing caused enhancement of intensity during the 1974 earthquake (Bishop 1974, McCahon et al, 1993). Since this earthquake was in a roughly similar position to our estimated worst case event, we feel there is some justification for this approach.

This map is based mainly on McCahon et al (1993), also incorporating information from Bishop (1974) and Adams & Keen (1974). As for the Design Event, the areas of >20m thickness of unconsolidated sediment are outlined as areas where intensification of shaking by approximately 1 division on the Modified Mercalli scale may occur. Areas where some lesser degree of intensification may be expected are also shown. It must be stressed that the degrees of intensification are very rough estimates and in any particular event, intensities may locally rise higher than this. Without detailed and complex modelling of wave propagation, such effects are beyond the scope of this report. It should be noted that the greatest thickness of sediment occurs in a linear zone extending from Caversham along the western margin of the St. Kilda and St. Clair flats to the coast. For the purpose of presenting the map, we have not differentiated this zone from other areas with >20m sediment, but it is possible that any enhancement effects may be more intense here.

Estimates of peak spectral acceleration at such high intensities are extremely difficult to make but are likely to exceed 0.7g (McCahon et al 1993).

The area shown on the map as being prone to liquefaction is taken directly from McCahon et al (1993, fig. 6.1) and is based on testing samples of the various soils in the area. All tests showed at least some soils in the depicted area to be liquefiable during a Worst-case Event and, hence, it is highly likely that localised liquefaction would occur within the area shown.

Liquefaction in the Dunedin Area

Liquefaction

Liquefaction is the act or process of transforming cohesionless soils from a solid state to a liquefied state as a consequence of increased pore pressure and reduced effective stress.

- Liquefaction is usually associated with and initiated by strong shaking during earthquakes, which causes certain soils (mainly cohesionless, uniform fine sands and silts) to compact, increasing pore water pressure and decreasing shear strength. The definition is independent of deformation or ground failure movements that might follow the transformation to a liquid state. The liquefaction process always produces a transient loss of shear resistance, but not always a longer-term loss of shear strength.
- Liquefaction is most likely to occur in saturated, relatively uniform, cohesionless, fine sands, silty sands, or coarse silts of low relative density (loose), generally at depths of up to 15 to 20 m below ground level, in areas where the water table is within 5 m of the ground surface. Such materials have a relatively low permeability and dissipate increased pore water pressures (drain) slowly. Although liquefaction effects are observed only in loose soils, dense sands and silts may show initial liquefaction (strain softening) effects, but these are rapidly inhibited by the dilatancy characteristics of such soils.

From a soil mechanics point of view, it is believed that the basic cause of liquefaction in saturated cohesionless soils during earthquakes is the build-up of excess pore pressure due to the application of cyclic shear stresses induced by the earthquake ground motions. These stresses are considered to be due primarily to upward propagation of shear waves in a soil deposit, although other wave motions also have an influence. If the liquefaction effect is sufficiently severe and extensive, loss of ground strength may result in damage to any structures located in the affected area. Bearing capacity failure will cause buildings or superficial structures to settle and tilt, and buried structures such as underground pipes and tanks may float upwards. Liquefaction of a confined subsurface layer can cause large vertical and lateral displacements of the ground surface, or possibly only minor effects such as sand boils or water ejections. If the area is on a gentle slope, or close to a free face such as an incised river channel or open drain bank, then lateral spreading failures can occur.

The development of excess pore water pressures leading to the liquefaction of a soil mass during an earthquake depends on:

- Soil grain size, permeability, and thickness.
- Soil layer up to 20 m below ground surface.
- Depth to water table of less than about 5 m (possibly 10 m).
- Duration and intensity of strong shaking at least MM VII for liquefaction at the most susceptible sites.
- Hydraulic boundary conditions and confining pressures.
- Level of stress and amplitudes of strain in the soil mass.

Liquefaction generally occurs at strong levels of ground shaking. On the Modified Mercalli Intensity (MM) scale, liquefaction effects become clearly evident at MMVIII, at distances of 100 - 150km from magnitude M7 to 7.5, and up to 400km from the epicentres of great (M8 - M9) earthquakes.

An Earthquake Commission (Soils and Foundations, 1993) study concludes that large areas of South Dunedin are underlain by saturated soils (sands and silts) that are potentially susceptible to liquefaction, and although supporting data is sparse, it suggests that liquefaction is likely to be widespread during large earthquakes that generate strong shaking above MM VII intensity.

Other parts of Dunedin that may be susceptible to liquefaction induced ground damage during such large earthquakes are:

- Areas of reclaimed land and causeways around Otago Harbour and other inlets, possibly including parts of Port Chalmers.
- Former swampy areas that have been drained and later developed, including large parts of the Taieri Plain.

Possible Liquefaction Damage Scenarios

The greatest liquefaction damage in Dunedin would be caused by a large magnitude (≥M7) earthquake on the Akatore Fault. The liquefaction damage caused by this event would be widespread and most disruptive and possibly similar to that which occurred in 1995 Kobe earthquake (Park et al 1995 and Brunsden et al 1996).

Ground damage caused by liquefaction might rupture buried pipelines, especially those that are of brittle materials, disrupting water and gas supplies, sewage and stormwater disposal, power supplies, telephone lines (especially if buried), transport routes road and rail, port facilities, and cause damage to shallow founded buildings - especially houses. Ground and related liquefaction damage may take months to repair.

Lesser liquefaction related damage might be caused by a magnitude M7.5 to M8 earthquake on the Alpine Fault. An earthquake of this size has a higher probability of occurrence and would cause long duration shaking, possibly reaching an intensity of MM VII -VIII in parts of Dunedin. The facilities at risk would be similar to the example above, but damage is expected to be much less severe, and likely to be repairable within a shorter time frame (a few weeks).

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Appendix - The Modified Mercalli Scale

The relevant parts of the Modified Mercalli scale are below. The intensity scale proposed by a Study Group of the New Zealand Society for Earthquake Engineering (1992) is given.

MM VII

People
General alarm.
Difficulty experienced in standing.
Noticed by motorcar drivers who may stop.

Fittings
Large bells ring.
Furniture moves on smooth floors, may move on carpeted floors.

Structures
Unreinforced stone and brick walls cracked.
Buildings Type I cracked and damaged. A few instances of damage to Buildings Type II.
Unbraced parapets and architectural ornaments fall.
Roofing tiles, especially ridge tiles may be dislodged.
Many unreinforced domestic chimneys broken.
Water tanks Type I burst.
A few instances of damage to brick veneers and plaster or cement-based linings.
Unrestrained water cylinders (Water Tanks Type II) may move and leak.
Some windows Type II cracked.

Environment
Water made turbid by stirred up mud.
Small slides such as falls of sand and gravel banks.
Instances of differential settlement on poor or wet or unconsolidated ground.
Some fine cracks appear in sloping ground.
A few instances of liquefaction.

MM VIII

People
Alarm may approach panic.
Steering of motorcars greatly affected.

Structures
Buildings Type II damaged, some seriously
Buildings Type III damaged in some cases.
Monuments and elevated tanks twisted or brought down.
Some pre-1965 infill masonry panels damaged.
A few post-1980 brick veneers damaged.
Weak piles damaged.
Houses not secured to foundations may move.

Environment
Cracks appear on steep slopes and in wet ground.
Slides in roadside cuttings and unsupported excavations.
Small earthquake fountains and other manifestations of liquefaction.

MM IX

Structures
Very poor quality unreinforced masonry destroyed.
Buildings Type II heavily damaged, some collapsing.
Buildings Type III damaged, some seriously.
Damage or permanent distortion to some buildings and bridges Type IV.
Houses not secured to foundations shifted off.
Brick veneers fall and expose frames.

Environment
Cracking of ground conspicuous.
Landsliding general on steep slopes.
Liquefaction effects intensified, with large earthquake fountains and sand craters.

MM X *Structures*
Most unreinforced masonry structures destroyed.
Many Buildings Type II destroyed.
Many Buildings Type III (and bridges of equivalent design) seriously damaged.
Many Buildings and Bridges Type IV have moderate damage or permanent distortion.

Definition of Building Types

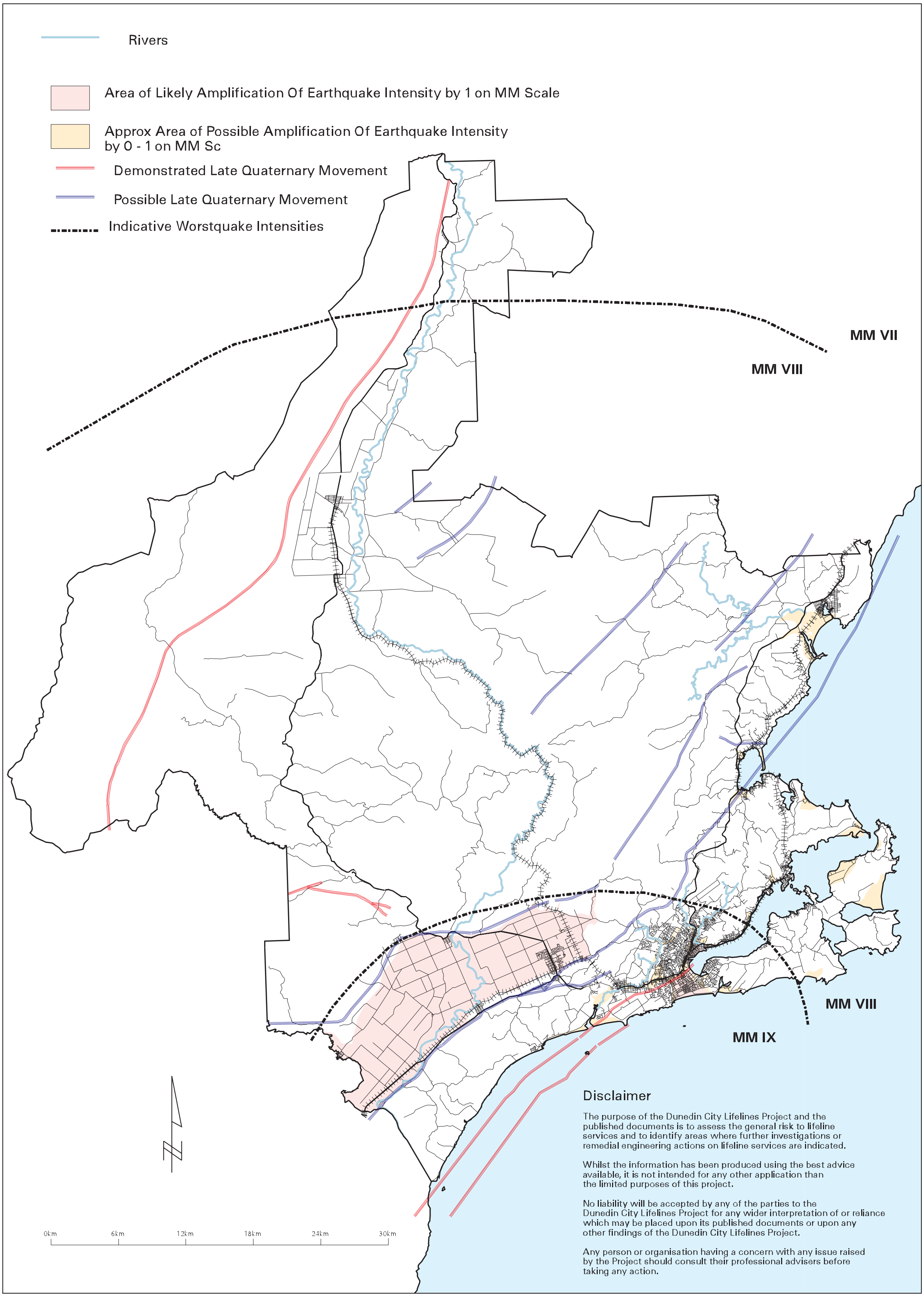
Type I: Weak materials such as mud brick and rammed earth; poor mortar; low standards of workmanship.

Type II: Average to good workmanship and materials, some including reinforcements, but not designed to resist earthquakes.

Type III: Buildings designed and built to resist earthquakes to normal use standards, i.e. no special damage-limiting measures taken (mid 1930's to c 1970 for concrete or c 1980 for other materials)

Type IV: Since c 1970 for concrete and since c 1980 for other materials, the loading and materials codes have combined to ensure fewer collapses and less damage than in earlier structures. This arises from features such as: "capacity design" procedure; use of elements (such as improved bracing or structural walls) which reduce racking (i.e. drift); high ductility; higher strength.

Earthquake Hazard - Faultlines



Disclaimer

The purpose of the Dunedin City Lifelines Project and the published documents is to assess the general risk to lifeline services and to identify areas where further investigations or remedial engineering actions on lifeline services are indicated.

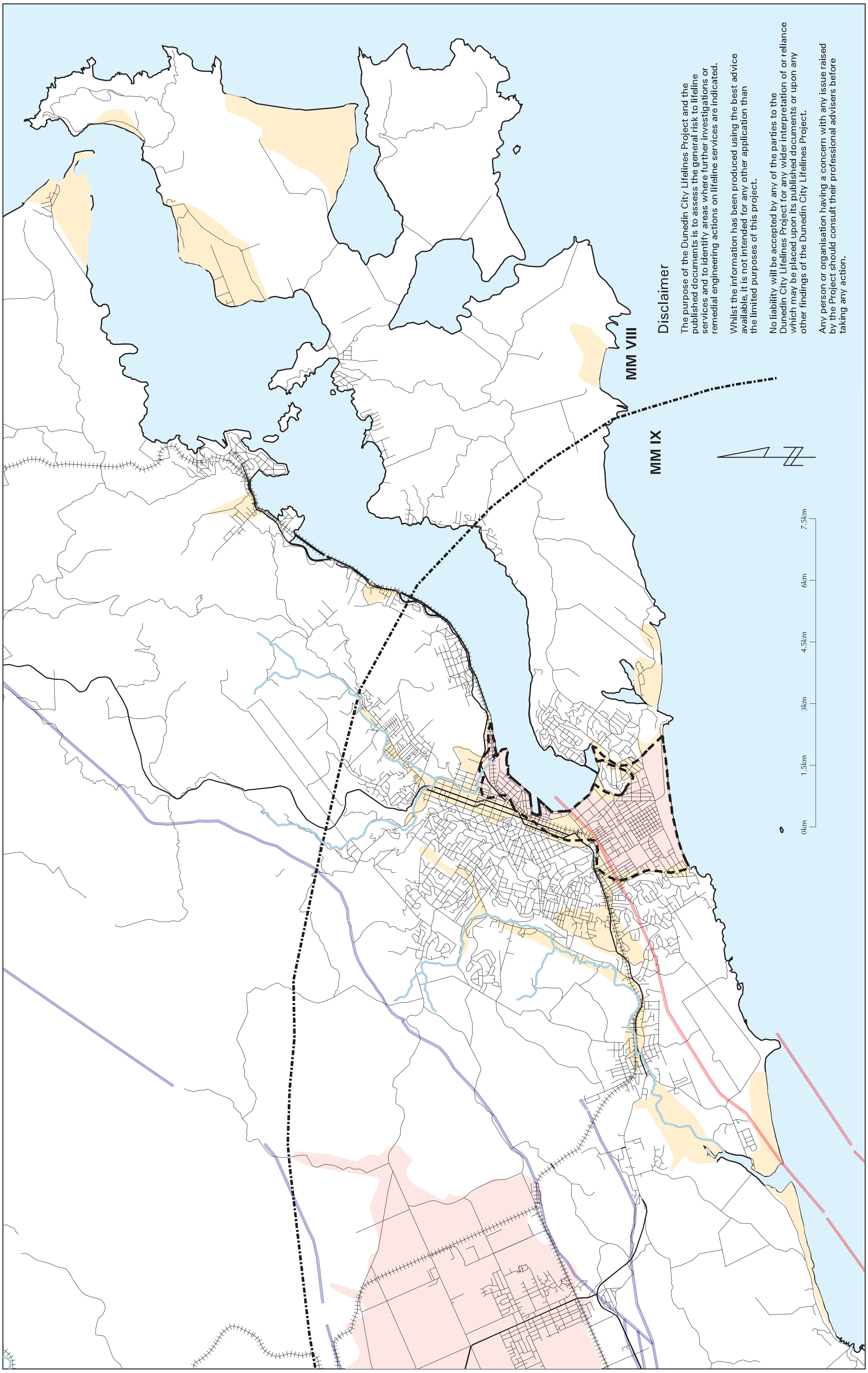
Whilst the information has been produced using the best advice available, it is not intended for any other application than the limited purposes of this project.

No liability will be accepted by any of the parties to the Dunedin City Lifelines Project for any wider interpretation of or reliance which may be placed upon its published documents or upon any other findings of the Dunedin City Lifelines Project.

Any person or organisation having a concern with any issue raised by the Project should consult their professional advisers before taking any action.

City Consultants
August 10, 1998

Earthquake Hazard - Areas of Intensification of Shaking



Area of Likely Amplification Of Earthquake Intensity by 1 on MM Scale

Approx Area of Possible Amplification Of Earthquake Intensity by 0 - 1 on MM Sc

Demonstrated Late Quaternary Movement

Possible Late Quaternary Movement

Boundary of Soil Types Susceptible to Liquefaction

Indicative Worstquake Intensities

City Consultants
August 11, 1998

FLOODING HAZARD

Mr David Hamilton, David Hamilton & Associates Ltd. (Previously Director Technical Services, Otago Regional Council).

Introduction

Flooding and river and stream control within the greater Dunedin City area has always been an issue. Works have been undertaken to either define or confine the watercourses to allow development of floodplains. Occasionally these works can be outflanked or overtopped by either super-design events or structural failure of elements of the works. In these circumstances the damage to infrastructure that has been based on a "protected" status may be high. The 1980 Taieri flood, which made Dunedin Airport inoperative for 53 days, is such an example. Flood and weather warning systems are in place to attempt to reduce actual danger to people and livestock and assist utility operators to better manage their facilities during events. Localised flooding due to high intensity rainfall, often associated with thunderstorms, is covered in the Meteorological Hazards section.

Topographic Features

The major river is the Taieri River, which has a catchment area of 5,650sq.km. While 43% of the catchment area is in the Central Otago District the peak flood flows at Outram derive from within the Dunedin City part of the catchment. The principal floodplain is the 16,000 hectare Taieri Plain, some of which lies below sea level and relies on pumping systems to remain productive. The significant tributaries that directly feed into and through the plains area are the Silverstream, Owhiro Stream, Waipori River, and the West Taieri Contour channel which picks up the streams coming off the Maungatuas.

The main coastal catchments are the Waikouaiti River (catchment area 425sq.km), Pleasant River (130sq.km), Waitati River (50sq.km), Water of Leith (43sq.km), and Kaikorai Stream (55sq.km). The low-lying land in South Dunedin relies to a large extent on a pumped stormwater system and thus flooding from local rainfall can occur.

The Strath Taieri area is characterised by an entrenched Taieri River with a relatively narrow floodplain and numerous steep creeks and fans draining the Rock and Pillar Range.

Estuary and river mouths can occasionally become blocked. This generally occurs after prolonged periods of low freshwater flow and high seas. Main areas affected are the Hawkesbury Lagoon (Waikouaiti), Hoopers Inlet and Kaikorai Estuary.

Recorded History of Events

The most recent major event was in June 1980, which affected the whole Dunedin City area. A summary of the major historic events is at the appendix to this section.

Subjective Reporting of the Hazard

Damage from flooding can be through the erosive power of water, debris and sediment carried by a flood, or the quiet ponding of floodwaters inundating valuable property, or combinations of the these. Utilities with structures, pipelines or cables in or over watercourses can expect lateral or vertical scour and debris in large flood events to cause problems. Utility operators with facilities in "protected areas" must realise that most river, flood control and land drainage systems are not designed to cope with the extremely rare event, and damage or failure in such conditions may occur in unpredictable locations.

Areas known to have flooded are shown on the maps and relate to major floods from the larger rivers and streams. They do not show localised stormwater or flood discharges from smaller creeks and streams which may result from high intensity rainfall in a small area.

Taieri Plains

The Lower Taieri Flood Protection Scheme has been designed to provide a nominal 1% standard of protection to both the east and west Taieri areas and a lesser standard of 10% to the Berwick flats and the East Taieri upper ponding area.

Strath Taieri
March Creek at Middlemarch has been realigned to reduce flooding in the town but can expect to be outflanked in large events. No major community works exist on the Taieri River through the Strath Taieri.

Coastal/Estuary/River
Blocked outlets of streams and estuaries can lead to flooding situations even without significant rainfall and work is normally arranged to open outlets in this situation. Coincident timing of high tides with high river flows may result in greater flood levels although this becomes less significant in major events when river levels are well above high tide level.

Localised/ City /Roading
Flooding in the urban areas by the overwhelming of stormwater and flood control systems in a major event can be expected. In South Dunedin this would tend to be a quiet rising of the floodwaters while in Glenleith there may be trees and boulders carried by fast flowing waters undercutting roadways or destroying bridges. Utilities may be temporarily or more permanently put out of action by floodwaters.

The Water of Leith and Kaikorai stream design standard is for a nominal 1% flood whereas Lindsays Creek is designed to a lesser standard in the upper reaches.

Flood Hazard Risk Summary

State Highways 1 and 87 can be affected in a number of places by flooding.
The South Island main trunk railway line and Taieri Gorge railway can also expect outages in a major flood.
The Water of Leith and Lindsays Creek are short steep catchments which can produce large floods with only a short warning time and may affect housing, roading and services.
The whole Taieri Plain is subject to flood risk in an extreme event. Mosgiel, Outram, and Dunedin Airport may be affected if the flood control and drainage systems in place are overwhelmed or fail in critical locations.
Utilities that cross watercourses can expect scour problems.
Stormwater problems will be accentuated if there is loss of power to pumping stations.
Power generation on the Waipori system may be affected.

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Otago Regional Council 1993: Floodplain Management Plan Dunedin District – Rural Areas (Draft).

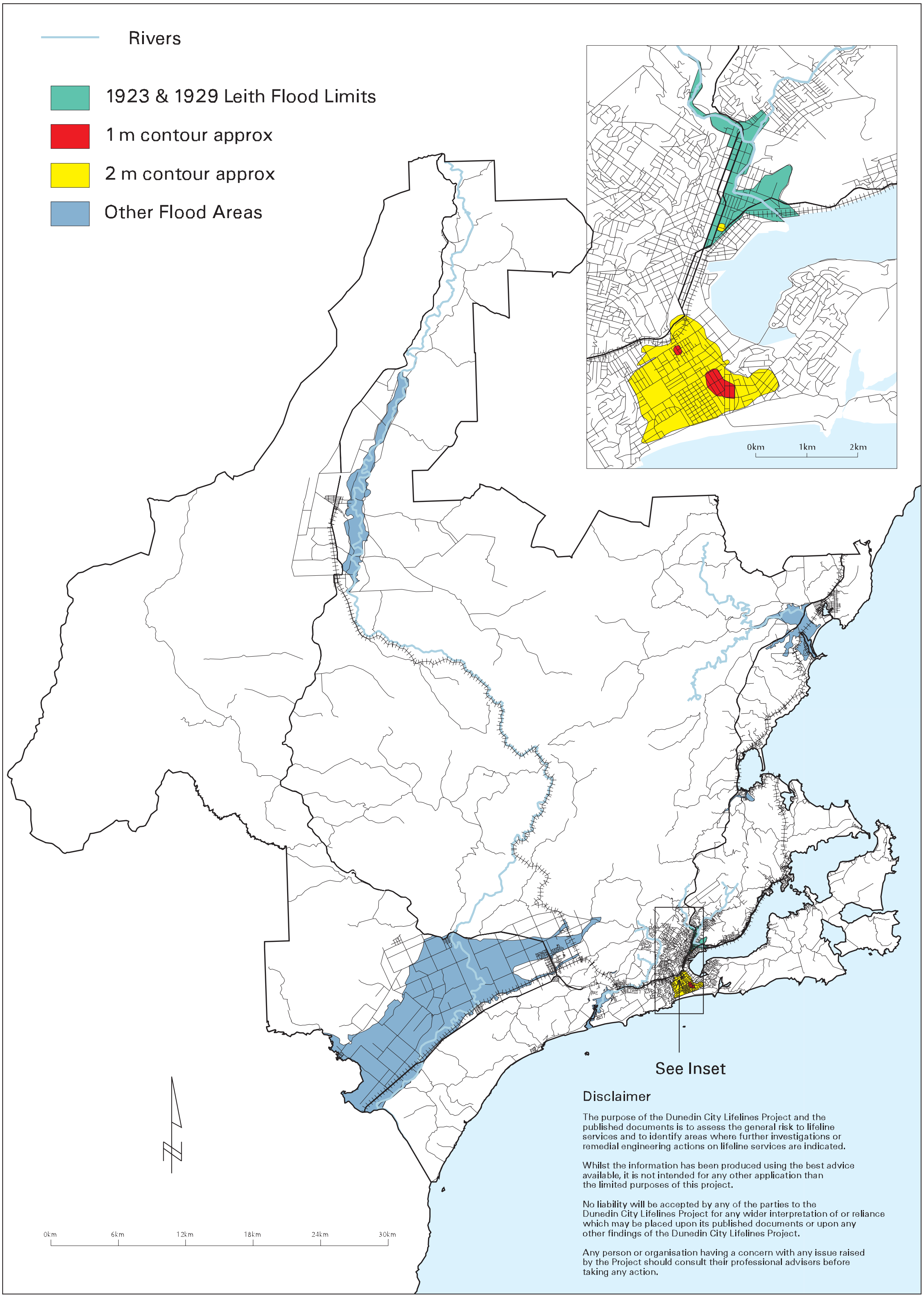
MacLean, F.W. et al 1931: Water of Leith and Lindsay’s Creek. Dunedin City Council.

Otago Catchment Board 1985: Lower Taieri Flood Control & Drainage Scheme Final Proposal.

Appendix -Summary of Historical Flooding Events

MONTH/YEAR	CATCHMENTS AFFECTED	FLOWS IN m^3/s	COMMENTS	UTILITIES AFFECTED
February 1868	Taieri at Outram Waitati Waikouaiti Leith	2200	Waitati affected Acre of Botanic lost About 12,000 ha flooded lower Taieri include Outram	Blueskin, Waikouaiti & 3 Leith bridges washed out
February 1877	Taieri @ Outram Leith	1650	Botanic Gardens houses and lower Frederick St flooded	River bank protection works lost on Leith
November 1883	Leith		Many houses flooded	Roadway lost, bridges damaged
May 1917	Taieri @ Outram	1600		
April 1923	Leith		Flooding low-lying areas	
May 1923	Taieri @ Outram Leith	1150	About 11,000ha flooded on lower Taieri plains Less intense in Leith but April debris not fully cleared	
March 1929	Leith, Waitati	est. 320 Largest reported on Leith	Very high intensity rainfall, 500 homes flooded North Dn, Debris, gravel, boulders on roads, houses	3 bridges swept away. Water supplies disrupted, pipes and reservoir siltation
May 1940	Taieri @ Outram	1800		
May 1944	Taieri @ Outram	1750		
May 1957	Taieri @ Outram, Silverstream, Mill Creek, Owhiro Creek, Waitati	2000	Extensive damage Strath Taieri, Silverstream & Contour channel banks breached, Mill and Owhiro Creeks overflowed Waitati homes evacuated	Railway at Otokia damaged. Main road and rail out for several days
March 1968	Waitati		Houses in Waitati township flooded	3/4 of formation width SH1 lost over 80m length
June 1980	Taieri @ Outram	2500	Floodbanks breached LB below Outram, Silverstream, Contour channel, Waipori River, with 4800 ha flooded West Taieri. Stock losses. Approx. damage $12m (1980$). Largest known flood in South Taieri area (check cf. 1993)	SIMT Railway and S.H.1 out for weeks. Airport outage 53 days. CO Railway line washouts. Outram bridge lost 2 spans and a pier. SH1 Waitati bridge threatened. Bucklands Crossing bridge washed out. Power outages, Waikouaiti. Merton water supply. SH1 closed in 9 places. Waipori No.2A power station inoperable for weeks.
March 1986	Waikouaiti			SH1 closed
December 1993	Taieri @ Outram	1500	Damage to new spillway structure E. Taieri	SIMT Railway closed for a few days

Flood Hazards



Disclaimer

The purpose of the Dunedin City Lifelines Project and the published documents is to assess the general risk to lifeline services and to identify areas where further investigations or remedial engineering actions on lifeline services are indicated.

Whilst the information has been produced using the best advice available, it is not intended for any other application than the limited purposes of this project.

No liability will be accepted by any of the parties to the Dunedin City Lifelines Project for any wider interpretation of or reliance which may be placed upon its published documents or upon any other findings of the Dunedin City Lifelines Project.

Any person or organisation having a concern with any issue raised by the Project should consult their professional advisers before taking any action.

City Consultants
August 10, 1998

LANDSLIDE HAZARD & THE VARIABLE GEOLOGY OF DUNEDIN

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The Nature of Landsliding

Landslides (also known as landslips) are masses of rock and soil that have moved downhill under the influence of gravity. Landslides may move very rapidly (as in rockfalls) or slowly creep at a few millimetres a year, and may range in volume from a few cubic metres to several cubic kilometres.

Triggering mechanisms include:

- Rainstorms.
- Ground shaking during earthquakes.
- Undercutting of river banks.
- Artificial over-steepening of banks or removal of landslide toes during construction activities.
- A combination of the above factors.

Landslides are generally classified by type of failure and movement mechanism (e.g. Varnes, 1978).

Landslides of any type pose a hazard to human activities and constructions with the degree of danger to life related to the speed of failure. The severity of damage to property is generally related to the size of failure.

The location of landslides is constrained by three factors:

- Slope angle
- Strength of underlying materials (rock or soil type)
- Water content.

The steeper the slope, the weaker the rock, and the higher the water content of the rock, the greater the likelihood of landsliding at any locality. Each of these factors can be quantified, and landslide hazard maps can be developed which will show areas most at risk of future landsliding. This type of hazard zonation has not been undertaken for this study.

Factors Influencing Landslides in Dunedin City

In Dunedin City, landslides are both numerous and widespread, and in the past have caused considerable damage (e.g. Abbotsford; Hancox et al, 1980). Known landslides have been mapped from aerial photographs, from detailed studies on Otago Peninsula (Leslie, 1974) and in south west Dunedin (McKellar, 1990), and from personal knowledge of the writers . The factors governing the distribution of these landslides can be inferred from a combination of geological and topographic maps, together with the landslide distribution maps, and are expanded on below.

Slope

The steepest slopes in the greater Dunedin City area are found in and around the Taieri Gorge and the Silverpeaks, where erosion (dissection) is deepest. This is partly reflected by the intense concentration of landslides in that region. Elsewhere, it can be seen that slopes of only moderate angle may be susceptible to failure, such as on the seaward flank of Saddle Hill where the average slope is 10 degrees. Some very steep slopes, such as the St Clair cliffs, are relatively unaffected by landsliding because of the strength of the underlying rock.

Geology

Rock type exerts the greatest influence on the formation and location of landslides. The geology of most of the Dunedin region is relatively well recorded at 125,000 scale (Bishop & Turnbull 1996), and more detailed maps are available for some areas (e.g. Bevan 1968, McKellar 1990). Comparison of these geological maps and landslide maps shows that landslides are preferentially developed on slopes underlain by schist, by sedimentary rocks of Cenozoic age, and by volcanic rocks.

Variations on this general theme are largely due to the influence of slope angle and water content, but within these landslide-prone rocks, other factors are also relevant. In areas underlain by schist, the attitude (angle) of the schistosity, and the presence of other rock defects (joints, or faults) are particularly important. Within the sedimentary rocks, mudstone and siltstone are weakest (compared with sandstone or breccia) and most landslide-prone, and the very unstable areas of the Kilmog and Saddle Hill are underlain by such sediments. Landslides within the volcanic rocks generally occur along weak layers of ash or volcanic breccia between much stronger lava flows. As these are distributed throughout the volcanic areas, they cannot be easily isolated.

Overlying all other rock types in Dunedin City is a layer of loess (clay) and weathered rock, up to 5m thick in many places, which is also prone to small-scale landsliding. This layer, known as "regolith", cannot be easily mapped, and regolith landslides have only been recorded in detail on the Otago Peninsula (Leslie, 1974).

Water Content
Water influences landsliding in several ways. It decreases rock strength when it saturates the ground, by causing clay minerals to expand, or by lubricating rock defects. It can also exert an upward pressure if it becomes trapped beneath an impermeable rock or soil layer, effectively "floating" the upper layers so less gravitational force is required to make them slide downhill.

Other Factors
Other contributing factors in the landsliding process include possible ground shaking (from earthquakes) triggering potentially unstable slopes; the density or absence of vegetation, which controls the rate of infiltration of water into the ground; and the amount of artificial slope modification and drainage - again affecting water within landslide-prone areas.

History of Landsliding in the Dunedin Area
This study has not investigated historical records of landsliding around Dunedin. The earliest scientific studies of landslides are those of Benson (1940, 1946). Studies of individual landslides have been made throughout the 1960s until the present day, mainly from the aspect of designing remedial measures, and to develop methods for avoiding land use practices which may encourage landsliding (e.g. Robins 1982).

Future Landsliding in Dunedin City
This report does not attempt to assess the vulnerability of any particular area within Dunedin to future landsliding, apart from intuitive assessment of risk based on local knowledge of geology, slope, groundwater conditions and the presence of past landslides. This report does not differentiate between areas of higher or lower landslide hazard, although the zonation of landslide hazard has been the subject of some research (e.g. Forsyth et al 1995).

The Dunedin area will undoubtedly, experience more landslides, some of which will affect lifelines. Where they may occur can be estimated, based on our understanding of geology, slope, water and other factors, as discussed above but in contrast knowing where they will occur is, relatively unpredictable, but can be assessed in terms of the likelihood of triggering mechanisms.

The most likely triggers for the majority of small-scale landslides are high-intensity rainstorms (e.g. Stewart 1996) or prolonged periods of wet weather resulting in very high ground-water levels. Return periods for such events are discussed in the section on meteorological hazards.

Large-scale landslides such as Abbotsford generally have more complex causes, particularly unfavourable combinations of geology, water and slope, and their future occurrence is consequently hard to predict. Landslides in the Silverpeaks region could be analysed with more certainty (given adequate field studies) as the factors there are easier to analyse.

No information is available on which, if any, landslides may have been earthquake triggered. Large landslides such as the Swampy landslide and possibly others, may be examples of landslides triggered by earthquake shaking. Subsequent movement of these landslides may be due to complex circumstances such as internal shear planes trapping groundwater and raising pressures to the extent that the landslide is kept in a potentially unstable state. The likely return periods of earthquakes of sufficient magnitude to trigger landsliding events are discussed in the earthquake hazard section.

Specific Landslide-Prone Areas of Dunedin in Relation to Lifelines

Based on available mapping of landslides and geology, and a qualitative assessment of slope and groundwater conditions, it is possible to isolate areas which are more or less prone to future landsliding, and relate these to the location of Dunedin's lifelines. This section, discussing specific landslide-prone areas, is based entirely on the authors' personal experiences.

Kilmog

The Kilmog Hill, north of Waitati, is underlain by large areas of sedimentary rocks, which include siltstone and mudstone. The coast road past Karitane, the Main Trunk Railway, and State Highway 1 all traverse large landslides, some of which are either active or have only recently been temporarily stabilised. Landslides in this region tend to be chaotic masses of mudstone, often including blocks of overlying volcanic rock or sandstone floating in a softer matrix.

Taieri Gorge - Silverpeaks

This region includes the very steep-sided Taieri Gorge, and many deeply incised streams. Landslides here are in schist rocks, and are controlled by several types of defects within the schist. Landslides include rock falls, triggered by undercutting of slopes by the Taieri River, and (generally the larger examples) landslides which have failed along schistosity planes (planes of weakness) inclined down-slope. These landslides threaten the Taieri Gorge railway line as well as water pipelines and power lines. Similar landslides in schists occur on the eastern face of the Maungatuas and in the Waipori Gorge. Landslides in schist derived regolith are particularly common in places such as the Chain Hills (M.W. Harris, pers. comm.).

Otago Peninsula - Port Chalmers Swampy Summit Region

Landslides in these areas tend to be on a smaller scale than in the above regions, and are strongly influenced by the presence of clay-rich weathered volcanic ash and scoria layers between lava flows. Many landslides also occur in regolith composed of loess and transported volcanic rock, in which the clay-rich weathered volcanic debris has already been moved down-slope. These smaller features threaten road and street networks and, to a minor extent, State Highway 88 to Port Chalmers.

Some very large landslides are recorded in volcanic rocks, such as the Swampy landslide mapped by Benson (1968), but these are considered to be very old and currently stable features. The western slopes of Swampy are also inferred to be landslide-prone, but very few lifelines are under threat in this region.

South-West Dunedin

This area includes the Abbotsford landslide, the Church Hill Road landslide, and the many failures around Saddle Hill and is underlain by large areas of mudstone and siltstone within the sedimentary rock sequence. Landslides tend to occur either as dip slope failures where rock masses slide down bedding planes (even where very gently inclined on slopes as low as 7 degrees), or as failures on steep slopes cutting across bedding planes, such as the Church Hill Road slide. All these slides may threaten road and street networks, underground and above ground services, and to a lesser extent, the main trunk railway.

Landslide Maps

The landslides shown on maps have been derived from information provided jointly by the Dunedin City Council, the Otago Regional Council, the University of Otago, and the Institute of Geological & Nuclear Sciences Ltd. The maps are based on limited available information regarding the nature and distribution of landslides in and around Dunedin City and should therefore be considered neither exhaustive nor comprehensive. The landslide maps show the location of the majority of known landslides in the study area, but give no data on activity, type, potential for future failure, or triggering mechanism(s). Locations and boundaries of landslides shown in the risk maps cannot be considered consistently accurate.

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McKellar, I.C. 1990: Miscellaneous map of New Zealand - South-west Dunedin urban. Map (1 sheet) and notes (64p.). Department of Scientific and Industrial Research, Wellington.

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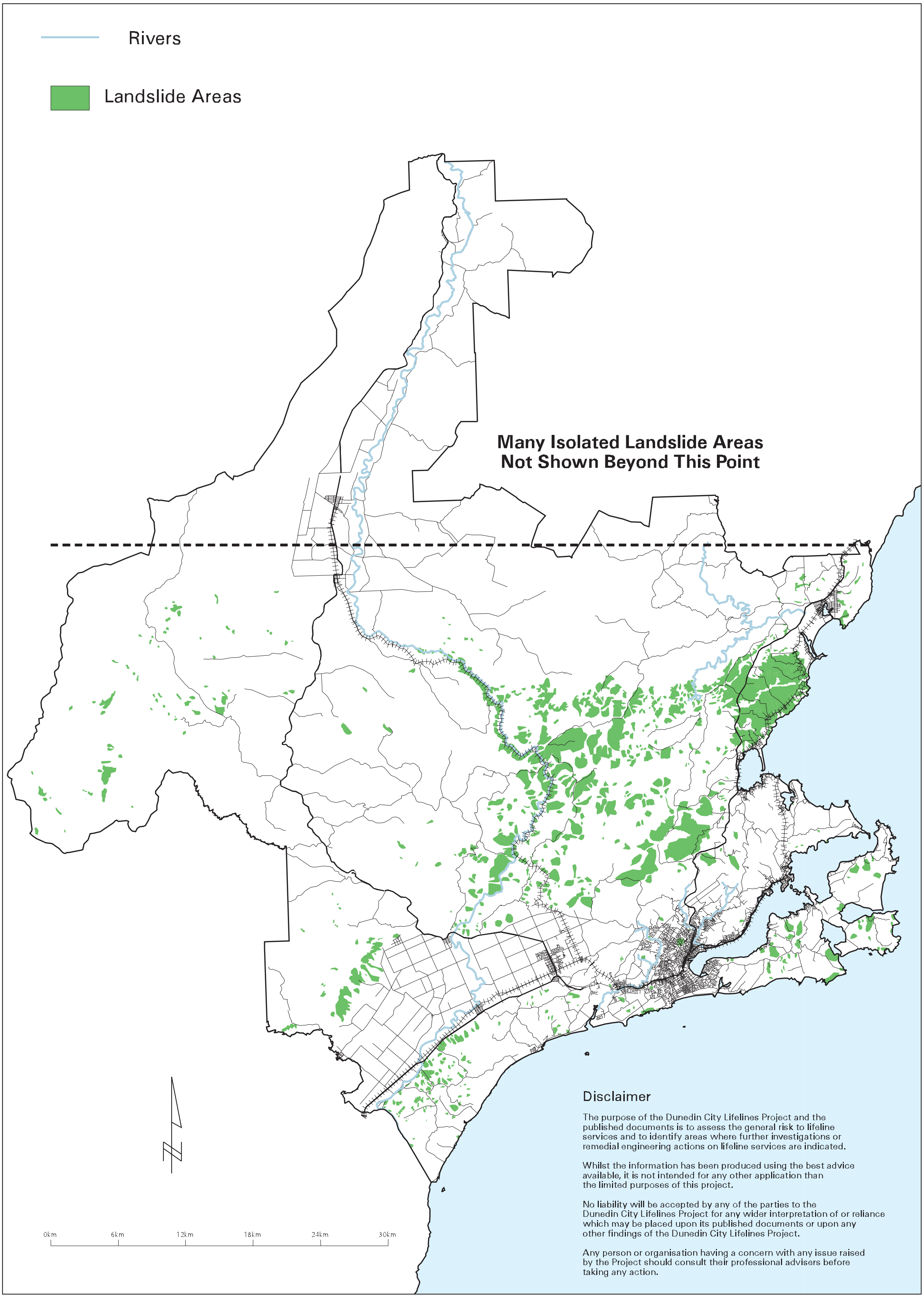
Stewart, D.L. 1996: Landslides triggered by the 17-19 March 1994 rainstorm, Dunedin area. *Institute of Geological & Nuclear Sciences Science Report 95/42.*

Varnes, D.J. 1978: Slope movement types and processes. Chapter 2: Landslides, Analysis and Control. Special Report 176, Transportation Research Board, National Academy of Sciences, Washington DC.

Data Sources

Two pages (that are available from the authors) of information sources that may be accessed, for specific areas and landslip conditions, on application to D.C.C., I.G.N.S., Otago & University and Otago Regional Council.

Landslide Hazards (Greater Dunedin)



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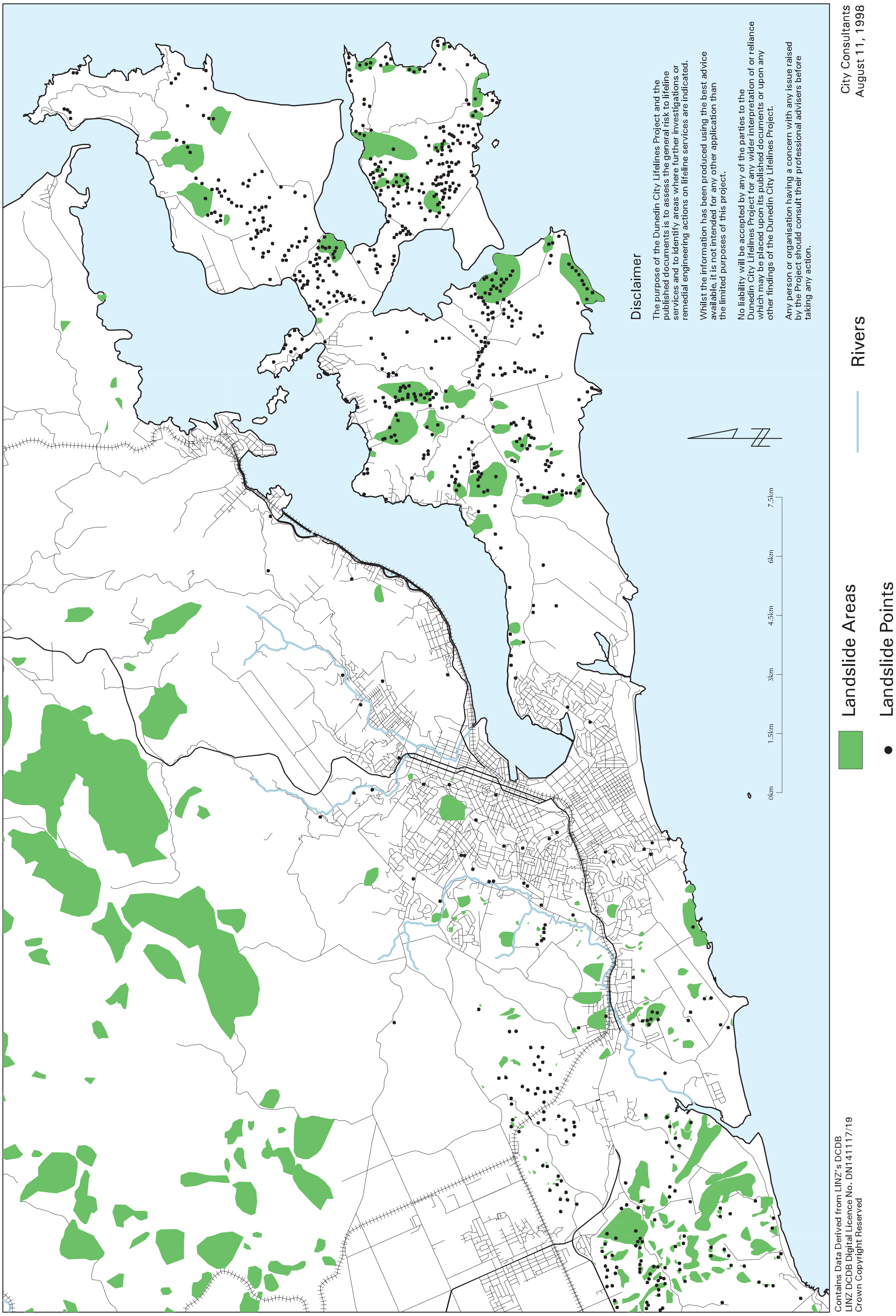
City Consultants
August 12, 1998

Landslide Hazards (Urban Area)



METEOROLOGICAL HAZARDS

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Dr David Murray, Hydrologist, Geography Department, University of Otago.
Mr David Stewart, Hydrological Consultant, Raineffects Ltd, Dunedin.

Sources of Meteorological Hazards

The major hazards that are likely to affect lifelines are:

- Windstorms.
- Heavy snow and persistent ice.
- Sub-tropical cyclones (heavy rain, wind, storm surge).

Information Available

An extensive climate database is maintained by NIWA. It contains all weather measurements taken at official climate stations in the Dunedin area. Some of these measurements extend back to 1865, although they have been made at a variety of specific sites. These sites are often some distance from critical lifelines. Return periods of some large meteorological events are available. Since Dunedin has more than 100 years of recorded climate information, these estimates are very useful for developing design events. Information about historical weather events has also been accessed from archives of the Otago Daily Times. This information is valuable as it describes the general nature of the event, gives details about the impact on Dunedin City and environs and often outlines the effect on lifelines. Design events are developed for wind, snow and sub-tropical cyclones. These are based on known events that have occurred over the past 100 years, on statistical analysis of extremes, and on the climatological experience and judgement of the sub-group members. They represent large but credible events that will probably occur.

Windstorms

Winds from the North-west

These occur when a deep trough advancing across the Tasman Sea is squeezed against an intense blocking anticyclone to the east of the South Island. A very strong pressure gradient develops between these features and mean wind speeds rise to above 50 knots (93km/h). Extreme turbulence occurs in the lee of the mountains and gusts may exceed 80 knots (148km/h). Wind speed tends to rise and may reach storm force, until the passage of a cold front across the city brings rain or snow, and the direction shifts to the south-west. Wind speeds then slacken, but can remain strong. Such windstorms can last for 6-12 hours.

Extreme examples of this event occurred in August 1975 and to a lesser extent in September 1972. Reports from the Otago Daily Times describe widespread damage occurring to property, the closure of the airport, power lines brought down and electrical sparks igniting fires. By the nature of the synoptic events that generate these pre-frontal wind storms, the weather often suddenly changes to give heavy rain and sometimes snow, which complicates the response to fixing the wind damage.

Southerly Gusts

Extreme wind gusts, but of shorter duration can occur with a sudden change to southerly within a "gust front" or "southerly buster". These events are associated with rapid progression of cold air up the eastern coast of the South Island. Wind speeds of 80 knots have been recorded at Taiaroa Head from such events. They tend to be of short duration, lasting less than one hour, but their sudden blustery onset can cause damage to loose roofing, fences, signs and power lines and can blow down trees.

Winds During Sub-tropical Cyclones

These are infrequent events and little statistical information on wind is available. Winds of at least 100 knots can be expected, probably from the north-east to south-east directions which will cause widespread felling of trees across roads, rupture of power lines and closure of the airport.

Design Event

There is statistical information available as to maximum wind gusts and their return periods for 1991-1996. Data from Swampy for this period are given in the appendix. These values refer to 30-minute averages and expected wind gusts will be at least 75% higher. On high exposed ground, a maximum wind gust of 70 knots (130km/h) can be expected in most years, with 100 knots (185km/h) likely at least once a decade. A design wind gust with a 100-year return period is estimated at 130 knots (241km/h).

Maximum wind gust annual probabilities are:

- 70 knots 100%
- 100 knots 10%
- 130 knots 1%

Lifelines Affected
The main lifelines likely to be affected are electricity power lines, some telephone lines, the airport and main roads (trucks, caravans, motorcyclists, cyclists, and pedestrians).

Heavy Snow and Persistent Ice

Nature of Events
Once or twice a decade, Dunedin is affected by deep snow on the ground to near sea level, although the hill suburbs are affected most winters. The weather situation is one in which very cold air masses are advected from the south with an upper level moisture source from the north. Snow may fall to sea level for one to three days and form into wind drifts. An advancing anticyclone maintains cold temperatures and the snow for several days, with persistent, severe frosts and widespread ice. Freezing rain can also occur.

Extreme examples of snow occurred in July 1939, June 1969 and in July 1996. The 1939 snowstorm was undoubtedly the most severe of this century. Even at sea level the snow was 30cm deep and in the suburbs it was 60cm deep, but formed into drifts sometimes more than two metres deep on Mount Cargill. The city was isolated for three days, with roads in and out of Dunedin being impassable and even trains and trams stopped. Most public transport was brought to a standstill. Heavy snow loads collapsed roofs and gutters and brought down power and telephone lines. The airport was closed. In the hill suburbs, vehicular traffic was almost completely halted. The response of emergency services was slow. In outlying areas of Greater Dunedin, people were isolated and without food and the Army was called in to help (as it was again in 1969 and 1972).

Design Event
The "great snow of 1939" is taken as the design event. Strong winds from the south will accompany heavy snowfalls and snow over 30cm deep at sea level will last for up to three days. Temperatures will remain at or below freezing for this period. Snow on the Northern Motorway will exceed two metres in drifts. Lookout Point and the Chain Hill sections of the southern road outlet will have 50cm depth of snow. The inevitable thaw will cause local flooding re-freezing at night will continue to make roads very icy. The probability of this design event is estimated at once in 100 years.

Lifelines Affected
Because of the steep hills these events cause traffic blockages on roads and widespread damage to power lines caused by the combination of strong winds and heavy snow loads. Power outages will occur and some telephone lines will be lost. All road access in and out of Dunedin will be very difficult. The rail line will be affected the airport will be forced to close and emergency services will struggle to get to critical locations.

Tropical Cyclones

Nature of Events
Tropical cyclones are infrequent but are a definite part of Dunedin's climate. They are deep depressions that form in the tropics, often as hurricanes. As they move south towards New Zealand they usually curve eastwards and lose intensity. Nevertheless, they are powerful storms with huge amounts of rainfall, very strong winds and a marked storm surge that gives higher than normal sea levels. They are rarer and much more intense than the mid-latitude depressions which more commonly affect New Zealand.

Extreme examples of sub-tropical cyclones that affected Dunedin occurred in 1923, 1929 and in 1968 (the "Wahine storm"). Rainfalls are far heavier than normally experienced in Dunedin. For example, the largest flood in the Water of Leith from 1975-1996 occurred in February 1991, when an active depression lay to the north. Northeast rains brought widespread flooding to East Otago and disruption to railway and road access to the city. Twenty-four-hour rainfalls were 125mm in Dunedin and 117mm at the airport. This serious situation is relatively modest when compared with the 1923 sub-tropical cyclone event, where 24 hour rainfall at Musselburgh was 261mm, or more than double the 1991 event. A report on the February 1991 flood event, compiled by the Otago Regional Council, is available.

Both the 1923 and 1929 events caused major flooding in the city. North Dunedin was hit hard in 1929, with a lake forming east of Great King Street and stretching all the way from High Street to North East Valley. In 1923, extensive flooding also occurred in South Dunedin and Caversham. Many slips disrupted communications and damaged buildings. There was widespread damage to roads, footpaths and bridges, shipping was delayed, the railway line was cut and many roads inundated. Water mains burst and the storm water system was unable to cope with the huge volume of water produced by the intense rain.

A report on the 1929 flood is given in MacLean, McGregor Wilkie and Alexander (1931).

Design Event
Return periods for heavy rainfalls at sample climate stations in the Dunedin area are given in the appendix. Some stations have shorter records, so their statistics do not include the tropical cyclone events of the 1920s and are therefore not as reliable for very large rainfalls as those for older stations. Because of the nature of weather systems affecting Dunedin, most heavy rain falls within a 24-hour period, so that 48-hour and 72-hour totals are not much greater than these. Twenty-four-hour rainfalls with 50 year return periods range from 85mm at Middlemarch to 242mm at Sullivans Dam.

The design event for sub-tropical storm is based on the 1929 event. The storm will approach Dunedin from the north or west. Winds will be from the south-east through north-east and will be strong (50-100 knots). Rainfall will be in excess of 220mm, most of it falling within 24 hours and intensities greater than 30mm/hr can be expected. A storm surge of 1-2m could occur along the coast and water levels in the harbour could rise by up to 0.5m.

Lifelines Affected
Major disruption to many lifelines can be expected from an intense sub-tropical cyclone. Severe flooding will affect main roads and railway lines in low-lying areas and near the coast. Storm water systems will be overwhelmed and many overflows and burst pipes could occur. Slips and debris flows will be widespread in hilly areas, which could further disrupt lifelines. The airport will probably close, power outages are likely and telecommunications will be disrupted.

Mapping of Meteorological Hazards
Meteorological hazards are likely to affect the whole of the city simultaneously, although, there will be sections of lifelines that will be at greater risk than others. These are subjectively identified, as detailed spatial data on climate is usually not available at this scale. The degree of hazard is often related to various aspects of topography.

Mapping is based on the design events developed by the meteorological sub-group and their judgement of the lifelines likely to be affected. An intensity scale is indicative of the severity of likely impact.

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Appendix - Historical Information on High Winds

Annual Maximum Windspeed
(30 minute averages)
As measured on top of Swampy 1991 -1996

Year	Speed Knots	Speed km/h	Direction (E of N)
1991	45.9	85.0	85
1992	44.6	82.6	260
1993	43.4	80.4	305
1994	44.8	83.0	270
1995	49.6	91.9	265
1996	43.4	80.4	275

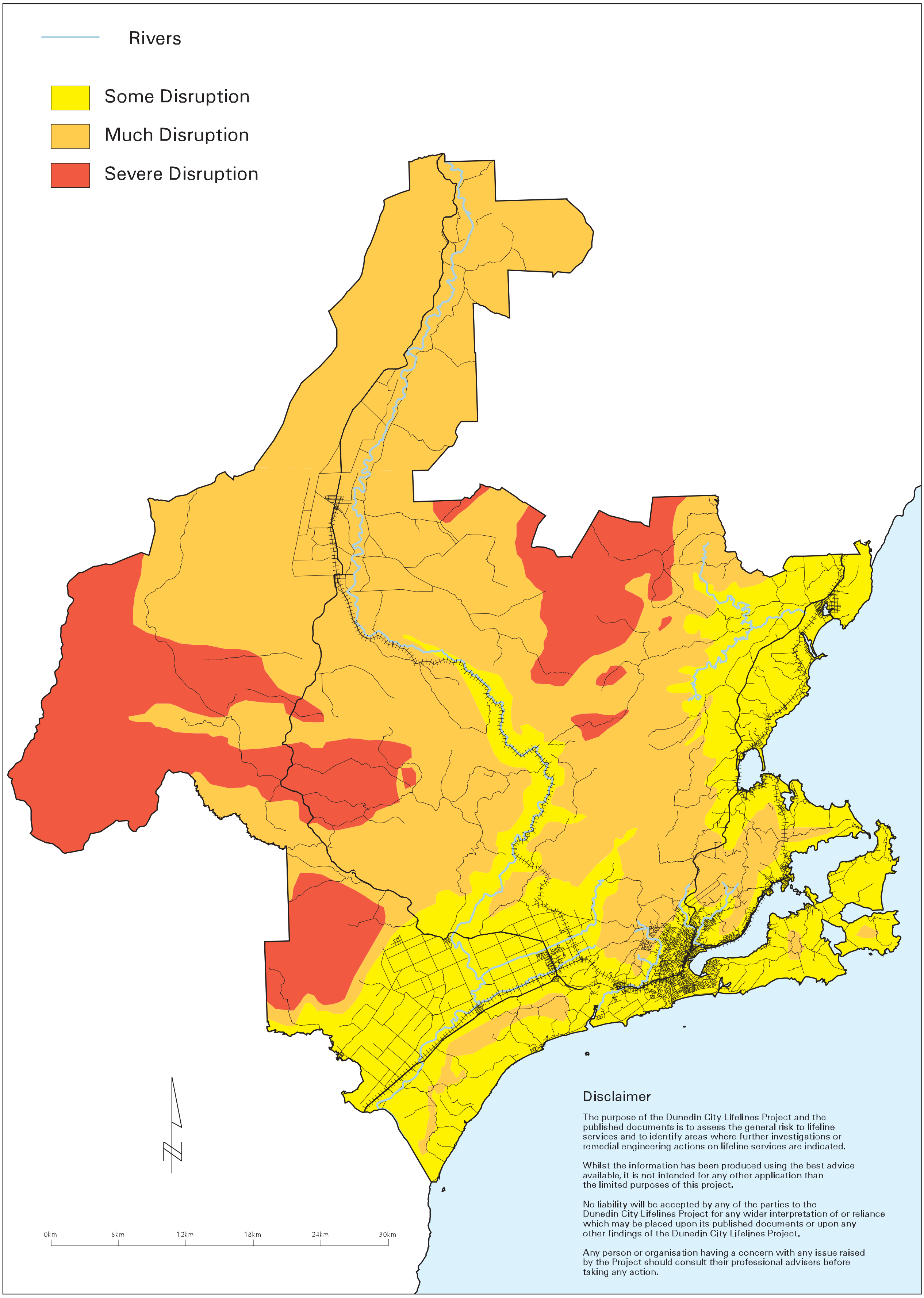
Appendix - Sample Rainfall Depth/Duration/Frequency

Based on Daily Rainfalls (from N Z Met.Service 1980)

Frequency of Heavy Rainfalls (millimetres)

Rainfall Station	Duration (hours)	T = Return Period in Years 2	5	10	20	50	Number of Years of Record
I50512	24	44	57	66	74	85	49
Garthmyl, Middlemarch	48	50	64	74	83	95	54
1916-1980	72	52	68	78	88	100	58
I50662	24	67	110	139	167	203	14
Cherry Farm Hospital	48	79	130	165	197	240	14
1967-1980	72	85	140	176	211	256	14
I50852	24	67	99	120	141	167	50
Dunedin Botanical Gardens	48	82	119	144	168	199	54
1913-1980	72	90	129	155	180	213	55
I50853	24	87	137	170	201	242	14
Sullivan Dam	48	106	185	238	288	353	14
1967-1980	72	119	201	255	307	374	14
I50921	24	47	70	85	100	119	17
Dunedin Airport	48	59	96	120	144	174	17
1962-1980	72	67	106	131	156	188	17
I57561	24	56	90	112	134	162	61
Musselburgh, Dunedin	48	68	107	133	157	189	61
1918-1980	72	74	113	139	163	195	61

Windstorm Hazards



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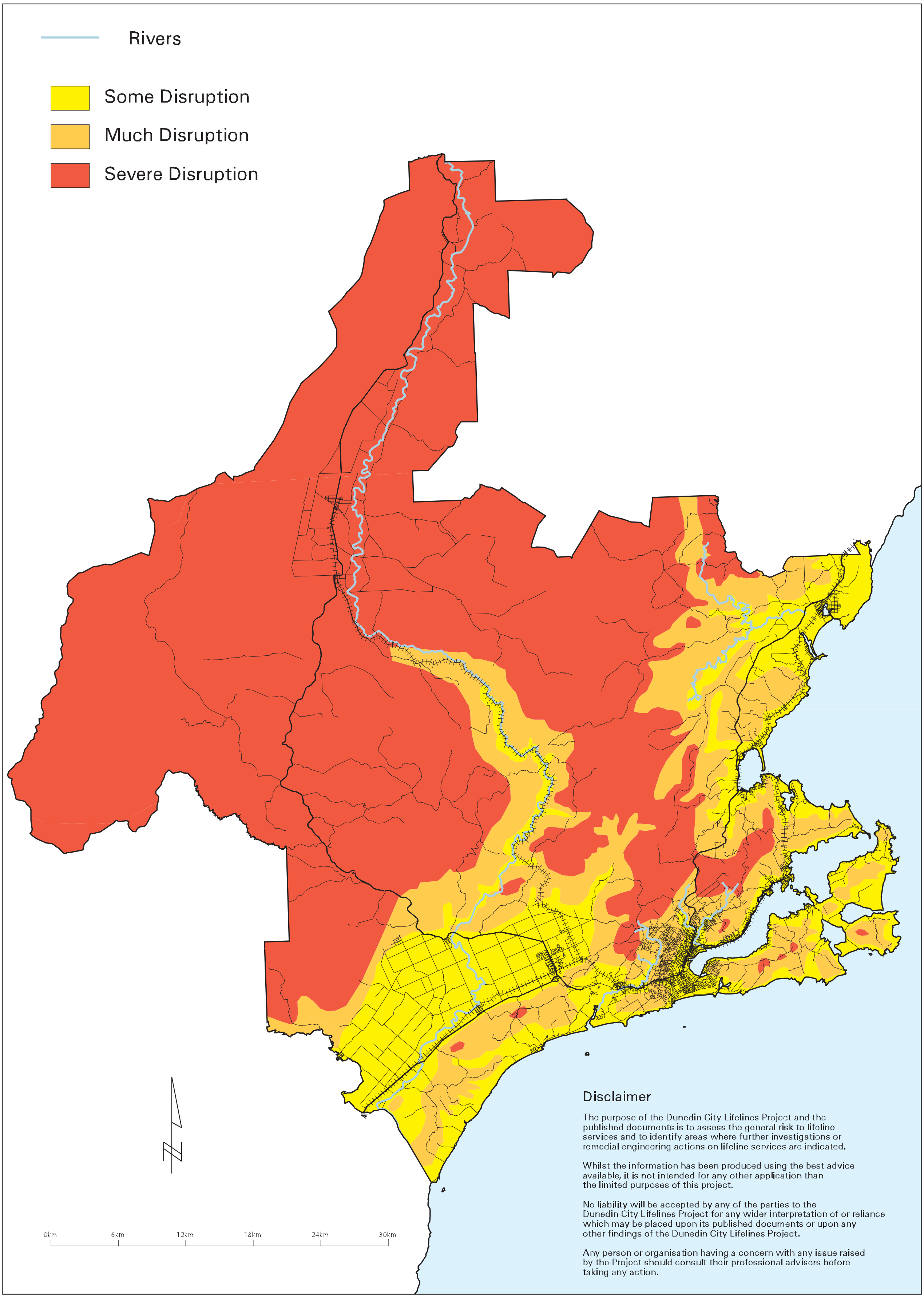
City Consultants
December 23, 1998

Snowstorm Hazards



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City Consultants
August 10, 1998

TSUNAMI & STORM SURGE HAZARD

Mr David Hamilton, David Hamilton & Associates Ltd. (Formerly Director Technical Services, Otago Regional Council).

Introduction

The Dunedin coastline has been subject to tsunami in the last 150 years, although no major impacts have been involved (see appendix for summary).

Tsunamis are seismically generated sea waves capable of inflicting catastrophic damage at sites remote from their generating areas. They contain vast amounts of energy and can travel great distances. They normally require earthquakes of magnitude M6.3 or greater and displacement of the sea floor to initiate them.

Tsunami wave behaviour at the shore is extremely variable; only one wave may be received or there may be many, there may be draw down of the sea before resurgence and breaking, or not. Previous behaviour of waves at a target shore is not necessarily a good guide to future behaviour. Large tsunamis generate a powerful surge of water that can be very damaging to structures and debris carried by such flows adds significantly to their danger and destructive effect.

Storm surges arise from low atmospheric pressure accompanied by wind stress on the water surface.

A report prepared for the Otago Regional Council by Tonkin and Taylor Limited in 1997, scoped the impact of tsunamis and storm surges on the Otago coastline. A more detailed study to evaluate the effects of these hazards, taking into account the approach and shore conditions, is currently the subject of a further consultancy study for the Otago Regional Council. This paper primarily draws on the Tonkin and Taylor report for information.

Topographic Features

The Dunedin coastline is approximately 280km in length, generally exposed to the east or south. Low lying land with potential for a tsunami or storm surge to affect significant numbers of people and infrastructure occurs at Waikouaiti, Karitane, Warrington, Waitati, Purakanui, Long Beach, Port Chalmers, Aramoana, Tomahawk, Portsmouth Drive, Waldronville-Brighton, and Taieri Mouth. Areas along the shores of Otago Harbour and downtown Dunedin may also be affected.

Tsunami

Tsunami may have amplitudes as small as 0.15m in the open ocean and they travel very rapidly. The average depth of the Pacific Ocean is 4,000m and this gives average tsunami propagation speeds of 713km per hour. At the edge of the continental shelf the speed will reduce (in 130m of water) to 130km per hour and in Blueskin Bay (20-30m of water) the speed would reduce still further to about 50-60km per hour.

Once at the shoreline tsunamis are known to reach elevations 30m above sea level, and 5-10m is not uncommon. There are substantial numbers of people, associated infrastructure and facilities within 2-3 metres above MSL in Dunedin and therefore a better understanding of possible impacts upon areas that may be affected is desirable.

A distinction is made between near-field and far-field tsunami. Near-field tsunamis are created in or close to the target area and no effective warning may be possible. Warnings should be achievable for far-field tsunami and New Zealand relies on the International Tsunami Warning Centre in Hawaii for timely notice of these. This service has proven reliable. It takes over 12 hours for a tsunami to arrive in New Zealand from South America or 9 hours from Hawaii.

Maximum Credible Tsunami Event

The maximum credible scenario for the water level in a far-field tsunami was set at 20% above the 1868 event (nominally a 118 year return period event), to coincide with a spring tide, and include a 0.2m long term sea level rise. The scenario was combined with light sea conditions and mean river flows. The resulting water levels from a tsunami of this magnitude were estimated to be 3.9m above MSL for stretches of the

open coast oriented to the south, 2.8m above MSL for the open coast oriented to the north, and 1.7m above MSL at Dunedin Harbour. Based on limited information on the magnitude of past tsunami events, the 'best guess' estimate of the return period for the maximum credible tsunami is in the order of 350 years. The joint probability of the tsunami peak coinciding with high tide is estimated to be in the order of 4,000 years.
An earthquake causing rapid vertical displacement of up to 2 metres, centred on the Akatore or nearby parallel fault off the Otago coastline, could generate a near-field tsunami. The maximum credible tsunami wave height from such an event is 2m with a return period estimated to be in the order of 1,500-2,000 years.

The far-field tsunami is considered a higher risk to the Dunedin City coastline, with higher wave heights for shorter return periods, than a near-field tsunami.

Storm Surge

Maximum Credible Storm Surge Event

The maximum credible storm surge scenario was calculated from the combination of maximum calculated inverse barometric effect from the most extreme low air pressure recorded at Taiaroa Heads, and a calculated wind stress from a sustained gale force wind. The magnitude of the surge under these conditions was calculated to be in the range of 0.7 - 0.9m above the tide level. This level of surge is approximately double the maximum-recorded storm surge at Dunedin from events identified in the study. For the scenario, the surge was combined with a high spring tide to give a maximum still water level of 1.7m above MSL. The storm wave climate associated with this level of surge was calculated from a gale force wind blowing for a duration of 6 hours. The resulting maximum wave run-up height above the scenario still water level was calculated to be of the order of 6 to 8m for steep beaches and 2 to 3m for flat beaches.

Areas Affected

Dunedin is at risk from tsunami and storm surge, although such events are rare. The results of a study currently underway will better define the areas that may be affected, by using better ground contour information. Preliminary assessment concludes the following:

- Areas with ground elevations less than 3m above MSL are at high risk from both tsunami and storm surge. Those areas that are south facing on the open coast and are less than 4m above MSL ground elevation are also at high risk from tsunami.
- Taieri estuary, the road from Port Chalmers to Aramoana, and other harbour-side roads are at high risk from tsunami inundation.
- Sites with a high risk of inundation during storm surge and associated run-up include Port Chalmers, low-lying parts of Dunedin, Aramoana Spit, Karitane Estuary, and Purakanui Inlet.

References

Tonkin & Taylor "Otago Region Tsunami and Storm Surge Study Final Report" prepared for Otago Regional Council June 1997.

De Lange, W.P. and Healy, T.R.: New Zealand Tsunamis 1840-1982. New Zealand Journal of Geology and Geophysics 29(1):115-134.

Appendix - Historic Reporting of Events

Historic Notes on Tsunami from DeLange and Healy.

1868 August 13 Northern Chile

Oamaru
The tide rose and fell 4.6m dropping to 2.4m below normal low water mark. The largest wave reported was 1.5m high following a sudden 3.6m drop in water level in one 5-minute period.

Port Chalmers
At 10.00am on 15 August the water rose 0.3m in a few minutes. Water continued to fluctuate slightly all day. The harbour master later attributed considerable changes in the harbour entrance to the tsunami.

1877 May 10 Northern Chile

Oamaru
Small variations occurred until noon on 11th when a large wave struck. Maximum fluctuations were about 2.5-3.0m. Several vessels collided or broke moorings.

Port Chalmers
Reported a 0.15m rise in 7 minutes.

Kaitangata
At 10.00am on 11 May a 0.5m bore was reported followed by a 1.2m rise in the river. It receded 20 minutes later.

1883 August 27 Krakatoa

Port Chalmers
A 0.6m wave was noticed at midnight on the 28th. The waves were still noticeable between 11.30am and 3.00pm with a maximum of 0.4m at 1.00pm.

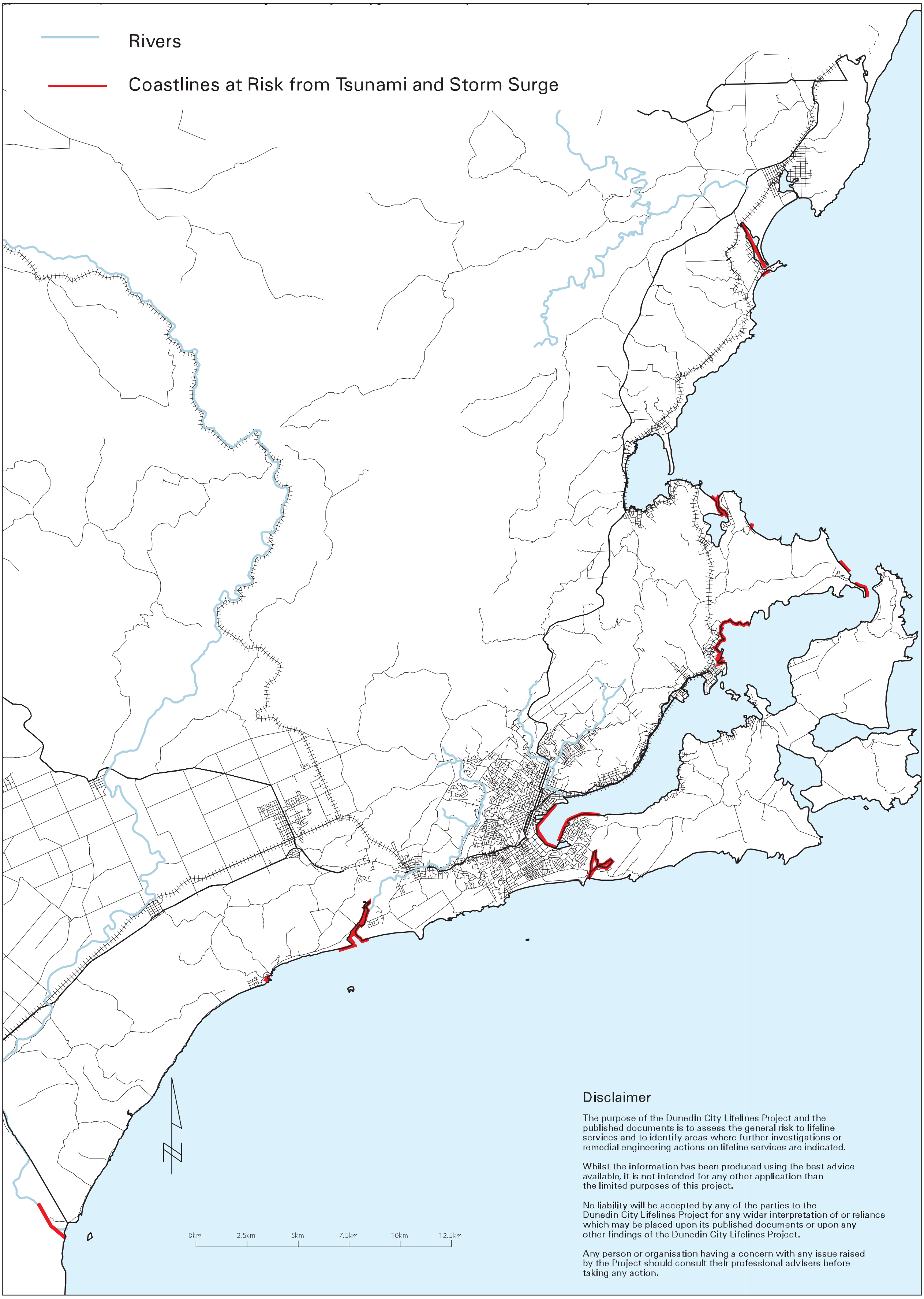
1960 May 22 Southern Chile

Oamaru
The oscillations began at about 9.00pm on the 23rd. At 10.05pm the water rose 0.6m before dropping 1.5m in 10 minutes. Fluctuations of 0.9 - 2.8m occurred during the following 30 hours.

Port Chalmers
The maximum level recorded was 0.45m above high water for a period of 18 minutes and involving a 1.3m fluctuation.

Dunedin
The maximum level recorded was 0.4m for 35 minutes.

Tsunami and Storm Surge Hazards



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City Consultants
August 10, 1998

TECHNOLOGICAL HAZARDS

Mr Neil Brown, Civil Defence Officer, Dunedin City.

Introduction

Technological hazards arise from the human introduction of substances and practices which have potential to cause harm or damage by accident or as a result of malicious or negligent acts.

Some technological hazards have a clearly defined source and surrounding risk area. Risk areas for others are more difficult to define because they are regularly transported, are relatively safe in isolation from other factors or are dependent on external mechanisms including another hazard to trigger a consequential technological hazard.

None, however, should be discounted as a risk to lifelines without adequate consideration of their potential for:

- Physical disruption of lifeline services.
- Isolation of key components of lifelines.
- Forcing evacuation of personnel from critical operating sites, with possible long-term delays for re-occupation due to contamination.
- Vital plant having to be shut down to prevent damage to systems or to avoid exacerbating the original hazard.
- Causing the death of essential personnel - especially where there is a concentration of expertise in one vulnerable location, either associated with the actual lifeline services, at a corporate office or on any mode of transport.
- Infiltration of piping or service ducts by dangerous substances.
- Corrosive effects on vital equipment.
- Economic loss and loss of public confidence due to inability to supply service.

Explosion

Potential sources of explosion include gas, petroleum products, explosives, oxidisers, dust and steam.

Gas

Liquefied Petroleum Gas (LPG) is the predominant stored gas in Dunedin. Supplies are delivered by coastal tanker to the Liquigas bulk storage depot. No other vessel is allowed to operate in the harbour channel at the same time as the LPG tanker. The Liquigas Depot, built in the early 1980's on land reclaimed from the harbour, incorporates sophisticated monitoring and safety systems for its thirteen 100 tonne storage tanks - the largest stored volume of LPG in the City. Road tankers transfer LPG to above ground storage tanks at service stations and industrial sites around Dunedin.

LPG in gas form yields around 270 times its liquid volume and is heavier than air, so it will flow and collect in low lying areas and drains. Its flammable range is between two and ten percent concentration in air. An LPG storage vessel affected by fire is at risk of a Boiling Liquid Expanding Vapour Explosion (BLEVE).

Methane gas produced by decomposition of materials at the Green Island landfill is collected, purified, an odouriser added then pumped through a pipeline to Citigas Otago in Hillside Rd, where it is used to produce tempered gas for reticulation. Up to 50 tonnes of LPG are stored at the Citigas site.

Methane is lighter than air and so disperses more readily than LPG does. Methane is flammable in concentrations of five to fourteen percent in air and has a lower flashpoint than LPG.

The NZ Fire Service identifies a risk radius of 1,000m around bulk gas installations.

Petroleum Products

Petroleum products are delivered to Dunedin by coastal tankers which offload through fixed pipe networks to bulk storage depots in Parry Street and Fryatt Street. All are above-ground tanks with fire protection. Road tankers transfer the fuel to underground storage tanks at service stations and industrial sites and some small above ground diesel tanks for boilers.

The explosion risk from petroleum products stored underground is minimal. It is more likely that there will be burning from vents or broken pipes.

The NZ Fire Service identifies a risk radius of 1000m around bulk petroleum installations.

Explosives
Blasting explosives and ammunition are stored in quantity at two sites in Dunedin, neither of which is assessed as posing a danger to lifeline services. Bagged ammonium nitrate is stored at one site and poses an explosion risk if it comes into contact with a quantity of hydrocarbons, such as diesel fuel.

Oxidisers
Large quantities of oxidisers stored in Dunedin include hydrogen peroxide, chlorine, ammonia and oxygen. No attempt has been made to define hazard areas as these are too dependent upon factors such as volume released, wind direction and topography as well as their interaction with other agents which may trigger explosive reactions.

Dust
A dust explosion occurs when fine combustible dust in suspension in air is ignited. The rapid burning and subsequent release of gaseous products causes a rise in pressure which can prove damaging to plant and personnel and lead to a secondary, often larger, explosion.

New Zealand Standard 6101; Part 2: 1990 lists in excess of 400 dusts which have the potential to explode. No attempt has been made to establish how many of these may be present as a result of processes carried out in Dunedin.

Steam
The Dunedin Hospital laundries has a coal-fired boiler which produces steam used at the laundry and also transferred by underground pipe to the hospital and other buildings.

Spillage/Contamination
Because of the random nature of the results of spillage or contamination, no risk areas for spillage or contamination are defined or mapped.

Gases
Liquid petroleum gas has an anaesthetic effect but is non toxic for exposures up to two hours. By excluding oxygen where concentrations are high it can cause asphyxiation. While methane disperses more readily than LPG in open air, it can cause asphyxiation in a confined working space. The greatest risk to lifelines is the hazard to employees and the need to evacuate installations and isolate sources of ignition.

Petroleum Products
The consequences on lifeline services of petroleum products being released from either bulk storage sites or during transportation are primarily the infiltration of below-ground pipe or duct systems. This could allow dangerous vapours to spread for considerable distances, possibly reaching critical elements of lifeline services such as pumping or switching points.

Oxidisers
Apart from their possible toxicity to personnel, oxidisers may have a corrosive effect on many elements of lifeline systems, particularly electrical and electronic equipment.

Toxic Substances
Many toxic substances are used in and transported around and through the City.

Radioactive Substances
Radioactive substances are used by Dunedin Hospital and the University of Otago. The quantities in use pose no appreciable risk to lifelines.

Biological Organisms
There are no known major sources of potentially harmful biological organisms in Dunedin. The main risk from biological organisms would be the contamination of water supplies.

Fire

Due to the random nature of fires, risk areas cannot be identified.

Urban

Fires in the urban area during normal fire risk conditions have a wide range of causes, although the predominant factor in the 900 fires responded to each year is human error. Historically, the loss of water supplies and ready road access following earthquakes has lead to significant losses of community assets from fire.

The risk to lifelines from such fires is from direct involvement or from hazardous substances released due to fire damage.

Rural

Rural fires generally arise either from agricultural burn-offs escaping from control or from maliciously or accidentally started fires.

The primary risk is to services such as water pipelines and electricity and communication transmission lines crossing rural areas. Radio repeater sites, sub-stations, bridges and other lifeline structures in proximity to combustible vegetation may also be at risk.

Transportation Accidents

Transportation accidents could arise from air crash, rail accident, road accidents or an incident involving shipping. Proximity of vital elements of lifeline networks to transportation ‘nodes’ such as ports, airports and busy road/rail interfaces should provide some indication of possible risk exposure.

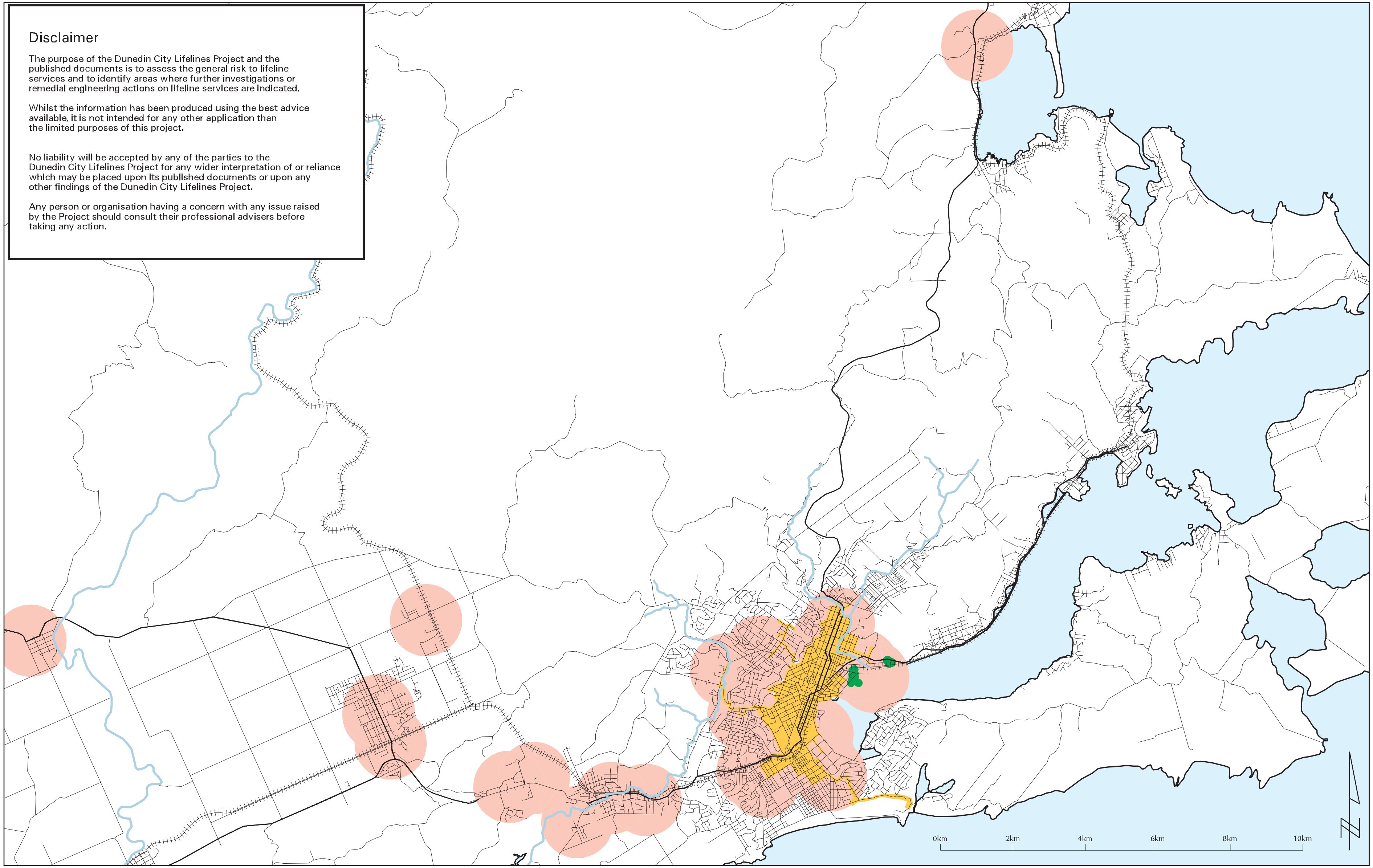
Structural Failure

Failure of major structures such as dams, bridges and buildings without external influence has a low probability but should not be entirely discounted.

Terrorism/Sabotage

The possibility of terrorist action or malicious sabotage is always present and there have been recorded incidents of threats or actual damage to a number of lifeline facilities in recent years. It is not possible to identify risk areas for this type of threat, although lifeline owners should consider whether security for key elements of their networks is satisfactory.

Gas and Petroleum Sites



Extent of Reticulated Gas Supply

Rivers

LPG Bulk Storage Showing Risk Area

Major Petroleum Storage

City Consultants
August 11, 1998

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WATER - DESCRIPTION OF SERVICE

Raw Water

Urban Water Schemes
The raw water to supply the Dunedin urban area is taken from 14 gravity intakes, 5 pumped intakes and 9 borehole supplies. The gravity intakes range in elevation from 249m to 775m above Otago Datum. Of these gravity intakes, Deep Stream and Deep Creek are the most important as they are the highest, and capable of delivering the most water to the upper levels of the city. Of the pumped sources, the Taieri borefield is the most important as this source has the capability to supply significant quantities of water to the low lying areas of the city.

A detailed analysis of possible daily intake flows is set out below:

SOURCE	TYPE	ELEVATION M	POSSIBLE DAILY VOLUME M3/DAY	%
Deep Stream	Gravity	524	38,500	40.3
Deep Creek	Gravity	775	6,800	
Cedar Farm	Gravity	504	1,200	
Burns	Gravity	485	1,300	
Jeffersons	Gravity	480	300	
Williams	Gravity	477	1,300	
Upper Morrison	Gravity	409	2,000	
West Branch	Gravity	401	2,000	15.3
Lower Morrison	Gravity	308	1,200	
Nicols	Gravity	275	1,200	
McKenzie's	Gravity	258	1,800	
Sligo	Gravity	255	1,800	
McQuilkan's	Gravity	255	1,800	
Ross	Gravity	249	1,200	
Silverstream (Powder Ck.)	Intake & pumped	181	8,000	
Taieri Bore #1	Infiltration & pumped	101	10,500	
Taieri Bore #2	Infiltration & pumped	101	10,500	35.7
Taieri Bore #3	Infiltration & pumped	101	10,500	
Outram Bore	Infiltration & pumped	101	624	
Mosgiel - Reid Avenue	Bore	117	696	
Mosgiel - Battleaxe	Bore	120	530	
Mosgiel - Severn St.	Bore	120	810	
Mosgiel - Cherry Dr.#1	Bore	118	1150	
Mosgiel - Cherry Dr.#2	Bore	118	1300	8.7
Mosgiel - Old Council Yd.	Bore	117	770	
Mosgiel - Ayr St.	Bore	113	1350	
Mosgiel - Eden St.	Bore	116	1250	
Mosgiel - Watt St.	Bore	114	1920	

The Deep Stream pipeline, laid in the 1970's, transports water from the Deep Stream catchment 58 km to the Mt Grand Treatment Plant. It is also possible to divert water to Wingatui Treatment Plant and Southern Reservoir. The pipeline varies in diameter from 600 to 840mm and is a mixture of rubber ring jointed concrete pipe in low pressure areas and welded epoxy painted steel pipe in high pressure areas and spans across gullies. This pipeline has a single intake.

The Deep Creek pipeline, laid in the 1930's, transports water from the Deep Creek catchment to the Booth Road Treatment Plant and Sullivans Dam. Water can also be diverted to Southern and Ross Creek Reservoirs.

Normally, excess flows from the Deep Creek line are spilled at the Booth Road Treatment Plant into Ross Creek and thence to the Ross Creek Reservoir. This pipeline has a single intake.

The Silverstream pipeline is laid along the line of the old open race to the Southern Reservoir. This race was replaced with a mixture of concrete and steel pipe over a period of time from the 1940's to the early 1970's. The pipeline varies in diameter from 375mm to 760mm, with the larger size being downstream from the Wingatui Treatment Plant where it also carries Taieri bores water. This pipeline has four intakes, namely the Silverstream, McKenzie's, Sligo's and McQuilkan's creeks.

The Taieri bores pipeline runs from the Taieri borefield near Outram, via the Puddle Alley Pumping Station to the Wingatui Treatment Plant, where it joins the Silverstream pipeline. The pipeline is 600mm diameter and is rubber ring jointed concrete pipe between the borefield and Puddle Alley, beyond which it is concrete lined steel. This pipeline has three bore pumps, one of which has a booster pump. The Puddle Alley pumping station, containing three booster pumps, lifts the water up the hill to the Wingatui Treatment Plant and the Southern Reservoir.

The pipelines in the Waitati - Leith - Ross Creek system were laid in the early twentieth century and run from the top of the Waitati River catchment to Sullivans Dam and on to Booth Road and Ross Creek treatment plants. The pipes are mainly either lead jointed cast iron or leadite jointed steel and vary from 225mm - 500mm in diameter with a small amount being concrete lined steel pipe and rubber ring jointed concrete pipe. There are three intakes in the Waitati River catchment, from Burns, Jeffersons, and Williams Creeks. The intakes on the Leith are West Branch, Upper Morrisons, Lower Morrisons and Nicols Creeks as well as an intake on Ross Creek.

The Port Chalmers area is normally supplied from Cedar Farm and Rossville Reservoirs which are small dams on Cedar Creek (Cedar Farm) and unnamed creeks above Sawyers Bay (Rossville) but there is also a treated water back-up supply from Dunedin.

The Outram pipeline transports water from a small bore at the Taieri borefield to the Outram Reservoir. The pipeline is 150mm diameter and consists of asbestos cement pipe in the buried sections and concrete lined steel in the section which is attached to the Taieri River bridge on SH 87. This system also has a back-up supply from the main Taieri bore pumps.

Mosgiel's supply is pumped from nine borefields within the township directly into the reticulation system with the Quarry Hill Reservoir acting as a balancing tank. The pipes vary in diameter up to 450mm and are mainly lead jointed cast iron pipe, gibault jointed concrete lined steel pipe and rubber ring jointed asbestos cement pipe. Mosgiel also has a back-up supply from the Wingatui Treatment Plant.

Rural Water Schemes
Waikouaiti's Merton, Karitane and Seacliff raw water is pumped from the Waikouaiti River to the treatment plant through a 150mm diameter asbestos cement pipeline.

Warrington is supplied from two springs above the Reservoir Road Treatment Plant through 80mm and 50mm diameter asbestos cement or PVC pipelines.

The Waitati supply is from an intake on Whetherstons Creek, a tributary of the Waitati River along a 125mm diameter asbestos cement pipeline to the Donalds Hill Road Treatment Plant.

The Rocklands - Pukerangi Rural water scheme is supplied by a 125mm diameter PVC pipeline from the Deep Creek pipeline.

The West Taieri Rural Water Scheme is supplied by a 150mm diameter PVC pipeline from the Mill Creek, a tributary of the Waipori River.

Storage and Treatment.

Urban Water Schemes
Raw water storage for the urban part of the city is limited to 7 to 10 days supply, assuming that the reservoirs are full and there is no incoming flow.

The table below shows the capacities of the various reservoirs.

RAW WATER RESERVOIR	CAPACITY (Raw Water) cubic metres
Southern	204,000
Sullivans Dam	110,700
Ross Creek	122,200
Cedar Farm & Rossville	130,000

Treated water storage is limited to the capacity of the treatment station contact tanks, which in most cases amounts to only a matter of hours. The primary function of these is to provide contact time for disinfection rather than storage capacity.

Contact tank capacities and treatment station outputs are:

TREATMENT STATION	CONTACT TANK CAPACITY cubic metres
Southern #1	1,135
Southern #2	2,275
Wingatui	4,546
Booth Road	1,023
Mt Grand	2,275
Ross Creek	340
Port Chalmers	1,350
Outram	2,275

TREATMENT STATION	AV. PLANT OUTPUT cubic metres per day	PEAK PLANT OUTPUT cubic metres per day
Southern	12,000	30,000
Wingatui	3,000	6,000
Booth Road	10,000	15,000
Mt Grand	17,000	30,000
Ross Creek	2,500	6,000
Port Chalmers	1,200	1,500
Outram	186	200

Rural Water Schemes
Raw water storage on the rural water schemes, with the exception of Waikouaiti and West Taieri, is very limited as can be seen from the tables below. (* = Run of system)

RAW WATER RESERVOIR	CAPACITY cubic metres
Waikouaiti-Karitane-Merton-Seacliff	3,409
Warrington	112
Waitati	0*
Rocklands	0*
West Taieri	10,500

Treated water storage is limited on the rural water schemes, however each property should have 1 to 2 days storage on site. The exception to this is Waikouaiti township where the service connections are unrestricted as in the urban area.

Contact tank capacities and treatment station outputs are:

TREATED WATER RESERVOIR	CONTACT TANK CAPACITY cubic metres
Waikouaiti-Karitane-Merton-Seacliff	3409
Warrington	46
Waitati	46
Rocklands	138
West Taieri	184

TREATMENT STATION	AV. PLANT OUTPUT cubic metres per day	PEAK PLANT OUTPUT cubic metres per day
Waikouaiti	1170	2,875
Warrington	175	250
Waitati	160	300
Rocklands	300	426
West Taieri	1018	1,400

Reticulation

Urban Water Schemes
The primary distribution network which carries water from the treatment stations' contact tanks to the distribution reservoirs around the city consists of pipe of varying materials from 150mm to 600mm in diameter cast iron, steel, asbestos cement and ductile iron being the most common.

As this distribution network is complex it is described in tabular form rather than narrative.

TREATMENT STATION	PIPELINE & RETICULATION ZONE DESCRIPTION	PIPE DIA mm
Southern	Southern to Sommerville St Pumps and Green Hill Res.	300-375
Southern	Southern to Green Island, Abbotsford Res. & Waldronville Res.	300
Southern	Southern to Emmerson St Pumps & Concord Res.	150
Wingatui	Wingatui to Wingatui & Taieri Industrial Estate	450-225
Wingatui	Wingatui to Fairfield Res.	200
Ross Creek	Ross Creek to North End Res. & University Area	450-150
Booth Road	Booth Road to Beta Res. & Epsilon St Res.	200-350
Booth Road	Booth Road to Glenleith Res.	150
Booth Road	Booth Road to Upper Pine Hill, Pine Hill Res & Campbell Road Tanks	300-150
Booth Road	Booth Road to Opoho & Signal Hill Res.	300-150
Booth Road	Booth Road to Wakari Pumps & Stoney Knowe Res.	300-225
Mt Grand	Mt Grand to Maori Hill Res.	550
Southern	Southern to Montecillo Res., Low levels* & North End Res.	300-600
Port Chalmers	Port Chalmers to Roseneath, Sawyers Bay, Port Chalmers, Careys Bay & Deborah Bay	150-225
Mosgiel Bores	Mosgiel Bores to Mosgiel & Quarry Road Res.	450-150
Mosgiel Bores	Mosgiel Bores to Kinmont Pumps and Kinmont Res.	150
Outram	Outram to Outram reticulation	150

DISTRIBUTION RESERVOIR	CAPACITY M^3	PIPELINE & RETICULATION ZONE DESCRIPTION	PIPE DIA mm
Maori Hill	5,054	Maori Hill Res. to City Rise & North East Valley	250-150
Maori Hill	"	Maori Hill Res. to City Rise, Low Levels* & North End Reservoir	550-225
Montecillo	5 045	Montecillo Res. to Low levels*	600-150
Green Hill	8,105	Green Hill to Waverley, Andersons Bay, Tomahawk Centre Road Res.,	250-150
		Sunshine & Macandrew Bay Res.	250-150
Macandrew Bay	1,600	Macandrew Bay Res. to Mac. & Company Bays & Grassy Point Res.	150
Grassy Point	1,025	Grassy point Res. to Broad Bay & Portobello	150
Centre Road	79	Centre Road to Upper Tomahawk	150
Signal Hill	4,546	Signal Hill Res. to Mt Mera Res.	150
Signal Hill	"	Signal Hill Res. to Ellesmere St. Res.	250
Signal Hill	"	Signal Hill Res. to St.Leonards Res. & Gerrys Road. Res.	150
Ellesmere St	455	Ellesmere St. Res. to Lower Ravensbourne	250-150
St. Leonards	1,137	St. Leonards Res. to St. Leonards, Maia & Roseneath	150
Mt Mera	1,137	Mt Mera Res. to Mt Mera & Normanby	150
Gerrys Road	91	Gerrys Road. Res to Upper Ravensbourne	150
Glenleith	391	Glenleith Res to Glenleith, Leith Valley & Wakari	150
Stoney Knowe	2,275	Stoney Knowe Res. to Brockville, Upper Wakari & H'bush.	300-150
Abbotsford	1,350	Abbotsford Res. to Abbotsford & Green Island (Balancing tank)	300-150
Waldronville	477	Waldronville res. to Waldronville	150
Concord	1,093	Concord Res. to Concord	150
Beta St	3,495	Beta St. Res. to Caversham, Corstorphine, Kew & Upper St Clair	375-150
Beta St	"	Beta St. Res. to Belleknowes, Kaikorai Valley, Maori Hill & Lower Wakari	375-150
Epsilon St	2,334	Epsilon St Res. to Mornington & Glenpark Res.	300-150
Glenpark	1,000	Glenpark Res. to City Rise	200
Fairfield	909	Fairfield Res. to Fairfield, Westwood & Brighton Res.	150
Brighton	4,000	Brighton Res. to Brighton	200-150
Quarry Hill	4,550	Quarry Hill Res to Mosgiel	450-150
Kinmont	239	Kinmont Res to Kinmont	150

Distribution reservoir zones are subdivided into lower pressure areas by pressure reducing valves. These have not been tabulated for reasons of simplicity.

Of these pressure reducing valves, Kaikorai Valley, Caversham Valley Road, Jervois Street, Manor Place, Rattray Street, Hanover Street, Castle Street, Cosy Dell and Kyle Street valves are the most important as they supply the Central Business District, wharf and South Dunedin areas.

**Note: "Low Levels" refers to the Central Business District, wharf, South Dunedin, St Kilda, Lower St. Clair and Musselburgh Rise areas.*

Rural Water Schemes

The primary distribution networks in the rural water scheme areas consist of pipes varying in diameter from 15 to 200mm and of varying pressure rating (often very low). The most common materials are PVC, asbestos cement and polyethylene.

TREATMENT STATION	PIPELINE & RETICULATION ZONE DESCRIPTION	PIPE DIA. RANGE mm
Waikouaiti	Waikouaiti TS to Waikouaiti	200-150
Waikouaiti	Waikouaiti TS to Karitane	150
Waikouaiti	Waikouaiti TS to Merton & Seacliff	150
Warrington	Warrington TS to Warrington & Evansdale	80
Waitati	Waitati TS to Waitati - Doctors Point	100
Rocklands	Rocklands TS to Rocklands & Pukerangi	125
West Taieri	West Taieri TS to Berwick & Henley	150

DISTRIBUTION RESERVOIR	CAPACITY M^3	PIPELINE & RETICULATION ZONE DESCRIPTION	PIPE DIA. mm
Ramrock (Waikouaiti)	1200	Ramrock Res to north end of Waikouaiti	150
Puketeraki Merton	26	Puketeraki Res to Apes Road & Puketeraki	32
Seacliff Merton	1136	Seacliff Res to Seacliff & Merton	150
Church Road Merton	23	Church Road Res to Church Road & Steep Hill	32
Hornes (West Taieri)	23	Chain Hills	40
Otokia (West Taieri)	46	Chain Hills	65
Cuttances (West Taieri)	23	Chain Hills	40

Pumping

Urban Water Schemes

Pumping stations range in size from those which serve just a few households to those serving suburbs. Ross Creek, North Taieri Road and Fairfield are not normally used.

DISTRIBUTION PUMPING STATION M^3 PER DAY	ESTIMATED DELIVERY	PIPELINE & RETICULATION ZONE DESCRIPTION mm	PIPE DIA.
Ross Creek	4,000	Ross Creek TS to Maori Hill Res.	300
Sommerville St.	7,000	Low Levels Reticulation to Green Hill Res.	300
Roseneath	1,500	St Leonards Reticulation to Port Chalmers Contact tank	150
Wakari Road	2,300	Wakari Reticulation to Stoney Knowe Res.	225
North Taieri Road	decomm-issioned	Abbotsford Reticulation to Abbotsford Res.	150
Emerson St	2,000	Lower Concord Reticulation to Concord Res.	150
Church Hill Road	150	Green Island Reticulation to Church Hill Road Res.	100
Fairfield	5,100	Wingatui TS to Fairfield Res. (Booster)	200
Kinmont	456	Mosgiel Reticulation to Kinmont Res.	150

Rural Water Schemes
The pumping stations listed below are in daily use.

DISTRIBUTION PUMPING STATION	RATE M^3 PER DAY	PIPELINE & RETICULATION ZONE DESCRIPTION	DIA. mm
McGrath Road	1,300	Waikouaiti TS to Ramrock Road (Kia Toa) Res.	150
Apes Road	1,500	Waikouaiti TS to Seacliff Res.	150
Omimi	60	Seacliff Res. to Church Road.	32
Hornes	56	West Taieri Retic. to Hornes Res.	40
Cuttances	250	West Taieri Retic. to Wallaces Res.	40
Otokia	160	West Taieri Retic. to Otokia Res.	65

Principal Depots

Mt Grand
The Mt Grand Treatment Station is the hub of the water telemetry control system and a radio telephone (RT) base set is installed at this site together with a copy of the city's water reticulation plans. There is a hard standing area for the storage of large diameter pipes for trunk mains repairs.

Midland Street Yard
The Midland Street Depot is sited on reclaimed land near Portsmouth Drive and has buildings of reinforced concrete block construction with asbestos roofing. A set of the city's water reticulation plans and a Water Business Unit RT. base set are kept here. An A3 sized copy of the plans is held in each repair crew's truck. This is the dispatch centre for all repair work during normal work hours. After hours dispatch is carried out by a private firm.

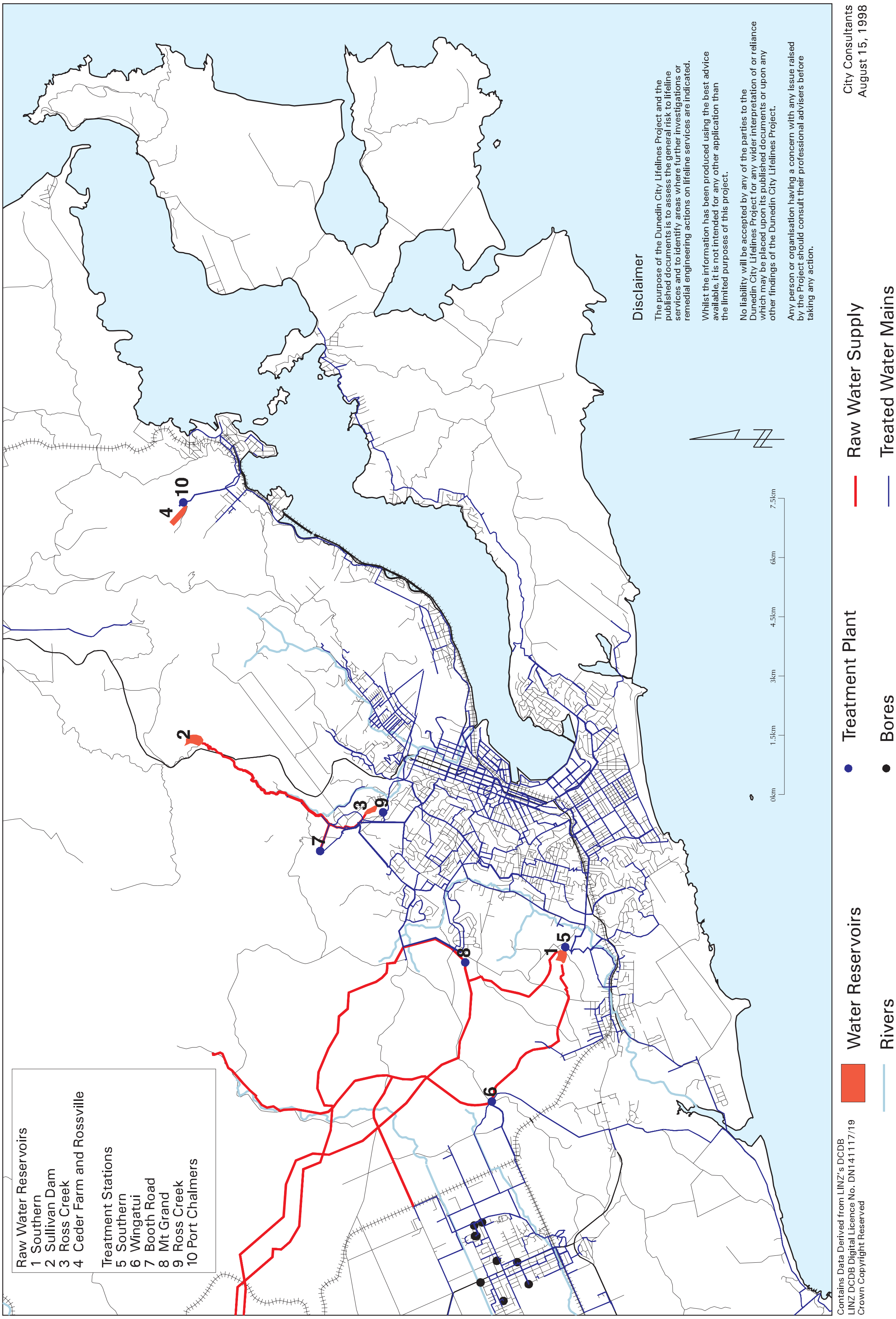
The main store holds a stock of fittings for the repair of most sizes of mains, although only sufficient to meet ordinary operations and maintenance requirements. There would not be sufficient fittings to repair the expected number of broken mains and service dislocations resulting from a large earthquake.

Carlyle Road Yard (Mosgiel)
This depot is situated at the end of Carlyle Road in Mosgiel. Copies of plans of the larger untreated supply watermains are held here as well as plans of the various rural water schemes. A small range of repair fittings is held.

There is no Water Business Unit RT base set at this depot and staff working from this depot rely on vehicle mounted and hand held RT sets when away from their vehicles. Reduced (A3 sized) plans of the rural water schemes are held in each 4WD vehicle.

Civic Centre
A Water Business Unit hand held RT set is installed on the first floor of the Civic Centre and two copies of the city's water reticulation plans are held here. The supply telemetry system can be monitored from the first floor of the Civic Centre.

Water Supply and Distribution



WATER - ASSESSMENT OF VULNERABILITY

Urban Raw Water

Deep Creek Pipeline (1930s)
This is an old pipeline which is laid across farm land adjacent to roads. It is particularly vulnerable at the intake, the gorge section immediately below the intake, the Deep Stream bridge, the Taieri River pipe bridge and where it spans the Silverstream.

The intake could be damaged by rock fall as could the new section of pipeline laid through the Deep Creek Gorge and the pipeline is also susceptible to earthquake or flood damage where it crosses the Deep Stream on a disused road bridge.

The three pinned arch support bridge at the Taieri is vulnerable to earthquake or landslide, particularly on the steep true left bank, resulting in destruction of the bridge due to a massive rock fall and the access track on that side sustaining substantial damage. This bridge could also be prone to damage by helicopter strike.

The pipe bridge across the Silverstream could be damaged by earthquake or flood, but in this case the site would remain relatively accessible.

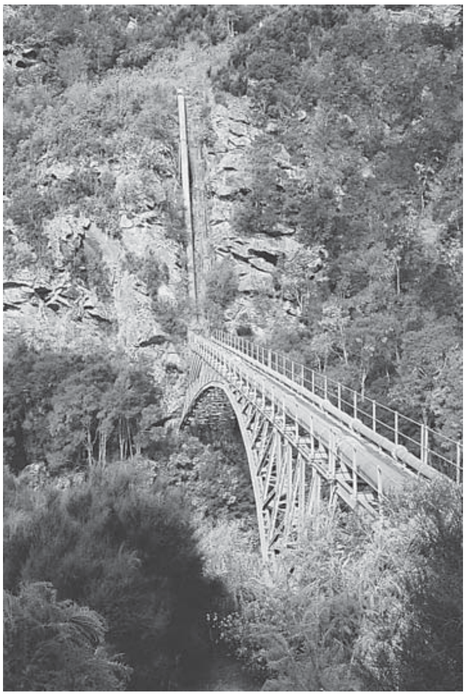
Apart from the first 1,400 metres, which was renewed recently, the pipeline itself is particularly fragile due to corrosion with leakage at joints being the most common current mode of failure.

Supply through this pipeline is partially backed up by the Waitati-Leith system.

Deep Stream Pipeline (1970's)
This pipeline is laid mainly across farm land, with access for maintenance being by a 4WD access track along most of the route.

The main points of vulnerability are at the intake, at two tunnels and at the Taieri River crossing where the pipe is on the same pipe bridge as the Deep Creek pipeline, making this the single most vulnerable point in the city's raw water supply. Likely earthquake damage includes rock fall at the intake, fracturing of the concrete pipes, joints being pulled out, buckling of steel pipe spans and damage due to swaying of the break pressure towers. Corrosion failure has not been a problem to date, but breakages on concrete pipes near anchor blocks have occurred.

This pipeline is backed up by the Deep Creek pipeline and the Waitati - Leith system for supply to the higher areas of the city and by the Silverstream and Taieri bores pipelines for the lower areas of the city, but complete failure of the Taieri River bridge would take out both the Deep Creek and Deep Stream pipelines resulting in significant loss of supply to the upper parts of the city, necessitating rationing.



Taieri River Pipe Bridge - Civil Defence

Port Chalmers System
The Cedar Farm and Rossville Reservoirs are connected by an open watercourse which is not considered to be vulnerable, nor is the short length of main from the Rossville Reservoir to the Port Chalmers Treatment Station. Little is known about the condition of this pipeline or even its exact location.

Waitati - Leith - Ross Creek Pipeline System (1860 - 1920's)
The Burns pipeline which supplies Sullivans Dam from the Waitati River catchment is prone to damage from land movement. Parts of this section are laid on timber supports which have to be jacked up from time to time.

The pipelines in Leith Valley Road between Sullivans Dam and Booth Road Treatment Station and those from the side creek intakes of West Branch, Upper - Lower Morrisons and Nicols Creeks are all prone to landslide damage and to earthquake damage where they cross road bridges at Cedar and Nicol's Creeks.

The pipeline from Ross Creek intake and Ross Creek Reservoir is supported by the road bridge across McGouns Creek in Wakari Road and as it is cast iron and concrete lined steel, shaking would cause failure of the lead or leadite joints.

Silverstream Pipeline (1950's)
This pipeline is laid through forestry and farm land, with access via farm tracks and forestry roads. The most vulnerable components are the intake pump station, crossings of the Silverstream and the pipe spans near Invermay and pipe breakages would be expected to occur on those sections laid in asbestos cement and concrete pipe. Historically, the asbestos cement pipe sections fail due to softening of the pipe itself, whereas damage to the concrete pipe sections have mainly been attributable to bedding failure.

The intake pump station would be affected by electricity failure as there is no back-up power supply, although the three gravity intakes could still remain operational and this pipeline is backed up by the Taieri bores pipeline.

Taieri Bores Pipeline (1950's)
The first section of this pipeline is laid adjacent to State Highway 87 with subsequent sections traversing farm land.

The three bores which supply this pipeline are exposed to flooding damage when the Taieri River inundates the borefield and the electrical control systems in the main control valve pit would fail if the seals around the cable conduits leak. The borefield and pipeline is prone to earthquake damage, with vertical shaking of the pumps causing damage to cast iron casings and internal ceramic bearings as well as to the electricity cables. Electricity failure at either the bore pumps or the Puddle Alley booster pumps will shut the water off as there is no standby generator at either site and dislocation of the pumps and pipework at the Puddle Alley Pump Station by an earthquake would also render the pipeline inoperable.

The aged road bridge which supports the pipeline over the Silverstream at Wingatui Road is another vulnerable point on the supply line and the section from Wingatui Treatment Station along the Silverstream pipeline is continually damaged by land movement with the concrete pipe having to be frequently jacked up and rejointed following ground settlement.

Silverstream Pipeline, showing jacking up - Civil Defence

Outram Bore Pipeline
The bore is on the same borefield as the Taieri bores and the pipeline runs across the Outram Bridge, both of which are vulnerable to flooding. There is no back-up for this pipeline.

Mosgiel Bore System
Electricity supply failure would take out some or all of the nine bores as none have stand-by generators although in the event of a complete electricity failure Mosgiel can be supplied from the Wingatui Treatment Station.

Earthquake damage to reticulation is a significant hazard as many of the mains are constructed from asbestos cement pipes. Recent assessment of the condition of these pipes showed that some are badly softened and susceptible to damage. Vertical shaking of the pumps could damage cast iron casings and internal ceramic bearings as well as the electricity cables.

Flooding of Mosgiel could result in contamination of the bores and the reticulation system, particularly as this system is unchlorinated.

Urban Storage

Southern Reservoir
This is an earth dam built around the early 1900's which has no recorded history of leakage, but its resistance to earthquake damage is not known. Failure of the dam could result in significant damage to the microstrainer building as well as to the main treatment station building, which is the only one servicing the Green Island and Concord areas.

Sullivans Dam
This is an earth dam built in the 1920's with no known history of leakage from the dam, but equally no known resistance to earthquake damage. Failure of the dam would result in significant damage to the supply mains in Leith Valley Road and would mean that the Booth Road Treatment Station would be entirely reliant on supply from the Deep Creek pipeline.

Ross Creek
The earth dam was built in the 1860's and the overflow channel was deepened in the late 1970's to lower the top water level because of concerns about leakage near the top of the embankment. It is not known how earthquake resistant this structure is. Failure of the dam would probably take out the distribution pipeline downstream of the treatment station where it spans the creek, but damage to the treatment station itself would be minimal and in any event, loss of this supply would not be critical as the University area can be supplied from the Southern and Mt Grand Treatment Stations.

Rossville Reservoir
This reservoir is supplied from local catchments, and augmented from the Cedar Farm Reservoir near the top of the Port Chalmers catchment. Failure of the Cedar Farm earth dam would not result in damage to the Rossville Reservoir, but failure of the Rossville earth dam would cause loss of supply to the Port Chalmers Treatment Station and possible damage to the distribution pipelines downstream of the station where they cross the creek. In the event of such a failure, Port Chalmers could be supplied from the St Leonards Reservoir through the pipeline along State Highway 88, provided the distribution mains beyond the Port Chalmers Treatment Station remain undamaged.

Urban Treatment

Southern Treatment Station
This station was built around the 1950's and utilises a microstraining and chlorination process to supply the Central City, Green Island, South Dunedin, St Kilda, Andersons Bay and the Peninsula.

The main treatment and microstrainer buildings are constructed from reinforced concrete masonry brick cladding and iron roofs, which should perform well in an earthquake and the mains in and around the station are constructed in concrete lined steel pipe which are believed to be robust. The microstrainer drums are housed in reinforced concrete chambers and have close tolerances on their sealing faces, which means they could be jammed if shaken out of alignment, though the microstrainers can be operated independently of each other or by-passed entirely. The cast iron frames of the drums are susceptible to twisting damage and the fine mesh straining fabric could be damaged easily by falling masonry.

The three unrestrained 920kg portable chlorine drums operate on a vacuum system designed to shut down in the event of their flexible supply pipes being punctured and in this event it is expected that significant dispersal of the chlorine would take place before it could reach heavily built up areas.

As there is no back-up electricity supply, a power failure could result in untreated water being be distributed.

If this station was totally destroyed Green Island would be without water as there are no back-up links from other treatment stations, but the central city area, including the hospital, could still be supplied from the Mt Grand and Ross Creek Treatment Stations.

Wingatui Treatment Station
This station was built around the 1960's and utilises a microstraining and chlorination process to supply Wingatui, Fairfield and Brighton well as being the back-up supply for Mosgiel, Kinmont and East Taieri.

The main treatment building is constructed from reinforced concrete with brick cladding and the mains in and around the station are constructed in concrete lined steel pipe and are believed to be in good condition. Issues relating to the microstrainers, the single 920kg portable chlorine drum and electricity supply are the same as for Southern Treatment Station.

If this station was totally destroyed, Wingatui would be without treated water unless a back feed from the Mosgiel bore systems was implemented. Fairfield would remain without water as there is no back-up link from Green Island. A limited supply to Brighton could be back fed from the Waldronville system.

Booth Road Treatment Station
This station was built around the 1960's and consists of a microstraining and chlorination process. The issues relating to building, microstrainers and power supply are the same as for the Southern and Wingatui Treatment Stations.

The rectangular reinforced concrete contact tank is a below ground structure which cannot be by-passed if the tank is damaged but if Booth Road Treatment Station is shut down, the Mt Grand Station takes over.

Chlorine is stored in drums at this station but while it is relatively remote from housing, the shape of the land would mean that chlorine could accumulate in the built up parts of Leith Valley if a drum were to rupture.

Mt Grand Treatment Station
Mt Grand Treatment Station was built in the 1970's and is a full filtration plant in which initial sediment removal is carried out in a parallel plate separator constructed in 1986 and which should be reasonably earthquake resistant.

The main treatment building which houses the control and dosing equipment is constructed from reinforced concrete block with a timber truss roof and houses the hub of the telemetry system. The filter building containing the sand and anthracite filters is constructed in reinforced concrete and steel pipes connect the dosing and mixer structure with the filter building.

Up to five 920kg chlorine cylinders are held at Mt Grand, along with three smaller cylinders. While the likelihood of these rupturing is remote, if it were to happen, it would be necessary to evacuate part of Brockville below and adjacent to the plant.

There is no back-up power supply which means that all of the plant except for the telemetry system will shut down in the event of a power failure. If the shut down is for a protracted period, the Booth Road station would supply to the upper areas of the city with Southern (which has a two hour battery back-up system) supplying the lower areas.

In the event that all these stations were out of service, the raw water by-pass below Mt Grand could be opened to supply untreated water to the city.

Ross Creek Treatment Station
This station was upgraded in 1993 to a clarification and magnetite filtration process, with the main treatment building constructed from reinforced concrete and the clarifier being a steel structure. The mixer and magnetite regeneration equipment are housed in the main treatment building and loss of the magnetite process is not critical as the station would still be capable of supplying good quality water through its sand filters.

Failure of the 920kg drum of chlorine could result in chlorine going into the Woodhaugh area.

There is no back-up power supply which means the plant would shut down on power failure, although loss of this station would not be critical so long as Mt Grand and Southern are available to supply the university and hospital areas.

Port Chalmers Treatment Station
The control and filter building are of reinforced concrete block construction built in the 1970's, the clarifier, added in the 1980's is of shotcrete construction and the pipework around the plant consists of steel and PVC pipes.

The gas chlorination system consists of a 920kg drum and some smaller cylinders, but spillage of chlorine would probably disperse before reaching a built up area.

This station relies on pumping water up to a contact tank above the treatment station, but there is no back-up power supply and in the event of prolonged power outage affecting just the treatment station, Port Chalmers could be supplied from the St Leonards system.

Outram Treatment Station
The treatment building consists of a reinforced concrete shed which would easily be moved around in an earthquake and while there is no backup supply for Outram, it would be relatively easy to rig up a portable filtration unit in the event of the treatment plant being destroyed. There is no back-up power supply.

Urban Reticulation

Urban Water Schemes

Southern Reservoir to Somerville Street Pumps and Green Hill Reservoir
The distribution feed to the Somerville pumps is from a tee-off in Cumberland Street from the trunk main linking Montecillo and North End reservoirs and is laid beneath the main trunk railway line and shunting yards then continues along Portsmouth Drive and across Bayfield Park to the Somerville Street Pump Station and thence along Somerville Street up to Green Hill Reservoir at Rotary Park.

The most vulnerable components in this pipeline would be the asbestos cement pipes in Portsmouth Drive between Strathallen and Shore Streets, followed by the pumping station itself. The asbestos cement section will be vulnerable to repeated fracturing due to shaking and liquefaction while the pump station is vulnerable to power failure as there is no on site standby supply and the pumps themselves are subject to mechanical damage.

The Portsmouth Drive section is also exposed to tsunami damage due to the fact that it is laid on the harbour side of Portsmouth Drive.

Failure of any component of this system between Strathallan Street and Green Hill Reservoir will shut off the supply to the reservoir as there are no large back-up mains.

Southern Reservoir to Green Island, Abbotsford Reservoir & Waldronville Reservoir
The trunk main from Southern Treatment Station to Green Island follows a route through farm land above the freezing works and along the channel of the Kaikorai Stream beside the old cement works and along Boomer Street to Carnforth Street. From Carnforth Street the supply splits into two mains with the primary supply continuing through Abbotsford with a secondary feed along South Road. From Abbotsford the trunk main continues up North Taieri Road to the Abbotsford Reservoir. This main also connects the secondary main in South Road and extends back along Brighton Road to Waldronville Reservoir.

The most vulnerable part of the trunk main is the 300mm asbestos cement section between Southern Treatment Station and Carnforth Street, and in particular, that length which is attached to the concrete wall beside the Kaikorai Stream. This section could be susceptible to earthquake or flooding damage and is only partly backed up by a 250mm diameter trunk main from Southern to Eclipse Road. This back-up would be fairly tenuous as it is laid alongside the 300mm dia trunk main to the entrance to the freezing works car park.

Southern Reservoir to Emerson Street Pumps & Concord
The 250mm trunk main from Southern Reservoir to the Emerson Street pumps follows a route through farm land above the freezing works across the Kaikorai Stream down Eclipse Road on to South Road along Stevenson Avenue and Emerson Street to the pumps and then to the Concord Reservoir via Seddon Road.

This pipeline would be vulnerable to earthquake and flood damage where it crosses the Kaikorai Stream and the pump station would also be prone to mechanical damage and power failure as there is no back-up power supply. From South Road to the Concord Reservoir there is no back-up pipeline.

Wingatui Treatment Station to Wingatui & Taieri Industrial Estate
This trunk system consists of two trunk mains laid in Gladstone Road as far as Magazine Road, following a route along Gladstone Road and Wingatui Road towards Mosgiel, terminating at a pressure reducing valve which connects into a 450mm asbestos cement main which traverses open country and Centre Road before crossing the Silverstream on a pipe bridge.

The vulnerable components on this pipeline are expected to be the first steel section, pressure reducing valve, asbestos cement section and pipe bridge which are susceptible to earthquake and flooding.

Supply can, however, be backed up by the Mosgiel bore system provided the 450mm diameter asbestos cement section between the corner of Severn Street and Centre Road remains intact.

Wingatui Treatment Station to Fairfield Reservoir
This main crosses open country traversing a series of steep gullies before reaching the Fairfield Reservoir. Designed to operate as a gravity line, its carrying capacity can be boosted by means of the pump at the Wingatui Treatment Station. It is vulnerable to shaking, slips and flooding at gully crossings and there is no back-up to supply the Fairfield Reservoir.

Ross Creek Treatment Station to North End Reservoir & University Area
This trunk main is laid in 300mm cast iron through the bush to Malvern Street, along Duke Street as far as Cumberland Street where it reduces in diameter to 150mm cast iron along Brook and Leith Streets where it connects into the 450mm asbestos cement outlet main from North End Reservoir.

The components vulnerable to earthquake or flooding are the Leith crossings above and below Woodhaugh Street and in Dundas Street, although, while the whole line is expected to be fragile given its age and the type of pipe material, supply is well backed up from other sources.

Booth Road Treatment Station to Beta Sreet & Epsilon Street Reservoirs
This trunk main system consists of a single 500mm diameter steel main as far as the valve house at the corner of Wakari and Burma Roads where it splits into two trunk systems, the first section of which is relatively close to a fault and vulnerable because there is no back-up other than from Mt Grand.

This part of the system is older and consists of two parallel mains from the valve house across the Balmacewen Golf Course, Balmacewen Road and Highgate to Beta and Epsilon Street Reservoirs. Points of vulnerability are the valve house, which is an old brick building and where the pipeline crosses the Stuart Street overbridge, although the two parallel mains give partial back-up.

The second section runs from the valve house, along Wakari Road, through the Wakari Hospital grounds and through open country to Frasers Road, Kaikorai Valley Road, Northview Crescent and on to Beta and Epsilon Street reservoirs, thus forming a ring main with the first section. Consequently the Booth Road to Beta and Epsilon Street Reservoirs trunk system is well backed up.

Booth Road Treatment Station to Glenleith Reservoir
Supply to the Glenleith Reservoir branches off the Booth Road - valve house main and if lost could be supplied from Mt Grand.

Booth Road Treatment Station to Upper Pine Hill, Pine Hill Reservoir & Campbell Road Tanks
This system branches off the Booth Road to Beta & Epsilon system at Drivers Road and Highgate to Stonelaw Terrace, the Woodhaugh Gardens and across the Leith, up Pine Hill Road to the Pine Hill Reservoir and the tanks in Campbells Road. The most vulnerable section is where the pipe crosses the Leith and rises up the steep hillside to Pine Hill Road where it is subject to flooding and land movement, with no back-up from the Leith crossing onwards.

Booth Road Treatment Station to Opoho & Signal Hill Reservoir
This system also branches off the Booth Road to Beta & Epsilon system at Drivers Road, follows Highgate to Stonelaw Terrace, the Woodhaugh Gardens then crosses the Leith at the George Street bridge. From there it crosses the Northern Soccer Club ground and crosses Lindsay Creek at the Botanic Gardens, then follows Opoho Road to its end and crosses open country to the Signal Hill Reservoir. The vulnerable points on this pipeline are the Lindsay Creek crossing which is susceptible to flooding and the section through open country which could be affected by land movement. There is a history of failure of rubber ring joints on parts of this system and there is no back-up pipeline from Woodhaugh Gardens onwards.

Booth Road Treatment Station to Wakari Pumps & Stoney Knowe Reservoir
This trunk main follows Wakari Road from the valve house to the Wakari Road pumps at the intersection with Taieri Road then up Taieri and Three Mile Hill Roads to the Stoney Knowe Reservoir.

The vulnerable components are the asbestos cement main between the pumps and the reservoir and the Wakari Road pumps themselves, both of which would be damaged by shaking. Power failure would stop the pumps as there is no back-up generator.

Mt Grand Treatment Station to Maori Hill Reservoir
This pipeline which runs through Brockville, Frasers Gully and Wakari, to Maori Hill is the trunk main to both the high and low levels of the city. It is the main outlet from the Mt Grand Treatment Station and is of robust construction. The Maori Hill reservoir at the termination of the trunk main is the distribution point to the intermediate and low levels of the city and this reservoir can also be supplied from Booth Road Treatment Station.

Southern Reservoir to Montecillo Reservoir, Low Levels & North End Reservoir
This trunk system consists of three steel mains which run through the old Caversham railway tunnel. From there, two of these mains incorporate pressure reducing valves, which enable water to be supplied to the southern low levels area of the city via South Road and the third runs along South Road to Montecillo Reservoir. All three pipelines are particularly vulnerable to collapse of the old Caversham tunnel and the trunk main to Montecillo Reservoir is vulnerable where it is supported by the Hudson Street road bridge.

From Montecillo Reservoir the trunk main passes through the Town Belt to Manor Place, along Cumberland, Castle and Leith Streets and up Lovelock Avenue to the North End Reservoir. The entire pipeline is vulnerable to shaking and the pressure reducing valves at Manor Place, Jervois Street, Rattray Street, Hanover Street, George/Union Street and Castle Street could be dislocated from the main. From Hanover Street to Lovelock Avenue the main is vulnerable to flooding and is also vulnerable where it crosses the Leith near Leith Street.

The loss of this system at a critical point such as the old Caversham tunnel would mean that Mt Grand Treatment Station would have to fully take over supplying the low levels and failure at later points could require Mt Grand to take up part of this load.

Port Chalmers Treatment Station to Roseneath, Sawyers Bay, Port Chalmers etc.
Two parallel mains are laid from the Port Chalmers contact tank down Reservoir Road to the Stevenson Avenue intersection. Branches from both mains are laid along Stevenson Avenue to supply Sawyers Bay and Roseneath, while another main along Borlases Road, State Highway and George Street extends as far as the entrance to the Container Wharf then continues around Macandrew Road through Careys Bay to Deborah Bay in smaller diameter pipe. The mains in Reservoir Road are vulnerable to shaking, while the main from Careys Bay to Deborah Bay could be vulnerable to tsunami and there is no back-up pipeline.

Mosgiel Bores to Mosgiel & Quarry Road Reservoir
Mosgiel has nine bores which feed directly into the reticulation system, with the main from the Watts Street bore supplying the Quarry Road Reservoir. The asbestos cement section of the Watts Road to Quarry Road Reservoir pipe would be easily damaged in an earthquake and is the main point of concern, although it is reasonably well backed up by cross links in the network as well as by the alternative Wingatui supply.

Mosgiel Bores to Kinmont Pumps and Kinmont
The trunk supply to Kinmont is from the Quarry Hill Reservoir to pumps in Kinmont Crescent and then up to the Kinmont Reservoir. The steep section between the Quarry Road reservoir and State Highway 1 is vulnerable to earthquake and flooding while the section from State Highway 1 onwards is likely to be affected by landslide. There is no back-up pipeline for this section of distribution main.

Outram Treatment Station to Outram
Both the Outram Reservoir and main are vulnerable to earthquake given their proximity to a fault line and there is no back-up supply.

Maori Hill Reservoir to City Rise & North East Valley
The Maori Hill Reservoir is a rectangular reinforced concrete structure set in the ground with precast concrete roof units supported by concrete columns and is a vital distribution point for water to various parts of the city including the Central Business District and the oil depots.

The distribution main to City Rise is connected to the Glenpark Avenue Reservoir and while there are no specific points of vulnerability on the pipeline, breakages of the cast iron main would be expected. This distribution system is however partially backed up by the Glenpark Reservoir supply.

Distribution to North East Valley is in cast iron with major points of vulnerability from flooding at the road bridge crossings of the Leith and Lindsay Creek. Partial back-up of the North East Valley distribution could be achieved by back feeding from the Mt Mera Reservoir.

Maori Hill Reservoir to City Rise, Low Levels & North End Reservoir
The distribution main from Maori Hill Reservoir to low levels and North End Reservoir is a vital lifeline as it supplies the hospital, central city area and the oil depots although it is backed up by the Montecillo to North End trunk main.

This pipeline is laid in 550mm steel pipe with welded joints and follows a route down Drivers Road to a pressure reducing valve at Cosy Dell, then across Queens Drive to a pressure reducing valve at Kyle Street, along Queen Street and down Union Street West to connect to the trunk main from Montecillo Reservoir. There is also a connection from this main where it crosses George Street which feeds water via a pressure reducing valve into the 300mm distribution main in George Street.

Vulnerable points on this main are the pressure reducing valves at Cosy Dell and Kyle Street which could be flooded, affected by landslide or dislocated from the pipeline by earthquake. These sites also rely on reticulated power supply to run the telemetry equipment as there is no back-up power supply.

Montecillo Reservoir to Low Levels
This main supplies water from Montecillo Reservoir to South Dunedin and St Kilda from a circular reinforced concrete structure constructed out of precast panels. The main, constructed from 300mm ductile iron pipe and 225mm cast iron pipe which goes down Eglinton Road, South Road, Burns, Bradshaw, Kirkaldy and Moreau Streets, is particularly susceptible to earthquake damage as it is laid across reclaimed land, and could also be damaged by flooding.

There is reasonable back-up to this supply from the pressure reducing valves at the old Caversham tunnel and the mains in South Road, Forbury Road, Surrey Street and King Edward Street, although an earthquake in this part of town would probably severely damage these back-up mains as well as the interlinking smaller reticulation mains and service pipes.

Rotart Park Reservoir - Civil Defence

Green Hill Reservoir to Waverley, Andersons Bay, Tomahawk & Sunshine
The Green Hill Reservoir located at Rotary Park has two separate concrete tanks, one which is precast and the other in situ so that this site has storage back-up. Reticulated power supplies the telemetry repeater at Green Hill Reservoir, which is the most important link in the telemetry network. There is no back-up power supply on site.

The distribution main, constructed in steel, cast iron and asbestos cement pipes, is laid down Highcliff Road, Tomahawk Road and Centre Road, with the most vulnerable point being the asbestos cement section where the pipe crosses the outlet of the Tomahawk Lagoon at which point it is vulnerable to earthquake and tsunami. There is no back-up main.

Green Hill Reservoir to Macandrew Bay
This main is laid in various classes of asbestos cement pipe from the reservoir across slip prone farm land to the Macandrew Bay Reservoir with off takes to supply Irvine Road and St Ronans Road. It has proven to be extremely fragile, with damage experienced in numerous places by landslides following heavy rain. There is no back-up main.

Macandrew Bay Reservoir to Grassy Point Reservoir
The Macandrew Bay Reservoir is constructed in precast concrete. The valve house containing the inlet and outlet control valve is located some distance down hill from the reservoir and contains a pressure reducing valve by-pass which can be used if the reservoir is decommissioned. The inlet control system relies on reticulated power to operate the inlet valves and telemetry has no back-up supply.

The distribution main is laid in asbestos cement and PVC pipes across farm land with off-takes at Featherston and Greenacres Streets to supply Macandrew Bay and at Bayne Terrace, Eventide Home, McTaggart Street and Raynbird Street. It is prone to damage by landslides at various locations along its route, and, as there is no back-up supply, once the Macandrew Bay Reservoir runs dry, Macandrew Bay and Company Bay would be out of water.

Grassy Point Reservoir to Broad Bay & Portobello
The Grassy Point Reservoir and valve house is of similar construction to those at Macandrew Bay.

The distribution main from the reservoir to Portobello is constructed in PVC pipe laid across steep farm land as far as Matariki Street, (with an off take to King George Street en route), then passing along Waikana and Clearwater Streets, Portobello Road, Oxley Terrace, Portobello Road, Beaconsfield Road and Harington Point Road. The sections through farm land are close to existing landslides and there is no back-up main.

Centre Road Reservoir to Upper Tomahawk
The Centre Road Reservoir is a small volume balancing tank on the end of the Green Hill Reservoir - Tomahawk distribution main and is not a critical component of the system.

Signal Hill Reservoir to Mt Mera Reservoir
The Signal Hill Reservoir is a circular precast concrete structure located approximately 600 metres to the west of the Signal Hill Monument, with the valve house located some distance away and containing a by-pass pressure reducing valve which can be used when the reservoir is decommissioned for maintenance.

The distribution main which is laid through bush covered country between the reservoir and Grandview Crescent in Opoho, then down McGregor Street, along Evans Street and through open country above North East Valley to the Mt Mera Reservoir has been damaged in the past by land movement following heavy rain. Although there is no back-up main between Signal Hill Reservoir and Mt Mera Reservoir, a partial supply could be achieved by diverting water from the Opoho reticulation system into the main to Mt Mera and the area could then be supplied from the Booth Road Treatment Station.

Signal Hill Reservoir to Ellesmere Street Reservoir and St Leonards & Gerrys Road Reservoirs
The distribution main from Signal Hill Reservoir to Ellesmere Street Reservoir is laid across bush covered country and down Rimu Street to the Ellesmere Street Reservoir above Ravensbourne and is vulnerable to damage by landslide. The main then continues past Ellesmere Street Reservoir along Ellesmere Street, through open country to the St Leonards Reservoir. There is also an off take from the main to supply the Gerrys Road Reservoir.

The steel sections of pipeline have proven to be resistant to the slips which have occurred in those areas in the past but there is no back-up pipeline for this main.

Ellesmere Street Reservoir to Lower Ravensbourne
The Ellesmere Street Reservoir is an old circular cast insitu reinforced concrete structure with questionable earthquake resistance and the valve house containing the by-pass pressure reducing valve is located close to the reservoir.

The distribution main, laid down Taupo Street, feeding into the smaller reticulation mains at that point and also supplying the Ravensdown Fertiliser Works, can be partially backed up by opening the zone valve near the fertiliser works which could allow the lower part of Ravensbourne to be supplied from the city’s low levels system.

St Leonards Reservoir to St Leonards, Maia & Roseneath
The St Leonards Reservoir is a circular precast concrete structure located in farm land above St Leonards with a by-pass pressure reducing valve located in a pit close to the reservoir.

The distribution main is laid along the access track from the reservoir, along Harrier Road, down Huia Street, St Leonards Drive, SH 88 and along District Road to the Roseneath pumps. There is also a pressure reducing valve at Huia Street and a pressure sustaining valve at Wren Lane. There is no back-up supply for this main.

Mt Mera Reservoir to Mt Mera & Normanby
The Mt Mera reservoir is a circular precast concrete structure located about 300 metres from North Road with a by-pass pressure reducing valve situated in a pit close to the reservoir.

The distribution main from Mt Mera Reservoir to Normanby is laid through farm land to North Road and down North Road to connect into the smaller reticulation mains near the Normanby Tavern and the only vulnerable point of concern is the asbestos cement outlet main. There is no back-up main.

Gerrys Road Reservoir to Upper Ravensbourne
The Gerrys Road Reservoir is a small rectangular cast insitu structure located above Ellesmere Street in Ravensbourne and the distribution main from the reservoir is laid along Ellesmere Street. The Signal Hill to St Leonards main can be used to back-up this system.

Glenleith Reservoir to Glenleith, Leith Valley & Wakari
The Glenleith Reservoir is an old circular cast insitu concrete structure with a by-pass pressure reducing valve in a valve house attached to its side. There is a small LPG driven generator in the pit which supplies power to the telemetry system. The reservoir is possibly vulnerable to earthquake as it is close to a fault.

The distribution main is laid through bush covered country and along Wakari Road as far as Helensburgh Road to serve Helensburgh. There is also a branch off this main at Tanner Road to serve Glenleith. This system can be backed up from Booth Road supply.

Stoney Knowe Reservoir to Brockville, Upper Wakari & Halfway Bush
The Stoney Knowe Reservoir is a circular cast insitu concrete reservoir located at the intersection of Whare Flat and Three Mile Hill Roads and acts as a balancing tank for the Wakari pumps. The inlet-outlet main between the reservoir and the pumps also acts as the distribution main to Halfway Bush with a branch main carrying water from this main along Dalziel Road to supply Brockville.

The proximity of a fault means that the reservoir and the asbestos cement main are at risk from an earthquake but the Brockville leg of this supply system can be backed up from the Mt Grand - Maori Hill Reservoir pipeline.

Abbotsford Reservoir to Abbotsford & Green Island
The Abbotsford Reservoir is a circular precast concrete structure which can be by-passed as it simply operates as a balancing tank on the end of the Southern to Abbotsford trunk main described earlier.

Waldronville Reservoir to Waldronville
This circular cast insitu concrete structure and the distribution main, which runs down Brighton Road towards the estuary supplying side streets en route, are sited close to the Akatore Fault.

The valve house is close to the reservoir and contains a by-pass pressure reducing valve to enable water from Green Island to continue to be supplied if the reservoir is decommissioned and the main is also linked to the Fairfield - Brighton trunk main which may be able to provide back-up supply for Waldronville.

Concord Reservoir to Concord
The Concord Reservoir is a circular precast concrete structure at the intersection of Seddon and Blackhead Roads, with a valve pit close to the reservoir containing sluice valves which enable the reservoir to be by-passed. The distribution main, which runs a short way along Seddon Road before turning down Blackhead Road to Mulford Street, has no back-up and is susceptible to earthquake.

Beta Street Reservoir to Caversham, Corstorphine, Kew & Upper St Clair
The Beta Street Reservoir near Belleknowes supplies Caversham, Corstorphine, Kew and upper St Clair, and also Kaikorai Valley. It is a below ground rectangular cast in situ structure with precast concrete roof panels supported on columns. The valve house containing the inlet control and telemetry system and a by-pass pressure reducing valve is located alongside the reservoir. Reticulated electricity operates these systems and if this fails there is no back-up supply.

The distribution main becomes overloaded at times of peak demand so that its performance could readily deteriorate through relatively minor leakage following an earthquake and could be exposed to enhanced shaking from Mailer Street to Middleton Road. If it were to burst near Lookout Point significant damage to State Highway 1 could occur and there is no back-up to supply the area if this main fails.

Epsilon Street Reservoir to Mornington & Glenpark Reservoir
The Epsilon Street Reservoir, located at the corner of Epsilon Street and Kenmure Road, is a circular precast concrete structure with the valve pits containing the inlet control equipment and telemetry equipment located alongside.

The distribution main which supplies Mornington and the Glenpark Reservoir runs down Kenmure Road, along English Avenue and Elgin Road then down Mitchell Avenue and along Glenpark Avenue to the reservoir. It becomes overloaded at times of high demand and its capacity could be further reduced by relatively minor leakage following an earthquake and the section from English Avenue onwards is expected to be particularly vulnerable to shaking. Theoretically there is some back-up by utilising the smaller reticulation mains but this would be of a very low pressure and tenuous nature.

Glenpark Reservoir to City Rise
The Glenpark Reservoir in Glenpark Avenue supplies an intermediate zone in tandem with the Maori Hill Reservoir. It is a rectangular below ground cast insitu structure with precast roof panels supported by a central beam and columns and has a valve house which contains the inlet control system, telemetry equipment and the by-pass pressure reducing valve.

The distribution main follows Glenpark Avenue, Neidpath Road, Eglinton Road and connects to the Maori Hill Reservoir distribution main at the intersection of High and Alva Streets and is partially backed up by the Maori Hill distribution main.

Fairfield Reservoir to Fairfield, Westwood & Brighton
The Fairfield Reservoir is of circular precast concrete and the valve pit adjacent to the reservoir houses a sluice valve operated by-pass.

This main goes through a steep bush covered gully then along Fairplay Street, Old Brighton Road and Jeffcoates Road to the Kaikorai Estuary, from where it follows Brighton Road up Scroggs Hill Road to the Brighton Reservoir. It is particularly vulnerable to flood damage in the first section from the Fairfield Reservoir and to tsunami near sea level, with earthquake shaking in the section from the estuary to the Brighton Reservoir. Subsidence due to old coal mines beneath Brighton could also be a problem. There is no back-up for Fairfield but partial back-up for Brighton may be possible from Waldronville.

Brighton Reservoir to Brighton
The Brighton Reservoir, located on the edge of farm land on Scroggs Hill Road is of circular precast concrete construction and the valve pit beside it houses the inlet control valves and telemetry system.

The distribution main in Scroggs Hill Road acts as an inlet-outlet main and runs down Scroggs Hill Road and along Brighton Road. It is vulnerable where it crosses the Otokai Creek on the road bridge and there is no back-up main.

Quarry Hill Reservoir to Mosgiel
The Quarry Hill Reservoir above Quarry Road acts as a balancing tank and provides fire fighting storage for Mosgiel. It is trapezoidal in shape, partially buried and of cast insitu concrete with a colour steel roof supported on timber beams which are in turn supported by concrete columns. It is suspected to be leaking at construction joints which calls into question its structural integrity and is built adjacent to a hillside with a recent history of land movement. The control valves are buried under cast iron covers.

The reservoir has three inlet - outlet distribution mains, the largest of which runs through reserve land near the reservoir, then through a built up area crossing the main trunk railway line to the Owhiro Stream from where it connects to the Wingatui trunk main. Vulnerable sections are the Owhiro Stream crossing and under the railway but there are other back-up mains available.

Kinmont Reservoir to Kinmont
The Kinmont Reservoir is a circular precast concrete structure which acts as a balancing tank for the Kinmont pumps and has a single asbestos cement inlet - outlet main. The distribution main runs through Dee Street

and Quarry Road to and from the booster pumps. This is a combined inlet and outlet main between the pumps and reservoir with reticulation off-takes on route and has no back-up.

Rural Water Schemes

Waikouaiti Water Scheme
The intake building is a silo shaped cast insitu concrete structure at the edge of the Waikouaiti River containing two pumps which lift the raw water from the river by a pipe to a circular cast insitu concrete reservoir at the Waikouaiti Treatment Station, with all components vulnerable to earthquake, flooding and electricity supply failure.

The treatment station is a relatively new structure and built to modern earthquake design standards so the primary vulnerability is power failure. Chlorine is stored in three 70kg cylinders in this station but if these were to leak significant dispersal would occur before reaching any built up areas. The contact tank is a circular cast insitu concrete reservoir and the earthquake resistance of this reservoir and the identical raw water reservoir are not known.

The asbestos cement main from the contact tank to the McGrath Road valve pit is vulnerable to shaking or landslide, and loss of this main close to the contact tank would mean that Waikouaiti, Karitane, Merton and Seacliff would be without water for some time.

The McGrath Road pump station houses a single pump and is vulnerable to electricity supply failure and earthquake. The pipeline from the pumps across the road bridge at Orbell's Crossing to the Ramrock Road Reservoir is vulnerable to flood damage. The reservoir is a rectangular partially buried cast insitu concrete structure with precast concrete roof panels, and is thought to be susceptible to earthquake.

The 150mm asbestos cement main from Ramrock Road to Henry Street on the outskirts of Waikouaiti has a history of repeated failure and is very fragile. This distribution main has the capability to supply the upper and northern end of Waikouaiti because of the elevation of the Ramrock Road reservoir, and is only partially backed up by the newer PVC main which supplies the lower or main part of Waikouaiti.

The 200mm PVC main which runs across farm land from the McGrath Road valve pit and crosses beneath the Waikouaiti River near the road bridge on State Highway 1 is the primary distribution main for Waikouaiti, with the most vulnerable sections on this main believed to be at the McGrath Road valve pit and the river crossing, though the majority of this pipeline is laid through country which would be prone to shaking.

Karitane Water Scheme
This area is supplied by an asbestos cement pipe which runs south east from the McGrath Road valve pit along McGrath Road across State Highway 1 and then beneath the estuary and main trunk railway and on through farm land to Kerr Street at Karitane. This main has a history of breakages through the estuary, can be considered to be relatively fragile and will be susceptible to damage due to enhanced shaking and liquefaction, with no back-up main if damage occurs.

Merton Water Supply Scheme
The Merton area is served by an asbestos cement main which runs south from the Waikouaiti Treatment Station across farm land, beneath State Highway 1 and along Apes Road to a pump station. Part of this main is laid through unstable open country with a history of pipe breakages. This station has two pumps which lift the water up to the Seacliff Reservoir. The electricity supply has no standby generator.

The Seacliff Reservoir is a cast insitu concrete structure which services the Omimi Pump Station, Church Road Reservoir and the Puketeraki tanks. There is much evidence of breakage due to landslip and there is no electrical supply backup.

An earthquake would almost certainly result in pipe joints being pulled out and brittle pipe breakages over significant portions of the pipeline. This would not just be confined to the asbestos cement pipe as much of the polythene pipe is of a low pressure grade. Location of these faults would be time consuming as the plans showing the location of the pipes lack detail.

Warrington Water Scheme
This water scheme has two spring intakes which are located on slip prone farm land near the reservoir to the north of Warrington. The upper spring intake consisting of a circular brick structure and the lower

spring using collector pipes are both susceptible to landslip. There is no effective storage system and the general reticulation pipework quality would be subject to damage in earthquake.

The distribution main from the reservoir to Warrington is in 80mm asbestos cement and the system is vulnerable to landslide and earthquake. An earthquake of reasonable magnitude could destroy the upper spring, dislocate the treatment building from the main and fracture the main, particularly the asbestos cement sections. Warrington residents would then be reliant on any surviving storage tanks on each property as there is no back-up main from the other water schemes to the north or south of Warrington.

Waitati Water Scheme
The intake for this scheme is located about 4.5km to the south of Waitati on Weatherstons Creek, consisting of a simple grate over the end of a pipe protruding into the creek and an asbestos cement main which carries the water to a gravel filter. This filter consists of stone chips contained in a rectangular cast insitu concrete box and the whole system is not very robust. The distribution pipe then follows a route through farm land crossing Weatherstons Creek on a concrete road bridge on the way to the treatment plant and reservoir at the intersection of Donalds Hill Road and Mt Cargill Road.

This scheme, which has no back-up supply, is primarily vulnerable to earthquake due to the nearby geological fault and to flood damage because of the proximity of the pipe line to Weatherstons Creek. The type of damage which is likely to occur is cracking of the asbestos cement pipe, dislocation of the filter and breakage of the main with a particular point of vulnerability at the creek crossing.

Rocklands Rural Water Scheme
The Rocklands Rural Water Scheme takes its water from the Deep Creek pipeline through an in-line strainer in the pipeline and is therefore susceptible to any damage to the primary supply source.

Water is chlorinated and carried by gravity to a reservoir tank farm of generally robust construction and is seen to be secure apart from shaking of the schist landscape capable of fracturing the solvent jointed pipe. Toppling of tanks and broken pipe connections at the tanks would probably occur and there is no back-up supply for this scheme.

West Taieri Water Scheme
The West Taieri Rural Water Scheme's intake is on Mill Creek and is in the form of a reinforced concrete weir keyed into rock. Two steel intake pipes are laid a short distance to a concrete scour box which houses the intake screen and a PVC main runs from the scour box through steep bush covered country to a raw water reservoir near the treatment station. The raw water reservoir is an open pond with a partial concrete apron and rubber liner, connected to a precast concrete flocculator tank and a precast concrete filter. The plant's contact tank consists of eight precast concrete tanks. The treatment building houses chlorine gas cylinders and relies on reticulated electricity for which there is no standby supply. It should also be noted that the system has no alternative supply of raw water from the city.

A PVC distribution main runs through farm land and then alongside Marshall, Centre, Henley and Berwick Roads crossing the Taieri River on the road bridge at Henley. From the Taieri River the main connects to the Horne's Booster Pump Station which houses a duty and standby pump and delivers water to Hornes Reservoir which consists of two precast concrete tanks. There is no power backup to these pumps.

A second distribution main branches off at Centre Road and runs along that road before crossing the Taieri River on the State Highway 1 road bridge to the Otokia Booster Pump Station. The main then runs to the Otokia Reservoir and on to Cuttances Booster Pump and reservoir.

The scheme has been shown to be vulnerable to flood damage in the past, when the intake was destroyed and part of the pipeline from the intake to raw water reservoir washed away. Because access to this section is difficult, material has to be either carried in by foot or helicopter. This section of pipeline is continuously susceptible to landslip as a result of the loss of bush cover due to snow and the pipeline from the intake also follows a geological fault.

Other points of vulnerability would be at the two Taieri River crossings. It should be noted that the two distribution mains which link the northern side of the scheme to the southern side, cross State Highway 1 and the Main Trunk Railway and there are also numerous smaller pipeline crossings of ditches and waterways which are vulnerable to flood damage. Furthermore, the scheme is generally vulnerable to enhanced shaking on the plains and likely failures would be pulled rubber ring joints on the larger diameter pipes and cracking of the smaller PVC pipes. Disconnection of reservoirs and farm tanks by fracture of pipelines is probable.

Principal Depots

Mt Grand
This is located in a relatively low risk area of Dunedin, but is susceptible to damage to storage tanks and mechanical equipment due to earthquake shaking and access to the depot may be restricted by earthquake and severe weather conditions.

Midland Street Yard
This depot is vulnerable to enhanced shaking in an earthquake, to flooding and the effects of a tsunami which would mean that immediate access to a wide range of fittings would be lost. It is of concern that some of our suppliers' warehouses are also located in this area.

Carlyle Road Yard (Mosgiel)
This depot is vulnerable to enhanced shaking in an earthquake because of the underlying gravel soils and it is also vulnerable to flooding should the Silverstream overtop the flood channel.

Civic Centre
This building is of modern construction and considered unlikely to sustain earthquake damage.

Water department monitoring equipment and telemetry system may suffer from earthquake shaking and from loss of power from any cause, as most elements do not have backup power facilities.

WATER - MITIGATION STRATEGIES

Notes on Mitigation Strategies

In developing these mitigation strategies it was necessary to depart from the strict order laid down by the vulnerability analysis scores as the numerical analysis made no distinction between high risk elements related to bulk supply against those related to smaller distribution areas.

The proposed strategy has therefore focused on the elements of our network which would cause the greatest amount of havoc should they fail.

It is important to note that there are other components (unlisted at this stage) which are very fragile and whose failure would shut down the supply to significant portions of the city. Such weaknesses are under constant review and will be the subject of progressive treatment under existing management planning.

Identified Water Supply Components Under Review

A series of worksheets has been prepared in respect of established elements of the system which are known to be at risk. The principal components selected for consideration are:

Unique I.D	Component
1/DS/PL	Deep Stream & Creek Pipelines (Taieri River Bridge)
2/TB/BF	Taieri Borefield
3/TB/PL	Taieri Bores Pipeline (Outram - Puddle Alley P.S)
4/TB/PS	Taieri Bores Pipeline (Puddle Alley P.S)
5/TB/PL	Taieri Bores Pipeline (Puddle Alley P.S - Southern Res)
6/SR/RES	Southern Reservoir
7/SD/RES	Sullivans Dam
8/SD/RES	Ross Creek Reservoir
9/T/TS	Mt Grand Treatment Station
10/D/PL	Southern T.S to Sommerville St. P.S (Distribution watermain)
11/D/PL	Booth Road. T.S to Epsilon & Beta St Reservoirs (Distribution watermain)
12/D/PL	Beta St. Reservoir to Caversham & St Clair (Distribution watermain)
13/D/PL	Booth Rd T.S to Opoho area & Signal Hill Reservoir. (Distribution watermain)
14/D/PL	Mt Grand T.S to City (Distribution watermain)
15/D/PL	Montecillo Reservoir to North End Reservoir (Distribution watermain)
16/D/PL	Signal Hill to St Leonards Reservoir (Distribution watermain)
17/D/PL	West Taieri Rural Water Scheme (Intake to T.S pipeline)
18/D/DEP	Water Business Unit Deport at Midland Street.

The above list sets out the priority for tackling mitigation measures over the next 10-20 years.

The risks considered in this study have been mainly related to earthquake and flooding, as snow and wind events are not expected to have a significant long term impact on the water supply network other than some disruption to communication systems.

The mitigatory measures identified are detailed in worksheets for each component and range from relatively “quick fix” solutions such as anchoring down computers and control cabinets ($5,000 per site) to re-laying sections of pipeline ($4,000,000). In some cases however some of the larger items are already provided for in the Water Upgrade Programme. It is important to note that the estimated costs shown in the work sheets are very rough estimates and are only intended to indicate the relative costs of the projects listed.

Conclusions

It is expected that given the demand for funds from the community for the current water upgrade programme, realistically only the less expensive items will be attended to in the first instance.

There are a number of actions within pumping stations etc. which may be carried out to secure plant and the associated control cabinets etc. These should be attended to in a short period timescale.

Planning should be reviewed with respect to “general repairs” activity following a hazard event, noting that there will be a demand for certain replacement parts and a need for access to highly skilled labour.

Recommendations

Maintain the listing of priority components in the form of a Record Worksheet and review progress annually towards completion of the list and securing adequate repair supplies.

Commence immediate protection of pumps and controls from earthquake damage by strapping or other security measures.

Review the existing system for prioritising labour and material availability in the event of hazard damage.

Re-examine the implementation of providing standby power supply.

SEWERAGE - DESCRIPTION OF SERVICE

Catchments Serviced

Throughout this section the convention has been adopted that drainage systems will be described on the basis of a catchment served by a treatment plant. The drainage schemes are:

- Dunedin Metropolitan
- Green Island
- Middlemarch
- Mosgiel
- Ocean Grove
- Macandrew Bay/Company Bay (Transferred to Dunedin Metropolitan System from April 1999)
- Broad Bay/Portobello (Transferred to Dunedin Metropolitan System from April 1999)
- Port Chalmers (Transferred to Dunedin Metropolitan System from July 2000)
- St Leonards/Burkes (Transferred to Dunedin Metropolitan System from July 2000)
- Karitane/Waikouaiti
- Seacliff
- Warrington

Dunedin Metropolitan System

General Description

The focus of this catchment is the Tahuna wastewater treatment plant situated in Tahuna Road. This catchment is by far the largest within urban Dunedin and caters for approximately 80,000 people. The reticulated area extends from Maia in the north east, encompasses the urban areas of central Dunedin, the western hill suburbs and the Otago Peninsula to Proctors Road, but excluding Ocean Grove. Within the catchment are a number of significant trunk sewers and one very major pumping station. The Tahuna treatment plant discharges to the sea at Lawyers Head.

Main Trunk Sewers

Main Intercepting Sewer
This line, which varies from 1,650mm to 375mm diameter, commences at the Musselburgh Pumping Station and makes its way to the Gardens, following the line of the shoreline that existed in the year 1900 for most of the route. For much of its length the line is extremely flat (design gradient of 1 in 3,000) and with depths commonly in excess of 5 metres. Much of the line is laid within very soft soils which have high ground water-tables. The larger pipes in the system are of pre-cast concrete with rigid joints.

Andersons Bay Trunk
This line, which again commences at the Musselburgh Pumping Station serves the Tainui, Andersons Bay, Waverley and Cove areas. The maximum line size is 600mm and in parts is 6m deep. The line is constructed in a variety of ground conditions including rock adjacent to the Musselburgh pumping station and soft silts in the Bayfield Park area. The line is part reinforced concrete pipe and part ceramic. All joints are rigid and for much of its length the line is located in areas of high ground water-table.

Bayview Trunk
This line serves much of St Kilda, St Clair, and part of Corstorphine. The line commences at the main intercepting sewer at its crossing in Portobello Road and extends along the full length of Bayview Road. The maximum pipe size in the system is 900mm with very flat grades and depths generally in the 3m range. The line is constructed in typical South Dunedin silts which have a high ground water-table.

Caversham/Kaikorai Trunk
This line commences at the main intercepting sewer at its intersection with Midland Street, makes its way up Macandrew Road, along Surrey Street and South Road then becomes a twin line and passes through the old Caversham railway tunnel. It then continues as a twin line along Kaikorai Valley Road. The catchment for this sewer includes much of South Dunedin, Caversham, Corstorphine, part of Mornington, Brockville, the southern part of Halfway Bush, much of Kaikorai and that part of Roslyn north-west of the Highgate ridge. Pipe sizes in the lower reaches are 900mm and 600mm diameter and, in common with conditions in South Dunedin, pass through silts with high ground water levels. This line provides some of the service to Wakari Hospital.

Hillside Trunk
This line, which serves some of the South Dunedin area and much of the Mornington area, and in particular the Glen, commences at the main intercepting sewer in Orari Street, proceeds along Hillside Road, Burns Street and then follows the Glen Gully to Mornington. Typical South Dunedin silts are encountered in the South Dunedin area and clay in the steeper parts of the catchment. The maximum pipe size is 750mm and the line is laid at depths of up to 4m.

School Creek Trunk
This line originates at the intersection with the main intercepting sewer at the corner of Frederick Street and Harrow Street and passes along Castle Street before making its way up Leith Valley and thence to the Wakari area. The line provides service to the Leith Valley, Pine Hill, Wakari and the northern part of Halfway Bush with a maximum pipe size of 600mm. Service to the main block of Wakari Hospital is provided by this line.

St Andrew Street
This line, which is predominantly 450mm in diameter, joins the main intercepting sewer at Anzac Avenue and provides service to much of central Dunedin and City Rise in the Littlebourne area. Included in the catchment is the southern end of Dunedin Hospital.

Frederick Street
This 300mm diameter line provides service to the commercial area north of Frederick Street and also to Mercy Hospital in Burwood Avenue and the Ward Block of Dunedin Hospital.

West Harbour
The West Harbour trunk accepts flows from the Maia and Ravensbourne communities and includes two comparatively small pumping stations. The trunk line follows the main railway line to Parry Street where flows from that immediate vicinity, together with the flows from Ravensbourne and Maia are pumped across the Leith by the Parry Street Pumping Station. From there the line flows by gravity to meet the main intercepting sewer in Frederick Street. The maximum size of pipeline in this trunk is 375mm.

Pumping Stations and Treatment Plants
It is to be noted that this major catchment of 80,000 people is reticulated with the assistance of only a few comparatively small pumping stations i.e. those at Maia, Ravensbourne, The Cove and Ivanhoe Road and in each case, these serve quite a small sub-catchment. The Parry St pumping station is a more significant installation which serves its local area and also receives flows from Ravensbourne and Maia.

The Musselburgh pumping station is the most critical component of the sewerage system for Metropolitan Dunedin. It is a major facility with a maximum output of 4.4 m3/second and is connected to the Tahuna Wastewater Treatment Plant by three 1,050mm rising mains which are of varying age and condition. The pumping station has diesel generating plant capable of powering the full capacity of the station.

Beyond the Tahuna Wastewater Treatment Plant, the outfall line is 1,800mm diameter pipe and, where it is under Lawyers Head, is a 1,800mm diameter tunnel terminating in two 1,350mm diameter outfalls to the sea. A by-pass pipeline from the head of the Tahuna Wastewater Treatment Plant parallels the 1,800mm diameter outfall pipe to Lawyers Head where it joins the tunnel.

The Tahuna Wastewater Treatment Plant has a capacity of 2.55m3/sec and has a diesel stand-by generator capable of supporting basic treatment functions only eg. scrapers, comminutors, sludge pumps, and control systems.

Outlying Systems

Green Island

General Description
The Kaikorai Estuary system, of which the focus is the Green Island Wastewater Treatment Plant, provides foul drainage service for the communities of Green Island, Wingatui, Fairfield, Waldronville and Brighton. In addition, it provides services for the wool scour and woollen mills at Mosgiel. The discharge from the PPCS meat processing plant on the Taieri industrial area joins the system below the plant and shares the outfall for discharge to the sea 500m offshore. From January 2000 the effluent from the Mosgiel Treatment Plant will also be pumped to down-stream of the main Green Island Treatment Plant, disinfected and discharged to the outfall.

Trunk Sewers
The largest pipelines in this system are twin trunks which follow the Kaikorai Stream. The larger trunk is 1,050mm diameter reinforced concrete pipe with flexible joints and was principally laid to serve the Burnside meat processing plant. The older line is 375mm diameter pipe, much of which has been recently relined in high density polyethylene.

The Waldronville, Westwood, Ocean View, and Brighton communities are served by a gravity and pumping main system which discharges to the Green Island Wastewater Treatment Plant and for much of its length is in 300mm diameter pipe. There are seven small pumping stations in this system.

The Fairfield and Wingatui communities, together with the wool scour and woollen mills at Mosgiel are served by the tunnel pipeline which has a combination of gravity pipelines and pumping mains. The system includes five pumping stations.

There is a pressure pipeline (Silverstream pipeline) dedicated to providing tradewaste service to the PPCS meat processing plant in the Taieri industrial area. Both the tunnel and Silverstream pipelines utilise the old Chain Hills railway tunnel.

Pumping Stations
Small pumping stations exist on the Green Island system at Brighton Road, Waldron Crescent, Watson Street & North Taieri Road.

On the tunnel pipeline, local pumping stations are located in Gladstone Road and Wingatui Road. A major pumping station is located in the Wingatui Racecourse and another key station at Walton Park.

Three comparatively small stations serve the Fairfield community. No stations in this system have any alternative power source.

Middlemarch
This system is a comparatively small one serving only the urban population of Middlemarch. The system was constructed in the early 1960's and has a maximum pipe size of 225mm. There is one pumping station in the system with treatment being provided at an oxidation pond adjacent to the Middlemarch Golf Course with ultimate discharge to the Taieri River.

Mosgiel
General Description
The focus of the Mosgiel foul sewer system is the Mosgiel Wastewater Treatment Plant situated in Carlyle Road. Flows of treated effluent are discharged to the Taieri River via 300mm and 525mm diameter outfall sewers. The catchment served includes urban Mosgiel, the Taieri industrial area, the Invermay Crown Research Institute and East Taieri but excludes the tradewaste servicing to the PPCS meatworks, the woollen mill and woolscour which are led to the Green Island system. The whole of the flow from the catchment is pumped at the treatment plant and there is a significant pumping station in Burns Street and three smaller pumping stations serving the Taieri industrial area. There is also a small pumping station in Gladstone Road serving the East Taieri area.

Trunk Sewers
Trunk foul sewers are located in Carlyle Road, Tyne and Murray Streets, Factory Road and Argyle Street. These lines are up to 775mm in diameter and are laid at depths of up to 4m. Only the pumping station at the Mosgiel Wastewater Treatment Plant has any standby power. From January 2000, the effluent from the plant will be pumped to the Green Island Treatment Plant and discharged through the Green Island outfall.

Ocean Grove
This system serves the small Ocean Grove community and comprises a treatment plant with discharge to land and one pumping station. The maximum pipeline size in this system is 225mm diameter and much of the system is very deep and is in water charged sands.

Macandrew Bay/Company Bay
The treatment plant serving this catchment is located in McTaggart Road with an outfall to the Otago Harbour at Company Bay. The catchment served is the urban communities of Company Bay, Macandrew Bay and the Rosehill and St Ronans Road areas. The trunk sewer follows Portobello Road and has five small pumping stations. The treatment plant will be decommissioned in April 1999 and the sewage pumped to the Dunedin metropolitan system.

Broad Bay/Portobello
Treatment facilities for this catchment are provided by a recently constructed treatment plant sited in Camp Road. Discharge is to the Otago Harbour via an outfall at Grassy Point and the trunk sewer system, up to 300mm in diameter, follows Portobello Road. The system includes 10 small pumping stations. The treatment plant will be decommissioned in April 1999 and the sewage pumped to the Dunedin metropolitan system.

Port Chalmers
The Port Chalmers Wastewater Treatment Plant at Sawyers Bay provides services to the communities of Roseneath, Sawyers Bay, Port Chalmers, Careys Bay and Deborah Bay. Discharge from the treatment plant is conveyed to Burkes via a 300mm diameter rising main constructed in 1994. Discharge to the Otago Harbour is via a combined discharge with the Burkes/St Leonards catchment. The treatment plant will be decommissioned in July 2000 and the sewage pumped to the Dunedin metropolitan system.

Within the system are eight local pumping stations with a major pumping station being located at the treatment plant to pump treated effluent through the rising main to Burkes. Part of that rising main passes through the Roseneath railway tunnel.

St Leonards/Burkes
This system serves the Burkes and St Leonards communities and basically comprises a trunk line following the state highway and includes two pumping stations at St Leonards. Treatment facilities are provided at Burkes, adjacent to the state highway, with the effluent being pumped to the outfall to the Otago Harbour through the shared outfall from the Port Chalmers plant. The treatment plant will be decommissioned in July 2000 and the sewage pumped to the Dunedin metropolitan system.

Karitane/Waikouaiti
Treatment facilities for this catchment are provided by a wastewater treatment plant adjacent to the Waikouaiti Beach with the flows from Karitane being conveyed to it via a submarine pipeline under the Karitane Estuary. Within the Karitane system there are three small pumping stations as well as four small pumping stations in the Waikouaiti area. Effluent disposal is by spray irrigation into a forested area. Reticulated services at the Hawkesbury Development (previously Cherry Farm Hospital) are totally self contained and are not operated by the City.

Seacliff
A small system exists at Seacliff to provide services for the 35 properties that are connected. Treatment facilities are provided by what is basically a large septic tank with effluent disposal being achieved by a sand filtration system. The maximum pipe size in the system is 150mm.

Warrington
This system, which was constructed in the late 1980's largely comprises 150mm diameter pipe and includes one small pumping station. Treatment facilities are provided by the Warrington Wastewater Treatment Plant with discharges of effluent into an adjacent forested area.

Interconnecting Sewers
There are few points within the drainage system where any ability exists to divert flows from one system to another. The points where some possible by-passing can be undertaken are listed below:

Musselburgh Pumping Station - Rising Mains
The three rising mains which link the Musselburgh Pumping Station to the Tahuna Wastewater Treatment Plant can be individually closed and therefore can be operated in any combination. However 80% of the pumping station output is carried by one pipeline a short distance to the start of the three rising mains.

Lawyers Head Outfall
Down-stream of the Tahuna Wastewater Treatment Plant, are two outfall sewers. The main line and the old outfall sewer are interconnected below the treatment plant and join to pass through a single tunnel under Lawyers Head.

Caversham/Kaikorai Trunk
Within Kaikorai Valley Road, the trunk services are provided by 525mm and 300mm diameter lines. At a point opposite Townleys Road those lines converge at a manhole and leave as 225mm and 525mm diameter lines. Under low flow conditions, it is possible to divert the total flow to the 525mm diameter line through the old Caversham tunnel. At the point adjacent to Kaikorai Valley High School where the Kaikorai Stream crosses Kaikorai Valley Road, a by-pass valve is installed on the 300mm diameter line so that under emergency conditions the line can be totally by-passed to the Kaikorai Stream.

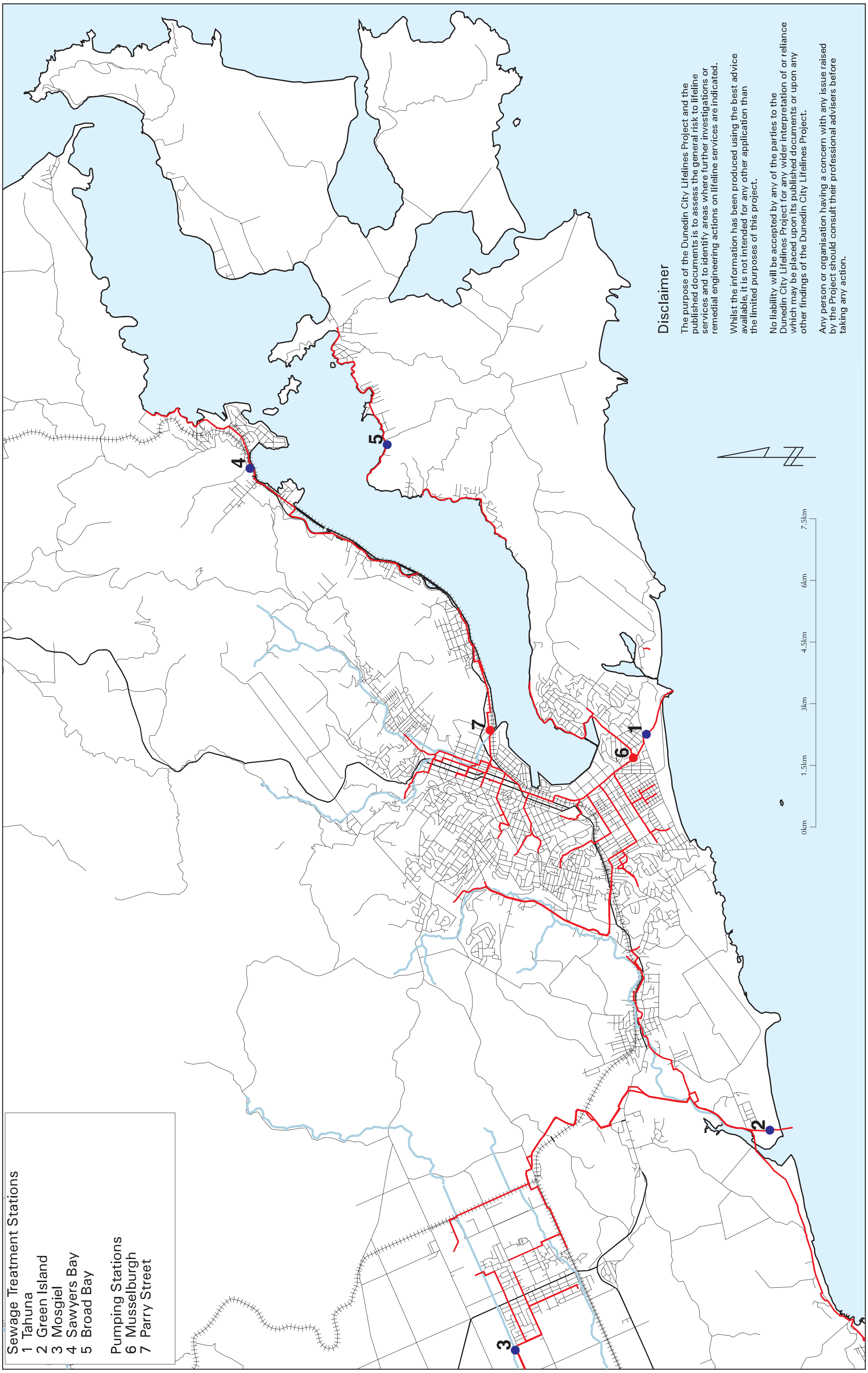
Harbour Valves
A valve at the intersection of St Andrew Street / Anzac Avenue allows the combined sewer flows to enter the main intercepting sewer. In emergencies, the flows in the combined sewers can be diverted to the Otago Harbour.

Mosgiel Outfall
The 525mm and 300mm outfalls are interconnected and the dry weather flow can be handled by the 525mm outfall alone. From January 2000 the discharge from the Mosgiel Plant will be pumped to the Green Island Treatment Plant and the existing outfall will only be used for emergency discharges.

Tunnel/Silverstream Pipeline
Within the Wingatui Racecourse these two lines are interconnected by a valve system so that either the Silverstream pipeline or tunnel pipeline can take a combined, but restricted flow. Careful operation of the system in this mode is essential if major damage to the pipelines is to be avoided.

St Leonards
Only limited provision exists to connect flows from the Port Chalmers rising main to the system serving St Leonards.

Sewage Treatment and Reticulation



Rivers
Pump Stations
Sewage Treatment Plants
Sewage Reticulation

City Consultants
September 18, 1998

SEWERAGE - ASSESSMENT OF VULNERABILITY

Catchments Serviced

The twelve separate catchments within the city network constitute a degree of diversity which is likely to ensure that the entire system is not damaged to the same degree in all locations. It is clear from the community view, however, that the Dunedin metropolitan area, Mosgiel and Port Chalmers networks are the most significant, on a population basis, and probably at the most risk of hazard damage due to their extent and age. The risk of damage to connections from properties (not part of the public system) must also be considered.

Recent development of integrated sewerage disposal systems along the harbour frontage and elsewhere, may increase future vulnerability and requires further study.

Dunedin Metropolitan System

The metropolitan system is relatively old and important elements are, by the nature of the service, located in low lying areas of the city and in many instances in areas which consist of filled ground. As a consequence, the water-table is often high and the ground susceptible to enhanced shaking and possible liquefaction under earthquake conditions.

Vitally important elements of the sewerage system identified are pumping stations (buildings and equipment), main trunk sewers and rising main sewers. The principal element at risk is Musselburgh Pumping Station, which may suffer damage by shaking of pumping systems, collapse of the precast concrete roof, fracture of intake sewers and rising mains and differential settlement.

Major sewer lines which are likely to suffer from settlement and consequent joint fractures, separation of manholes and the like are predominantly located in the South Dunedin/Anderson Bay area and the older part of the city and university area.

The vulnerability assessment of both “Network” and “Community” vulnerability is not significantly different in order of presentation, and it appears that there is a widespread risk to extensive elements of the system, although the Tahuna Water Pollution Control Plant is at lower risk, having been designed to modern standards.

Outlying Systems

On a similar basis of assessment, the Green Island outfall appears to be at risk, again because of the ground conditions and proximity to active faulting. This condition must also apply to all major outfalls and pollution control plant around the harbour edge.

Mosgiel systems, though susceptible to enhanced earthquake and flooding are of generally newer construction, but it is to be expected that the main outfall sewers to the Taieri River and back to Green Island are at risk on the lower lying plain.

The community vulnerability of outlying station sewerage systems is generally lower than that of the metropolitan area as the main line sizes are smaller and less susceptible to joint fractures. However the risk of failure of power supplies is probably higher than at the major facilities. Analysis of individual catchments serving smaller communities indicates that risks are low and as a consequence are not addressed in detail.

Interconnecting Sewers

Some of the elements of the system which are capable of accepting diverted flows present particular vulnerability. Failure of the interconnecting length of sewer from Musselburgh pumping station to the rising mains is clearly the most serious risk as it is in rigid joint pipe which is susceptible to fracture by shaking. The Lawyers Head outfall is likewise subject to earthquake damage and the cost and time for repair make this a high community risk element of the system. By comparison with the above elements, other interconnecting sewers are likely to suffer less damage and are at lower risk.

SEWERAGE - MITIGATION STRATEGIES

Notes on Mitigation Strategies

In considering the impact of hazards upon the extensive network of reticulation it has been necessary to review the order of importance established under the vulnerability assessment, to ensure that elements which would cause major disruption are addressed. The reticulation has a considerable number of elements which are ageing, and in the lower lying area of the city the ground conditions are conducive to severe shaking in earthquake conditions, following which it is anticipated that there will be some widely distributed dislocation of pipe collars and associated settlement problems. Some trunk sewers pass through areas of potential liquefaction and these may be unusable in the long term.

The prospect of effective mitigation over such a widespread area of the lower city presents major difficulty in selection of appropriate mitigation strategies and more importantly on expenditure which cannot reasonably be justified commercially. Events which are likely to cause localised damage are currently considered as being undertaken by management of repairs, for which a reasonable stock holding of spare parts and locally obtained labour skill is available. For more significant and widespread failure, and for failure of larger specifically designed lines, structures or major plant items, resources in skills, materials and plant are likely to be inadequate or unavailable in the short to medium term. Innovative solutions and repairs will be necessary to restore some systems to early operation.

There are a number of issues which can be addressed by modest expenditure, such as the strengthening of pumping station structures, provision of flexible inlet and outlet junctions and securing pump mountings, control boxes etc.

Significant Elements at Risk.

A series of "Record Worksheets" has been prepared in respect of elements which are considered to be at risk. Listed elements are as set out below:

- Musselburgh Pumping Station (P.S).
- Rising Main-Musselburgh P.S to Tahuna Water Pollution Control Centre (WPCP).
- Main Intercepting Sewer (M.I.S)-Musselburgh P.S to Orari Street.
- Macandrew Road Trunk Foul Sewer (T.F.S).
- Outfall-Tahuna W.P.C.P to Beach.
- Hillside Road Trunk Foul Sewer-Timaru St/Burns St.
- M.I.S-Orari St to Jervois St.
- Bayfield Road Trunk-Portobello Road/Surrey St.
- Green Island T.F.S-Green Island plant to Waldronville.

Conclusions

The majority of network elements at risk require large capital sums to be invested to achieve a significant increase in the level of protection against hazard events, which are likely to be random and possibly widespread. In view of the current expenditure involved in managing the asset, which incorporates some general upgrading, it is considered more appropriate to allow for restitution following the event, rather than to expend large sums on random or extensive replacement. A replacement policy should be adopted which establishes that, when trunk or critical sewers require replacement or repair, consideration should be given to replacement with pipes and fittings which will provide a higher level of security in the event of a hazard occurring. For example, longer joints, flexible connections and alternative materials could be used.

Pumping station security should be reviewed and the provision of standby power supply would be appropriate at installations where this is not already available to an adequate level. eg Mosgiel Treatment Plant.

Independent outlying systems are not considered to be at significant risk and accordingly few provisions for mitigation are necessary.

Recommendations

Continually review plans for restoration of operating systems in the event of major hazard damage.

Undertake pumping station mitigation engineering, including structural examination, securing power supply and control systems. Relatively modest expenditure is likely to be involved.

Adopt the mitigation work identified in Record Work Sheets with a view to undertaking such works in the 10-20 year period following this initial report. Replacement policy should follow the conclusions reached above.

For upgraded or new systems, note areas of susceptibility and avoid installation in these areas wherever possible.

STORMWATER - DESCRIPTION OF SERVICE

General Description

Within urban Dunedin, considerable use is made of watercourses and streams, including the Kaikorai Stream, Water of Leith, Lindsay Creek, Owhiro Stream and Silverstream, for the conveyance of stormwater. This is particularly true in the steeper parts of the city and therefore there are few major stormwater pipelines.

Central Dunedin

General Description

Within the steeper parts of metropolitan Dunedin, stormwater is collected by stormwater sewers, generally 900mm diameter and less, and conveyed to the closest watercourse. Where watercourses are not available, the flows are directed to the Otago Harbour or the Pacific Ocean. There are major trunk stormwater sewers which convey stormwater flows from the eastern side of the Highgate/Mornington ridge to the Otago Harbour.

The very flat, low lying and densely populated areas of South Dunedin, St Kilda and Tainui are served by a pumped stormwater system as much of this area is below the highest recorded tide level.

Trunk Stormwater Systems

Tainui High Levels
Flows from the vicinity of the Andersons Bay Cemetery are conveyed in 1,500mm and 900mm diameter pressure pipelines within Tainui Road and Shore Street, discharging to the Andersons Bay Inlet.

South Dunedin/St Kilda Catchment
A number of significant stormwater sewers pass through this area and are led to the Timaru Street stormwater aqueduct and thence to the Portobello Road Stormwater Pumping Station. The Timaru Street stormwater is parallelled by a trunk line in Andersons Bay Road and these two lines link at five points. The outfall from the pumping station is to the Otago Harbour via two 1,500mm diameter lines. This pumping station has diesel powered standby, capable of running the station at 40% output. Trunks include the St Kilda aqueduct, Bay View trunk, Macandrew Road and Hillside trunks.

Tainui Low Levels
This area adjacent to the Musselburgh Pumping Station is pumped at the Musselburgh Pumping Station into the South Dunedin/St Kilda catchment and is again pumped at the Portobello Road Stormwater Pumping Station. On site standby power generation equipment can provide electricity for the full output of the Tainui low level pumps.

Forbury Aqueduct
Stormwater flows from the hill area of Kew and St Clair are intercepted by a stormwater aqueduct in Forbury Road. That line, which is a rectangular cast in situ concrete conduit, discharges to the Pacific Ocean at Second Beach. Some of the line is 6m deep.

Wilkie Road Trunk
This catchment, which caters for a significant part of Mornington, Caversham and Corstorphine discharges to the Otago Harbour at the intersection of Orari Street and Portsmouth Drive. In the section between the Otago Harbour and Glen Road, the conduit is a 2.7m x 2.7m semi elliptical pipe of cast insitu concrete. The line operates under pressure for most of its length and is up to 8m deep under the Southern Motorway. Upstream of Glen Road, the conduit follows South Road as a 1.8m x 1.8m semi elliptical pipe, terminating in Playfair Street.

Jervois Street Trunk
The catchment served by this system is bounded by the Oval in the south, the Town Belt in the west and Stafford Street in the north. The major line in this system is a 1.65m x 1.35m brick arch stormwater sewer in Jervois Street and, crossing the railway yards, continues to the Otago Harbour in 1.5m diameter pipe.

Rattray Street Trunk
Flows from the Maclaggan/Rattray Streets areas are conveyed beneath Rattray Street in a 1.8m x 1.8m brick arch sewer which follows High Street to the Railway Station, passes under the railway lines, and continues down Mason Street as a 2.18m diameter pipe. It discharges to the Otago Harbour at the foot of Mason Street.

Hanover Street/Halsey Street Trunk
This is a major system catering for both the northern part of the central business district and also for the steeper catchment beyond that area. Flows from the steeper part of the catchment are conveyed in a pressure system whereas flows originating in the central business district are conveyed in a parallel gravity system, both discharging under the wharf at Halsey Street.

St David Street Trunk
This trunk stormwater sewer provides service to much of North Dunedin and also the Cosy Dell area. It is constructed within St David Street in 1050mm diameter pipe and discharges to the Water of Leith at its crossing of St David Street.

North East Valley
Stormwater systems in North East Valley comprise a number of sections of pipe which are led to the Lindsay Creek. The role of Lindsay Creek should not be underestimated in the service provided to this catchment and it is to be noted that Lindsay Creek, upstream of Craigleith Street is significantly under capacity and that any flooding of Lindsay Creek results in flooding of North Road.

Pumping Stations

Portobello Road
This station has an output of 6.5 cubic metres per second and has the ability to operate at 2.5 cubic metres per second using diesel power.

Union Street
This pumping station, which is adjacent to Logan Park, provides a stormwater pumping facility for the low lying area around the Otago Polytechnic, Dunedin College of Education and Logan Park. The discharge is led to the Opoho Creek. No back-up power supplies are provided.

Hanover Street
This station caters for a local low lying area which includes the Dunedin Central Fire Station and discharges to the Hanover Street trunk stormwater sewer.

Mosgiel

General Description
Stormwater facilities for Mosgiel are provided by discharges to the Owhiro Stream, Blackies Ditch and at three points on the Silverstream. The discharges to the Silverstream are pumped through stations located in Carlyle Road, Reid Avenue and adjacent to the Reid Park School.

Trunk Stormwater Systems

Carlyle Road
The total stormwater flow for north-west Mosgiel is conveyed to the Carlyle Road Pumping Station by way of trunk stormwater systems in Carlyle Road and Tyne Street. Pipe sizes up to 1,200mm in diameter are involved.

Blackies Ditch
This channel, which is an Otago Regional Council 'scheduled' drain, receives discharge from a trunk stormwater system at the intersection of Mure Street and the urban development. Trunk stormwater pipelines are located in Mure Street and Ayr Street.

Reid Avenue
Stormwater flows from much of central Mosgiel are conveyed by way of pipe systems and open channels to the Reid Park Pumping Station and discharged to the Silverstream.

Mosgiel East
A trunk stormwater system comprising 1200mm, 1050mm and 900mm diameter lines exists within property adjacent to Cherry Drive, in Rentons Road and within the wool scour property. These pipelines terminate at the Mosgiel East Stormwater Pumping Station adjacent to the Reid Park School with discharge to the Silverstream.

Stormwater Pumping Stations

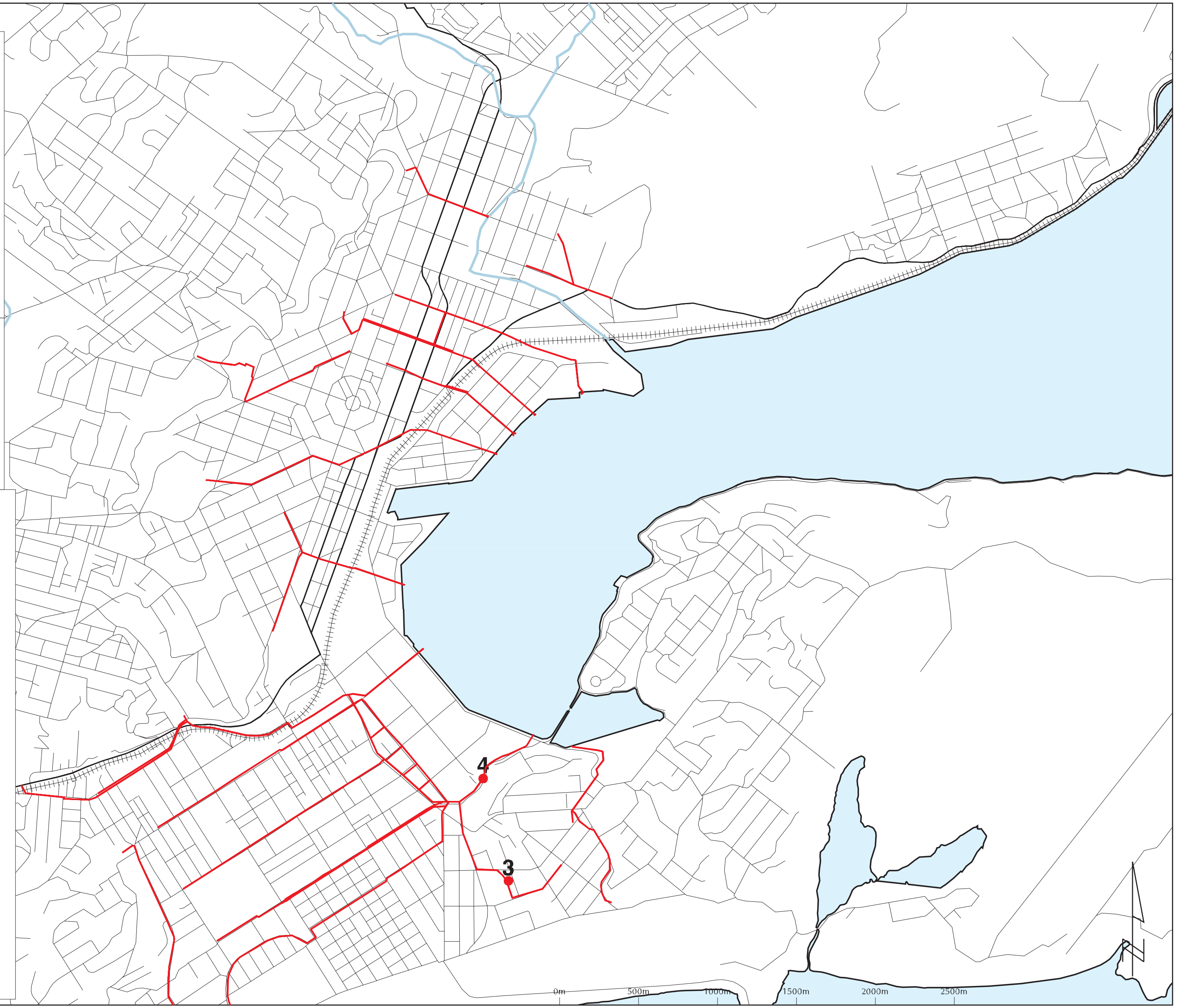
Carlyle Road
This station has a capacity of approx 3.0 cubic metres per second and is adjacent to the Mosgiel Waste Water Treatment Plant. No standby power is provided.

Reid Park Pumping Station
This station has a rated capcacity of 2.0 cubic metres per second and no standby power supply is available at this site.

Mosgiel East Stormwater Pumping Station
This pumping station has an installed capacity of 2 cubic metres per second and has no provision for standby power.

Balance of Urban Areas
Throughout the balance of the urban areas, stormwater systems convey flows by gravity to the nearest watercourse utilising the shortest route.

Principal Stormwater Reticulation



Disclaimer

The purpose of the Dunedin City Lifelines Project and the published documents is to assess the general risk to lifeline services and to identify areas where further investigations or remedial engineering actions on lifeline services are indicated.

Whilst the information has been produced using the best advice available, it is not intended for any other application than the limited purposes of this project.

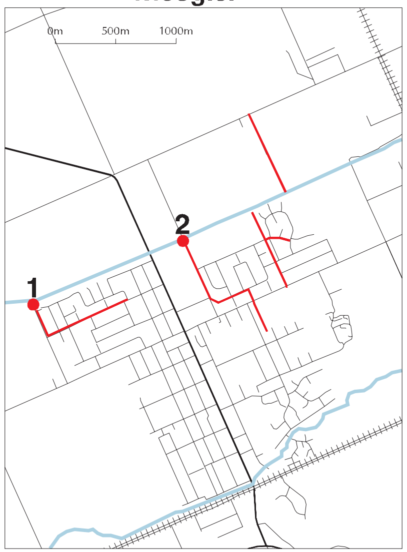
No liability will be accepted by any of the parties to the Dunedin City Lifelines Project for any wider interpretation of or reliance which may be placed upon its published documents or upon any other findings of the Dunedin City Lifelines Project.

Any person or organisation having a concern with any issue raised by the Project should consult their professional advisers before taking any action.

Pumping Stations

1 Carlyle Street
2 Reid Avenue
3 Musselburgh
4 Portobello Rd

Mosgiel



Rivers

Pumping Stations

Stormwater Reticulation

City Consultants
September 18, 1998

STORMWATER - ASSESSMENT OF VULNERABILITY

General Description

The general vulnerability of the stormwater system exists in the pipe sewers rather than the many open watercourses which transport stormwater to the harbour or streams.

Leith in Flood, University Area - TerryWaterhouse, University of Otago

There are damage risks from earthquake shaking and faulting which may impact upon stream channels, with the greatest risk likely to be from overturning of constructed channel walls resulting in channel blockage and consequent flood damage. Slips into watercourses also present a significant risk.

Central Dunedin

Study of the vulnerability analysis in terms of "Community Vulnerability" shows that the greatest risk to the piped system occurs in the South Dunedin /St Kilda area and to a lesser extent in the lower central city. Damage to trunk stormwater sewers is likely to occur from opening of joints, settlement due to liquefaction and further serious damage through flood discharges from fractured lines.

An earthquake could cause differential settlement at pumping stations, resulting in damage at inlets and outlets, and it is probable that there will be damage to insecurely fixed pumping equipment.

Silverstream in Flood - Debris collection
Photo: DCC/Terry Dodd

Outlying areas will be less severely affected and, because of the relatively smaller flows, it is probable that a greater proportion of sewers will survive without damage. Certainly, the more isolated communities do not present an overly significant lifeline hazard.

Mosgiel

Although relatively free from risk under the vulnerability analysis, there is a possibility of damage to pumping stations at Carlyle Road and Reid Avenue due to shaking and associated damage to pump mountings and inlet/outlet connections may be fractured due to differential settlement. Consequential scour damage to the Silverstream stopbank may cause more extreme flooding.

STORMWATER - MITIGATION STRATEGIES

Notes on Mitigation Strategies

It is clear that in the event of a major earthquake in the Dunedin area widespread damage with disruption of service is likely to occur. Much of the damage which is anticipated will occur in the lower levels of the city, particularly where ground conditions are highly susceptible to enhanced shaking and liquefaction. Much of the stormwater system in this area is of relatively recent construction and it is unlikely to be as severely damaged as the foul sewer reticulation.

It is noted that a health hazard may be generated by the infiltration of sewage into the stormwater system and each system is likely to suffer from damage to the other in some way.

If a period of rainfall follows an earthquake the risk of flooding is likely to be high and compressed in time scale. The ensuing free discharge of stormwater may cause landslips and flood damage.

Because of the inability to judge where damage may be specifically located in such an event, it is thought that much of the work undertaken should be directed towards response planning, with identification of likely areas of weakness which would need priority treatment.

There are a number of general mitigation measures which may be effected in pumphouses, such as power supply protection, strapping of control systems etc. All of these should be able to be done at a minimal cost. General and continuing maintenance of open channels should continue.

Critical Stormwater Components
Components of the network which have been identified as critical are scheduled below, and should be regularly reviewed and (over the next 10 to 20 years) have appropriate action taken to increase protection from hazard:

- St Kilda Aqueduct
- Forbury Aqueduct
- Lower St Andrew Street
- Timaru Street Conduit - Portobello Road/Orari St
- Wilkie Road Conduit - Harbour/King Edward St
- St Andrew Street - Anzac Avenue/Great King St
- Portobello Road Conduit to Portobello Road P.S
- Portobello Road Pumping Station
- Wilkie Road Conduit - King Edward St/Glen Road
- Hanover Street to Halsey Street
- Portobello Road discharge main (to harbour)
- Reid Avenue Pumping Station - Mosgiel
- Carlyle Road Pumping Station - Mosgiel
- Mosgiel East Pumping Station

Conclusions
Because of the topography of Dunedin City the stormwater system is often subject to high velocity flow and any damage arising from earthquake events is likely to cause severe disruption to the service in the event of subsequent rainfall. Since damage is likely to be randomly distributed, it is generally best treated as recoverable by repair after the event.

A replacement policy should be adopted which establishes that when trunk or critical sewers require replacement or repair, consideration should be given to replacement with pipes and fittings which will provide a higher level of security. Longer joints, flexible joints, and more hazard resistant materials should be used.

A matter which is increasingly evident as an impediment to recovery is the provision of spare componentry in the form of pipes and fittings, electrical and control systems (at pumping stations and valves etc) and the difficulty of obtaining sufficient skilled repair personnel.

Recommendations
Adopt the listed components above as priority repair/mitigation items within a timescale for mitigation action of between 10-20 years.

Implement a repair/replacement policy which reduces the exposure to hazards of critical elements.

Prepare and review the reaction and recovery proposals to a major earthquake or flooding event which may impact upon the list.

Undertake pumping station mitigation engineering including structural examination, securing power supplies and control systems and provide standby power at critical facilities if not already installed eg. Reid Avenue, Mosgiel.

Schedule in asset management plans for maintenance work on buildings and open channel drainage.

Examine the availability of materials and recovery skills locally, noting dependence on supplies from out of the area and identify whether there should be a greater holding of spares for critical items.

REFUSE DISPOSAL - DESCRIPTION OF SERVICE

General Description

Consideration of refuse disposal as a lifeline is based upon the effect which disruption of the service would cause to public health and industrial operations. Refuse disposal (including demolition material) is a service that will be in demand following emergencies such as a significant earthquake or flooding.

Dunedin has landfill areas for the disposal of refuse at Green Island, Sawyers Bay, Waikouaiti and Middlemarch. The latter three locations are essentially community landfills servicing a wide area and there are some smaller country areas where clean fill is permitted on a reduced scale. A transfer station near the Dunedin wharfs and a landfill area located opposite the Green Island landfill, are provided by a private company.
Green Island landfill is the only one licenced to accept hazardous (or special) wastes and industrial waste material. It covers an area of 34 hectares and is currently filled to an approximate depth of 6 metres. It is proposed that this landfill will be extended over a period of 25 years to a maximum height of some 15 metres above the present level by forming mounds.

REFUSE DISPOSAL - ASSESSMENT OF VULNERABILITY

Green Island Landfills

The location of the landfill site on lower lying land adjacent to the Kaikorai Estuary places the area at risk from flooding and exposure to storm surge or tsunami. The area is also susceptible to enhanced earthquake shaking which may induce liquefaction and consequent settlement. The earthquake effect inducing settlement is not likely to cause any major long term disruption to the landfill service, but access to the site may be affected for a period and the production of landfill gas curtailed. In general, however, the vulnerability of the landfill site at Green Island is seen as being only modest and the private contractor's landfill facility has the same level of risk from hazard as that of the Green Island landfill area opposite.

Leachate Collection System

A leachate collection system at the Green Island Landfill intercepts leachate which is then pumped to the Green Island foul sewer. This collection system would be damaged if settlement were to occur and the pumping system and associated controls are vulnerable to settlement, inundation from tsunami and storm surge.

Power supply interruption due to weather conditions and flooding is possible, and while all of these hazards would not stop operation of the landfill, services would need to be re-established fairly quickly to avoid environmental damage.

Sawyers Bay, Waikouaiti and Middlemarch Landfills

These landfills are all considered to be at lower risk than the Green Island Landfill, and are susceptible to lesser levels of flooding and ground shaking. It is not considered that they would suffer lengthy disruption of service.

REFUSE DISPOSAL - MITIGATION STRATEGIES

Notes on Mitigation Strategies

Because of the nature of landfill operations, there is little further which may be done to mitigate the impact of earthquake or flood events, although a number of mitigatory initiatives have already been carried out and will continue to be actioned in the changing landfill areas.

Attention has been drawn to the possibility of flooding in the case of the Green Island Landfill and the potential earthquake risk due to settlement of the fill causing damage to the leachate system. To minimise the impact of flooding, the leachate trench has been sealed over with clay.

Slope stability analysis indicates that earthquake damage risk can be minimised by using appropriate construction techniques around the landfill perimeter by placement of clean fill only. This technique is currently being implemented.

Similar but less damaging conditions apply to other city landfill areas, but it is generally not possible to carry out any further effective mitigation action.

Conclusions

Apart from risk to the leachate collection and pumping system at Green Island, which is partially countered by work already carried out, there is no further cost effective means of mitigating damage.

In the case of the leachate systems at other city refuse disposal areas, it is considered impractical to carry out further mitigatory work.

Recommendations

Re-consider present planning initiatives in respect of managing reinstatement work on refuse disposal sites, giving due priority to the principal site at Green Island.