Dunedin City Lifelines Project Report

DUNEDIN CITY LIFELINES PROJECT

DUNEDIN CITY LIFELINES PROJECT REPORT

December 1998

DUNEDIN CITY LIFELINES PROJECT

DISCLAIMER

The purpose of the Dunedin City Lifelines Project and its 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.

ISBN Number
First Printing August 1999
Editorial Sources:
Printing: Dunedin City Council Printing Services
Published by: Dunedin City Lifelines Project

CONTENTS

"Civilisation exists by geological consent, subject to change without notice."

Philosopher/Historian, Will Durant (1885/1981)

FOREWORD

Dunedin is wonderfully endowed with a variety of landforms, coastline and weather conditions.

It is this variety that makes Dunedin such an attractive place to residents and visitors alike. It is also this variety that presents a challenge to those who have responsibility for the vital lifeline services upon which our population and industry depend.

If Dunedin is to retain its healthy population and environment with continued opportunity for businesses to develop and grow, we must assure in so far as we possibly can, continuation of these vital services to the community.

For this reason it gives me great pleasure to introduce this report covering the extensive work carried out for the Dunedin City Lifelines Project. This project has involved many people and organisations in seeking to increase the resilience of our community and its vital services to all manner of hazards.

While nobody living in or visiting Dunedin should feel unsafe, we will never be immune to the impacts of hazards, including the recently recognised increased probability of major movement of the Alpine Fault. It would have been imprudent of the community not to address these risks and this is why Council initiated and helped to sponsor the Dunedin City Lifelines Project.

In the interests of promoting wider community emergency awareness and planning, I commend this publication to citizens, businesses and organisations, who should carry out their own analysis of vulnerability based on the extensive information presented here.

I wish to express gratitude on behalf of the people of Dunedin to all of those who, under the guidance of the Lifelines Co-ordinator, have worked so willingly and diligently on this project. I am sure that the mitigation strategies arising from their work will lead to development of a more secure base for the economic and social future of Dunedin.

Sukhi Turner
Mayor of Dunedin

ACKNOWLEDGEMENTS

The Dunedin City Lifelines Project wishes to acknowledge with gratitude the involvement of the large number of people and organisations who have actively helped with the work of critically examining the city's lifelines. This acknowledgement recognises the assistance and unstinted co-operation of all project personnel, associates and staff members who have given their time, support and encouragement to the project.

The majority of the work has been undertaken without any charge to the project and represents a valued contribution to community resilience, confirming the strong social conscience of our lifelines management.

Special thanks are due to members of the academic, scientific and engineering team who addressed the question of hazard definition and thereby established the basis for assessment of vulnerability.

The staff at City Consultants made a vital contribution by preparing GIS mapping which has been and will continue to be invaluable in progressing the objectives of the Dunedin City Lifelines Project. Their enthusiasm, patience and professionalism have been sincerely appreciated.

The provision by the Dunedin City Council Civil Defence & Rural Fires Department of project administration and accommodation for the Project Co-ordinator and the many meetings held is gratefully acknowledged.

The project further acknowledges the financial support given by the following organisations:

Principal Sponsor	Dunedin City Council Civil Defence
Major Sponsors	Otago Regional Council Ministry of Civil Defence Earthquake Commission (EQC)
Sponsors (alphabetically)	Dunedin Airport Limited Dunedin City Council Building Control Dunedin City Council City Consultants Dunedin City Council Contracts & Asset Management Dunedin City Council Environmental Health Dunedin City Council Waste Services Dunedin City Council Water Department Dunedin Electricity Limited Otago Power Limited Port Otago Limited Telecom New Zealand Limited Transit New Zealand Transpower New Zealand Tranz Rail New Zealand Limited

PROJECT PERSONNEL

Lifelines Project Co-ordinator
Mr Gordon Taylor

Steering Committee

Mr John Henderson (Chairman)	Technical Services Engineer, City Consultants, Dunedin City Council
Mr John Brimble	Group Manager, Operations and Services, Dunedin City Council (until March 1999)
Mr Neil Brown	Manager, Civil Defence & Rural Fires, Dunedin City Council
Dr Robin Falconer	Group Manager, Hazards & Mapping, Institute of Geological & Nuclear Sciences Limited
Mr Phil Glassey	Engineering Geologist, Institute of Geological & Nuclear Sciences Limited
Mr David Hamilton	Director, David Hamilton & Associates Limited (previously Director, Technical Services, Otago Regional Council)
Mr Peter Morton	Contracts & Asset Manager, Dunedin City Council
Mr Mike O'Cain	Regional State Highways Manager, Transit New Zealand
Mr Lou Robinson	Director, Hadley & Robinson Limited Consulting Engineers
Mr Mike Sawyer	Manager, BP Oil Limited (Chair, Petroleum Industry Emergency Action Committee)
Mr Gordon Taylor	Lifelines Co-ordinator, Dunedin City Lifelines Project
Ms Helen Walker	Group Manager, Planning & Policy, Dunedin City Council
Mr John Walsh	Chief Executive, Dunedin Electricity Limited
Mr Greg Walsh	Radio Spectrum Management Group, Ministry of Commerce

Hazard Analysis Group

Mr David Hamilton (Leader)	Director, David Hamilton & Associates Limited (previously Director, Technical Services, Otago Regional Council)
Dr Helen Anderson	Research Director, Earth & Ocean Sciences Research Limited
Mr Dick Beetham	Engineering Geologist, Institute of Geological & Nuclear Sciences Limited
Mr Neil Brown	Manager, Civil Defence & Rural Fires, Dunedin City Council
Mr Trevor Buchanan	Waste Services Manager, Dunedin City Council
Prof Blair Fitzharris	Associate Professor, Geography Department, University of Otago
Mr Phil Glassey	Engineering Geologist, Institute of Geological & Nuclear Sciences Limited
Mr John Henderson	Technical Services Engineer, City Consultants, Dunedin City Council
Prof Peter Koons	Geophysicist, Geology Department, University of Otago
Mr Rod Macleod	Senior Design Engineer, City Consultants, Dunedin City Council
Prof Richard Norris	Professor, Geology Department, University of Otago
Mr Ian Pickard	District Chief Fire Officer, New Zealand Fire Service
Mr Ian Scarf	Manager of Engineering, Otago Regional Council
Mr David Stewart	Hydrological Consultant, Raineffects Limited
Dr Ian Turnbull	Geologist, Institute of Geological & Nuclear Sciences Limited

Civil Supply Systems

Mr John Henderson (Leader)	Technical Services Engineer, City Consultants, Dunedin City Council
Mr Trevor Buchanan	Waste Services Manager, Dunedin City Council
Mr David Hamilton	Director, David Hamilton & Associates Limited (formerly Director, Technical Services, Otago Regional Council)
Mr Nigel Harwood	Water Manager, Dunedin City Council
Mr Brian Laws	Planning Engineer, Water Department, Dunedin City Council
Mr Gerard McCombie	Operations Engineer, Water Department, Dunedin City Council
Mr Darrel Robinson	Reticulation Engineer, Waste Services Department, Dunedin City Council
Mr Ian Scarf	Manager of Engineering, Otago Regional Council
Mr Brian Turner	Waste Control Engineer, Waste Services Department, Dunedin City Council

Energy

Mr John Walsh (Leader)	Chief Executive, Dunedin Electricity Limited
Mr Ray Basher	Operations Support Manager, Transpower NZ Limited
Mr John Beekhuis	Senior Consulting Engineer, Duffill Watts & King Limited
Mr Terry Jones	Network Manager, Otago Power Limited
Mr John MacKenzie	Senior Project Manager, Montgomery Watson Limited
Mr Stan McKay	Retail Manager, Solid Energy Limited
Mr Lindsay McLennan	Network Manager, Dunedin Electricity Limited
Mr John Heaven	Manager, Otago Citigas Limited
Mr Mike Sawyer	Manager, BP Oil Limited
Mr Kevin Small	Assistant Chief Executive, Dunedin Electricity Limited (Waipori Power Generation Limited)

Transportation

Mr Peter Morton (Leader)	Contracts & Asset Manager, Dunedin City Council
Mr Tony Arnesen	Development Engineer, Port Otago Limited (until April 1997)
Mr Rene Bakx	Chief Executive, Port Otago Limited
Mr Neil Campbell	Regional Manager, Tranz Rail Limited
Captain Charles Corkill	Harbourmaster, Otago Regional Council
Mr Tony Dicks	Technical Services Manager, Port Otago Limited
Mr Don Hill	Transportation Planning Manager, Dunedin City Council
Mr John McCall	Chief Executive, Dunedin Airport Limited
Mr Grant Meldrum	Special Projects Engineer, Montgomery Watson Limited
Mr Brendan Moore	Chief Controller, Dunedin Airport, Airways Corporation of NZ Limited
Mr Mike O'Cain	Regional State Highways Manager, Transit New Zealand
Mr David Turner	Principal Traffic Engineer, Montgomery Watson Limited
Mr Dave Potter	Regional Secretary, N.Z. Road Transport Association
Mr Peter Ramsay	Senior Engineering Officer, Tranz Rail Limited
Mr Doug Rodgers	Technical Officer, Asset Management, Contracts & Asset Management Department, Dunedin City Council
Mr Gary Williams	General Manager, Citibus Newton Limited
Mr Colin McKay	Regional Highways Engineer, Transit New Zealand

Communications

Mr Greg Walsh (Leader)	Radio Spectrum Management Group, Ministry of Commerce
Mr Martin Balch	Technical Consultant (previously Radio New Zealand)
Mr Doug Graham	Operations Manager, Southern Television
Mr Ross Hunt	Area Manager, Contracts & Operations, Otago, Telecom New Zealand
Mr Bob Illingworth	District Manager, BCL
Mr Brent Marks	Business Analyst, Telecom New Zealand Limited
Mr Kevin McAlevey	Telecommunications Supervising Technician, Tranz Rail Limited
Mr Barry Paterson	Technical Manager, Radio Otago Limited
Mr Ian Robb	Team Leader, Network Operations, Bell South
Mr Peter Stones	Engineer, T.V.3
Mr Terry Webster	Senior Engineer, Clear Communications

Buildings & Services

Mr Lou Robinson (Leader)	Director, Hadley & Robinson Limited
Mr Colin Gray	Chief Building Control Officer, Dunedin City Council
Mr John Heenan	Director, Heenan Consulting Limited
Mr John Henderson	Technical Services Engineer, City Consultants, Dunedin City Council
Mr John MacKenzie	Senior Projects Manager, Montgomery Watson Limited
Mr Dave Marsh	Senior Station Officer, New Zealand Fire Service
Mr Murray Petrie	Senior Design Engineer, City Consultants, Dunedin City Council
Mr Ian Walsh	Senior Geotechnical Engineer, Opus International Consultants Limited
Mr Peter Watson	Consulting Mechanical Engineer, Montgomery Watson Limited

Health & Emergency Services

Mr Neil Brown (Leader)	Manager, Civil Defence & Rural Fires, Dunedin City Council
Inspector Dave Campbell	Area Manager, Dunedin, New Zealand Police
Mr Bob Cooper	Operations Manager, Order of St John Ambulance Service
Sr Mary Lucia	Chief Executive, Mercy Hospital
Mr Mark Lyne	Environmental Health Co-ordinators, Dunedin City Council
Mr Ewan McCombe	Manager, After Hours Medical Centre
Dr Tim Medlicott	Otago Medical Association
Prof Pat Molloy	Senior Medical Officer, Healthcare Otago
Mr David Seque	District Chief Fire Officer, Dunedin, New Zealand Fire Service

Special Contributors

Mr Andrew Buchanan	Surveyor, City Consultants, Dunedin City Council (until January 1997)
Mr Colin Fisher	Civil Defence Training Officer, Civil Defence & Rural Fires, Dunedin City Council
Mr Rob Garrett	Senior GIS Analyst, City Consultants, Dunedin City Council
Ms Valerie Hoyne	Administration Officer, Civil Defence & Rural Fires, Dunedin City Council
Ms Laura Nicol	GIS Analyst, City Consultants, Dunedin City Council

CHAPTER 1. EXECUTIVE SUMMARY

The primary function of the work undertaken in the Dunedin City Lifelines Project is to identify potential weaknesses in the services which provide for our community welfare and employment and wherever possible to make a positive physical improvement in the survivability of the service asset.

The in depth and critical examination of vulnerability to hazard events by the engineers and managers who operate the various services has been thorough and, at times, revealing.

In reporting upon their various service assets the operators have collectively answered the four questions asked of them:

- What assets do we have?
- How vulnerable are these to natural hazard?
- What are the most critical components of our at-risk systems?
- What can we do to help them survive?

The results of their work is contained in this report but there has been, and will continue to be, a benefit from the study by association and understanding developed between engineers, managers, scientists and academic personnel who have been involved in three years of input to the project.

Today's economic climate does not make delivery of physical improvements to our many service assets easy, particularly where earlier commitments made by our forebears as to the location and quality of some service assets makes mitigatory strategy costly. There are a number of areas within the city which we would now avoid building upon.

There are, nevertheless a number of less expensive strategies which may be undertaken which will have markedly beneficial effect upon our community welfare and early recovery following hazard events. In recognising these the project has aroused the awareness of the management and public alike to the serious possibility of hazard events and forms of preventative action which may be taken.

The three seminars initiated through the Lifelines Project were all well attended, with over ninety contributors present on average, and there can have been no doubt about the sincerity of their commitment to understanding the possibility of serious damage to our economic future if steps are not taken now to manage potential disaster.

Included in the report are details of how "assessment of vulnerability" was undertaken, adopting a scoring method which was used to avoid too much variation in assessment criteria by the task groups and which highlighted the proportionate importance of the various hazard effects in a standard manner.

It is considered significant that recent research on the Alpine Fault forecasts probable seismic events within the next 50 years at a level higher than previously expected and points out that such events are likely to mean that Dunedin may not be the recipient of help from further north, but will rather be in the position of having to help itself to recover and may be faced with the need to assist Central Otago towns with their recovery at the same time.

This report commends preparedness and the establishment of an ongoing lifelines review on an annual basis. It also recommends preventative action in mitigation of hazard damage to the critical components identified for each lifeline service over the next 10 to 20 years.

CHAPTER 2. PROJECT OUTLINE - CONTENTS

PROJECT OUTLINE

Introduction

Modern society is more than ever dependant upon the efficient and continued functioning of basic utility services, information technology and transportation.

Not only the community physical welfare, but the ability of industry to perform efficiently and economically in a world of increasingly high competition is intimately connected to the survival and early reinstatement of these basic service assets when disasters occur.

These service lifelines - for that is what they represent - are often taken for granted, and their importance under appreciated. Many are underground and most are never seen by the public.

Widespread or local damage due to a number of different natural and technological hazards can affect the lives and livelihood of thousands of people and when taken to extremes may cause economic damage which is irrecoverable.

In the last half of the 20th century, immense progress has been made in material improvement and design, resulting in more flexible structures and buildings. An older city like Dunedin has many examples of aging technology on display and many of our Lifeline assets have a potential towards failure in extreme hazard circumstances.

The greater Dunedin City area is fortunate in many respects that the history of seismic activity has not placed it among the most serious areas of such influence as in the case of Wellington and the east coast of the North Island.

Nevertheless, there has been in recent years local seismic activity of moderate magnitude and the nature of this hazard and other natural hazards are worthy of our understanding and study, with a view to reducing damage occurrence by mitigation strategies which may be adopted.

The study of lifelines has become an essential element of effective planning and economic development.

The United States of America, disturbed by continued seismic impact, commissioned a nation wide assessment of lifeline vulnerability in 1988. This formed the basis for establishing many other localised assessments which were generally based upon seismic reviews only. The USA work was completed in September 1991 and was regarded as a useful model by many cities working along similar lines - some extending the hazard range beyond seismic affects to cover particular local hazards.

In New Zealand, the Centre of Advanced Engineering at the University of Canterbury undertook a seismic assessment of lifelines in the capital city of Wellington and published their "Wellington Case Study" in August 1991. This was the first lifelines study to be undertaken and greatly benefited from the academic and engineering support of the University.

Since then, a number of major cities and some smaller towns in New Zealand have commenced lifeline assessments; Christchurch in 1993/4 and Dunedin in 1995/6. In the latter cases, the hazard base has been extended beyond pure seismic vulnerability to cover hazards such as flooding and landslip and this has involved a wider range of contributors and increased awareness of the hazard problems which may be encountered.

Objectives

The objective of the "Dunedin City Lifelines Project" is to study the effect of natural hazards upon the existing services which are essential to sustain community welfare and employment, and to determine what action may be taken to improve survivability in the event of disaster.

The examination of lifelines was undertaken in stages.

Identification of Hazards
Academic and scientific reporting was undertaken by people engaged in environmental study of hazards which might impact upon the region. Mapping to define areas of influence was prepared with the assistance of City Consultants.

Description of Service
The project sought to identify, describe and record all major elements of lifelines in order to assess the vulnerability of discrete elements and complete systems to damage from a number of natural and technological hazards.

Assessment of Vulnerability
Each element and complete system was examined by asset managers to determine the exposure of the lifeline to the hazards and to "rate" its vulnerability.

Mitigation Strategies
The final objective was to establish and develop practical engineering work strategies designed to increase survivability.

Methods of mitigation, questions of reinstatement periods, cost and availability of skills and materials came under review as peripheral issues arising from the asset vulnerability assessment. The importance of interdependence of services was also considered.

Hazards will almost always cause damage in some form or another and the availability of capital may limit the resources which may be directed towards mitigation. The project sought to give direction as to where money should be directed as it becomes available, and draw attention to future design considerations and planning initiatives.

Programme

Though partially modelled on the lifelines studies earlier carried out in the U.S.A. by the Federal Emergency Management Agency (FEMA/224/September 1991), and more specifically upon the work carried out by the Centre for Advanced Engineering (CAE) - University of Canterbury in their Wellington Case Study (August 1991), it was decided that the Dunedin City Lifelines Project needed to investigate a slightly wider range of hazards than that in the Wellington study and to be less "broad brush" than the U.S. study.

Accordingly, an initial programme covering a 32 month period was prepared, including three seminars to increase awareness of contributors and associated asset managers.

In the event, this programme and the estimate of progress during assembly of the data by the various groups within the study proved reasonably accurate, though the time required for publication of the results was underestimated, and the overall period to publication extended to become 36 months.

Administration

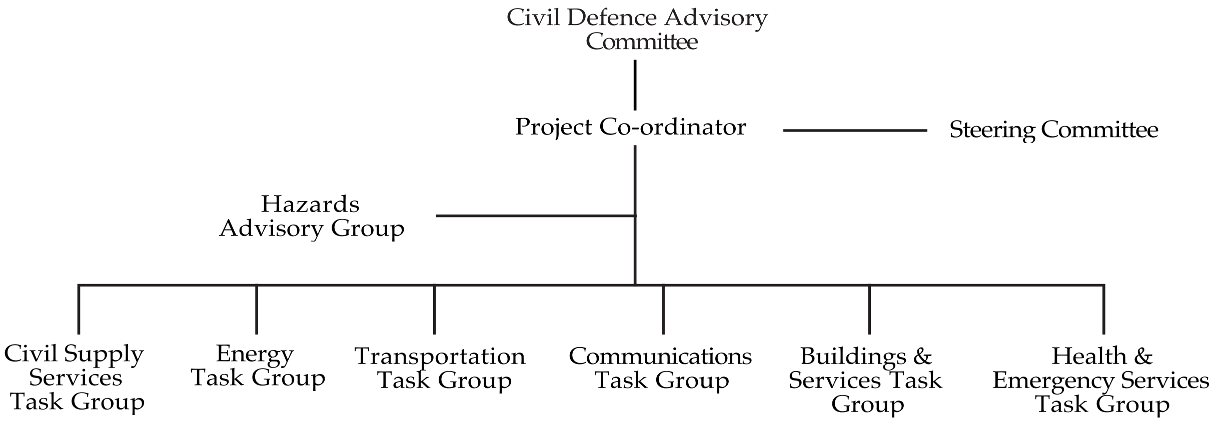
The project administration was undertaken in combination with the Civil Defence and Rural Fires Department of Dunedin City Council, by an appointed part time Co-ordinator. The appointment was made by the Civil Defence Advisory Committee.

The Co-ordinator was a retired consulting civil engineer with a wide number of contacts among engineering, management and academic personnel within the City of Dunedin and with a knowledge of various city services.

Guided by the order of work undertaken in the Wellington study, teams of engineering, academic and management people were assembled into task groups as follows:

- Civil Supply Systems
- Energy/Fuels
- Transportation/Harbour
- Communications/Information
- Buildings/Services
- Health and Emergency Services
- Hazard Analysis Group

A Steering Committee consisting of senior management, task group leaders and members of the Civil Defence Advisory Committee was appointed to maintain an overview of project progress. Control of finance was undertaken independently by Dunedin City Council on behalf of the Steering Committee.



Definition of Lifelines

Identification of lifelines and recording of asset detail was undertaken in the "Description of Service" part of the project.

The study involved all major lifelines in the greater Dunedin City area. While greater emphasis is placed upon urban locations with their substantially greater population, areas of primary production and tourism were not neglected.

Lifelines assets cover the supply of water, power, fuel, the treatment and disposal of waste waters, transport by road, rail and sea, communications and broadcasting.

Because of the essential service performed in the carriage of personnel and distribution of goods within the Dunedin City area, road transport equipment and maintenance facilities were considered as lifelines.

Major buildings including essential administration and commercial facilities, together with power generation, harbour, hospital, police, fire and ambulance services were examined against a background of survivability under hazard impact.

Advice upon their dependence on lifelines was sought from Health and Emergency Services groups and consideration given to the economic and planning aspects of all lifelines in their recovery from disaster.

Definition of Hazards

The project identified a range of hazards which may impact upon the lifelines either singly or collectively. The degree of severity of impact has been widely discussed between lifelines managers and interpretation sought from academic, scientific and engineering sources on the various hazards.

Hazards which are considered to offer a potential for damage of a significant nature to lifelines are:

- Earthquake - Shaking
  - Faulting
  - Liquefaction
- Tsunami - Near & far field events
- Flooding - Nominated locations
- Weather - Snow, wind, rain
- Landslide - Earthquake or natural instability
- Technological - Fire, explosion etc

These hazards have been defined by the Hazard Group and are set out in detail in Chapter 3 Hazards.

Methodology

Introduction
Hazard identification and mapping of areas of influence was prepared by a separate academic and scientific team and was made available to task groups.

The various stages of procedure adopted were undertaken by task groups concerned with the asset management of the particular service involved. Task groups were asked to prepare drawings of asset routes and other significant service locations and overlay maps were made available for subsequent review in assessing vulnerability.

Mapping, was prepared by City Consultants and has been retained on the Council's GIS system.

Description of Service
Description of Service involves the description and mapping of lifelines assets by the system operators and management. Asset managers were asked to describe the service purpose, location, quality of material etc. in a logical order to present a good word picture of the extent of the asset. From these statements the next stage of the study proceeded.

During this period the Hazard Analysis Group was involved in preparing data and mapping the hazards.

Assessment of Vulnerability
The Dunedin City Lifelines Project involved assessment of the vulnerability of lifeline services to various hazards. An understandable method of determining relative vulnerability was developed and applied in a common way to all lifeline services.

The basis of the methodology for assessing lifeline services' vulnerability to hazards is described below and takes into account a range of factors other than simple exposure to a hazard, incorporating quality, condition and location.

Terms used in hazard analysis are sometimes used in different ways in different methods. To avoid confusion, terms used in this project are defined below:

- *Hazard* is defined as a physical event with the potential to cause damage or loss.
- *Risk* is a measure of the level of exposure to a particular hazard in a defined location and is often described by the simple formula *Risk = Probability x Magnitude*. While giving a measure of the likely impact of the hazard, risk does not take into account the physical nature of assets affected and their relative importance to the community.
- *Vulnerability* is a measure of the consequences of identified hazards affecting a particular network (or its component parts). Factors taken into account by this method include the probability and magnitude of the sum of the hazards it is exposed to (total risk); its relative importance to the network (significance); the degree to which it is prone to damage (fragility); the likely delay before it can be re-instated (time); and the economic impact of the expected level of damage (cost).

For the purpose of assessment, vulnerability was broken down into three separate elements within the vulnerability analysis worksheets:

- Physical Vulnerability = Total Risk x Fragility
- Network Vulnerability = Total Risk x Fragility x Redundancy x Time
- Community Vulnerability = Total Risk x Fragility x Redundancy x Time x Cost

Computerised ranking of these elements enabled an assessment to be made of the order of importance of various parts of the lifelines and to identify where the highest risks lay.

Values for Calculating Vulnerability
For this calculation to produce a meaningful ranking of vulnerabilities of a range of assets, suitable weightings were established for the numerical values given to the risk for different hazards and the modifying factors for the assets, and a Vulnerability Calculation Chart was prepared (see appendix to this chapter).

Among criteria for the weighting of these numeric values were:

Total Risk
Values for each hazard established based upon:
- The level of magnitude (as defined in the hazard mapping).
- The probability of occurrence of that magnitude of event.
- The level of disruption to services likely to be caused.

The numeric values established had to bear relativity to each other so that a high probability event with little disruption potential did not outweigh a lower probability event with high disruption potential. Risk values for hazards to which any asset or part of an asset was exposed were added so that exposure to a number of events increased the weighting of the risk factor in the equation.

Redundancy
This factor is based on the relative impact of the loss of the asset (or component of the asset) to the network of which it is a part, taking into account the degree of redundancy provided for that element of the network. The more redundancies there are, the less vulnerable the network as a whole should be.

Fragility
This indicates a measure of the degree of protection from or resilience to damage of the asset. Considerations include:
- Age (in relation to its assessed economic life).
- Standard of construction, including any hazard resistance designed in.
- Type of construction.
- Current condition.

Time
Included in this factor are values based on the total time the asset is likely to be out of service or until an alternative is brought into use following the most disruptive event to which it is susceptible. The weighting of this factor is influenced by the availability of:
- Replacement componentry.
- Skilled personnel.
- Specialist equipment from outside sources.
- Outside contractors (for whom there may be competing requirements).

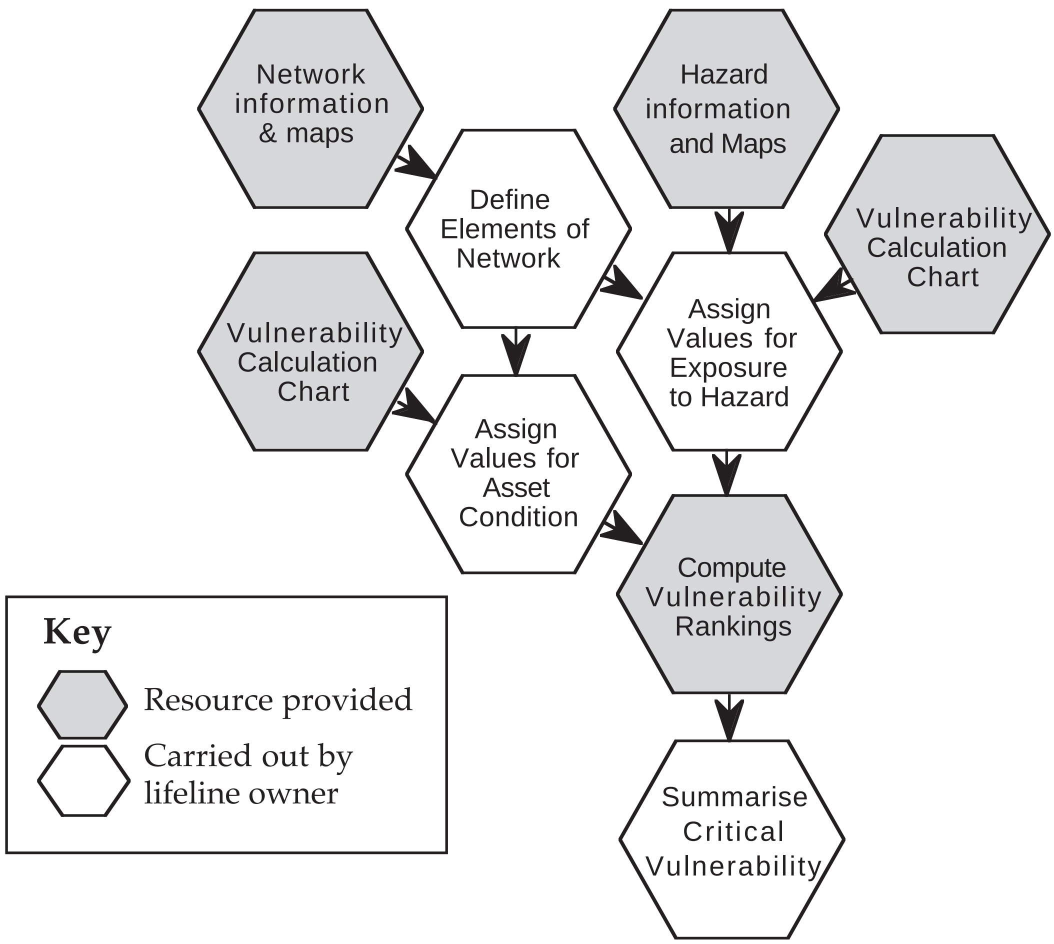
Cost
Determining the value of this factor (based on the most disruptive event to which it is susceptible) included:
- The cost of repairing or replacing the asset.
- Cost of temporary alternatives used to resume service.
- Whether there is insurance cover or other financial support for repairs or replacement.

The end result of this process was to produce a comparative vulnerability ranking for assets in a network rather than an absolute value.

Methodology for Lifelines Vulnerability Analysis
The process applied to the assessment of vulnerability was to:
- Use network maps appropriate to the lifeline group service.
- Divide the network into discrete elements and enter the description in the Lifeline Vulnerability Analysis Worksheet (see appendix for an example). This requires knowledge of the elements and their physical location.
- Overlay the network maps with the hazard boundary maps, or refer to the hazard definition papers presented by the academic and scientific group in their publication set out in Chapter 3.
- Determine exposure of each component to each hazard using the Vulnerability Calculation Chart to establish hazard values. Enter these onto the Lifeline Vulnerability Analysis Worksheet. These are factors which relate solely to the asset locality.

- Establish values for fragility, redundancy, time and cost to reinstate from the Vulnerability Calculation Chart, and enter these onto the Lifeline Vulnerability Analysis Worksheet. These are modifying factors and this element of the work required a good deal of engineering judgement and some imagination. Familiarity with the lifeline and knowledge of inherent weaknesses, whether due to age or location, was necessary to complete the assessment effectively.
- Submit Lifeline Vulnerability Analysis Worksheet for computer input. The computer programme calculated the three vulnerability categories of each element and sorted them into order. These worksheets have been retained for reference.
- Based on the calculated vulnerabilities, produce a written description of the anticipated type and extent of damage to each element of the network by exposure to hazard. This part of the work was important and required critical examination and full description of the vulnerability of the elements of the network. This work formed the basis for consideration of mitigation strategies.

Vulnerability Assessment



As some of the calculations had an element of commercial sensitivity, working documents remain confidential to the lifeline owner. Reporting on general intentions for mitigation strategies was the only outcome needed for inclusion in this report.

Mitigation Strategies

Background
Task groups were asked to formally report upon mitigation strategies designed to prevent damage and increase overall survivability of the critical assets identified in the summaries of vulnerability. To assist this process a Mitigation Strategy Record Worksheet was developed (see appendix) for task groups to complete and retain in-house for future reference.

A written statement on the prepared mitigation strategies, including conclusions and recommendations, was produced by each group.

VULNERABILITY CALCULATION CHART

EARTHQUAKE

Choose highest values applicable
Enter values on vulnerability analysis chart

	Shaking	Liquefaction	Active Within500m of a fault line	Non-active
Background	5	-	2	0
Enhanced	10	5	3	1

TSUNAMI

Choose highest value applicable
Enter value on vulnerability analysis chart

	Above 5m contour	Between 2 & 5m	Below 2m contour
Within 1km of coast or estuary	0	1	2

WEATHER

Choose and add highest values applicable
Enter total on vulnerability analysis chart

Disruption	Windstorm	Snowstorm
Some	0	0
Much	0.5	0.5
Severe	1	1

FLOODING

Choose and add highest values applicable
Enter totals on vulnerability analysis chart

Exposed	Leith/Lindsay	South Dunedin <2m	Kaikorai Estuary	Taieri Plain	Waikouaiti	Waitati
Yes	3	2	2	1	1	1
No	0	0	0	0	0	0

LANDSLIDE

Choose highest value applicable
Enter value on vulnerability analysis chart

	None	Infrequent	Significant
Exposure	0	1	2

TECHNOLOGY

Choose highest value applicable
Enter value on vulnerability analysis chart

	Not exposed	Exposed
Exposure	0	1

FRAGILITY

Choose highest value applicable
Enter value on vulnerability analysis chart

Economic Age	Hazard resistant	Meets current std	Meets older std	Inadequate std
First third	1	2	3	4
Second third	1	2	3	4
Last third	2	3	4	4

REDUNDANCY

Choose highest value applicable
Enter value on vulnerability analysis chart

Impact of loss	Full redundancy	Some redundancy	No alternative
Low	1	1	2
Medium	1	2	3
High	1	3	4

TIME

Choose highest value applicable
Enter value on vulnerability analysis chart

	Within 1 week	1-4 weeks	1-3 months	More than 3 months
Reinstatement time	1	2	3	4

COST

Choose highest value applicable
Enter value on vulnerability analysis chart

	Low impact*	Moderate impact*	Major impact*	Uneconomic*
Reinstatement cost	1	2	3	4

* Definition of financial impact on the owner of the asset
Low Impact means cost can be funded from within normal annual operating costs.
Moderate Impact means cost can be funded by some re-prioritising of existing capital works and maintenance.
Major Impact means cost need to be funded from external sources and/or considerable restructuring of financial plans.
Uneconomic means the cost is such that the asset is unlikely to be re-instated.

LIFELINE VULNERABILITY ANALYSIS

Page:

DUNEDIN CITY LIFELINES PROJECT

Network

Component

				Community Vulnerability													
				Network Vulnerability													
				Physical Vulnerability													
Asset Description	Shaking	Liquefaction	Fault proximity	EARTHQUAKE	TSUNAMI	FLOODING	WEATHER	LANDSLIDE	TECHNOLOGY	**TOTAL RISK**	FRAGILITY	**PHYSICAL VULN'Y**	REDUNDANCY	TIME	**NETWORK VULN'Y**	COST	**COMM'Y VULN'Y**

Assessed by: Date: Computer input by: Date:

Appendix - Mitigation Strategy Record Worksheet Example

Dunedin City Lifelines Project.
Stage 3 Mitigation Strategy.
Record Worksheet.

TASK GROUP NO: 1		Unique I/D: 1/DS/PL
UTILITY: Water Supply		Date: April 1998
INDEX HEADING: Supply System		

Description of vulnerable element (Include detail of location for identification):

1 Deep Stream and Deep Creek pipelines Taieri River Bridge 2km to the west of Taioma Road.

Nature of vulnerability (Exposure & consequences):

Earthquake, Land movement & Technology.

The predominant risks of failure of the 3 - pinned riveted truss lattice are:

1 landslide at the western abutment by either rapid movement or creep resulting in compression of the bridge and ultimate failure of the pipelines.
2 Rockfall from the steep bluffs above the true left abutment.
3 Distortion of the bridge or damage by rockfall induced by seismic activity.
4 There is also some risk of the bridge being badly damaged by a low flying aircraft such as helicopter.

Identify mitigation options (With estimated order of cost):

The following mitigation measures should be considered.

Protection of the bridge or stabilisation of the steep schist slopes on the true left bank. (Estimated Cost $500,000 ??)

The bridge should also be repainted in a more visible colour to make it easier to see from a helicopter. (Estimated Cost $200,000)

Recommended mitigation strategy (With reasons):

1 Establish survey levelling points on the bridge and compare camber of bridge span with design drawings on a yearly basis.
2 Set up a ground movement survey network on the Pipe Bridge and Mt Hyde slide complexes and survey yearly.
3 Consider relocating one or both of the pipeline river crossings upstream to the ridge on which the power transmission lines are located.
4 Repaint bridge.

Other design considerations:

The above mentioned upstream pipe route and crossing are flanked by landslides, however there does not appear to any other viable options.

Serious consideration needs to be given to buried pipe crossing of the river as opposed to a bridge option.

Works already planned/programmed (Where applicable):

Replacement or duplication of the bridge would only take place after 2007 when the Deep Creek pipeline is replaced. This is identified in the Water Upgrade plan but no funding provision has been made at this stage.

Interim contingency planning measures (until mitigation proposals are in place)

1 Regular walk over inspections of the bridge and pipelines to continue.
2 Consider regular level surveys.

General comments on mitigation strategies:

Consider alternative pipeline routes and crossing site and obtain consents to deviate one or both of the pipelines.

CHAPTER 3. HAZARDS – CONTENTS

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

Professor Richard Norris, Professor of Geology, University of Otago.
Associate Professor Peter Koons, Geophysicist, University of Otago.
Mr Dick Beetham, Engineering Geologist, Institute of Geological and Nuclear Sciences, Wellington .

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).

References

Adams, R.D. & Keen, R.J. 1974: The Dunedin Earthquake, 9 April 1974 Part 1: Seismological studies. Bulletin of the N.Z. National Society for Earthquake Engineering, 7: (3)

Bishop, D.G. 1974: The Dunedin Earthquake, 9 April 1974 Part 2: Local effects. Bulletin of the N.Z. National Society for Earthquake Engineering, 7: (3)

Brunsden, D.R., Britton, N.R., Carter, R.J., Crimp, R.F., Gates, E.F., Gordon, M.A., Hughson, G.J., Lamb, A.J.W., Leslie, P.D., Wabnitz, G., and Watson, A.C., 1986: Lessons for New Zealand lifelines organisations from the 17 January 1995 Great Hanshin Earthquake. Bulletin of the New Zealand National Society for Earthquake Engineering, Vol. 29, No 1, March 1996, 1-55.

Fairless G J and Berrill J B, 1984: Liquefaction during historical earthquakes in New Zealand. Bulletin of the New Zealand National Society for Earthquake Engineering, Vol. 17, No 4: 280-291.

Kawashima, K., Aizawa, K. & Takahashi, K. 1984: Attenuation of Peak Ground Motion and Absolute Acceleration Response Spectra. Proceedings 8th World Conference on Earthquake Engineering, San Francisco, 11: 257-264.

McCahon, I.F., Yetton, M.D. & Cook, D.R.L. 1993: The Earthquake Hazard in Dunedin. Report prepared for EQC, Project 91/56, 150pp.

Norris, R.J., Koons, P.O. & Landis, C.A. 1994: Seismotectonic evaluation of fault structures in East Otago. Report prepared for EQC, Project 91/53, 140pp.

Smith, W.D. 1978: Spatial distribution of felt intensities for New Zealand earthquakes. N.Z. Journal of Geology & Geophysics 21: 293-311.

Park, R., Billings I.J., Clifton, G.C., Cousins, J., Filliatrault, A., Jennings, D.N., Jones, L.C.P., Perrin, N.D., Rooney, S. L., Sinclair, J., Spurr D.D., Tanaka, H., and Walker, G., 1995: The Hyogo-ken Nanbu Earthquake of 17 January 1995. Bulletin of the New Zealand National Society of Earthquake Engineering Vol. 28, No 1, March 1995, 1-99.

Smith, W.D. & Berryman, K.R. 1983: Revised estimates of earthquake hazard in New Zealand. Bulletin of the N.Z. National Society for Earthquake Engineering, 16: (4) 259-272.

Soils and Foundations, 1993: The earthquake hazard in Dunedin. Report prepared by McCahon, I.F., Yetton, M.D., and Cook, D.R.L., with assistance from the University of Otago, 8 June 1993. Study funded by EQC, Research Project 91/56.

Study Group of the New Zealand Society for Earthquake Engineering. Bulletin of the N.Z. National Society for Earthquake Engineering 25: (4) 345-357.

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

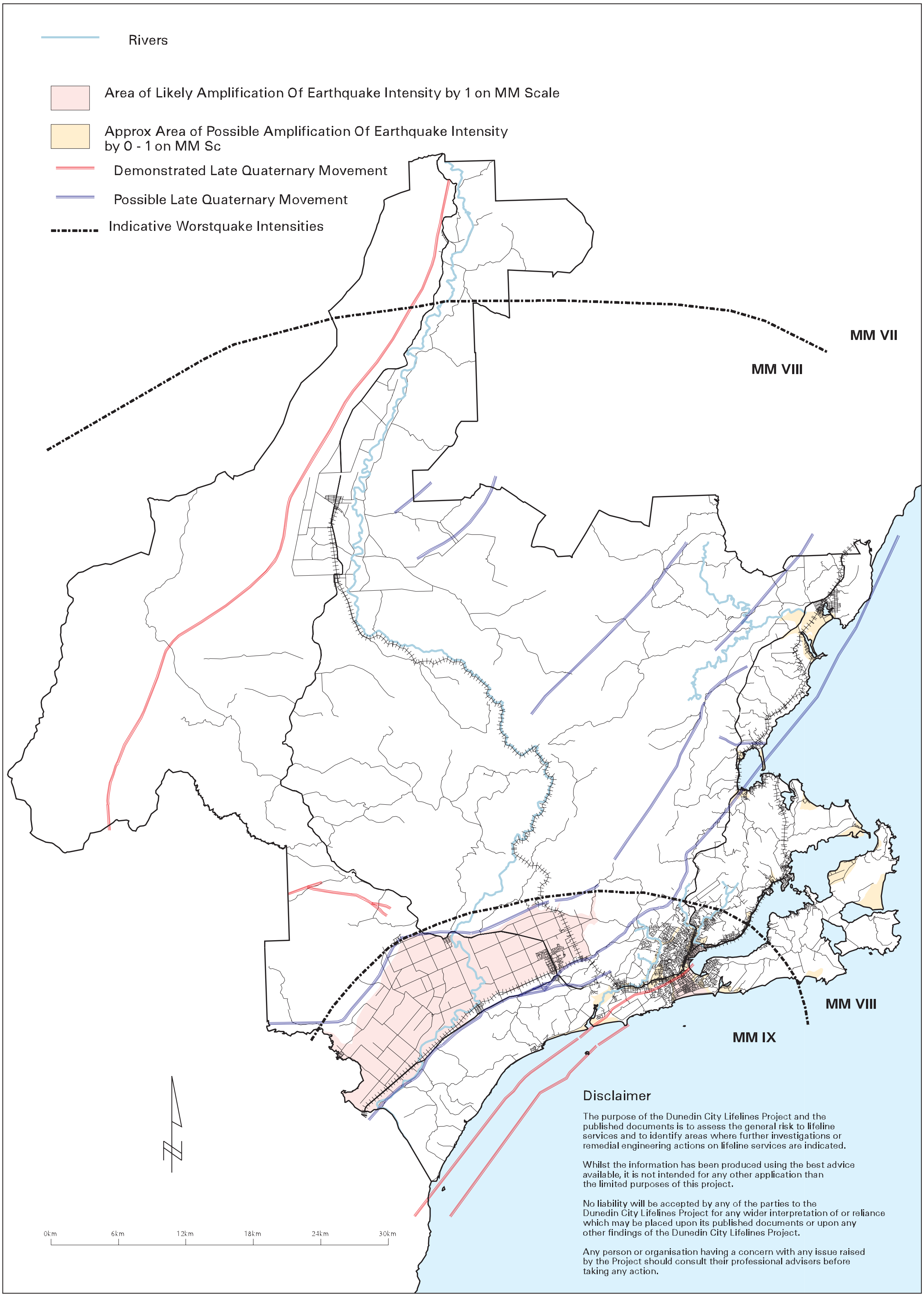
Type I: Weak materials such as mud brick and rammed earth; poor mortar; low standards of workmanship.

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)

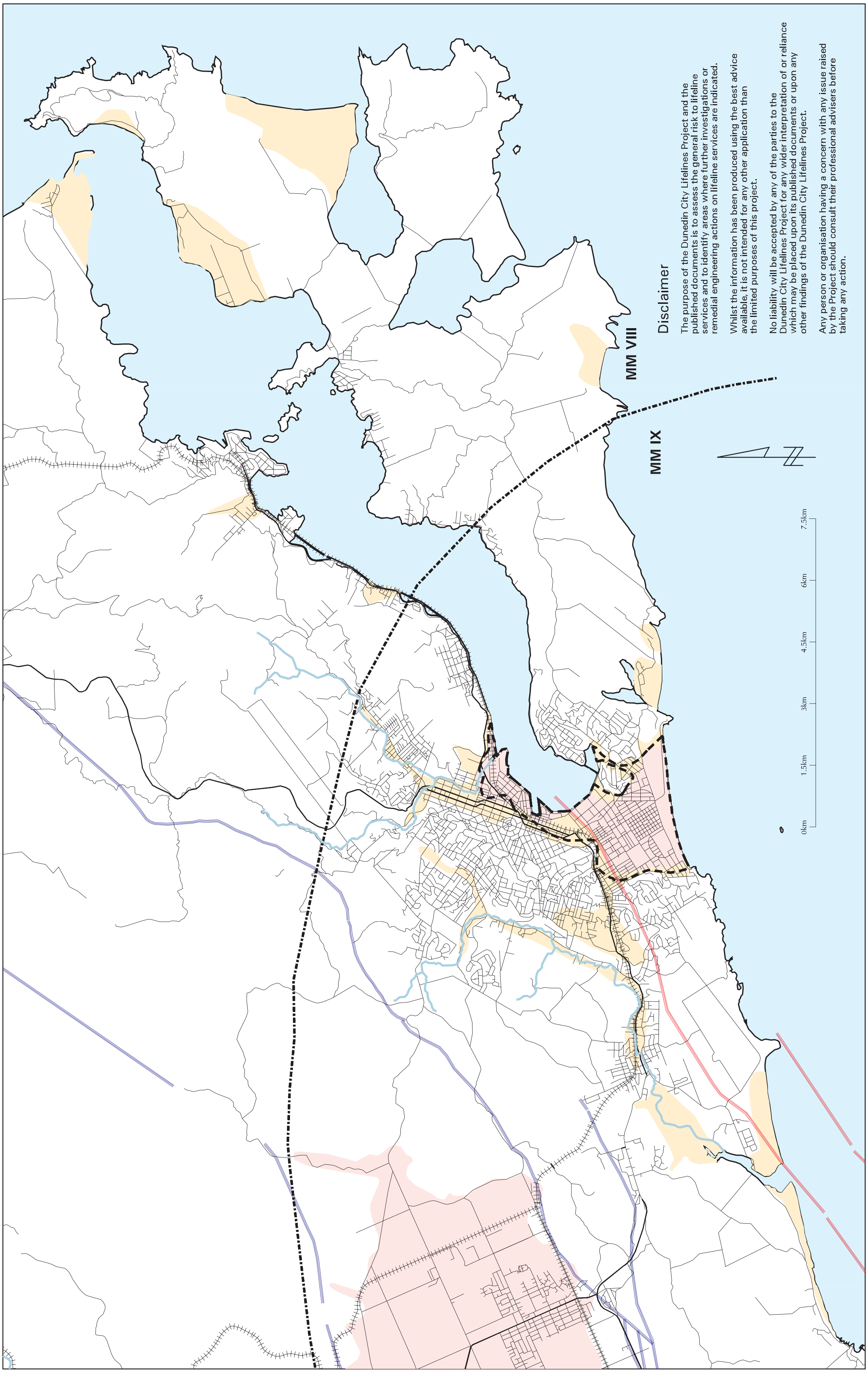
Type IV: Since c 1970 for concrete and since c 1980 for other materials, the loading and materials codes have combined to ensure fewer collapses and less damage than in earlier structures. This arises from features such as: "capacity design" procedure; use of elements (such as improved bracing or structural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

Earthquake Hazard - Faultlines



City Consultants
August 10, 1998

Earthquake Hazard - Areas of Intensification of Shaking



City Consultants
August 11, 1998

- Demonstrated Late Quaternary Movement
- Possible Late Quaternary Movement
- Boundary of Soil Types Susceptible to Liquefaction
- Indicative Worstquake Intensities
- 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

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.

References

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

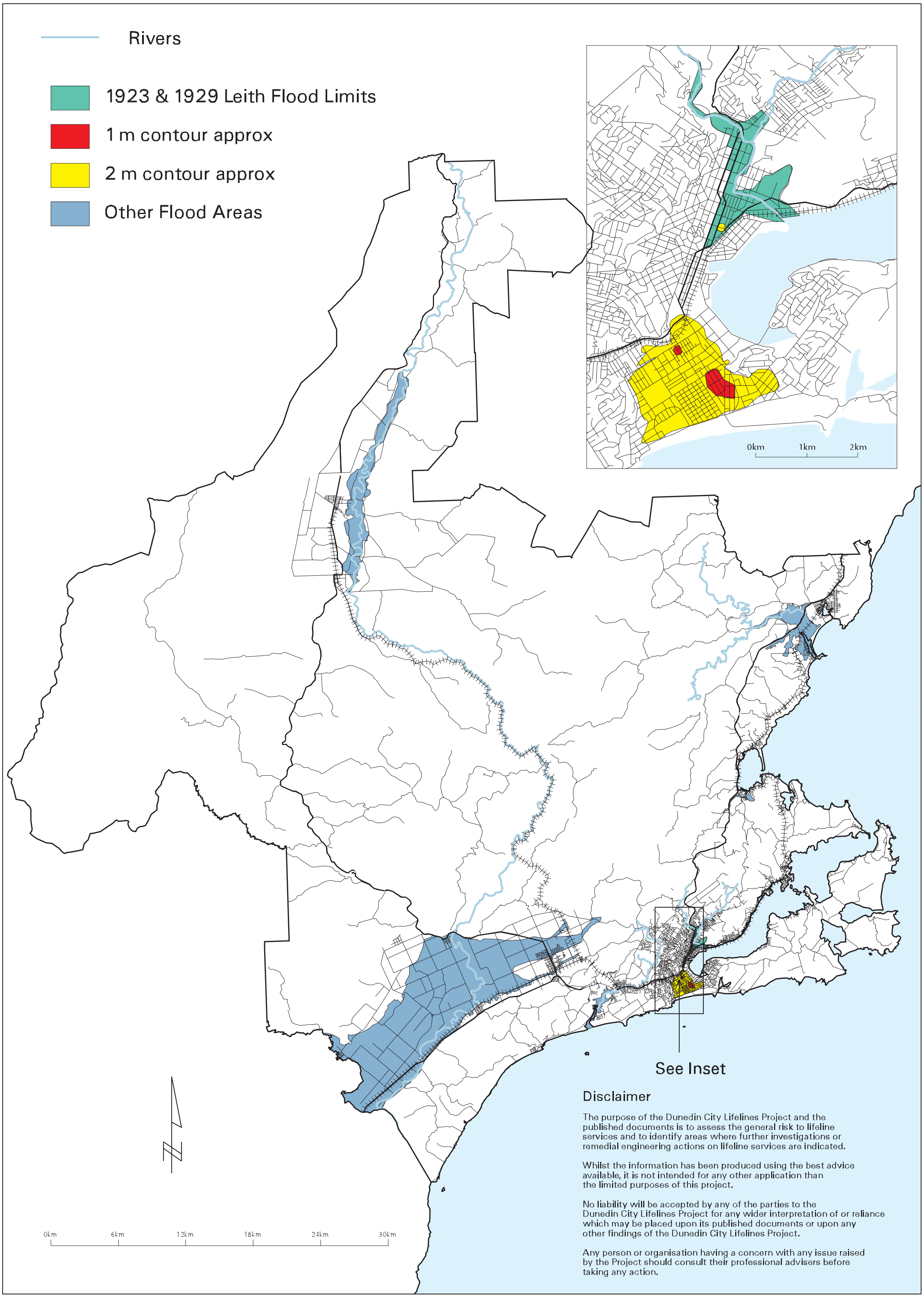
MacLean, F.W. et al 1931: Water of Leith and Lindsay's Creek. Dunedin City Council.

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

Mr Phil Glassey, Engineering Geologist, Institute of Geological & Nuclear Sciences Ltd, Dunedin
Dr Ian Turnbull, District Geologist, Institute of Geological & Nuclear Sciences Ltd, Dunedin

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.

References

Benson, W.N. 1940: Landslides and allied features in the Dunedin district in relation to geological structure, topography and engineering. *Transactions of the Royal Society of New Zealand 70: 249-263.*

Benson, W.N. 1946: Landslides and their relation to engineering in the Dunedin district, New Zealand. *Economic geology 41: 328-347.*

Benson, W.N. 1968: Dunedin district 1:50,000. *New Zealand Geological Survey miscellaneous map series 1.* Department of Scientific and Industrial Research, Wellington.

Bishop, D.G.; Turnbull, I.M. (compilers), 1996: Geology of the Dunedin area 1:250,000. Institute of Geological & Nuclear Sciences 1:250,000 geological map 21. 1 sheet and 52p. Lower Hutt, New Zealand Institute of Geological & Nuclear Sciences Ltd.

Forsyth, P.J.; Glassey, P.J.; Turnbull, I.M. 1995: Integrating natural hazards under the RMA. *Planning Quarterly September; 17-19.*

Hancox, G.T.; Bishop, D.G.; McKellar, I.C.; Northey, R.D. 1980: East Abbotsford landslide - presentation and assessment of engineering geological data and factors related to the cause of the slide. *New Zealand Geological Survey report EG 332.*

Leslie, D.M. 1974: Effects of basement lithology, regolith, and slope on landslide potential, Otago Peninsula, New Zealand. *New Zealand Soil Bureau Scientific Report 12.*

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.

Robins, M.J. 1982: Green Island Borough Urban Land Use Capability Survey. Otago Catchment Board Land Use Capability Survey L10397.

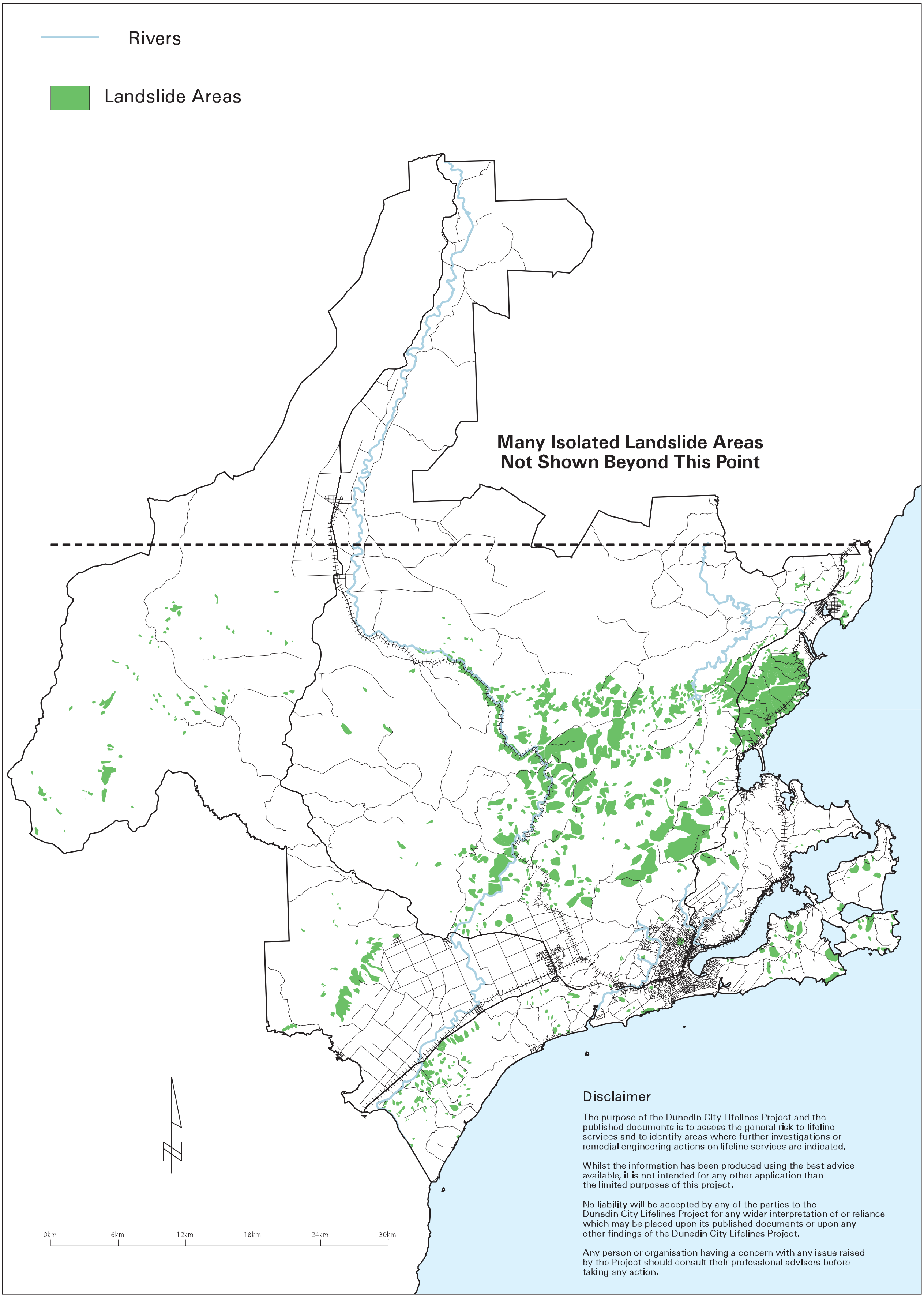
Stewart, D.L. 1996: Landslides triggered by the 17-19 March 1994 rainstorm, Dunedin area. *Institute of Geological & Nuclear Sciences Science Report 95/42.*

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)



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.

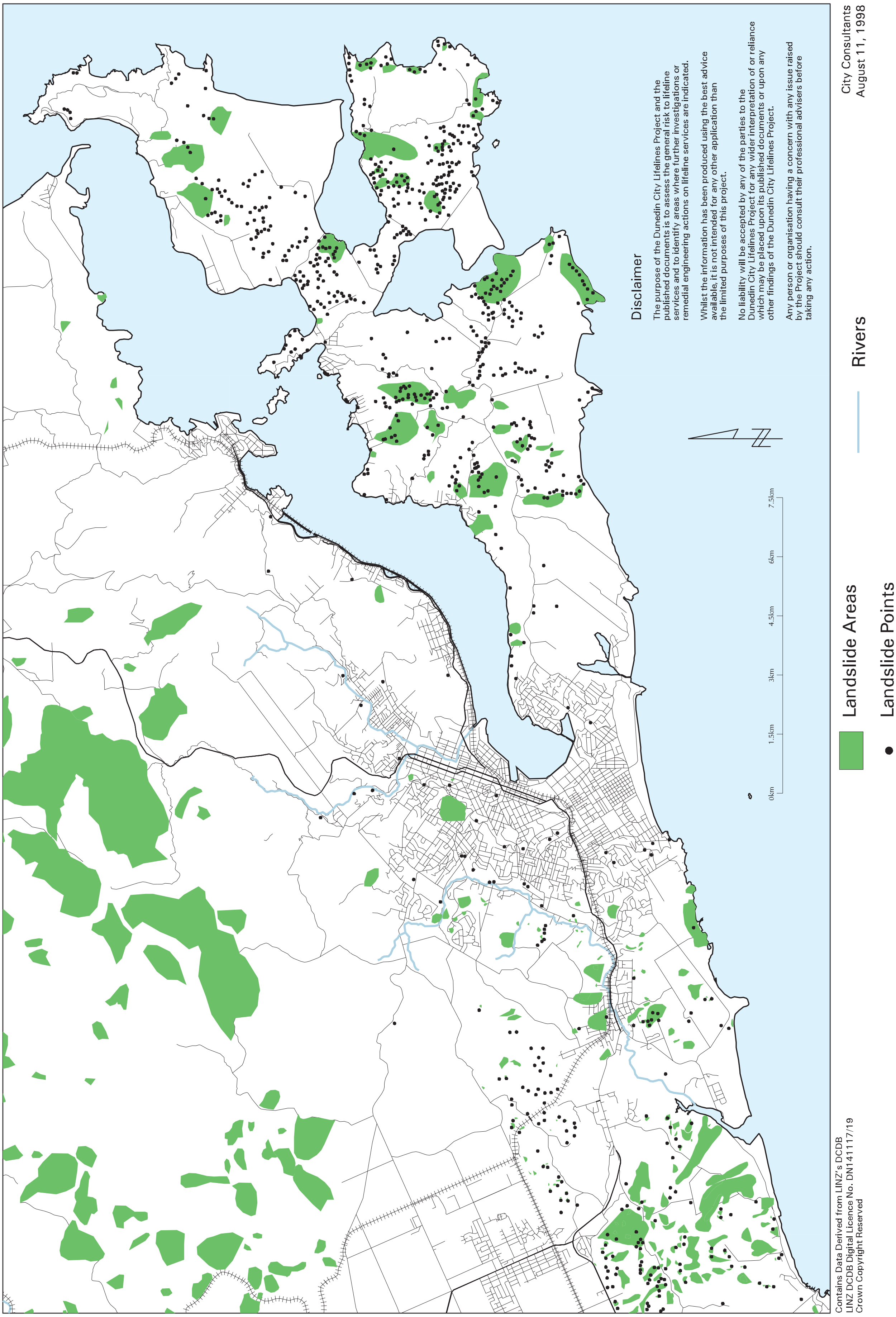
Whilst the information has been produced using the best advice available, it is not intended for any other application than the limited purposes of this project.

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 12, 1998

Landslide Hazards (Urban Area)



METEOROLOGICAL HAZARDS

Associate Professor Blair Fitzharris, Climatologist, Geography Department, University of Otago.
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.

References

MacLean, F.W.; McGregor Wilkie, J.; Alexander, J.G. 1931. Report on the floods in the Water of Leith and Lindsay's Creek.
Otago Regional Council 1991. Report on flooding 18/19 February 1991.
New Zealand Meteorological Service 1980: Depth – Duration – Frequency Tables Based on Daily Rainfalls. Supplement No.1 to The Frequency of High Intensity rainfalls in New Zealand: Part II (N.Z.Met.S.Misc.Pub.162).

Appendix - Historical Information on High Winds

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

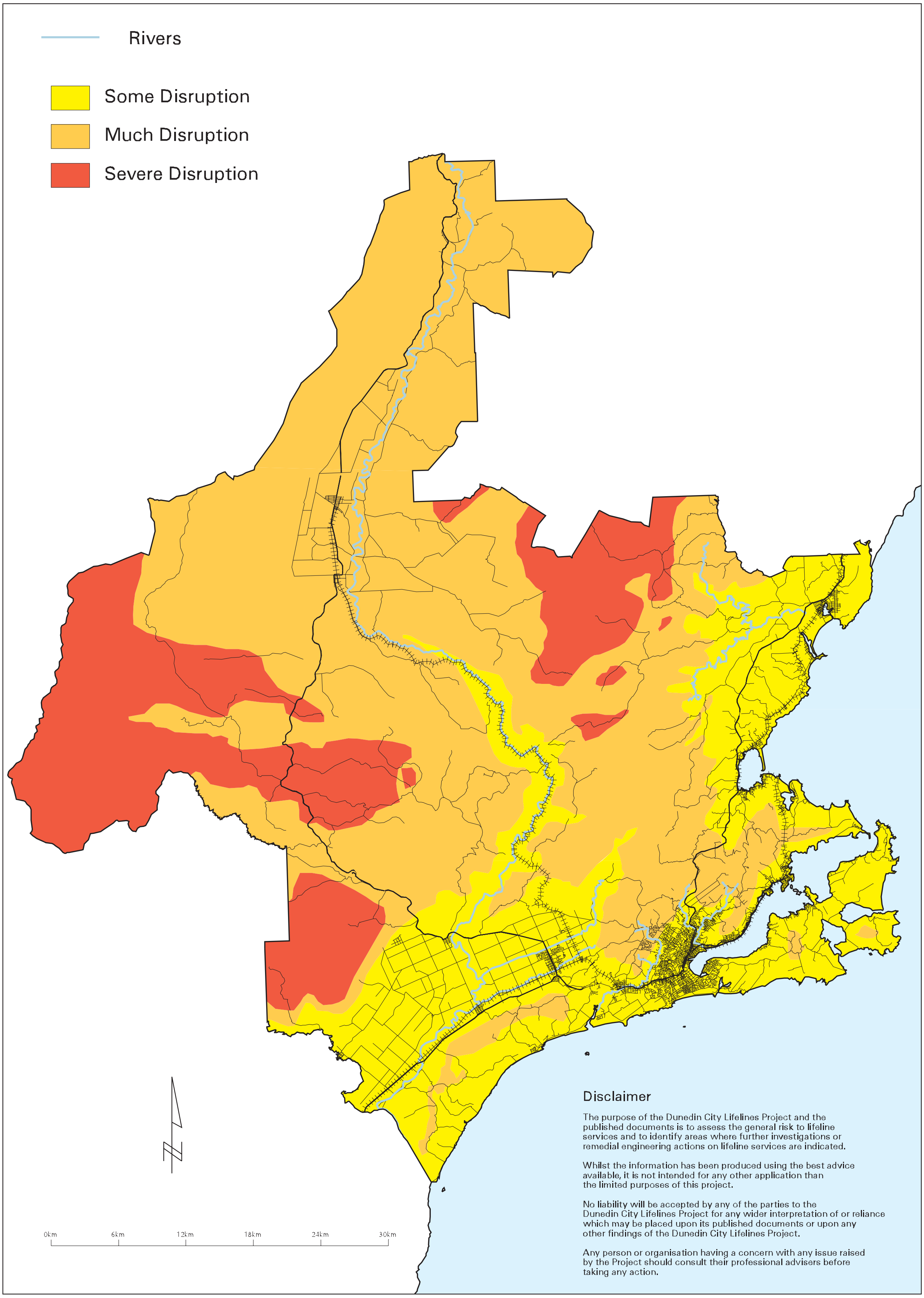
Year	Speed Knots	Speed km/h	Direction (E of N)
1991	45.9	85.0	85
1992	44.6	82.6	260
1993	43.4	80.4	305
1994	44.8	83.0	270
1995	49.6	91.9	265
1996	43.4	80.4	275

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					Number of Years of Record
		2	5	10	20	50	
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



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.

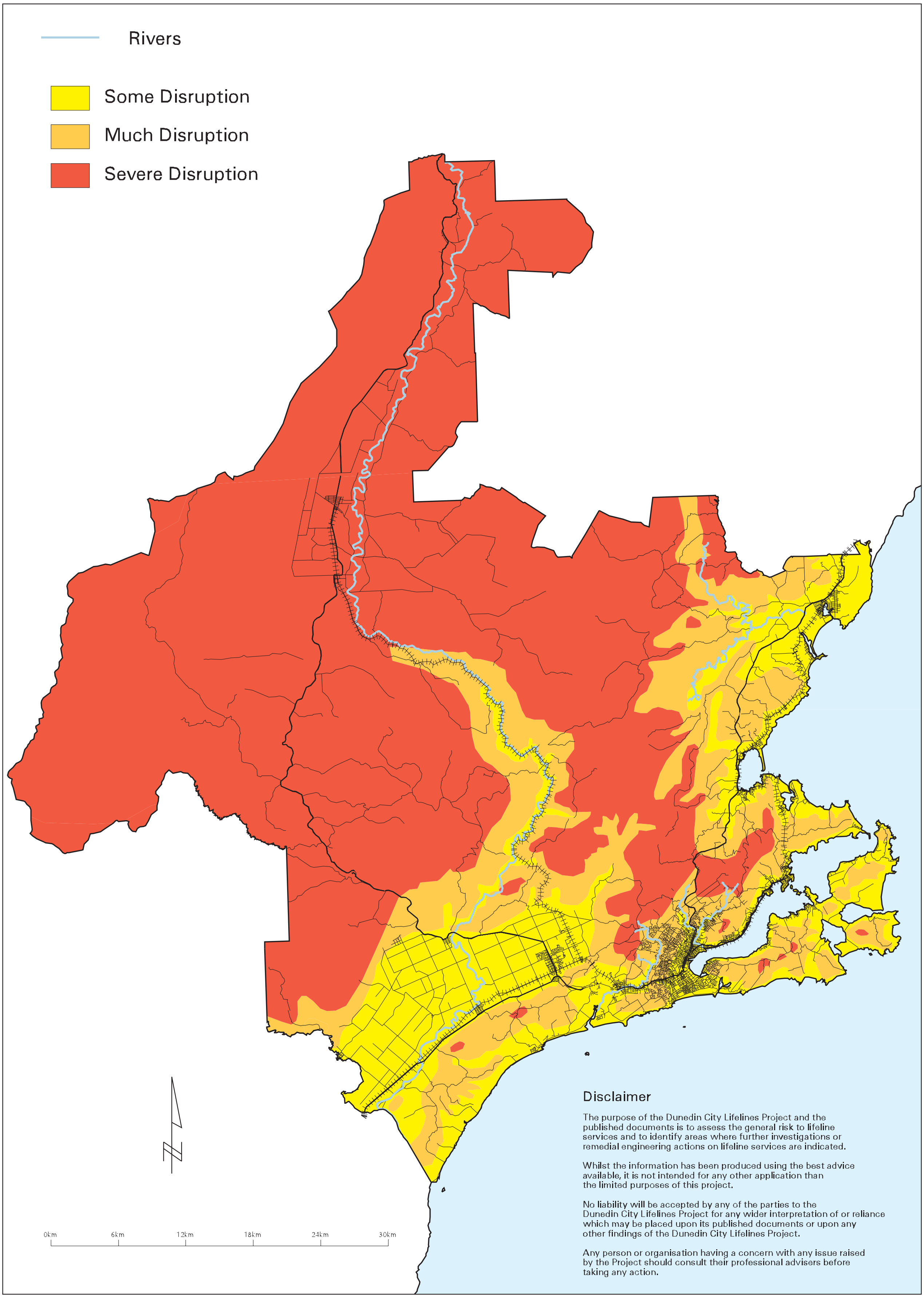
Whilst the information has been produced using the best advice available, it is not intended for any other application than the limited purposes of this project.

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
December 23, 1998

Snowstorm Hazards



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.

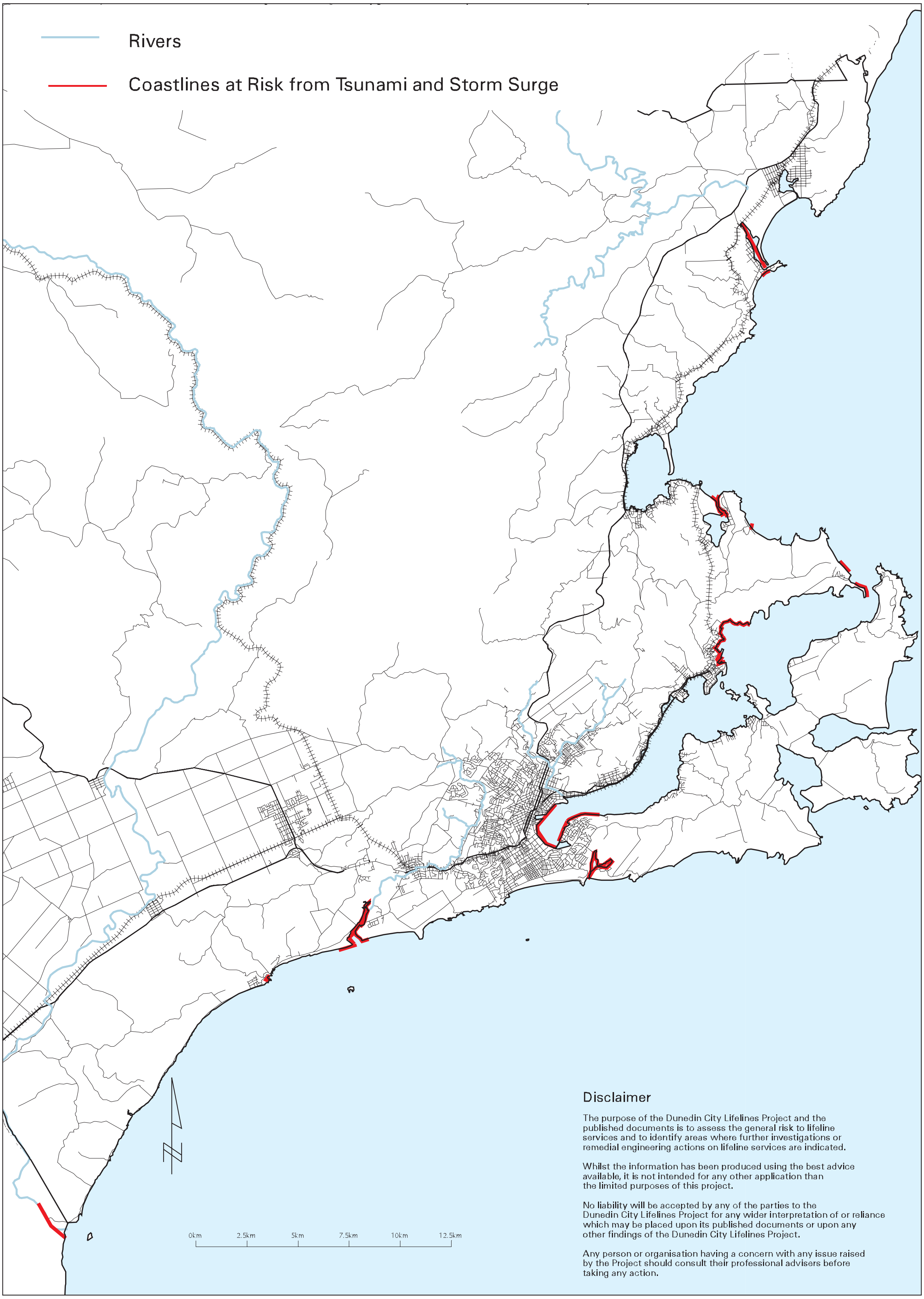
1960 May 22 Southern Chile

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



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

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.

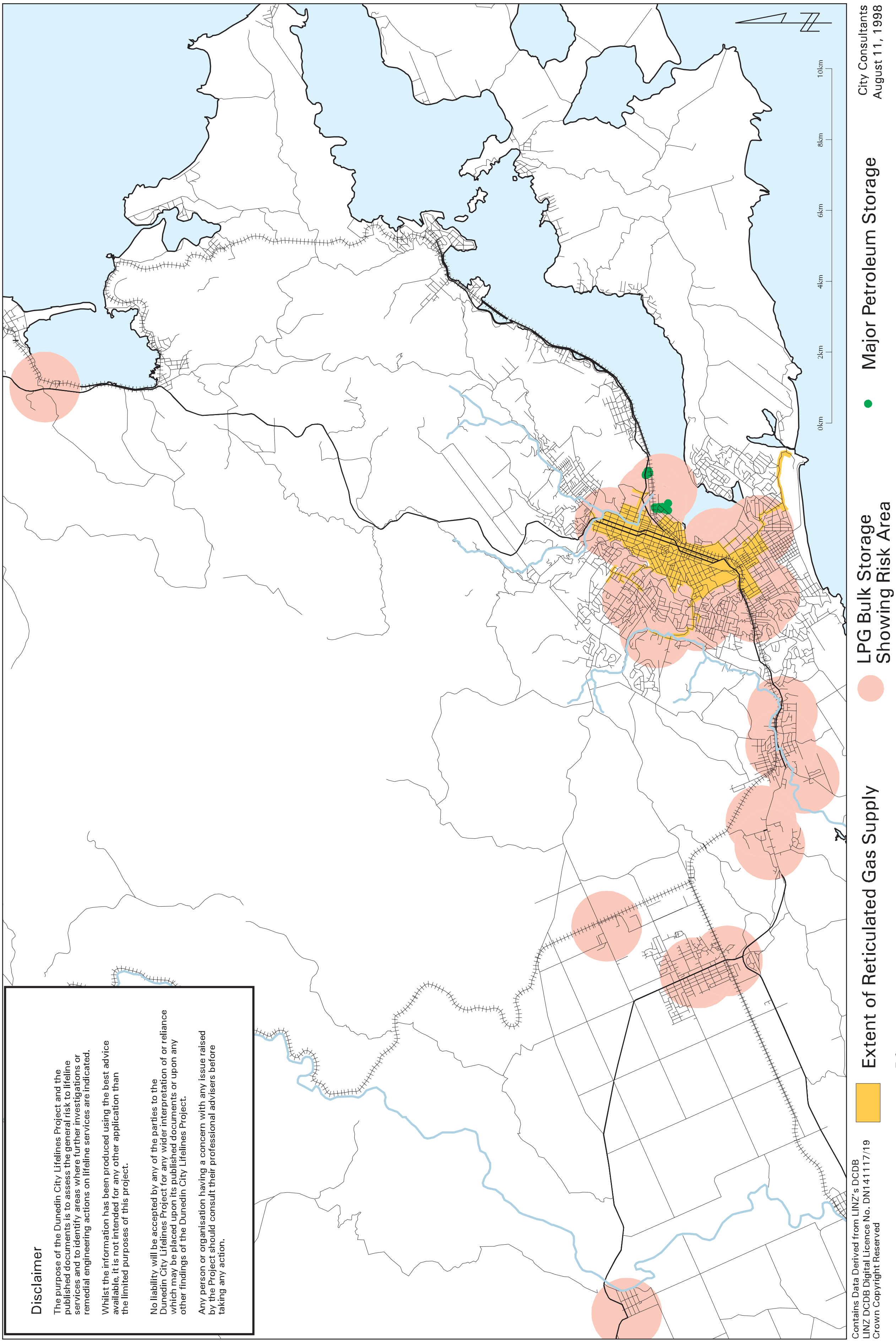
Structural Failure

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



CHAPTER 4. CIVIL SUPPLY SERVICES - CONTENTS

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.

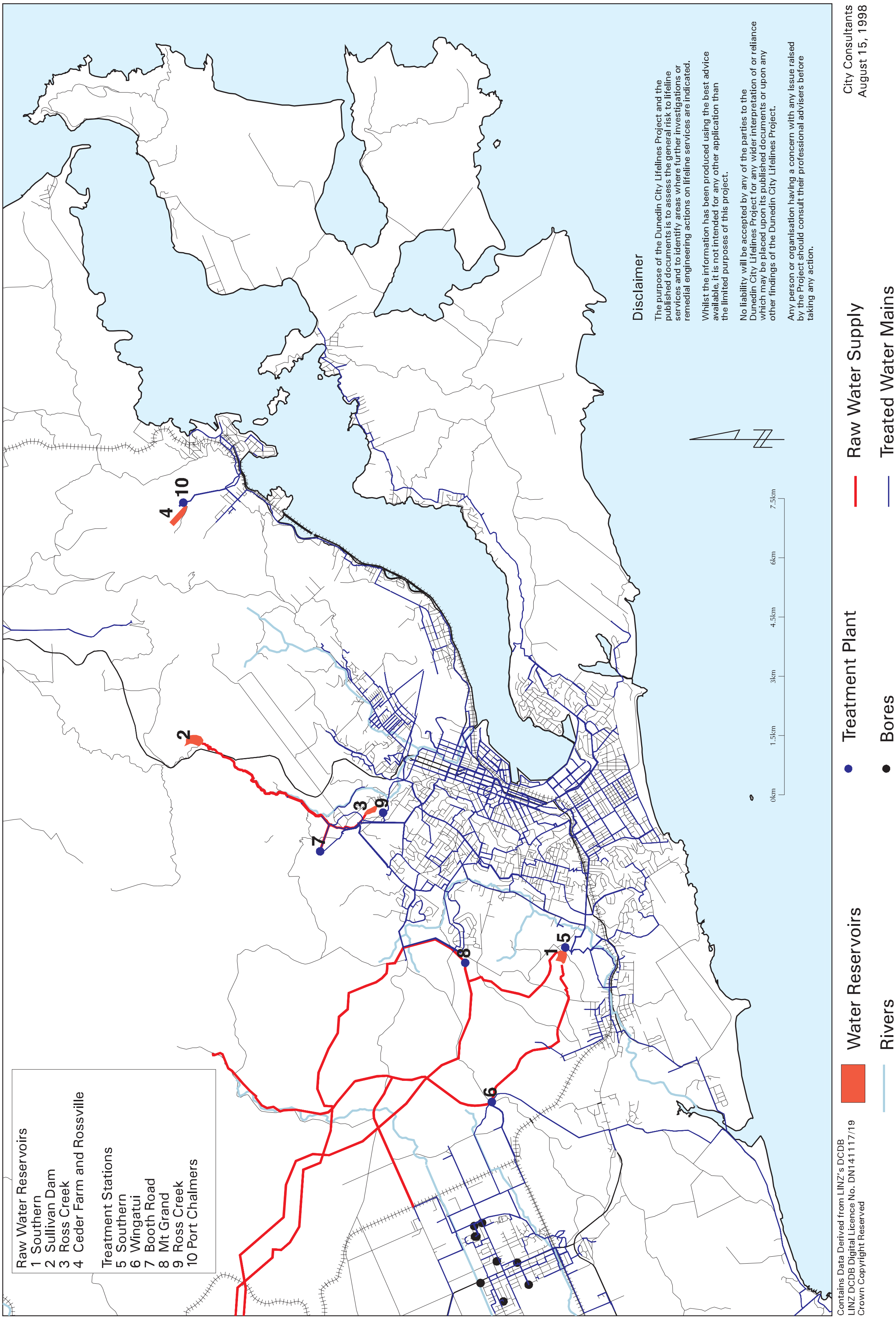
The main store holds a stock of fittings for the repair of most sizes of mains, although only sufficient to meet ordinary operations and maintenance requirements. There would not be sufficient fittings to repair the expected number of broken mains and service dislocations resulting from a large earthquake.

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.

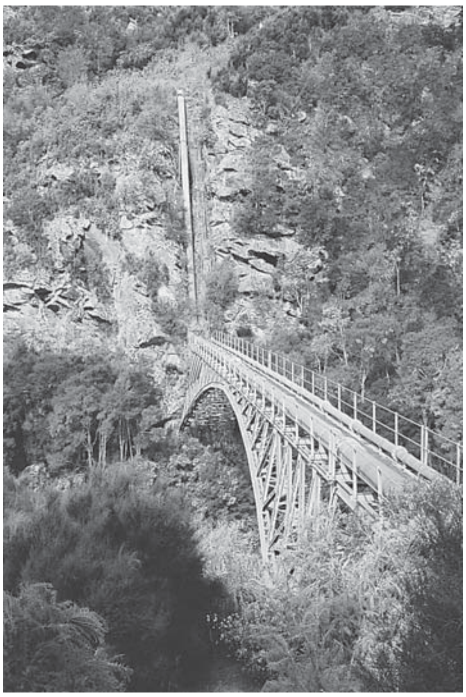
Apart from the first 1,400 metres, which was renewed recently, the pipeline itself is particularly fragile due to corrosion with leakage at joints being the most common current mode of failure.

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.

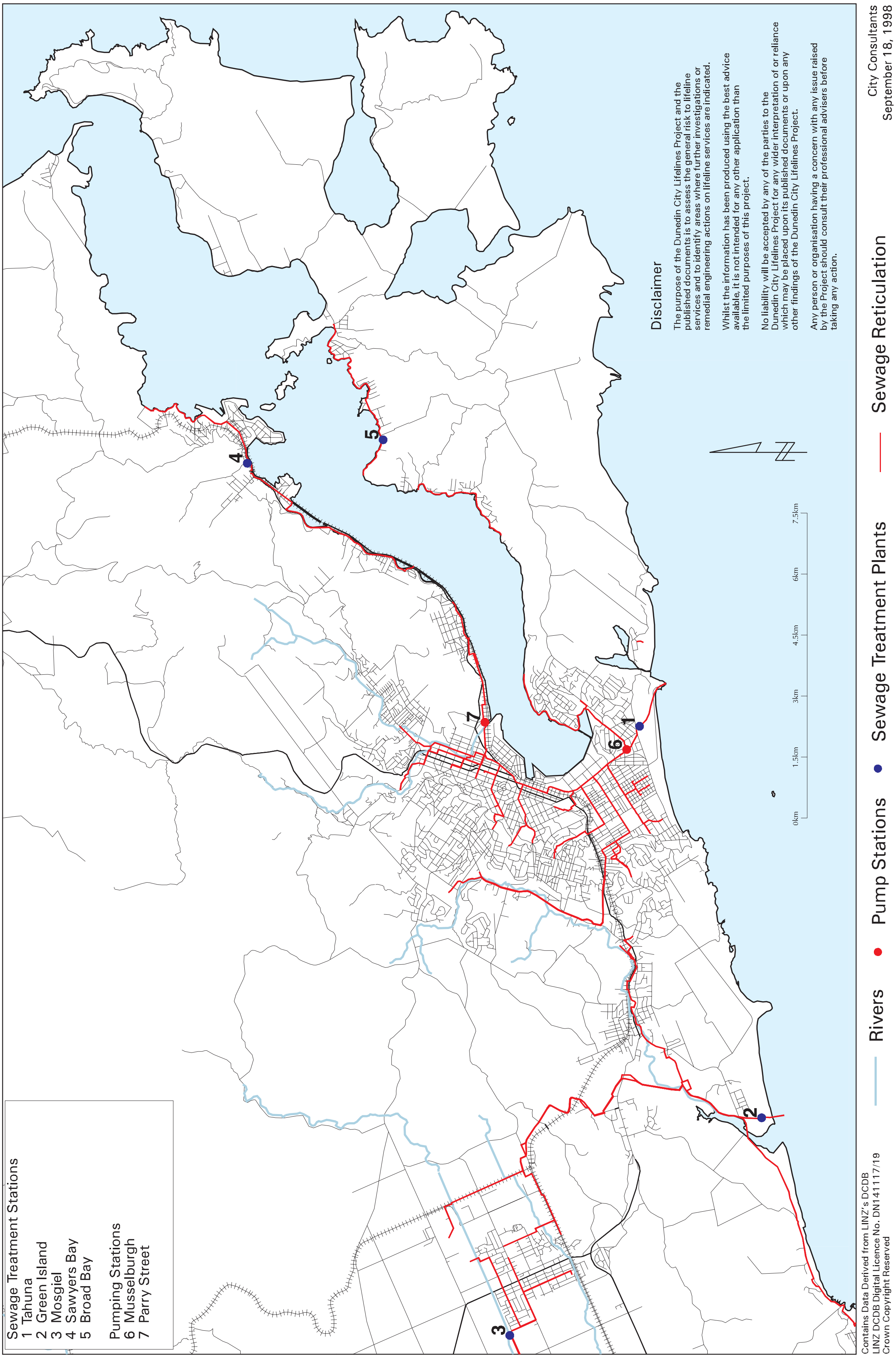
Harbour Valves
A valve at the intersection of St Andrew Street / Anzac Avenue allows the combined sewer flows to enter the main intercepting sewer. In emergencies, the flows in the combined sewers can be diverted to the Otago Harbour.

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



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

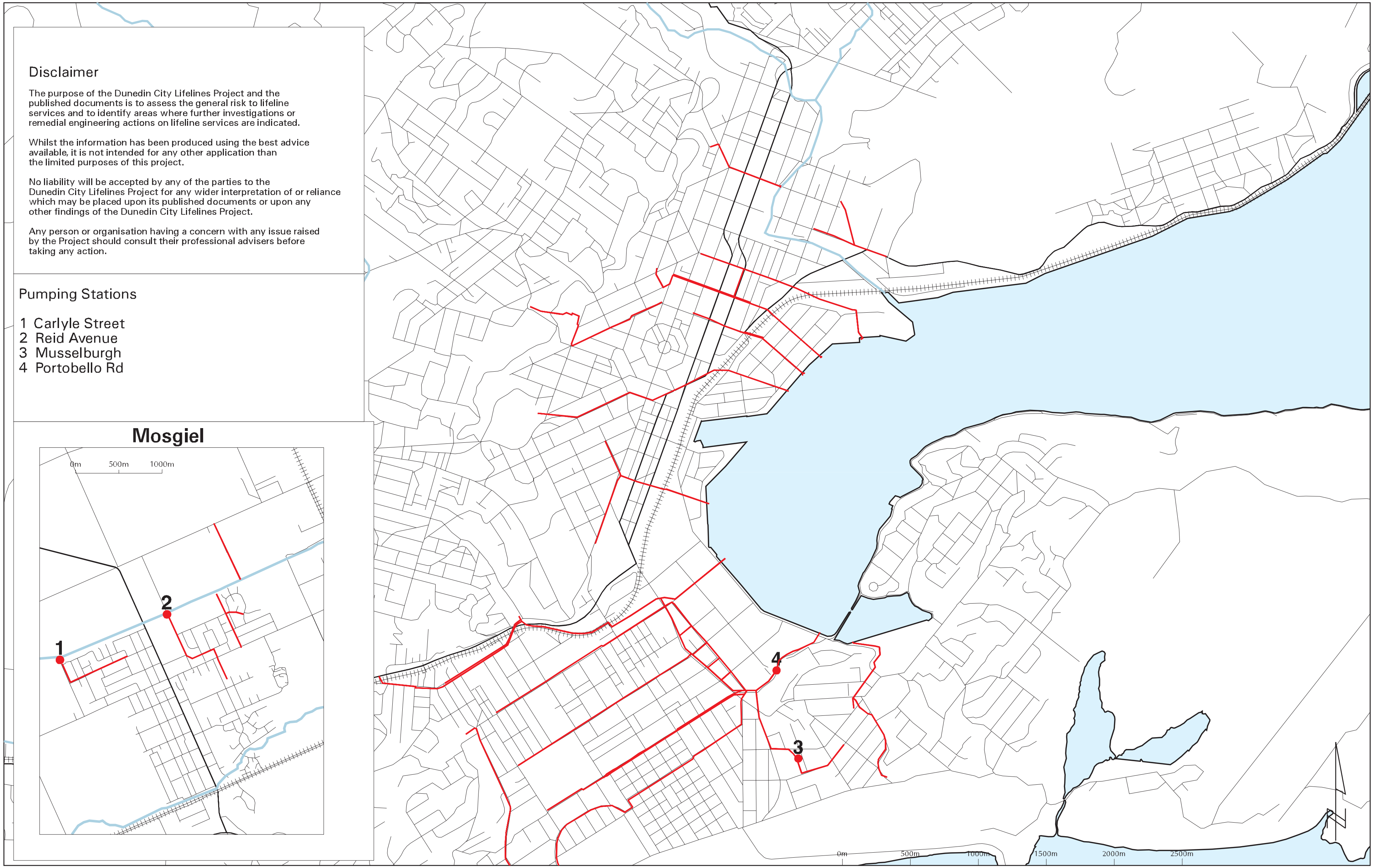
Carlyle Road
This station has a capacity of approx 3.0 cubic metres per second and is adjacent to the Mosgiel Waste Water Treatment Plant. No standby power is provided.

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

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.

CHAPTER 5. ENERGY - CONTENTS

ELECTRICITY - DESCRIPTION OF SERVICE

Waipori Power - Generation System

General Description
The Waipori system is a hydro-electric power generating complex located in the Waipori River Valley approximately 55km by road, southwest from Dunedin. Access to the locality is possible by four routes:
- From Berwick directly up the Waipori Gorge Road within the Waipori River Valley.
- From Berwick up Shaws Hill Road on the true right flank above the Waipori Gorge.
- From Lawrence via the Lawrence - Waipori Road to Waipori Falls Road.
- From Outram via State Highway 87 to Traquair or Lee Stream and then via Mahinerangi Road across the Edgar Stark Bridge and causeway to Waipori Falls Road.

The main elements of the scheme with Mahinerangi Dam at the upstream end and No. 4 power station at the downstream end, comprise:
- Mahinerangi Dam which impounds Lake Mahinerangi, the main storage reservoir for the scheme.
- No. 1A Power Station and associated intake and supply tunnel.
- No. 2 Dam and lake.
- No. 2A Power Station and associated supply tunnels and penstocks.
- No. 3 Dam and headpond.
- No. 3 Power Station and associated supply tunnel and penstock.
- No. 4 Dam and lake.
- No. 4 Power Station and associated supply tunnel and penstock.

The scheme utilises the water flow from the Waipori River catchment and the elevation difference of approximately 360m between Lake Mahinerangi and the tailwater (outlet) at No. 4 Power Station. Flow rates through the system vary up to a maximum of about 39cubic metres per second. The maximum combined generation output of all four power stations is about 80MW. Flood flows in excess of maximum generation flows are able to be by-passed via spilling facilities at the dams, down the natural river channel and downstream storage lakes.

The system is controlled from 2A Power Station. Recent technological changes have been made which now allow the system to be operated automatically on a pre-programmed basis or remotely through a Telecom communication link.

Dams

Mahinerangi Dam
Mahinerangi Dam is a concrete structure consisting of gravity abutments with a central circular gravity arch section between them, giving the dam a total crest length of approximately 166 metres and a maximum height from base to crest of about 38 metres. The dam was constructed in two stages commencing in 1929 and completed in 1946.

The volume of water impounded in Lake Mahinerangi at maximum operating level is approximately 216 million cubic metres. Flood flows are able to be passed from Lake Mahinerangi to downstream of the dam using:
- Spillway floodgate in left abutment of dam (maximum practicable discharge approximately 120 cubic metres per second).
- High level sluice outlet in left abutment of dam (maximum practicable discharge approximately 15 cubic metres per second).
- No. 1A station supply system and by-pass (maximum practicable discharge approximately 40 cubic metres per second).

In extreme flood conditions the dam could be overtopped without risk of structural failure. A 'low level' outlet at the base of the central arch section is currently not operational.

The dam is inspected annually in accordance with SEED (Safety Evaluation of Existing Dams) procedures which includes survey monitoring of:
- Crest movements
- Structural inspection of the condition of the concrete, joints and foundations
- Operational inspection of control gates and sluices
- Frequent monitoring of seepage.

To date these inspections have revealed no major defects which might cause concern about its condition or safety.

Although the dam was designed in the 1920's the structure was re-evaluated in 1995 using modern computer analysis techniques and applying current design criteria. The results of the analysis have indicated that risk of failure by sliding or overturning is low and that stresses due to applied loads including earthquake effects are also low and within acceptable limits.

No. 2 Dam
No. 2 Dam is a concrete gravity arch dam located approximately 1km downstream from Mahinerangi Dam and has a crest length of 55m with a maximum height of 20m from base to crest. The volume of water impounded in No. 2 lake at maximum operating level is approximately 320,000m3.

Flood flows are able to pass freely over the full crest length of the dam and down the original river bed. Up to 40cubic metres per second may be discharged through the 2A supply tunnels and power station. There are five manually operated sluice outlets through the base of the dam which are only used for draining the lake.

No. 2 Dam like Mahinerangi Dam is also subjected to annual SEED inspections and the results of these inspections together with the information gained from modifications, grouting and concrete repairs have indicated that the dam is structurally sound and functioning normally. Structural analysis of the dam carried out in 1992 indicated that stress levels for both normal and abnormal loading conditions are well within acceptable limits.

No. 3 Dam
No. 3 Dam is a small concrete gravity dam located approximately 220m downstream from No. 2A Power Station has a crest length of 24m and a maximum height of 10m. The volume of water impounded in No. 3 headpond at maximum operating level is approximately 20,000m3.

Flood flows are able to be passed using:

- Spillway floodgate which is capable of passing approximately 150cubic metres per second when fully open and without the dam being overtopped.
- Low level sluice which is capable of passing approximately 20cubic metres per second.
- No. 3 supply tunnel and power station, maximum flow approximately 20cubic metres per second.

The dam, constructed in 1953, is founded partly on schist bedrock and partly on the toe material of an existing debris slide. In 1985 the upper half of the right abutment block was anchor stressed to the bedrock below the dam following dislocation caused by the pressure of the debris slide thrusting against the abutment. In 1986 the rest of the dam was anchor stressed to the underlying bedrock to improve the overall sliding stability of the structure. The anchor stressing has been successful in reducing the rate of dislocation in the right abutment block from about 2mm/year to 0.45mm/year.

The dam is routinely inspected and carefully monitored for movement. Further remedial measures may need to be taken if the movement affects the operation of the dam or the risk of failure increases.

No. 4 Dam
No. 4 Dam, a concrete arch dam located approximately 5km downstream from 2A power station is the last or most downstream dam in the Waipori System. It has a crest length of 76.5m and a maximum height of 17m which impounds approximately 376,000m3 of water.

It incorporates a flood control gate and spillway capable of passing approximately 150cubic metres per second without overtopping the dam. The dam has a low level sluice outlet capable of passing approximately 20cubic metres per second and the supply system and power station are also capable of passing up to 20cubic metres per second.
No. 4 Dam is subjected to annual SEED inspections and to date the results from these have indicated that the dam is structurally sound and functioning normally. A computer analysis of the dam, carried out in 1991, has indicated that stress levels for both normal and abnormal loading conditions are well within acceptable limits.

Relevant File References

Further information and background information on the Waipori dams is held on the following Duffill Watts & King Ltd files:

- Mahinerangi Dam
  - 14/69/18 SEED Inspection Reports and Movement Monitoring Results
  - 14/69/26 Mahinerangi Dam Finite Element Analysis
  - 14/69/2 Lake Retention Levels and Spillway Test
  - 14/78/1 Lake Retention Levels (1979)
  - 14/78/3 Lake Mahinerangi Management Procedure
  - 14/111 Dam Inventory Data
- No. 2 Dam
  - 14/68/1 General Information
  - 14/68/10 Survey Monitoring of Movements
  - 14/68/11 SEED Inspection Reports
  - 14/68/13 No. 2 Dam Finite Element Analysis
- No. 3 Dam
  - 14/74/1/3 Survey Monitoring of Movements
  - 14/74/1/5 Design and Construction of Anchor Stressing 1985/86
- No. 4 Dam
  - 14/74/13 SEED Inspection Reports and Movement Monitoring Results
  - 14/74/17 Finite Element Analysis No. 4 Dam

Intakes/ Supply Tunnels/ Penstocks

1A Station Supply System

The supply system consists of:

- A reinforced concrete intake tower in Lake Mahinerangi.
- A concrete lined horseshoe shaped tunnel linking the intake tower to the turbine at 1A Power Station and also to the by-pass alongside the station.
- Control valves and gates to regulate the water flow from the lake and through the turbine or by-pass.
- A gate in the intake structure, capable of closing under full flow conditions.

The system can pass operational flows up to 37 cubic metres per second and a maximum flow of 42 cubic metres per second at a nominal net head of 27m. The turbine output is approximately 8.9MW under a net head of 27m at a flow of 37 cubic metres per second.

2A Station Supply System

The supply system consists of:

- Two intakes; No.1 intake through No.2 Dam and No.2 intake just upstream of the right hand abutment of No.2 Dam.
- Two parallel near horizontal concrete lined tunnels from the intakes to the base of the surge tank where they join to become the pressure tunnel.
- A single 1.98m diameter steel and concrete lined pressure tunnel from the surge tank to the base of the hillside behind 2A Station.
- Steel penstocks from the downstream end of the pressure tunnel to each of the three turbines in 2A Station.
- A surge tank at the upper end of the pressure tunnel to reduce pressure surges resulting from changes in flow velocities within the system.

The system can pass operational flows up to 36.8cubic metres per second under a net head at the turbine inlet valves of approximately 178m. The recorded total generation output from 2A Station under maximum operational flow conditions is 57.5MW.

The intake to the No.2 tunnel is fitted with three rectangular cast iron gates and the No.1 tunnel is fitted with a cast iron butterfly valve at its upstream end. The intake gates and butterfly valve are not used to control flows through the system but are primarily used to exclude water from entering the tunnels from No.2 lake during maintenance or inspection work.

Penstock System Waipori 2A Station - Waipori Power Generator Ltd

No.3 Station Supply System
The supply system consists of the following main elements:

- A concrete intake structure set into rock on the left bank of the Waipori River approximately 40m upstream of No.3 Dam. The intake is fan shaped in plan with three 1.83m x 1.22m cast iron gates set at 15° to each other which perform a stoplog function to exclude water entering the tunnel from the adjoining No.3 headpond.
- A 2.4m wide by 2.5m high concrete lined tunnel with semi circular roof, is 1,220m long from the intake to a differential surge chamber at its lower end.
- A 2.28m diameter steel penstock approximately 102m in length from the surge chamber to the No.3 power station.
- A reinforced concrete differential surge chamber with a main tank diameter of 10.67m and height of 13.72m above the tunnel-penstock connection.

The static head at No.3 power station is 50.29m and the current maximum output is 7.6MW at a flow rate of 18.9cubic metres per second.

No.4 Station Supply System
This system is similar to the No.3 Station system except that it operates under a higher head (57.3m) and that it has a steel conduit (penstock) section between the intake and the upstream end of the tunnel.

Specific details of the No.4 supply system are:

- A concrete intake structure incorporated on the upstream side of the right abutment of the No.4 Dam which is of similar size and form to the No.3 intake.
- A steel conduit, 2.28m diameter and approximately 39.6m long, linking the intake to the upstream end of the tunnel.
- A concrete lined tunnel of the same cross section as the No.3 system tunnel and an overall length of approximately 1,100m.
- A 2.28m diameter steel penstock approximately 102m long from the surge chamber to the No.4 Station.
- A differential surge chamber, of similar form and dimensions to the No.3 surge chamber, located above the tunnel-pressure conduit connection.

The current maximum output of No.4 Station is 8.2MW at a flow rate of 17.6cubic metres per second.

Power Stations
A summary of essential structural details of the four power stations in the Waipori complex is:

	1A Station	**2A Station**	**3 Station / 4 Station**
Completion of construction	1983	1968	1954
Construction materials: -substructure -superstructure	Reinf. concrete Struct. steel/ Precast concrete	Reinf. concrete Reinf. concrete/ Struct. steel	Reinf. concrete Reinf. concrete
Roof Cladding	Galv. steel sheeting	Precast concrete/ Galv. steel sheeting/Butyl rubber	Reinf. concrete Asphaltic membrane
Design Loading	NZS4203:1976	NZSA 1900 Chapt/8:1965	NZS 95 Parts I to IV Clauses 412 and 413 (b)
Overhead cranes (Machine Hall)			
SWL (tonnes)	55.5	52	40
By-pass facility	Tunnel and penstock 2.5m i.d x 59m long	Rect. reinf. concrete channel 5.5m wide x 3.9m high x 247m long	Natural river channel

Mechanical/Electrical Plant
The 1A station is equipped with a single vertical Kaplan turbine-alternator set of nominal 10,000 kW capacity. Under normal operation an external electricity supply is used to start the turbine alternator and run it up to speed. In emergency conditions a large capacity DC battery supply within the station is available to perform a “black start” or “cold start” which can only be done from within the station as it is a fully manual operation.

The hydraulic by-pass system, adjacent to the powerhouse is also able to be operated from the emergency DC power source to provide water downstream for the other power stations, should the generator be unserviceable.

The 2A station is equipped with three virtually identical vertical Francis turbine-alternator sets of nominal 20,000 kw capacity. Like 1A station, the machines require an external source of power for initial starting, following which they change over to their own internal power source. Only under very specific circumstances, not often prevailing, can a “black start” be performed on any of these machines.

No.3 and 4 stations are identical, each having a single vertical Francis turbine-alternator set of nominal 8,000 kW capacity. They both need an external power supply for initial starting before changing over to their internally generated power supply and neither can be “black started”.

Station Switchyard
Each of the four stations has an adjacent outdoor switchyard in which is installed the machine transformers and transmission line circuit breakers. Each major item of equipment is fitted with seismic restraints. The construction is unpiled reinforced concrete of a conventional type. Each plant item containing mineral insulating oil is surrounded by an oil retaining bund wall arrangement.

1A station switchyard operates at 33,000 volts, 2A at a combination of 33,000 and 110,000 volts, and both 3 and 4 stations are 110,000 volts.

Station Control Systems
Each machine is fully automatic to the extent that it will respond to a primitive start command; the machine starting, synchronising and waiting for loading commands. Likewise, the machines will respond to a simple stop command following which they will unload, de-synchronize and shut down, eventually coming to rest. These commands can be issued locally at each station or from the centralised control room at 2A station. Furthermore each machine is able to be manually loaded from the control room at 2A or locally in the stations. Interfacing each machine control system is an automatic programme feature, which can accept time/load profiles to start the machine, bring it to a set load figure for each half hour of the day, and shut the machine down. The operative loading profile is modified automatically by the hydraulic supply conditions to the turbine when water levels fall outside preset limits. The automatic programmes are resident at each station and will repeat on a daily basis until modified from a central processor at 2A station or from a remote access terminal at any point in the Telecom network. Each machine is also protected by monitoring systems that will alarm when a dangerous state is approached, and shut the machine down when a dangerous state is reached.

Generation Transmission
Two separate transmission systems are available for export of Waipori generation. No 1A station and up to two machines in 2A station can be connected to the 33,000 volts transmission system of the Dunedin Electricity network while up to two machines together with 3 and 4 stations export into the 110kV national grid at Berwick. For further detail see the Section on High Voltage Transmission.

Transpower (New Zealand) Limited - High Voltage Transmission

General Description
The electrical transmission system comprises a regional supply from the national grid to a local distribution network. The regional supply network is owned by Transpower New Zealand and the distribution networks owned and operated by Dunedin Electricity Limited and Otago Power Limited.

Dunedin Electricity's Dunedin network is supplied with electricity from two Transpower substations, one at Halfway Bush and the other at South Dunedin. Waipori Power Generation Limited also feeds some power into Transpower's network at Berwick Substation and Dunedin Electricity's distribution network from the Waipori 80MW power stations.

Otago Power's rural network is supplied from Transpower substations at Naseby, Balclutha and Palmerston. Otago Power Limited also has a 10MW power station at Paerau which can back feed into the Transpower network.

Transmission Lines
Dunedin and the eastern part of Otago are supplied with electricity from the national electricity grid via a number of transmission lines:

• Roxburgh - Three Mile Hill (A)	220kV Double circuit on single towers.
• Three Mile Hill - Halfway Bush	220kV Double circuit on single towers.
• Roxburgh - Halfway Bush (A)	110kV Double circuit on single towers.
• North Makarewa - Three Mile Hill (A)	220kV Double circuit on single towers.
• Gore-Halfway Bush (A)	110kV (Passes through Berwick) Single circuit on poles.
• Three Mile Hill - South Dunedin • Halfway Bush - South Dunedin }	220kV (Separate circuits on same set of 220kV poles/towers)
• Halfway Bush - Palmerston	110kV Two single circuits on single poles with a double circuit on single towers near Dunedin

The majority of the lines pass over hilly and sometimes rugged terrain as well as flatter plain areas.

There is inherently some redundancy built into the network, should a line go out of service. For example, the loss of Roxburgh - Three Mile Hill would still allow reduced capacity via the remaining Roxburgh - Halfway Bush, North Makarewa - Three Mile Hill, Gore - Halfway Bush lines.

The greatest disruption would occur from loss of the Three Mile Hill - South Dunedin/Halfway Bush - South Dunedin line with both circuits being on the same set of steel poles and towers. Some limited backfeeding could be achieved by Dunedin Electricity. Loss of both circuits between Halfway Bush and Palmerston would result in a complete outage at Palmerston.

Substations
There are four Transpower substations in Dunedin City:
- Halfway Bush
- South Dunedin
- Three Mile Hill
- Berwick

Halfway Bush Substation, Three Mile Hill Switchyard and South Dunedin are all equally important in the supply of electricity to Dunedin. Three Mile Hill and Berwick substations are only switchyards and are therefore unable to reduce the line voltages to the lower voltages supplied to Dunedin Electricity and Otago Power.

The loss of individual substations would effect the network to varying degrees, for example:
- Complete loss of Halfway Bush: There would be a reduced supply to South Dunedin via the single circuit Three Mile Hill - South Dunedin line. The supply to Palmerston would be completely disrupted.
- Complete loss of South Dunedin: Dunedin Electricity Limited could supply 70% of Dunedin via the Halfway Bush Substation.
- Complete loss of Three Mile Hill: Halfway Bush and South Dunedin could be supplied at a reduced capacity via the Gore - Halfway Bush line, Roxburgh - Halfway Bush lines and the Halfway Bush - South Dunedin line.
- Complete loss of Berwick: Reduced capacity with Gore - Halfway Bush line out and disrupted supply from Waipori.

Control System
Halfway Bush Substation is the focal point for the control of Transpower's network in the Otago area and is manned 24 hours a day, 7 days a week. Overall control of the South Island portion of the national grid is carried out at Transpower's South Island Control Centre, at Islington, Christchurch.

Transpower is able to use three independent means of communication to control its network:
- Power Line Carrier
- Telecom telephone network
- Two-way radios/digital microwave radio

The power line carrier system enables the high voltage transmission lines themselves to transmit voice and electronic communication. The two-way radio is an independent Transpower system utilising Transpower's own communication towers, microwave dishes and repeater stations. It is extremely unlikely that all three systems would fail simultaneously and any one of the systems would be sufficient to control and operate the Transpower network.

Dunedin Electricity Limited - Distribution

General Description
The Dunedin Electricity Ltd distribution network delivers approximately 900GWh annually to 50,000 consumers over a 1,100sqkm area. Of this amount, 90GWh are supplied from the 33kV connection to the Waipori Power Generation Ltd complex and the remaining energy is supplied from Transpower's Halfway Bush Substation (500GWh) and South Dunedin Substation(310GWh).

The Dunedin Electricity network comprises a total of some 1,900km of lines and cables of various voltages (33kV, 11kV, 6.6kV and 400V), 18 zone substations (33kV/11kV and 33kV/6.6kV) and 2,240 distribution substations (11kV/400V and 6.6kV/400V).

Transmission Lines

From South Dunedin
Five Dunedin Electricity zone substations are supplied from the Transpower South Dunedin substation via parallel 33,000 volt cable-transformer units. Thus a fault in a single 33,000 volt cable or zone substation transformer will leave the remaining cable-transformer unit able to cope with its design load. The five zone substations and their approximate areas of supply are as follows:

- North City
  - Cumberland Street
  - Connected via 33kV underground cable
  - 2,100 consumers
  - Part central business district, part North Dunedin
- South City
  - Crawford Street
  - Connected via 33kV underground cable
  - 2,700 consumers
  - Part central business district, south city area to Oval, Wharf Street area
- St Kilda
  - Corner Bayview Road/Prince Albert Road
  - Connected via 33kV underground cable
  - 4,200 consumers
  - St Kilda, Tainui, Portsmouth Drive areas
- Corstorphine
  - Corner Stephensons Road/Corstorphine Road
  - Connected via 33kV underground cable
  - 3,500 consumers
  - Corstorphine, St Clair, Concord
- Andersons Bay
  - Corner Somerville Street/Cranston Street
  - Connected via 33kV underground cable
  - 4,300 consumers
  - Andersons Bay, Waverley, Tomahawk, Highcliff, Macandrew Bay

From Halfway Bush
Nine Dunedin Electricity zone substations are supplied from the Transpower Halfway Bush substation in Wakari Road via parallel 33kV cable/line - transformer units. Thus a fault in a single cable/line or transformer will leave the remaining cable/line - transformer unit able to cope with its design load.

The nine zone substations are:

- Smith Street
  - Smith Street
  - Connected via 33kV underground cable
  - 3,800 consumers
  - Part central business district, Roslyn
- Willowbank
  - Great King Street
  - Connected via 33kV underground cable
  - 2,500 consumers
  - Part North Dunedin, Maori Hill, Gardens area
- Ward Street
  - Ward Street
  - Connected via 33kV underground cable
  - 1,500 consumers
  - Fryatt Street area, Ravensbourne, Logan Park area
- Neville Street
  - Behind Carisbrook
  - Connected via 33kV underground cable
  - 4,000 consumers
  - Part South Dunedin, Caversham, Mornington area
- Halfway Bush
  - Taieri Road
  - Connected via 33kV underground cable
  - 3,700 consumers
  - Halfway Bush, Wakari, Helensburgh
- Kaikorai Valley
  - Stone Street
  - Connected via 33kV underground cable
  - 2,700 consumers
  - Part Mornington, Kaikorai Valley, Brockville

- Green Island - Boomer Street
  - Connected via 33kV overhead lines
  - 3,200 consumers
  - Burnside, Green Island, Fairfield, Waldronville
- North East Valley - North Road near Watts Road
  - Connected via 33kV overhead lines and underground cable
  - 3,000 consumers
  - Pine Hill, North East Valley and part Opoho
- Port Chalmers - Church Street
  - Connected via 33kV overhead lines
  - 2,300 consumers
  - Port Chalmers from St Leonards to Aramoana, Peninsula from Broad Bay to Taiaroa Head

From Halfway Bush-Waipori Overhead Lines
A further four zone substations are teed off the three Dunedin Electricity 33,000 volt overhead lines which run between the Transpower Halfway Bush Substation and Waipori 2A Station. At the corner of Tirohanga Road and Gordon Road, three lateral 33,000 volt overhead lines connect the Waipori-Halfway Bush lines to the Mosgiel zone substation on Gordon Road near the Silverstream.

These substations are:

- Mosgiel - Gordon Road
  - Connected via 33kV overhead lines to HWB-Waipori lines
  - 2,200 consumers
  - West Mosgiel, North West Taieri
- East Taieri - Quarry Road
  - Connected via 33kV under ground cable to Mosgiel substation
  - 3,900 consumers
  - East Mosgiel, Brighton to Taieri Mouth
- Outram - Huntly Road
  - Connected to HWB-Waipori 33kV overhead lines
  - 800 consumers
  - Outram, Allanton, part Taieri area.
- Berwick - Outram-Berwick Road
  - Connected to HWB-Waipori 33kV overhead lines
  - 600 consumers
  - Berwick, Henley, part Taieri area

At Berwick, the three 33,000 volt lines continue to Waipori 2A station. These three lines normally operate in parallel and have a firm load capability of 34MW, which equates to approximately the maximum peak load of the four zone substations teed off these lines.

Distribution Lines (11kV and 6.6kV)
At each zone substation, approximately 12 HV (High Voltage) distribution circuits radiate to supply distribution substations. In the urban areas, these circuits intertie with each other so that a normally open meshed network is available to provide limited backup to faulted sections of the HV distribution network. For those HV distribution lines that supply rural loads, there are fewer interties and in some cases extensive lengths of spur lines with no backup may exist.

Supply of Essential Loads

- Dunedin Hospital - supplied via two parallel 6.6kV feeders from North City zone substation
- Wakari Hospital - supplied from consumer substation via a 6.6kV feeder from Halfway Bush zone substation.
- DCC Civic Centre - supplied from a consumer substation located in DCC Library via a 6.6kV feeder from Smith Street substation
- Civil Defence HQ - supplied from a distribution substation in Moray Place via a 6.6kV feeder from Smith Street substation
- Port Otago - supplied via a 11Kv feeder from Port Chalmers zone substation
- Dunedin Airport - supplied via a 11kV feeder from Outram zone substation

More detail on essential loads is given in the section on vulnerability.

System Control
The Dunedin Electricity Limited system control is located on the corner of Jutland and Halsey Streets, Dunedin. The control room is staffed during normal working hours. During the remaining hours, a telephone answering service attends to consumer calls and the SCADA (System Control and Data Acquisition) automatically initiates call-outs directly to the System Controller.

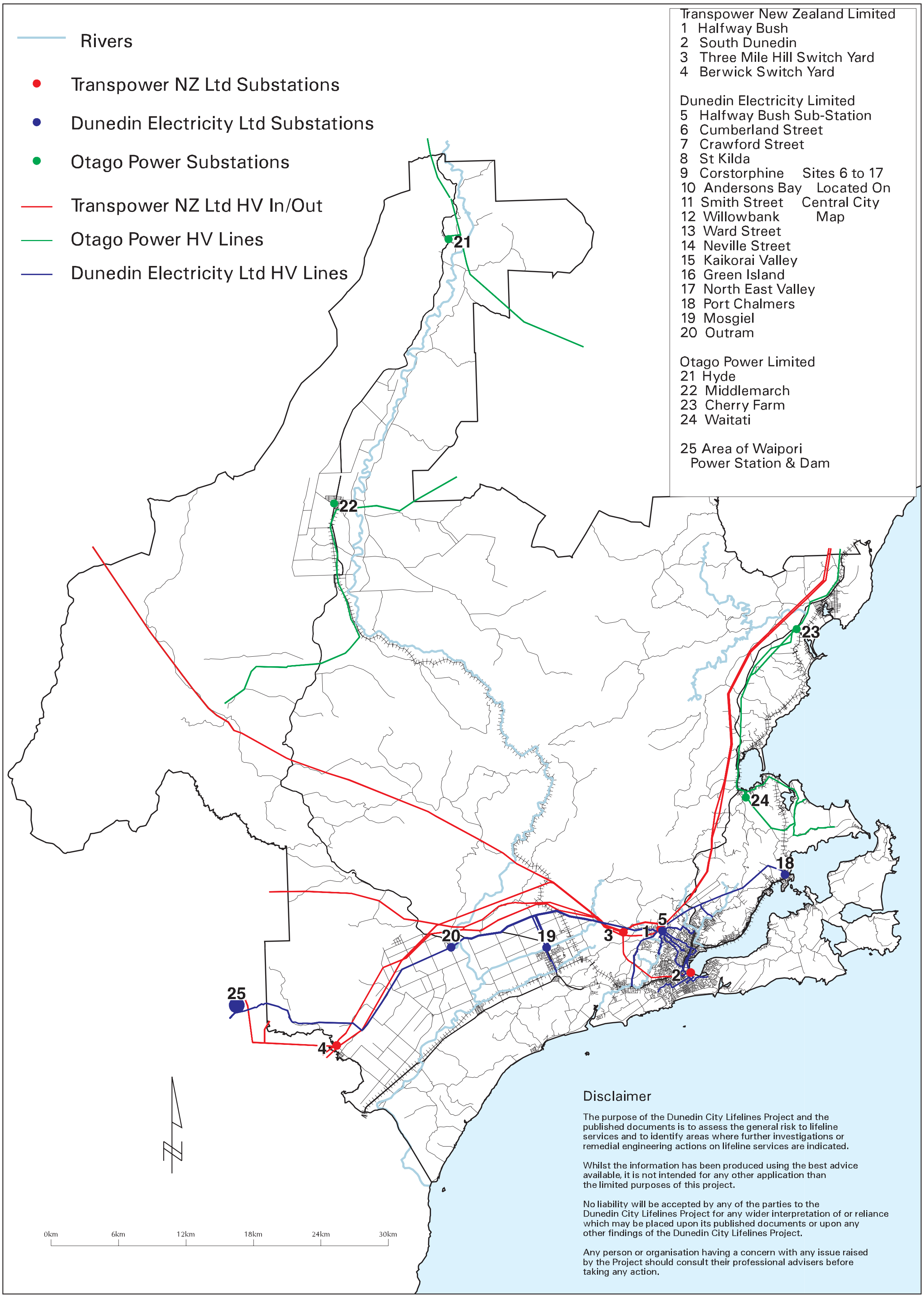
The functions of the control centre include:
- Co-ordination and planning of switching operations to allow maintenance contractors access to clearly defined parts of the electricity network under defined conditions for both planned and unplanned work.
- Co-ordination of fault response by contractors and handling consumer fault calls out of hours.
- Monitoring of system loads and operation of load management equipment.
- Attending to all alarms generated by the SCADA system.

Equipment installed within the control room to aid the controllers in their duties includes:
- A SCADA system which allows remote control of the 200 33kV/11kV/6.6kV circuit breakers and 36 tapchangers located at the 18 zone substations, plus approximately 1,500 indications, 1,000 alarm points and 300 analogue displays.
- Load management system (ripple control).
- VHF communications using "A" band to Telecom transmitter sites at Signal Hill, Swampy Summit and Saddle Hill for voice communication with contractor's vehicles.
- Plans of all network distribution circuits - both in paper and digital format.
- Office equipment such as facsimile, copier machines, etc.

A small diesel generator located on site produces a 230 volt supply for essential items within the control room.

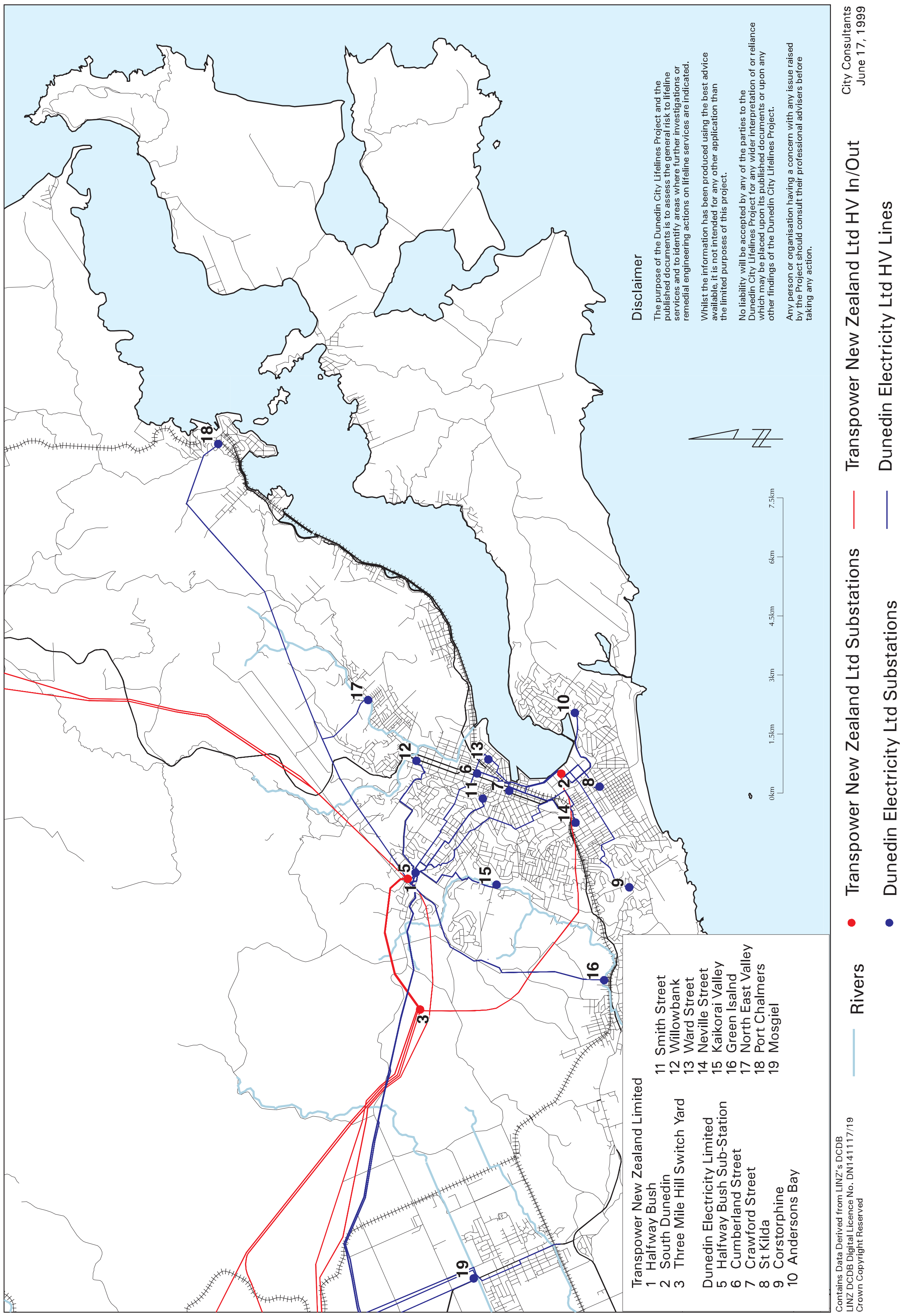
Typical Pole Mounted Transformer - Civil Defence

Electricity Supply (Rural Area)



City Consultants
June 17, 1999

Electricity Supply (Urban Area)



Otago Power Limited - Distribution

General Description
Otago Power has no major point of supply substations in Dunedin City. The northern coastal area, mainly encompassing Waikouaiti and Waitati, is supplied via two 110kV lines from Halfway Bush in Dunedin to Palmerston substation. These lines and substations are owned and operated by Transpower.

Otago Power takes supply at 33kV from Transpower Palmerston, and supplies Waikouaiti and Waitati, plus outlying regions, via a single 33kV line generally following a route close to State Highway 1. Otago Power substations are located at Cherry Farm (at the Karitane turnoff) and Waitati (corner of Killarney and Foyle Streets). These substations supply Waikouaiti and Waitati respectively via local 11kV lines.

The township of Middlemarch is supplied via a 33kV line from Ranfurly. There are only two sections where the line crosses into Dunedin City, these being a 14km stretch near Hyde and the final 10km into Middlemarch itself. Substations are located at Middlemarch and Hyde to supply the townships and surrounding districts via local 11kV lines.

Loss of these facilities could affect the supply to up to 2,000 homes.

Other susceptible elements of the network are:

- The 11kV line from Cherry Farm substation into Waikouaiti township.
- The 11kV line from Waitati substation feeding to Doctors Point, Purakanui, Long Beach and Heyward Point.
- The 11kV lines between Cherry Farm and Waitati substations, via Karitane, Seacliff and Warrington.

Other than these, Otago Power services supply only small localised areas.

ELECTRICITY - ASSESSMENT OF VULNERABILITY

Waipori Power - Generation System

Civil Components

Earthquake
Generally all major structures (dams, tunnels, and power stations) are founded or constructed on or within solid schist. The scheme is located approximately 25km north-west from the Akatore fault, the closest known active fault. Other faults have been identified closer to the scheme (principally McNamara's fault) but these are considered to be less active.

The vulnerability of the various structures has been assessed on whether they are free standing and above ground or whether they are contained within the ground itself. On this basis the dams, power stations, penstocks and surge tanks are regarded as prone to ground shaking without enhancement because of the presence of the rock foundation. The supply tunnels on the other hand are generally located within rock and are unlikely to be affected significantly by any ground shaking. Furthermore none of the tunnels are intersected by any known active faults and hence are unlikely to be damaged by dislocation. Liquefaction is unlikely to be of any concern because the required conditions for this phenomenon are not present at Waipori.

Flooding
Risks due to uncontrolled flooding from the Waipori catchment are significantly reduced by the implementation of the current lake management procedures for Lake Mahinerangi. Flood peaks can normally be absorbed within the operating regime of the lake without the need to spill excess water. The greatest vulnerability to flooding arises from uncontrolled inflows from side catchments below Mahinerangi Dam and No. 2 Dam. Such inflows can normally be catered for by generation control and in extreme events by floodgate control on the dams. In the unlikely event that floodgates are inoperable during a major flood, the lake level may rise to a point where some flooding of the upstream power station will occur. While the risk of structural damage from such an event may be trivial, inundation may affect the ability of the hydraulic control of generation flows to function.

There is an additional risk of flooding at 2A Station from the adjacent Governors Stream. Special measures which have been constructed to cope with deluges from this source since 1981 have significantly reduced the exposure of 2A Station to this risk.

At No. 4 Station the risk of blockage of the adjacent Aggie's Stream could lead to some inundation of the station.

Weather
The risk of damage to the various components by weather conditions is minimal as above-ground structures (dams, intakes, power stations, surge tanks and penstocks) are robust and well able to withstand the effects of wind, snow, ice or hail storms without significant damage and the tunnels, being underground, are unaffected by weather risks.

The only disruption is likely to be to access roads due to weather effects such as washouts and flooding from heavy rain, and blockages by snow drifts in severe snowstorms. The latter is normally only a risk for roads above 2A Station and around Lake Mahinerangi.

Landslide
The hillsides in the vicinity of 2A Station and No. 3 Dam are comprised of clay and weathered schist overlying sound schist angled gently at about 30 degrees towards the valley floor. Precise survey measurements of ground marks within this region since 1983 have indicated a slow but steady downslope creep of the overburden material. This rate varies from about 0.5mm to 3mm per year. Because of the gentle attitude of these slopes, various investigations have indicated that a sudden massive landslip failure of the hillside is unlikely.

The only structures directly affected by the creep movement are the 2A surge tank and No. 3 Dam. Remedial work has been carried out to these structures in the past (1983-85) and regular monitoring of deformation and movement continues to be carried out. To date only minor deformations have occurred with no disruption to the operation of the system.

A minor localised landslip has also been identified in the oversteepened sides of the trench for the No. 3 Station penstock. Further fretting of the slope may occur from time to time but is unlikely to disrupt the operation of the penstock.

Technology
The structures of the Waipori scheme in general are not prone to technological risks. Minor superficial damage such as broken lights, windows and cladding of buildings occurs from time to time but this does not affect the operation of the scheme.

Fragility
While the development of Waipori has spanned from the early 1900's to the 1980's, regular inspections and timely maintenance of the various structures has ensured that risks of damage arising from ageing and general deterioration by wear and tear are much reduced.

All structures are capable of sustaining normal operational loads without damage, but some of the older power station structures, because of the method of detailing, may be less able to resist extreme loadings from a major earthquake without significant damage.

Redundancy
The four power stations making up the scheme are arranged in a cascading series down the Waipori River from Mahinerangi Dam. By suitable operational control and use of by-passes around each station, the failure or non-operation of any one station does not prevent operation of the remaining stations.

Because of the relatively low output from 1A, 3 and 4 stations the impact of outage from any one of these three stations is medium to low. 2A Station on the other hand produces a significant quantity of the power generated from Waipori and hence has a high impact loss if an outage occurs.

Cost
In assessing the cost of reinstatement of damage to the various installations caused by one or more of the identified risks, the following groupings have been used:

Category	**Factor**	**Cost**
Low impact	1	<$100 000
Moderate impact	2	$100 000 to $500 000
Major impact	3	$500 000 to $1,000,000
Uneconomic/extreme impact	4	>$1,000,000

Furthermore it has been assumed that damage from any one event or combination of events will not result in the total loss of the facility or facilities.

In general, older structures which have not been designed to current standards will suffer greater damage in extreme events. Conversely, more recent structures will be better able to withstand extreme events.

The following table summarises the assumptions made in deriving the cost impact for the major civil components at Waipori:

Component	**Reinstatement (expressed as %age of total value of component)**	**Factor**
Dams:		
Mahinerangi	5%	3
No. 2 Dam	10%	2
No. 3 Dam	20%	2
No. 4 Dam	10%	2
Power Stations:		
1A Station	10%	3
2A Station	10%	3
3 Station	30%	2
4 Station	30%	2
Hydraulic Control:		
1A Supply	10%	2
2A Supply	10%	2
3 Supply	20%	1
4 Supply	20%	1
Hydraulic Supply Systems:		
1A	5%	1
2A	10%	2
3	20%	1
4	20%	1
Access Roads	5%	1

Mechanical/Electrical Plant

Earthquake
In general, the plant and equipment within the power house for the 2A and 1A power stations was specified to meet earthquake conditions corresponding to a horizontal acceleration of 0.75g. It is therefore extremely unlikely that any material damage will occur to the equipment itself as a direct result of the earthquake movements. Some short term disruption may result. Some disturbance to mechanical protection devices may occur as a result of "shaking". Minor damage to the building fabric or fittings may also lead to some

short term disruption. Numbers 3 and 4 stations, built in the early 1950's were designed to a lesser earthquake standard than currently adopted, but it is unlikely that any long or medium term disruption will result from a moderate seismic event.

With respect to outdoor equipment, major items have recently been secured with earthquake mountings and care has been exercised to ensure that the major electrical connections are of a type or design that will accommodate the anticipated differential movement likely to arise from a seismic event.

Flooding
Normal operational procedures, including lake management procedures for Lake Mahinerangi, minimise the risk of flooding from the major catchment area. The greatest risk arises from large inflows to the lower catchment combining with possible jamming of the floodgates at No.3 & 4 dams. In general this will only result in minor flooding to lower levels of the power stations where resultant effects will have minimum impact.

The two areas most at risk are No.2A station with the proximity of the two diversion channels and No.4 station with the proximity of Aggie's Creek.

Weather
The risk of damage to installations from weather effects is limited to the outdoor yards at the power stations or the overhead transmission and communications systems. Any damage is likely to be minimal and able to be rectified within a short period of time. The time taken for the restoration of overhead service will generally be governed by the ability to gain access and by possible landslide blockage.

Landslide
A monitoring programme, conducted since 1983 has confirmed a slow but steady creep in the hillside above 2A Station and No 3 Dam varying from 0.5 to 2mm per year. A geotechnical review of the hillside has concluded that a sudden large landslip is unlikely.

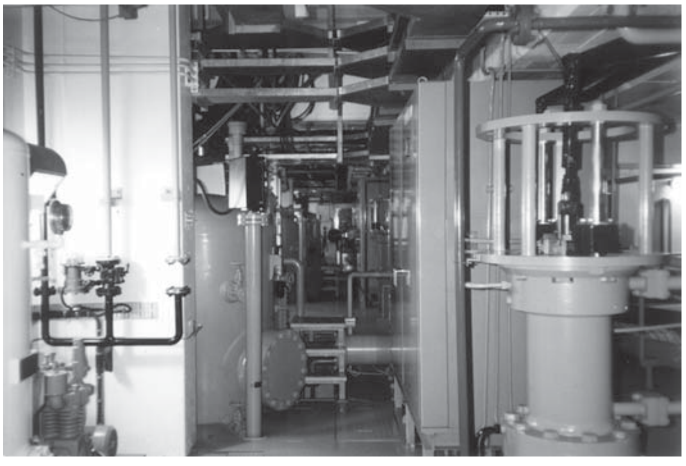
Other minor slip areas have been identified near No.3 surge tank and above the right abutment at No.4 dam but these are unlikely to cause disruption to plant operation.

Technology
Generally plant and equipment are not exposed to any technological risk.

Fragility

1A station:	all elements meet current standards, first third of economic life.
2A station:	all elements meet current standards, second third of economic life.
3 station:	turbine alternator control systems and switchyard meet older standards second third of economic life, remaining items meet current standard second third of economic life.
4 station:	same as 3 station

The equipment in 3 and 4 stations, because of its age and the standards prevailing at the time of manufacture, may be more susceptible to extreme loadings.



Interior, 2A Station, Waipori - Waipori Power Generation Ltd

Redundancy
The fact that there are four stations in the Waipori scheme, each capable of operating independently, creates some redundancy of generating plant.

With respect to the transmission, there are two separate systems through which the generated output can be delivered. Loss of either system would limit the amount of power output to approximately 50% of the maximum rating.

Time
With the exception of the generating sets and their control and protection equipment, first aid repairs and alternative procedures could return

the identified elements to service within one week. With regard to generating sets and control equipment, it is assessed that the only long term disruption to plant operation would result from a landslide or flood similar to events of 1980. Damage could be rectified or alternatives instituted within a period of three months. Only a major failure of the power station building itself would result in a long term problem. In such an instance, major failure of the station foundations affecting embedded or supported plant could require up to three years for planned replacement.

Transpower (New Zealand) Limited - High Voltage Transmission

System Design

Transpower's transmission lines, sub-station equipment and buildings in Dunedin vary in age from approximately 35 years (Halfway Bush Sub-station) to 20 years (Three Mile Hill Switchyard). Most equipment in switchyards has been sourced from overseas and is designed to withstand a variety of earthquake loadings from 0.25g or less for older equipment to 0.7g or more for new equipment. Some brittle equipment such as the 220kV circuit breakers and bushings, utilising porcelain structurally, has been designed to withstand in excess of 1.5g. This is due to the inability of such equipment to absorb earthquake energy without sudden and unpredictable failure.

As most of Transpower's equipment is more vulnerable to damage from moderate to severe seismic attack than the other hazards such as flooding, windstorm etc, a significant effort has been made in the past to improve the seismic restraint of critical items of equipment, including transformers, circuit breakers and switchyard and substation buildings.

Transmission lines and their supporting towers normally perform well during earthquakes due to their high strength-to-weight ratio. Wind and snow induced loads are the critical load cases for such structures. However, the foundations of transmission towers may be vulnerable to damage from earth movement, such as landslides or slope instability, triggered by a seismic event in combination with high soil moisture content in a few critical areas.

Transmission Lines

Transpower's transmission lines form a network, covering a number of routes over widely varying terrain from coastal plains to inland rolling hill country. Some redundancy is built into the system whereby an outage on any one line (depending upon time of day/time of year) may not affect supply to Dunedin Electricity's or Otago Power's distribution networks. This results in a relatively robust and reliable system with minimal outages under normal circumstances. The lines with the least redundancy are the Three Mile Hill/Halfway Bush to South Dunedin line and the Halfway Bush to Palmerston line. In both cases there are dual circuits either on the same set of poles/towers or dual lines running on a parallel route next to one another.

Most towers and poles supporting transmission lines are well founded to prevent collapse under high wind or ice conditions, and therefore are not highly vulnerable to earthquake induced slope instability. A few tower/pole sites however maybe vulnerable. A special and extensive study would be required to detect specific sites of high risk and could therefore constitute a possible mitigation measure.

Most transmission towers are not highly vulnerable to failure from wind or snow loadings as their design is based on worst case criteria which seldom if ever occur. Also their "as built" strength often significantly exceeds that required to withstand the design loadings. The conductors have a factor of safety in excess of two, based upon design loads and are usually clear of trees etc that may topple in heavy winds. Occasionally flashovers can occur when conductors are blown too close to one another.

During heavy snowstorms, transmission lines are the weak link in the system due to flashovers between phases or circuits. Flashovers can be caused by conductors becoming too close to one another when snow suddenly falls from a lower conductor, allowing it to spring up and hit a conductor above.

Transmission lines are largely unaffected by flooding, even in river beds, due to their relative high strength and small exposed surface area, provided the foundation embedment is sufficient to cover scour.

Substations and Switchyards
Substation equipment and buildings are vulnerable to some damage from a significant seismic event. A survey was carried out at all of Transpower's substations /switchyards in Dunedin:

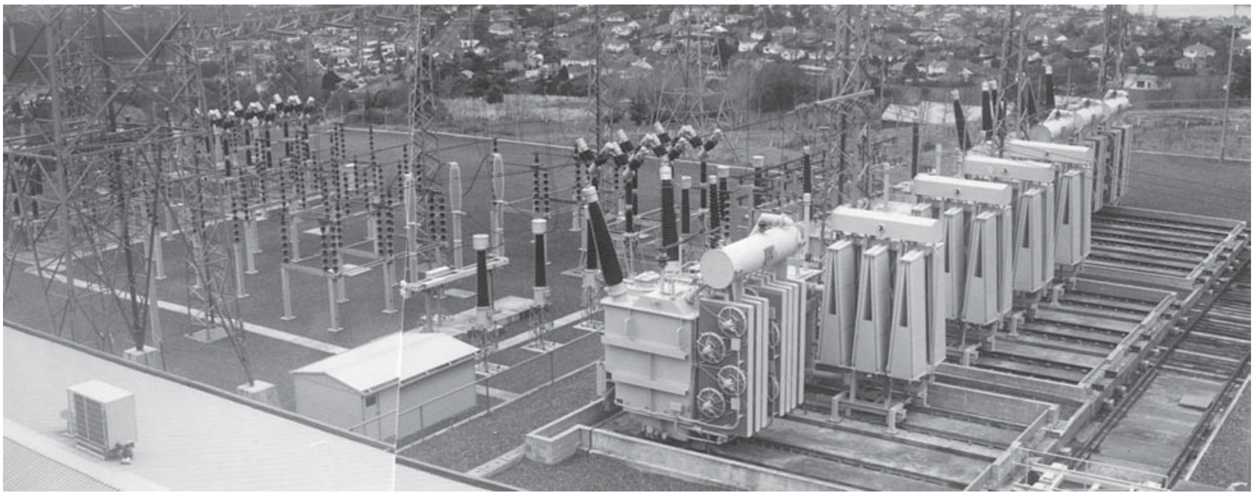
- Halfway Bush Substation.
- South Dunedin Substation.
- Three Mile Hill Switchyard.
- Berwick Switchyard.

Halfway Bush Substation (220/110/33kV)
Halfway Bush Substation was initially constructed in the 1950's with significant upgrading in the 1960's. It is sited on a hillside of predominantly volcanic rock under varying layers of clays and silts. This area has a moderate risk of seismically induced land slippage.

Although the buildings were constructed prior to the 1974 Loadings Code, the buildings now being used for operating the substation appear in the main to be of robust construction. The majority of the construction consists of reinforced cast in situ concrete walls, floors and columns which are likely to be well tied together. The only area which should be specifically checked is the north wall of the crane building which may be constructed of unreinforced masonry. The older buildings on the site will soon be entirely surplus to requirements and may well be demolished.

The most important elements of the switchyard equipment are the power transformers. All the transformers have been retro-fitted with seismic hold down brackets that will provide a high degree of protection from damage. The most vulnerable items are likely to be the 220kV circuit breakers and other items utilising relatively slender ceramic insulators or bushings.

Although newer items should be able to withstand 1.5g, which equates approximately to a maximum credible seismic event, older items could well fail. Studies of similar substations after major earthquakes, eg in California, tend to confirm this. As part of Transpower's on-going upgrading programme, three more circuits breakers have been upgraded recently.



Transpower Halfway Bush Substation - Transpower Limited

Transpower also has some spare circuit breakers in stock at Halfway Bush, South Dunedin and at its South Island warehouse in Addington, Christchurch.

Other areas that should be investigated further and possibly mitigated at Halfway Bush are:

- Check integrity of the standard Circuit Breaker (CB) frames.
- Check the hold down details of the oil storage tanks.
- Tighten some bolts and replace hold down bracket on TI transformer bank.
- Ensure all spares restrained adequately.
- Restrain all VDUs, faxes, filing cabinets and similar furniture.
- Secure drums and equipment in oil filter building.
- Restrain all loose cabling.
- Restrain hot water cylinder.

South Dunedin Substation (220/33kV)
South Dunedin substation was constructed in the 1970's on reclaimed land at the south end of Otago Harbour. The underlying ground of silty sands and marine mud has settled significantly subsequent to the construction of the substation. Such settlement appears to have been relatively even and has slowed down over time. Well founded (piled) buildings and equipment such as the crane building and power transformer foundations, have remained at their original level resulting in voids under the foundations.

The transformer pads were increased in depth approximately five years ago to minimise the lateral loading on the supporting piles.

All the substation buildings have been constructed in a robust manner, probably in accordance with the provisions of the 1974 Loadings Code. The most vulnerable items of equipment are likely to be the 220kV circuit breakers and similar equipment utilising slender ceramic insulators or bushings. Due to the underlying soils, any given earthquake is likely to be magnified resulting in higher seismic loads than at Halfway Bush, thereby increasing the risk to buildings, contents and equipment. Significant liquefaction may also occur.

South Dunedin has an exposure to damage from significant tsunami or storm surge events.

Areas requiring further investigation and possibly mitigation include:
- Investigate further the potential for the site to be subjected to liquefaction to assist with future strategic planning.
- Check the robustness of the standard CB support frames, and check on the capacity of the circuit breakers themselves.
- Inspect the transformers following significant upgrading work.
- Check the capacity of the standard timber battery racks.
- Check on the continued corrosion damage to many of the concrete poles supporting the bus work in the 220kV area.
- It is noted that the crane building is to be decommissioned.

Three Mile Hill Switchyard
The Three Mile Hill site was constructed in the 1970's and is essentially a switchyard as it does not have the facility to step down voltage to directly supply the distribution authorities. Its main function is to facilitate the control of a number of Transpower circuits:
- Roxburgh - Three Mile Hill.
- Three Mile Hill - Halfway Bush.
- North Makarewa - Three Mile Hill.
- Three Mile Hill - South Dunedin.

The switchyard is sited on the top of a hill on volcanic rock and clays and silts of varying depth. The area has a moderate to low risk of seismically induced landslide, but could be exposed to severe snowstorms. A severe seismic event has the greatest potential to result in damage and significant outages.

The buildings are likely to have been built in accordance with the 1974 Loadings Code and should survive a severe earthquake substantially intact. The most vulnerable equipment will be those items which have slender ceramic insulators for support.

Areas requiring further investigation and possibly mitigation include:
- Check manual CB channel support beam for torsional strength.
- Check on strength of Current Transformer (CT) base bracket.
- Increase strength of hold down detail for emergency generator fuel tank.
- Restrain fax machine, printer and light storage on overhead shelving.
- Check on base restraint of fire fighting water storage reservoirs.
- Change method of pole storage in adjacent yard to not rely on security fence posts for support.

Berwick Switchyard
Berwick switchyard is used to control the feed from the Waipori Power Station into the Gore - Halfway Bush transmission line. The switchyard is relatively small and the control building is a small light timber framed structure. The floor level of the building is raised up approximately one metre on a well braced piled floor. This has resulted in a seismically robust building which should also be above flood level.
The equipment, being 110kV, has less slender ceramic supports, and is therefore less at risk from seismic damage.

The site, being on alluvial soils in the Taieri Plain, is exposed to negligible risk of land slippage and only moderate risk of severe winds or snowstorm damage.

Areas requiring further investigation or mitigation include:
- Make good rusting gantry baseplates and replace missing bolt on one leg.
- Check strength of CB baseplate.
- Check strength of CT support frame.
- Straighten communications pole next to building.

Control System

Power Line Carrier
This system enables information to be carried over the main high voltage transmission lines and as such has the same vulnerability to loss of services as the transmission lines.

Two-way Radio / Digital Microwave Radio
This method of system control is an independent Transpower system involving communication towers or poles at substations, supporting transmitting and receiving equipment. Repeater sites are designed to resist most credible earthquakes, windstorms or snowstorms. A slight risk is the possibility of foundation damage due to land slippage at isolated sites. The major concern is the maintaining of the orientation of transmitting /receiving equipment to within the very tight tolerances required, although there would be a very low risk of a seismic event causing a permanent disorientation of such equipment. It would be more likely that a severe windstorm could cause a temporary mis-alignment problem.

Telecom Telephone and Cellular Networks
Refer to the Communications/Broadcasting vulnerability assessments.

Dunedin Electricity Limited - Distribution

General Description
In general, the subtransmission system is provided with sufficient redundancy to ensure supply to zone substations and most HV feeder circuits have sufficient inter-tie connections to provide continuation of supply to major consumers by alternative routing.

However, there are particular areas where, by virtue of location, the risk of hazard damage is higher than normal. One such area is South Dunedin, due to flood potential, earthquake faulting and/or liquefaction. In such locations the potential for serious and prolonged outages may be greater for underground cabling than for overhead reticulation.

A programme to check the seismic response of all zone substation plant commenced in 1996 with early efforts concentrating on the oldest substation.

It has been found necessary to carry out some remedial work by strengthening the hold-down arrangements for the main transformers and additional bracing for some structures. Less remedial work is expected to be needed for those zone substations constructed from 1970 onward and these will be surveyed during 1998/99.

Transmission Lines

From South Dunedin
The five zone substations supplied from the Transpower South Dunedin substation are all supplied via 33kV underground cables and all but one of these lies within the high risk area for damage by earthquake and flooding.

In particular the St Kilda substation is located in virtually the lowest part of Dunedin City and lies across what is inferred to be an active fault, as is the Transpower substation which feeds the five Dunedin Electricity Limited zone substations. St Kilda substation is liable to flooding, earthquake and liquefaction effects and loss of this substation is highly likely in such events.

The Andersons Bay, South City and North City substations are likely to be subject to damage by earthquake as they lie within the potential liquefaction zone and enhanced shaking area. They are however less exposed than the St Kilda substation and we may expect less damage to equipment and buildings and the flood risk is reduced as they are on higher ground. Corstorphine substation is relatively more secure, lying at higher levels and outside the enhanced earthquake shaking area.

All five pairs of 33kV underground cables which supply each zone substation from South Dunedin are particularly liable to be damaged by earthquake. As each pair of cables is laid in the same one metre deep trench, there is a risk that, where the cables cross the fault line, both circuits will be damaged. If this occurred then total loss of supply to the zone substation would occur with restoration time dependent on the number of simultaneous faults. Repair time for each circuit is likely to be several weeks. There is a lower risk due to flooding.

From Halfway Bush
Of the nine zone substations supplied from the Transpower Halfway Bush substation the Neville Street and Ward Street substations lie in the higher risk earthquake zone and are exposed to hazards similar to St Kilda. The exposure of Ward Street to flooding should also be recognised due to the relatively low level of the substation and its proximity to Otago Harbour.

Substations at North East Valley, Willowbank, Kaikorai Valley and Green Island will suffer less extensive damage due to shaking but still lie in enhanced shaking areas. We may expect damage to older buildings and disruption to substation equipment.

The remaining substations at Smith Street and Halfway Bush would appear to be exposed to the least risk and should suffer less damage.

The Neville Street, Ward Street, Willowbank, Halfway Bush, Kaikorai Valley and Smith Street substations are each supplied via a pair of 33kV underground cables generally laid in the same trench. The Ward Street and Neville Street circuits are exposed to the greatest risk since more of their length lies within the enhanced shaking zone. One mitigating factor is that there is a separate 33kV inter–tie cable between Neville Street and Ward Street substations which can be utilised as long as there is supply available to either Ward Street or Neville Street. If damage does occur, repair time is likely to take several weeks.

The Green Island, Port Chalmers and North East Valley substations are each supplied by two parallel overhead circuits on separate pole lines. These circuits are exposed to some shaking and landslip risk, although if damage does occur it is likely that repair will be in the order of days rather than weeks.

From Halfway Bush - Waipori 33kV Subtransmission Lines
The four zone substations serviced by the Halfway Bush - Waipori 33kV lines (Mosgiel, East Taieri, Outram and Berwick) will be subject to damage by earthquake but on a reduced scale. At the same time they may be prone to flooding damage due to their low lying location or proximity to water courses, although recent events such as the 1980 Taieri floods have shown the zone substations not to be affected. The Outram substation adjacent to the Taieri River flood bank and the Mosgiel substation adjacent to the Silverstream are the sites with most exposure.

The three parallel Half Way Bush-Waipori 33kV circuits which supply the zone substations of Mosgiel, East Taieri, Outram and Berwick are prone to extreme wind events where material blows across all three lines causing major interruptions to supply. Full supply to the Taieri area is available if two of the circuits are in service, but if only one circuit is available then supply is limited to 60% of maximum load.

Distribution Circuits (11kV and 6.6kV)
Underground cable circuits are less prone to risk unless they cross an active fault line or a landslip prone area. Ground mounted distribution transformers are exposed to flooding, liquefaction areas and landslip but have a reduced risk due to shaking.

Overhead pole mounted circuits are at risk from earthquake shaking and liquefaction. Particularly at risk are poles with transformers mounted on them which in the Dunedin area accounts for 70% of distribution substations. Many of these pole mounted transformers are small and, in rural areas supply only one or two consumers.

Essential Loads

Dunedin Hospital
Dunedin Hospital is supplied via two parallel 6.6kV feeders from North City substation. Whilst there is redundancy in the 6.6kV cables, this supply relies upon both North City zone substation and the Transpower South Dunedin substation, both of which have a high probability of loss.

Wakari Hospital
Wakari Hospital is supplied by a 6.6kV cable from Halfway Bush zone substation with alternative supplies available from Kaikorai Valley zone substation. The risk of total loss of supply is therefore minimal.

DCC Civic Centre and Civil Defence HQ
Both these sites are supplied from Smith Street zone substation and from Transpower Halfway Bush substation. As Smith Street is exposed to less risk than most zone substations, these supplies are more secure.

Port Otago
Port Otago is supplied by an 11kV feeder from Port Chalmers zone substation. Supply to this site is most at risk due to landslip (11kV cable and 33kV overhead lines) and to shaking.

Dunedin Airport
Dunedin Airport is supplied by an 11kV overhead line from Outram zone substation and there is an alternative supply using the intertie with the overhead lines from Berwick zone substation. The consumer substation as well as the adjacent HV circuits are prone to flooding and pole mounted equipment is also prone to shaking.

System Control
With the System Control Centre being located in a reasonably modern building (upgraded in 1998) the equipment and services are less susceptible to damage than zone substations.

The main equipment in the control room, essential for the co-ordination of restoration of supply following a disaster, consists of the SCADA, load management and communication systems. The SCADA and load management systems have some redundancy and the main risk will be to the associated power supplies and communications systems.

The main HV supply to the System Control Centre is from Ward Street and Halfway Bush substations. A standby diesel generator powers battery charging systems and essential circuits. Checks need to be made on the susceptibility of the generator to shaking and the possible rupture of fuel lines.

Communication circuits which are at risk include Telecom circuits associated with the VHF communications transmitters on Saddle Hill, Signal Hill and Swampy Summit. The communication circuits which link the SCADA system to the zone substations are also at risk especially those which cross the active fault or are in landslip areas. These circuits are owned by either Dunedin Electricity (pilot cables in Dunedin urban areas) or Telecom (mainly Taieri area).

General Vulnerability
The historical design of the distribution system is very similar to other urban distribution systems throughout New Zealand, Australia and Britain. The design of the subtransmission system is mainly based upon coping with single contingency events where random failures of equipment can be expected to occur and hence a single backup alternative circuit will be available.

Natural disaster poses a much greater risk to the system since there is a greater likelihood of multiple events, causing prolonged loss of supply to a significant portion of the network.

Otago Power Limited - Distribution

General Description
The distribution network operated by Otago Power Limited is susceptible to disruption from a variety of hazards because of terrain. Because of the lower density of population served the network does not provide any effective redundancy in a number of supply areas.

The principal hazards to the network are earthquake, flooding and weather and there are some areas where tsunami may be destructive.

Individual service lines of 33kV and 11kV are duplicated where they are critical to the network elements and the service area is significant, but some local damage may occur due to earthquake shaking of pole mounted transformers.

Transmission Lines

Cherery Farm Substation - Civil Defence

Supply From Transpower Palmerston
Supply at 33kV from Palmerston is by a single overhead line direct to a substation at Cherry Farm. There is an 11kV alternative supply line running along a similar route beside S.H.1. The 33kV line is not particularly vulnerable, running over undulating country with reasonable access from S.H.1. The line is reasonably well protected from weather, landslips and the earthquake potential is considered to be in the lower range.

There is some possibility of damage due to flooding or tsunami in the area around Cherry Farm Sub-station, which is located in a flood prone estuary.

Local supply between Palmerston and the Cherry Farm Substation is considered to be at relatively low risk, apart from the low areas from Waikouaiti to Cherry Farm where it is vulnerable to flooding.

From Cherry Farm Substation, the 33kV line has a low exposure to hazard except for the length running alongside Blueskin Bay, particularly the section leading to the Waitati substation where there is the possibility of flooding and tsunami impact. Earthquake effects are likely to be low, but may induce some land slipping, particularly on the 11kV line along Coast Road which services the Warrington and Seacliff areas.

The substation at Waitati is on a flood plain and may be damaged by extreme flood and, although remote, there is a possibility of tsunami effect in Blueskin Bay. The 11kV loop around Doctor's Point is exposed to weather conditions, but generally represents a low risk.

Supply From Ranfurly
The 33kV lines cross undulating country from Ranfurly substation to Waipiata and Hyde then onwards to Middlemarch, Clarks Junction and Hindon.

Because the supply lines are radial and there are no duplicate 33kV or 11kV lines the service is at risk from hazard impact. The substations are at low risk from flood and landslipping, but are exposed to damage from earthquake shaking owing to their proximity to the Hyde fault.

The 33kV line is susceptible to weather influences, particularly in the sections at Hindon and Clarks Junction, but because of the low population served are not a priority risk on the network.

ELECTRICITY - MITIGATION STRATEGIES

Waipori Power - Generation System

Civil Systems
The Waipori scheme has been developed over 95 years of design and construction. By the inherent nature of the terrain and age of the scheme, various elements are vulnerable to earthquake. For the purpose of a continued power supply the generation is shared across four dam/penstock/powerhouse segments and thus a redundancy is available for individual element failures.

The exposure downstream of the scheme from the worst scenario of uncontrolled discharge caused through a penstock or similar failure is an immediate increase in the level of the Waipori River. This discharge is self reducing (by the reducing retained lake level or, in the case of Lake Mahinerangi, controlled by gates), and as a result of both the roughness factor and length of the Waipori Gorge only a gradual overtopping of stop banks at Berwick is expected.

Continual re-examination of such critical elements of the supply system and regular maintenance form a reassuring picture of both dam and penstock reliability.

Overall reassessment by engineering consultants indicates that no meaningful mitigation measures other than regular maintenance are available and any damage from major natural hazard would be dealt with by “response management” at the time of impact.

Mechanical/Electrical Plant
The principal risks to electrical and mechanical plant and machinery arise as a result of the effects of an event causing damage to the civil structures and buildings of the hydro scheme. For this reason, the principal risk management strategies are focussed on the civil works themselves and rely upon duplication of essential electrical and mechanical systems and/or retention of a range of strategic spares.

Plant exposed to risk has been identified as falling into six defined categories.

Turbine Alternator Sets
In 1A and 2A Stations the machine design specification requires the plant to withstand a horizontal acceleration of 0.75g. In 3 and 4 Stations, designed in the early 1950’s no criteria was specified.

Little can be done at this stage to modify the plant in any meaningful way to increase the security of the turbine alternator sets against a seismic event. Steps can be taken however to increase the security of auxiliary plant by ensuring mountings meet expected loadings imposed by current design events.

Control and Protection Equipment
Electro-mechanical devices can be subjected to damage from shaking. Mitigation could be effected by total replacement with solid state devices but the cost involved in implementing this strategy is presently prohibitive. An acceptable strategy would be to ensure planned replacements adopt solid state technology. In the interim, the strategy adopted has been to maintain a strategic reserve of replacement devices.

Local Power Supplies
Each local supply facility is backed up from an alternative source. The strategy adopted to mitigate the effects of events involves a shared holding of spare componentry with Dunedin Electricity Limited.

Switchyards
As for local power supplies, redundancy, spares and alternative configurations provide mitigation.

Transmission
Sufficient spares are held to enable the effects of design events to be rectified within acceptable time limits.

Communications
Duplication of communication links along geographically different routes has been adopted to provide security. General area communications have been provided by telephone circuits backed up with VHF radio communication.

Conclusions

Civil Works
The existing mitigation strategy is to closely monitor the key older elements and to compare the performance of these elements against present NZ standards. An example of this is the Mahinerangi Dam, which was structurally analysed in 1993 using new techniques and found to be satisfactory. The process is a continual one which relates to the annual operational strategy of the scheme, involving ongoing monitoring under the SEED process combined with continual maintenance.

Mechanical/Electrical Plant
Probably the most significant risk to plant and equipment arises from the prospect of flooding of the installations. Current strategies to minimise this risk involve adherence to a lake level management plan to minimise the risk of a discharge from the main storage reservoir. This management plan is regularly reviewed in the light of additional hydrological information and the assessment of the risk from an expanded perspective by using alternative review consultants.

The risk of downstream flooding is mitigated by provision of facilities to prevent the ingress of floodwater to the installations and no further work is believed to be of practical advantage.

Recommendations
It is considered that the existing inspection arrangements, coupled with good and regular maintenance afford the best mitigatory strategy in increasing the survivability of civil, mechanical and electrical components of the system.

Transpower (New Zealand) Limited - High Voltage Transmission

General Description
Responsibility for the high voltage electrical transmission network rests with Transpower Limited who have a long standing record of attention to seismic aspects and other hazard mitigation of their facilities. This has included detailed surveys and, where appropriate, strengthening and upgrading of buildings and equipment.

Transpower Limited has a policy with the following objectives:

- To maintain power supplies during and after an Edgecumbe-size earthquake (MM IX).
- To restore power supplies to earthquake damaged areas within a maximum time of three days.
- To ensure the safety of the public and personnel.
- To minimise the resulting cost of repairs.

Involvement in Lifelines Projects such as Dunedin's, along with those of Wellington, Christchurch and Auckland, has provided a broader insight into earthquake and other disaster related issues. This in turn has led to the identification of specific concerns and items requiring attention in order that objectives be met.

Transmission Lines
Transmission lines generally were found to be robust against earthquake loading, with snow and wind storms being the likely causes of temporary outages. When an instantaneous flashover occurs due to conductors becoming too close together, usually during wind conditions that cause the conductors to oscillate, the protection systems will attempt to reinstate the circuit a given number of times before either the service is reinstated or shut down.

Transpower however are concerned about the foundations of some of its towers, particularly in areas of high slope instability potential. This has resulted in the commencement of a geotechnical investigation into some tower foundations in the Dunedin area. The towers to be inspected include a number on the Halfway Bush - South Dunedin and Roxburgh - Three Mile Hill transmission lines. All foundations found to be inadequate will be upgraded as part of an overall programme of increasing reliability.

Substations and Switchyards
Following the inspection of Transpower's four substations or switchyards in the Dunedin area, a number of specific items where identified as requiring either mitigation or further investigation.

All items that required mitigation and no further investigation have been put onto Transpower's routine maintenance schedule and will be attended to as soon as possible, while items that require further and more detailed assessment will be attended to as a separate issue, with the nature and timing of any investigation work being dependent upon the outcome of the assessment.

The availability of spares for damaged equipment is dependent on some held on site and others held at the Transpower South Island warehouse at Addington, Christchurch. It is critical that all spares are stored in such manner that damage to these during a moderate to severe earthquake is highly unlikely. This could be achieved by ensuring that spares are securely held down or stored lying horizontally on the ground to eliminate the chance of tipping over. It is not inconceivable that a major seismic event could hit both Christchurch and Dunedin simultaneously, thereby making help from Christchurch unlikely, so Transpower also holds an inventory of spares in their warehouses at Palmerston North and Otahuhu, (Auckland) which would be available in Dunedin when transport allowed.

All Transpower substations in the Dunedin region have a degree of redundancy and it is considered likely that sufficient equipment would withstand the earthquake to be able to restore some power supplies in a day or two or possibly less.

If a severe earthquake or other disaster was to hit the Transpower South Island Control Centre in Christchurch, Halfway Bush Substation could take over control of the national grid in their area. Supply could be normal in capacity but may be less secure than would usually be the case.

Transpower appreciates that the South Dunedin substation is relatively vulnerable to damage from earthquake, liquefaction, flooding and storm surge. In the longer term, these factors will be taken into account when further upgrading is required.

Transpower continually reviews design standards in line with experience gained from Edgecumbe, Northridge, Kobe, and other similar seismic events. Transpower also continues to develop operational procedures and training to respond to major earthquakes.

Control Systems
Although no specific areas of concern were identified, Transpower continues to review all existing control systems, and upgrade them with the latest technology when appropriate. This is an ongoing exercise due to the general trend of keeping manning levels to a practical minimum.

Transpower has always been aware of the need to build in redundancy to its control systems to ensure they remain operational at all times, including during and following a major disaster such as a severe earthquake.

Conclusions
As a result of continual re-examination of the integrity of their high voltage transmission systems, Transpower Limited have identified and listed on "Record Sheets" a number of relatively minor items for attention and one or two more significant strengthening objectives.

The general overview of the Transpower Limited systems indicates a high level of preparedness and satisfactory hazard resistance built into design.

Recommendations
Continue the present level of maintenance and progressively undertake works described on in house record worksheets.

Dunedin Electricity Limited - Distribution

General Description
As part of its routine operations, Dunedin Electricity is able to respond promptly to a wide range of emergencies. However, widespread damage to the distribution system will place very large demands upon resources and it will be necessary to utilise the resources of neighbouring power companies (where possible) and those from the large nationally based power contracting companies.

In the event of a major emergency, it is also likely that Transpower's supply system will be affected (especially the South Dunedin supply point) plus there will be damage to consumers' premises and thus some of the electrical load requirements will be reduced. This will facilitate the transfer of load from affected zone substations to alternate supporting zone substations.

Exposure to Earthquakes
Exposure to an earthquake is the most widespread risk faced by the network although the risk is greater for those items of plant in the vicinity of the Akatore fault line.

The following mitigation measures have been identified and a work programme is currently in hand (40% complete), with the pre-1965 substations being given top priority. Consultants have been employed to survey and advise remedial measure for each substation.

Zone Substations
Checking of:
- 33kV transformer hold down arrangements.
- 33kV transformer pad strengthened to resist overturning.
- The bracing on radiator banks, conservator tanks and switchgear support frames.
- 11kV switchgear hold-down arrangements.
- Control panel hold-down.
- Battery banks for support and bracing.
- The building (one building has had abutments added to the end walls to assist in carrying lateral loads).

Cable Systems
The 33kV cables could be damaged by excessive differential ground settlement during an earthquake but no 33kV cables were identified as being at risk by being supported on bridge structures. Temporary overhead lines may be erected to expedite the restoration of supply to some underground areas.

Overhead Line Systems
The mounting of transformers on two-pole substations should be checked and upgraded where necessary, although while damage to the overhead system may be widespread it should be repaired without too much difficulty as only standard components are used.

Ground Mounted Distribution Substations
Check the mounting of transformers in consumer substations.

General
For all the above situations, management of the restoration process will be enhanced by:
- Up to date plans and information which are available to as many of the contractors as possible. The establishment of a PC electronic based system with paper back-up will facilitate this.
- All spares are managed within a separate inventory system. Checks are to be made that the appropriate number of essential stocks of each item are held given the improved knowledge about each risk that is now available. In addition, some spares have been identified as being in need of securing against movement and additional bracing of these is under way.
- Ensure emergency stock levels of poles, line hardware and replacement conductor is available.
- Ensure emergency stock levels of distribution transformers are available. A new storage pad is currently being constructed providing for a hold-down arrangement to secure these transformers against movement during an earthquake.

Exposure to Flooding
Generally, the risk of flooding to any zone substation is relatively minor with the following zone substations considered to be most at risk:
- Ward Street
- North City
- St Kilda
- Willowbank
- Neville Street

The distribution network at the 6.6kV/11kV level is made up of many lines and cables able to provide many options and alternatives for at least a limited power supply.

Specific Flooding Mitigation Measures

- Prepare plans to identify essential services supplied from the above zone substations and keep up to date all plans for the transfer of load (where possible) to adjacent zone substations.
- Ensure sump pumps are in place and well maintained.
- Maintain a supply of sandbags at St Kilda, Ward Street and South City.
- Ensure an alternative emergency control room is available with a secure communications and power supply to the central control equipment. Currently, the back-up emergency control room is located at Smith Street zone substation which has almost nil risk from tsunami or flooding.

Exposure to Tsunami

The risk of tsunami is high for St Kilda zone substation and slightly lower for North City, South City, Andersons Bay and Ward Street zone substations and the control room in the Halsey Street office block.

Specific tsunami mitigation measures

- Prepare plans to identify essential services supplied from the above zone substations and keep up to date all plans for the transfer of load (where possible) to adjacent zone substations.
- Ensure sump pumps are in place and well maintained.
- Maintain a supply of sandbags at St Kilda, Ward Street and South City.
- Ensure an alternative emergency control room is available with a secure communications and power supply to the central control equipment. Currently, the back-up emergency control room is located at Smith Street zone substation which has almost nil risk from tsunami or flooding.

Conclusions

Managing the risks of a natural disaster is an integral part of Dunedin Electricity's Asset Management Plan. This is updated annually and provides detailed information on asset planning for the following 10 year period.

An extensive programme of strengthening work at major substation sites has been under way for two years and is targeted for completion in 2001. Expenditure on bunding around zone substation transformers is complete and has exceeded $350,000. In addition, the seismic survey programme currently under way for zone substations is expected to cost in excess of $300,000.

Recommendations

Dunedin Electricity has demonstrated a high commitment to improving the electrical infrastructure assets to minimise the impact of a natural disaster or hazard, and intends to continue with the direct preventative maintenance and upgrading activities already initiated.

Otago Power Limited - Distribution

General Description

The entire distribution reticulation system is subject to a wide range of hazard impact on a random basis. The extensive network traverses areas subject to earthquake shaking, flooding and landslip, and it is largely impossible to predict where such events would affect the supply.

Supply lines are built to normal standards with due regard to topography and receive maintenance associated with low levels of consumer demand.
At the time of examining the system network under the Lifelines Project, work has been undertaken to improve survivability of the substation at Cherry Farm from flooding and earthquake hazards.

In the next 1-2 years, there are plans to alter the supply arrangement to the northern coastal area by providing an alternative to the Cherry Farm and Waitati substations. This will improve the security of supply to both these areas.

Generally speaking, the mitigatory measures envisage carrying on with current levels of maintenance and providing for major hazard damage by rapid repair work following an incident.

Conclusions

It is recognised that there is a widespread potential for damage to the network from hazard events, but it is not possible, on economic grounds, to effect any meaningful mitigation strategy other than to provide for management of repair work following the event.

Recommendations
Continue general maintenance, select and effect securing of transformers and control equipment against earthquake shaking.
Re-examine reticulation routes with reference to stability of terrain at power poles and progressively strengthen under general maintenance programmes.
Review existing repair facilities with respect to skilled labour and quantity of spare components.

FUELS - DESCRIPTION OF SERVICE

Liquid Petroleum Products

General Description
This brief encompasses all bulk liquid petroleum products which are received into Dunedin from tankships discharging at the Fryatt Street Oil Wharf. These products are transferred by pipeline to above ground storage tanks pending distribution to inland markets by road delivery vehicles or to the marine market via pipeline sales. Storage tanks are situated on the premises of BP Oil at Parry Street, Caltex Oil at Fryatt Street, Shell Oil at Wickliffe Street and Fulton Hogan Bitumen Division at Fryatt Street.

Automotive Products
Two grades of petrol are stored and distributed in Dunedin from Caltex Oil and BP Oil Terminals. Unleaded 91 Octane and Unleaded Premium 96 Octane are delivered by road vehicles throughout Otago, primarily to BP, Caltex, Shell and Mobil branded service stations but also to individual farmers and commercial users. Diesel fuel, which can also be known as Gas Oil, AGO (Automotive Gas Oil), ADF (Automotive Diesel Fuel) or LDO (Light Diesel Oil), is stored and distributed from the premises of BP Oil, Shell Oil and Caltex Oil to all the above users and is also used extensively by road transport, rail, mining, manufacturing, contracting and fishing industries.

Aviation Fuels
Only one grade of aviation fuel, Jet A1 (aviation turbine fuel), is stored and distributed from Dunedin. This product is stored at BP Oil and delivered by road delivery vehicle to a small number of BP and Mobil customers. The principal user is the Air BP facility at Momona Airport with minimal amounts being delivered to other multi-user tanks at Wanaka, Queenstown, Te Anau and Taieri airfields.

Fuel Oils & Bitumen Products
Only one grade of fuel oil is stored and distributed from Dunedin. Light Fuel Oil (or LFO 220 Secs) is stored at the Shell Oil Terminal and is delivered by road to commercial and manufacturing users who utilise it as a heating/boiler fuel. Light Fuel Oil is also used extensively as a bunker fuel and pipeline deliveries are made to vessels berthed at the Oil Wharf in Fryatt Street.

Bitumen products, 180/200 and 45/55 Bitumen, are stored at the Fulton Hogan Bitumen Terminal in Fryatt Street and delivered by road vehicles to roading contractors in Otago and Southland.

Berthing Facilities & Connecting Pipelines
All replenishments of liquid petroleum products arrive in Dunedin by tankship which can only be discharged at the berth commonly known as the Oil Wharf at Fryatt Street. This wharf is owned and maintained by Port Otago Limited but tankship discharges are organised/controlled by the oil industry companies and their designated contractors. The oil wharf is the terminal point of the pipeline network which extends to the BP, Caltex, Shell and Fulton Hogan tankage. Connection between the tankship and the appropriate pipeline is made by way of heavy duty flexible cargo hoses. This wharf is also utilised for pipeline bunkers, where diesel or light fuel oil is delivered onto vessels from tankage at BP, Caltex or Shell premises.

In all there are five separate pipelines of 200mm diameter which are dedicated to transfer of product:

- An insulated and electrically trace-heated line to Fulton Hogan tankage in Fryatt Street, used for delivery of bitumen. This line is owned by Shell Oil.
- A Light Fuel Oil (LFO) line which runs along Fryatt Street, through the Caltex Terminal and under Wickliffe Street to a tank in the Shell Terminal, is owned by Shell Oil. This line is also used for the delivery of LFO pipeline bunkers to vessels berthed at the oil wharf.
- A petrol line runs above ground along Fryatt Street and then underground to the BP Terminal in Parry Street with a tee-off in Fryatt Street to the Caltex tankage. Ownership is 100% BP from the tee-off to Parry Street but equal BP, Shell and Caltex ownership from the tee-off back to the wharf.

- A diesel line with the same route and ownership as above extends through the Caltex Terminal, under Wickliffe Street to tankage in the Shell Terminal. This line is also utilised for the discharge of Jet A1 and for the delivery of diesel pipeline bunkers to vessels berthed at the oil wharf.
- A spare line, currently de-commissioned, which runs only to the BP Terminal in Parry Street, is owned by BP Oil.

Bulk Storage
Details of bulk storage tanks (by company with capacities expressed as millions of litres) are:

BP Oil - Parry Street

Tank	Current Product	Capacity
D1	Slops	2.2
D2	Diesel	2.2
D3	Unleaded 96	2.0
D5	Diesel	2.0
D6	Unleaded 96	1.5
D7	Jet A1	1.0
D8	Unleaded 91	6.0

Caltex Oil - Fryatt Street

Tank	Current Product	Capacity
502	Unleaded 91	4.6
503	Diesel	0.5
529	Unleaded 96	4.2
530	Unleaded 91	2.1

Shell Oil - Wickliffe Street

Tank	Current Product	Capacity
4	Diesel	6.8
7	Diesel	4.7
6	Light Fuel Oil	5.0

Fulton Hogan - Fryatt Street

Tank	Current Product	Capacity
1	45/55 Bitumen	1.3
2	180/200 Bitumen	0.5
3	180/200 Bitumen	3.2

It should be noted that facilities to load petroleum products into road delivery vehicles are not available at Shell Oil. The Shell tankage is piped up to the loading gantry at Caltex Oil and Shell vehicles load their product there. Mobil Oil do not have any bulk storage facilities and load their requirements from the BP Terminal at Parry Street.

Special User Bulk Storage
This category of user is now somewhat limited in numbers as the modern trend is for fuel requirements to be uplifted from service stations/truckstops by way of a card system. Police, fire service, government agencies, local authorities, transport and contracting companies all utilise this option for the vast majority of their requirements. The following storage could still be classified as special user:-

Air BP - Momona Airport	150,000 litres above ground tankage - Jet A1
Tranz Rail - Strathallan Street	100,000 litres above ground tankage - Diesel
St.John Ambulance - York Pl.	10,000 litres underground tank - Unleaded 91.

Gas

General Description
The present gas supply in Dunedin by Otago Citigas Limited was first established in 1863 and, though considerably reduced in service area and providing energy from a different source, continues to supply a significant number of customers in parts of the city (see map).

Up until 1986 coal gas was produced at the Andersons Bay Road plant, but from 1986 onwards Liquid Petroleum Gas (LPG) has been used as a feedstock. In 1990 a new plant to produce tempered LPG was commissioned and in 1995 the Land Fill Gas (LFG) system was added and placed on line to service approximately 500 customers.

Citigas Installations
The current (1997) gas supply system extracts LFG from the Green Island Landfill. The LFG is pressurised, scrubbed and delivered to the tempering plant in Hillside Road, Dunedin via a 100mm diameter pressure main (8 bar). This same area at Hillside Road provides for gas cylinder filling.

City Reticulation
The original (from 1863) city reticulation has been much reduced from a length of about 330 kilometres to a present day length of about 110 kilometres, which is administered from the DELTA Utility Services premises in Halsey Street. The principal service lines run from Hillside Road to consumers along Andersons Bay Road, Hillside Road, Cumberland Street, Princes Street and George Street to Normanby. There are substantial network areas in South Dunedin and Caversham.

Liquigas Plant (Including berth facility).
A substantial storage plant was constructed in 1985 at Fryatt Street, Dunedin. This plant receives LPG by sea tanker which berths alongside the plant area at a privately owned wharf. The entire plant and wharf area are electronically alarmed and protected against malfunction. Bulk LPG is loaded to road tankers and delivered to commercial users and bulk suppliers within the city area.

There are eight bulk storage tanks on the Fryatt Street site, each of 135 cubic metres capacity which in total represents a tanker vessel cargo and will normally sustain the Dunedin area for approximately three months.

Service Station LPG Storage
Throughout the city there are upwards of thirty service station LPG supplies stored in bulk tanks of approximate 5 cubic meters capacity. These tanks are predominantly located at service stations within the area between Mosgiel and the Gardens and are well protected from accidental impact. Gas supplies are delivered by road transport in all cases.

Special User LPG Bulk Storage
There are relatively few LPG bulk storage supplies operating for industrial clients, but isolated supplies are located at the brickworks at Abbotsford and the PPCS meat works on Dukes Road, Mosgiel. Supplies are delivered to these sites by road.

Solid Fuels

General Description
This brief encompasses all commercial and domestic grades of coal received into Dunedin in bag and bulk form. Such products are mainly received by road.

The main coal used in Dunedin is Ohai coal which comes from Solid Energy's Wairaki No. 6 underground mine situated at Ohai in Western Southland.

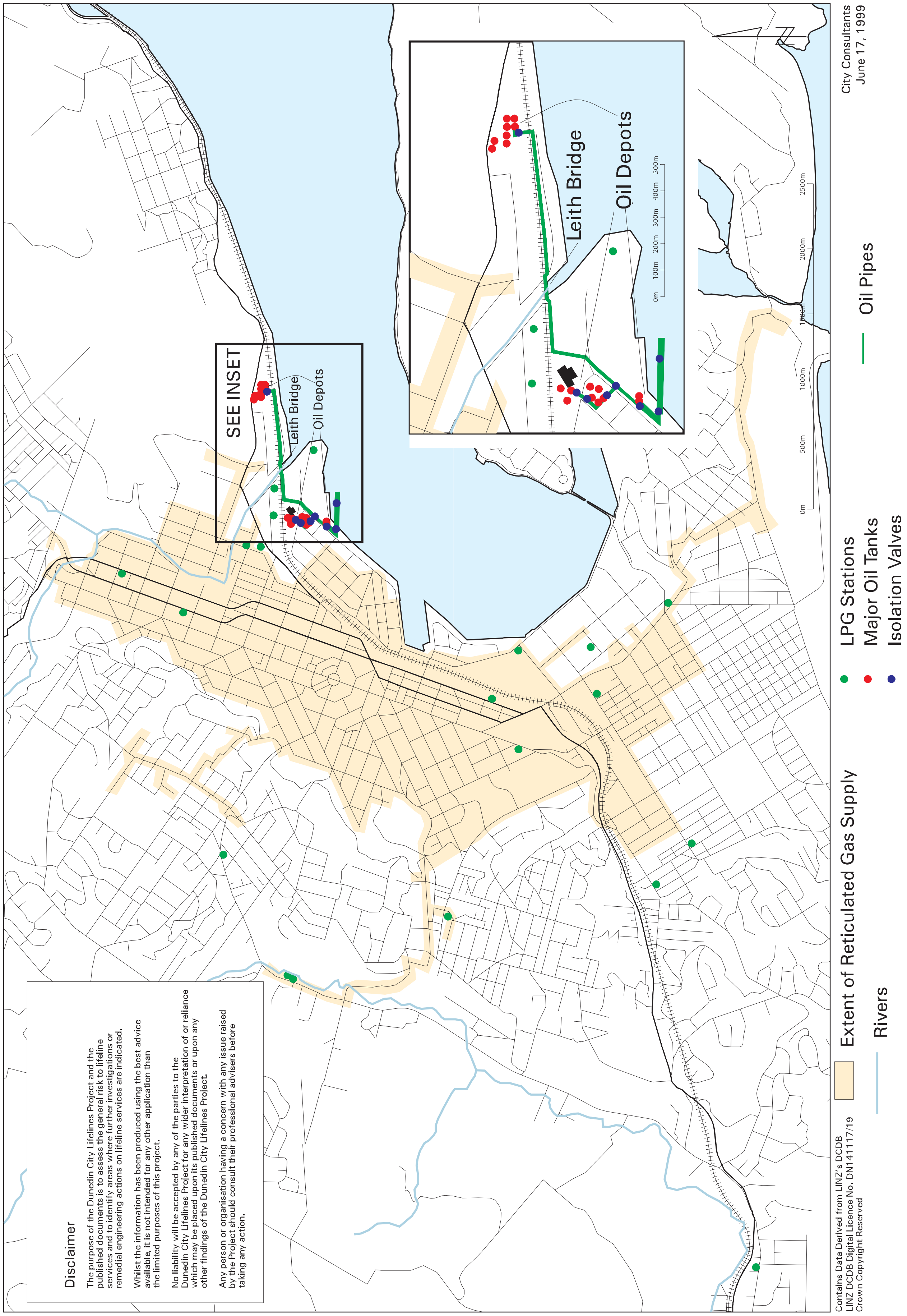
Other coals sold in Dunedin are Mossbank Ohai, Nightcaps coal by Southern Mining, West Coast coals from Strongman, Island Block Terrace and other private mines, Kai coal from Kaitangata in South Otago and lignite from Newvale Coal in Waiumu mine near Gore.

Domestic grades are stored in warehouses and merchant yards, with commercial grades being stored in individual customer bunkers.

Domestic Products
Domestic grade coals are the larger screening sizes, generally above 18mm diameter which are more suited for use on an open fire or multifuel appliance.

Commercial Grade Coal
Generally commercial grade coals are screening sizes less than 18mm. Ohai coal or Newvale lignite are the two main products supplied to industries in Dunedin.

Liquid and Gas Fuels



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.

Inward and Distribution Transportation
Solid Energy currently bags its domestic products which are then palletised and transported to Dunedin for distribution from its Portsmouth Drive Retail Centre. Other companies sell in bulk to resellers in Dunedin. Commercial coal from Ohai is supplied to individual customer bunkers in truck and trailer loads of 25 tonnes. If customers' bunkering facilities are unable to handle quantities of 25 tonnes then they are supplied via AJ Allen Industrial Coal from their site in Anzac Ave using smaller trucks.

Quantities Stored
Solid Energy stores 1,100 tonnes of bagged coal at Portsmouth Drive. (This falls to less than 100 tonnes by the end of winter). AJ Allen stores 300 tonnes of industrial grade coal in bulk. Coal Packers at Burnside store less than 200 tonnes. There would be less than 60 tonnes stored at smaller merchant yards. Dunedin Public Hospital stores 60-80 tonnes in its bunkering system, which is about 3 days' consumption in winter.

FUELS - ASSESSMENT OF VULNERABILITY

Liquid Petroleum Products

General Description
The susceptibility of bulk fuel supply to natural and other hazards arises from their being only a single harbour side wharf facility and the close proximity of all bulk storage. There is no diversity with respect to importation of bulk fuels which arrive exclusively by sea.

All of the bulk fuel installations lie within an area of enhanced earthquake potential and the order of vulnerability is consistent throughout the supply system network.

Fryatt Street Oil Wharf
This wharf is constructed on timber piling with a moderately heavy concrete deck but, because of it's robust design for berthing large vessels, it is likely to sustain only minor damage in the event of a worst case earthquake. It is anticipated that the wharf would not be put out of operation, but that some damage could occur to "on deck" pipelines and manifolds. This would include damage to lines which are installed for purposes of ship bunkering.

Steel Pipelines
Where lines are above ground, we may expect fracturing of support brackets due to the probability of some liquefaction and there is a potential for some leakage at flanges. Underground pipelines offer a better survival potential, due to their construction from continuously welded pipe.

It is not possible to differentiate between individual pipelines, but all are considered susceptible and all will suffer to a greater or lesser degree, dependent upon condition. It is probable that fracturing of lines will represent the greatest inhibition to supply, assuming that bulk supply by sea remains possible.

Leith Rail Bridge Crossing
This crossing represents an area of significant vulnerability to hazard impact, though loss of the bridge crossing will only isolate one storage area. The potential damage may be considerable if the structure of the bridge collapses, but is not likely to be a long term loss as temporary service could be made effective within a reasonable time.

Tank Farm Storage
Tests were initiated by BP Oil NZ Ltd. in 1994 to assess the potential damage to its Dunedin bulk storage installation. The conclusion of this report (which we believe may reasonably be extended to the other adjacent bulk storage facilities), was that there is little likelihood of settlement from liquefaction or extreme damage due to earthquake shaking, having due consideration of return periods and statistical probability of earthquakes producing felt intensities of MM VIII or more.

In considering the probability of faulting extending through the harbour area, it is nevertheless possible that intensities greater than MM VIII may occur, in which event we may anticipate some damage to the compacted clay bunds and bunded areas, with possible minor leakage from storage tanks into these areas. It is not anticipated that this event will produce a major derangement of tankage or supply pipelines.

Special User Storage
Above ground bulk user storage tanks at Momona Airport and the Tranz Rail depot in Strathallan Street are both susceptible to earthquake damage, especially from liquefaction settlement. Damage is most likely to result in fracture of supply lines from storage rather than damage to the tanks themselves.

The underground tank at St John Ambulance Station in York Place is expected to survive earthquake damage with minimal leakage.

Gas

General Description
The disasters most likely to cause serious disruption to the Otago Citigas systems are flooding, earthquake and gas fires or explosions.

Flooding
The following may result as a consequence of major flooding:
- Damage to above ground installations.
- Ingress of water into the low pressure system causing local or complete cessation of supply.

Earthquakes
The effects of earthquake will be more apparent on the older lead in jointed systems resulting in loss of supply, major leakage and fires or explosions. In the event of complete cessation of supply the entire system may have to be purged before any supplies can be safely restored.

Fires and Explosions
Under normal circumstances gas is distributed to an appliance, where it is mixed with air and allowed to burn safely. In the event of air entering a gas main in sufficient quantities, an explosive mixture may be created and could explode at any source of ignition. In the event of leakage, explosive concentrations may be found in buildings, underground cavities or any enclosed space which is poorly ventilated. Should leakage occur adjacent to poorly ventilated structures all unauthorised persons will be evacuated to a safe distance and the area will be ventillated.

Land Fill Gas Installation
The recently established Land Fill Gas installation is located in an area vulnerable to tsunami, but not to general flooding. The plant lies on the boundary of an area subject to “enhanced” earthquake shaking.

The effect of flooding from Kaikorai Stream upon the land fill area is considered to be small, but there is a more serious potential for damage from tsunami if the Kaikorai Stream is in flood. Such flooding would severely damage surface structures, cause settlement and markedly disrupt gas production.

Collector System
Because of the nature of the site fill, damage potential to the vertical “collector pipes” through shaking may be significant, particularly in the upper connections and collection manifolds. The proximity of an active fault line in the area increases the risk to this element of the plant installation.
Damage by vehicular impact or vandalism is considered to be small.

The 110mm diameter PVC pressure main from the LFG installation to the south entrance of the Caversham tunnel is encased within a cast-iron pipe sleeve which will suffer damage due to enhanced shaking during earthquake. The gas line however is “pliable” and though it may receive damage due to impact from the cast iron sleeve, it is not likely to be severely fractured in many places.

Beyond the tunnel’s cast iron north portal the line is again sleeved in cast iron pipe to near Carisbrook and thereafter to the Hillside Road plant is bedded in fine material in a trench. This section is likely to suffer displacement from liquefaction and may be severely damaged.

Although critical lengths of the LFG transmission pipe are encased in cast-iron sleeves, flooding may cause local “wash away” with resultant damage which may be accentuated by the light product weight providing no gravity resistance to floatation or sideways thrust when exposed. It is expected that damage will be light, but difficult to repair.

An area where flooding may cause disruption to the supply pipeline is close to the Green Island bridge at the Brighton Road intersection.

Tempering Plant and Storage
The tempering plant at Hillside Road (and other installations at this location which are above ground) are susceptible to enhanced earthquake effect including liquefaction because of the proximity of a fault. This area will likely suffer from derangement and supply may be inhibited for a considerable period. Less likely are effects from flooding and tsunami but, as the area is extremely low lying, they must be considered a risk to the system.

The gasometer at Kensington is founded on good quality rock, but is old and therefore likely to experience structural damage due to shaking or fault movement which could render it inoperable for a substantial period.

City Reticulation
The gas reticulation system is composed of a wide range of pipe diameters of variable quality and age, so any assessment of the vulnerability can only be generalised to give an appreciation of the potential damage. Because of the importance and density of the population area served by gas, further analysis is required.

It is virtually impossible to predict the location of damage to the gas reticulation, but it is expected that there will be many areas where dislocation of pipelines will occur due to ground shaking and many pipe joints and junctions are likely to fracture. This may result in local fire damage and possibly isolated explosion.

Significant areas are liable to liquefaction, tsunami and flooding and serious disruption to service is anticipated.

Little damage is anticipated from escape of gas due to vandalism, leakage or excavation accidents but damage may be considerable when caused by earthquake and followed by explosion or fire.

Service Station LPG Storage and Special User LPG Bulk Storage
The majority of service station bulk storage LPG tanks in Dunedin are within areas subject to enhanced shaking. A similar situation applies to tanks provided for special bulk storage at a number of industrial sites in Dunedin. The form of damage most likely is fracture of underground supply lines to filling points or to manifolds servicing industrial heating plant.

Construction of tankage, support and protection against impact from natural and technological events is already more than adequate with design incorporating protective screening.

Solid Fuels

General Description
As the supply of solid fuels to the city is principally dependent on road transport, disruption of the roading network, particularly towards the south, will have serious consequernces. Rail haulage may be an alternative so long as the permanent way is undamaged and tunnel access is clear.

Bulk Storage
Access to, and storage of, bagged domestic coal supplies at Solid Energy Limited Portsmouth Drive are subject to disruption by earthquake, liquefaction, flooding and tsunami.

At lesser risk are A.J. Allen's stockpiles at Anzac Avenue and many other smaller supplier's storage yards. Coalpacker's yard at Burnside is likely to experience shaking but not liquefaction.

Delivery and Distribution
In spite of the exposed nature of stockpiles, earthquake damage is expected to be minimal.

Dunedin Hospital
A particularly dependent user of coal is Dunedin Hospital for its boiler. Relatively small storage capacity and possible loss of road access make this user highly vulnerable to loss of continuous supply.

FUELS - MITIGATION STRATEGIES

Liquid Petroleum Products

General Description
The existing awareness of the importance of fuel supplies to the continued viability of Dunedin City and its hinterland has been reviewed with respect to the impact of hazards causing delay in replenishment of fuel stock due to damage to port and pipelines facilities.

Storage tanks are generally maintained at good levels, with products being substantially duplicated by the three supply companies involved. Each installation is protected against foreseeable hazard damage under rigid design criteria.

Oil Pipelines from Oil Wharf to Storage Tanks Crossing Leith Rail Bridge - BP Oil Limited

Potential damage may occur to pipelines crossing the Leith Bridge which is a common carrier for other service pipelines. Any failure here will almost certainly be fracturing of the pipelines due to bridge displacement rather than to inherent pipeline condition.

Similarly, pipelines upon the oil wharf may suffer damage due to wharf structure displacement and alternative means for handling product to storage will need to be found.

Distribution of product by land transport is dependent on the availability of suitable road access. The number of road tankers available appears adequate if road access is possible.

Conclusions
Analysis of the liquid petroleum products system has identified the oil industry tank farms and the pipeline network linking them to the Fryatt Street Oil Wharf as the areas where supply could possibly be disrupted by earthquake.

The pipelines are primarily underground with above ground sections in Fryatt Street and across the Leith rail bridge. The majority of the underground sections have been replaced in the 1980's and 1990's and the whole system is subject to a comprehensive annual engineering inspection and a remedial works programme is initiated following each inspection. Each product receipt via the pipelines is also preceded by a pre-use pressure test and visual inspection to verify integrity.

Any earthquake damage to an individual pipeline could easily be circumvented by utilisation of the other lines to receive fuels from a tankship. Likewise, it is envisaged that damaged sections of multiple lines (eg. the Leith Bridge crossing) could be by-passed with temporary pipework in cases of extreme need.

All oil industry tankfarms have been extensively upgraded in the 1990's to ensure their bunded areas are capable of retaining significant spillage. Two new tanks have been constructed in this period and a number of others have had major refurbishments to meet current code requirements which encompass seismic considerations. An ongoing programme of works is in place to accommodate inspection and upgrade of the remaining tanks.

Recommendations
Continue with the existing programme for tank refurbishments and pipeline inspections.

Re-examine contingency preparations for delivery of product from the wharf to the tank farm and across the Leith Bridge. Because there is diverse storage of the same fuels by separate companies and an existing policy of maintaining adequate stock levels, and because it is not practical to duplicate facilities at a lower risk locality, no further mitigatory actions are recommended.

Gas

General Description
Citigas installations and the associated reticulation have been reviewed in the vulnerability analysis, and much of the installation shows a relatively high element of risk. This risk is a function of the exposure of the reticulation and treatment plant to enhanced earthquake shaking, coupled with the age of the asset.

It is therefore difficult to present a case for other than replacement of significant lengths of pipeline, particularly as most sections of the principal gas main have no redundancy. It is considered, however, that progressive repalcement of the most vulnerable elements may be a more acceptable course of action. Indications are that the 400mm diameter main line from the tempering plant to the Kensington gasometer, and the gasometer itself need priority treatment.

Kensington Gasometer - Citigas Limited

Landfill Gas
Due to the modern design standard adopted for construction of the landfill gas plant and reticulation from Green Island, the risk of damage by earthquake is reduced but there may be damage to the vertical collector pipes and manifolds. Flooding at the landfill is a potential problem which may put the gas production out of action for a period, but is not likely to be long term in effect. Nevertheless the service may be unavailable for some weeks.

The tempering plant at Hillside Road is at risk because of its location. While the plant itself is on a good foundation base, there is a possibility of damage due to shaking and settlement between the plant base and its supply pipelines. This should be further examined for possible mitigatory action by installation of flexible connections.

Liquid Petroleum Gas Plant
This modern and sophisticated plant has effective protection against earthquake and flood. Hazard events have been taken into account in the design and it is considered that no further mitigatory works need to be incorporated.

Service Station LPG Storage and Special User LPG Bulk Storage
These users are supplied by bulk LPG road tankers and are essentially stand-alone tanks with modern sophisticated protection gear installed. The standards of design and maintenance are high and further mitigatory works appear to be unnecessary.

Conclusions
The Lifeline most susceptible to damage by natural hazard is that operated by Citigas Otago Limited. This damage potential is likely to be widespread within the reticulation system due to earthquake ground shaking which may cause random joint separation with attendant loss of gas into ground pockets, with resultant risk of fire or explosion.

As a result of age, the general quality of the reticulation pipework is variable with considerable lengths identified as “at risk” from damage by earthquake. Some risk from flooding is also possible and may cause disruption of service for several days whilst “purging” is taking place.

Recommendations
Any mitigatory work will need to be selective and it is recommended that further examination of the supply reticulation will be needed before commitment of capital to replacement of pipework or incorporation of more protective equipment.

In so far as the present review of the system has been made it is considered that mitigatory work should centre on the 400mm main close to the Kensington gasometer and on the gasometer itself.

Solid Fuels

Conclusions
Solid fuel supplies are considered to be at minimal risk from hazards but are dependant upon roading and availability of adequate stock.

Investigation has further raised awareness of the importance of coal supply to Dunedin Hospital and this would appear to be the most significant dependency on solid fuels.

No meaningful physical mitigatory action to ensure supply is required except to ensure continued diversity of stockpiling, adequate quantity availability (particularly in winter conditions) with normal protection being given to loading equipment and transportation vehicles.

Recommendations
Review adequacy of stockpiling with special reference to the Dunedin Hospital.

Prepare a contingency plan for re-supply of solid fuels from existing sources given loss of road or rail facilities.

CHAPTER 6. TRANSPORTATION - CONTENTS

ROADING - DESCRIPTION OF SERVICE

State Highways

General Description
Provision and operation of the principal motor transport routes into and around the City of Dunedin is vested in Transit New Zealand, which maintains a regional office and technical staff within the city in Skeggs House, Tennyson Street, Dunedin.

The responsibilities of the regional office are to provide technical and administrative supervision of all new construction and the general maintenance of the existing State Highway network throughout Otago and Southland.

The principal motor transport route is State Highway 1 (SH1) which passes through the city. Details of highways under regional office control both within and outside the city boundary are set out below.

State Highway 1 (North of City)
State Highway 1 is the major transport route serving the Dunedin area. To the north of the city the highway travels over the Northern Motorway to Waitati and then over the Kilmog Hill to Waikouaiti and beyond. At Palmerston there is a highway junction with State Highway 85. Beyond Oamaru the highway crosses the Waitaki River before entering Canterbury.

Major geographical features affecting the highway are the Waitaki, Kakanui, Waianakarua, Waikouaiti and Waitati Rivers as well as the steep hills of the Kilmog and Northern Motorway sections. The steep hills (particularly the northern motorway) are frequently subject to closures during winter due to snow. The major geological feature which affects the highway is the unstable southern yellow-grey earth formations of the Kilmog Hill which have given rise to continual slip and slump maintenance since it was constructed.

The highway carries moderate traffic volumes of 5,500vpd (vehicles per day) at the northern motorway decaying to 4,000vpd north of Palmerston. Heavy traffic makes up 13% of this volume.

State Highway 1 (South of City)
To the south, State Highway 1 is still the major transport route although there are alternatives within the city area. The highway consists of a one-way, 50km/hr pair from the Gardens through to Andersons Bay Road, followed by a short length of single lane each way partially divided carriageway 100km/hr by-pass around Caversham. The highway then climbs to Lookout Point through a three lane, two way (two southbound and one northbound) 50km/hr section before entering the four lane divided, 100km/hr carriageway Green Island Motorway. Following this the highway again reduces speed to 50km/hr through Sunnyvale followed by a short length at 100km/hr before entering the 50km/hr Fairfield straight. Beyond Fairfield the highway continues as 100km/hr apart from speed restrictions through smaller townships. The Mosgiel interchange is the main interchange south of Fairfield and connects SH1 and SH87. Further south the highway crosses the Taieri River, the Waipori River and, at Balclutha, the Clutha River. State Highway 8 joins the highway at Clarksville Junction just south of Milton.

Geographical features of importance include Saddle Hill, the Taieri floodplain and the hills north and south of Balclutha. The Saddle Hill area is occasionally closed due to snow in winter. Geologically the highway traverses relatively stable country to the south of Dunedin with the exception of silty flood plains between the Taieri River and the Waipori River. The section passing through Fairfield is located over disused coal mines.

Traffic volumes through the city are up to 30,000vpd on the one way pair. This decays rapidly beyond the Mosgiel interchange to be around 8,000vpd south of Allanton.

State Highway 87
State Highway 87 is one of three routes to Central Otago. The other two are State Highway 85 and State Highway 8. State Highway 87 runs from the junction with State Highway 1 at the Mosgiel interchange through the town of Mosgiel then along the western side of the Taieri Plain to Outram. From here the highway heads inland into the Taieri hills and west to the Strath-Taieri valley. The highway then goes through the town of Middlemarch and north to the Maniototo area where it joins State Highway 85.

Major geographical features are the Taieri River at Outram and at Kokonga and the Taieri hills. Frequently during winter the highway is closed between Middlemarch and Outram due to snow.

Traffic volumes are heavy at the Mosgiel interchange (12,500vpd) but drop off rapidly after Mosgiel and beyond Outram the volumes are as little as 500vpd. With the recent completion of sealing of this highway it is likely that traffic volumes will increase faster than the regional average traffic growth rate.

State Highway 88
State Highway 88 is the link between the Central Business District and the main port at Port Chalmers and joins the one-way system (State Highway 1) at St. Andrew Street and has a link to Stuart Street (designated as an off-ramp). From here it travels along Anzac Avenue over the Water of Leith and then sidles around the bottom of the West Harbour hills through Ravensbourne, Maia, St. Leonards, Burkes, past Roseneath and Sawyers Bay before entering Port Chalmers via George Street. The highway terminates on Beach Street prior to entering the port log storage area. The highway follows a narrow twisting route, supported in many places by retaining walls of varying conditions of repair. There are several speed zones in the 13km length of the highway.

Major geographical features are the steep slopes over which the highway sidles and the proximity of Otago Harbour. There are no major watercourses along the route. Geologically the main feature is the potentially unstable brown granular clay slopes which could compromise the retaining walls or slip on to the highway.

Traffic volumes are moderate at 9,500vpd on Anzac Avenue and 4,500vpd at Sawyers Bay. The heavy traffic proportion was 8% in 1990 and may have risen since due to the port generated traffic, particularly logging trucks.

State Highway 8
This State Highway which lies outside the Dunedin City area begins north of Timaru and runs west through the Mackenzie Country then south into Central Otago over the Lindis Pass then east through the Cromwell Gorge and Alexandra, alongside the Clutha River and out to State Highway 1 at Clarksville Junction. The route is a preferred one for vehicles from Dunedin into Central Otago and the Queenstown-Lakes area, and is therefore an important linking highway in servicing the city.

The highway has been subject to slips and flooding on a number of occasions in recent years and is also affected by snow and ice during winter. Traffic volumes are 1,700vpd west of Clarksville Junction.

State Highway 85
This State Highway runs from State Highway 1 at Palmerston through the north end of the Maniototo Valley then down the Manuherikia Valley to join State Highway 8 at Alexandra. The highway is affected by snow and ice during winter. Traffic volumes are 950vpd west of Palmerston.

Highway Structures
There is a total of 67 State Highway bridges, large culverts or subways within the Dunedin City area. State Highway 1 has 26 bridges, 6 large culverts and 5 subways, State Highway 87 has 18 bridges and 8 large culverts and State Highway 88 has 3 bridges and 1 large culvert. Most of these structures are made of reinforced concrete and have a modern form of construction, that is, built from 1955 onwards. This means that they have some features, such as linkage rods between spans, to minimise the chance of a superstructure span dropping off the piers during an earthquake. However one older bridge with multiple column piers has only limited ductility and this could lead to failure from a large seismic loading. In several places the highway is supported by retaining walls which may move during an earthquake. Any such failure is likely to affect any one lane and therefore would not entirely cut road access.

Principal structures considered are:

• State Highway 1 (North)	Tumai Overpass
	Waikouaiti
• State Highway 1 (South)	Waipori
	Taieri
	Allanton
	Mosgiel Overpass
• State Highway 87	Taieri Bridge Outram

Major City Connector Routes

Dunedin City has urban arterial routes running both north to south and east to west. The strongest of these routes comprise State Highways 1 and 87 and State Highway 88 to the port facility in Port Chalmers. Urban arterials under the City's control, form strong alternatives within the city boundaries.

The strongest non-State Highway route from the metropolitan area to the west is Three Mile Hill Road. This allows a western access to Mosgiel, the Taieri Plains and Central Otago. It also provides an alternative route to the Dunedin Airport. Three Mile Hill Road also connects to major routes to the south (State Highway 1) and west (State Highway 87).
Three Mile Hill Road starts at the top of Taieri Road and continues onto the eastern section of the Taieri Plains and further access to the west via Dukes Road. The Three Mile Hill Road has recently been resurfaced but is prone to closure in the winter from snow and ice.

Kaikorai Valley Road is an urban arterial that runs from the intersection of Stuart Street and Taieri Road and follows the valley until it intersects with the State Highway 1 on-ramp at Burnside Corner. It gives access, via Townleys Road, to the Southern Water Reservoir. It is wide in formation and has a pavement suitable for high volumes of traffic.

Alternative routes to the south include the Brighton Road route to Taieri Mouth Road which begins at the intersection of Main South Road and State Highway 1, at the southern end of the Green Island township. This route can also access State Highway 1 via the Taieri Mouth - Waihola Road. Brighton Road is a medium width road which is sealed but has surface undulation in many places and a history of pavement failure. This is due mainly to the excessive heavy traffic loadings involved with recent forestry developments and harvesting. At various places along Brighton Road there are alternatives to reach State Highway 1 and the airport. These are mainly unsealed, narrow and winding in nature, but provide an alternative. Brighton Road has numerous culverts and one bridge of importance located just south of the Island Park Golf Course and which straddles the Kaikorai Estuary and is old but appears adequate for is present purpose. Taieri Mouth Road continues to the township at Taieri Mouth which is outside the Dunedin City boundary.

The pavement characteristics of major urban arterials in Dunedin City are of adequate pavement depth with either a two coat chip seal or asphalt surface finish. All urban arterials are regularly maintained to ensure the integrity of the surface.

Major bridge installations serving the City include the Cumberland Street Overbridge, which straddles the rail precinct in the Central Activity Area and links State Highway 1 on Crawford Street. It is accessed through four on/off ramps and a central ramp from Crawford Street. There are also two bridges of major importance on Chain Hill Road over State Highway 1 and at the Mosgiel interchange. At the intersection of Stuart Street and Highgate a bridge on Highgate provides grade separation over Stuart Street. It has two on ramps and one off ramp, recently improved or of new construction.

Suburban Link Routes

Alternative connectors to State Highways are Leith Valley Road to the north and Kaikorai Valley Road to the south. Leith Valley Road is an unsealed winding road that runs adjacent to the northbound State Highway 1 and is accessed from George Street via Malvern Street and connects to SH1 above Waitati.

Routes to the north, other than State Highway 1 include the North Road/Norwood Street route to Mt Cargill Road. This also allows access to the port facility at Port Chalmers via Blueskin Road. The Norwood Street route was previously the main northern route out of Dunedin but is currently a collector road on the Dunedin City road hierarchy and is narrow, winding and sealed with many corners which have to be negotiated at low speeds.

Access from or to the beach fronts at St Clair and St Kilda can be gained by using Queens Drive, King Edward Street and Andersons Bay Road in the north and Forbury Road in the South. Both Forbury Road and Andersons Bay Road are of high quality pavement catering for medium to high traffic volumes and both have sufficient width for two lanes of traffic in each direction if required. Forbury Road, however, has the St Clair cliffs overlooking it. King Edward Street, a collector road in the Dunedin City Council road hierarchy, starts at Victoria Road and continues until it intersects with Princes Street at the southern end of the Central Activity Area.

Routes to and from the Otago Peninsula are based around either Highcliff Road or Portobello Road. Portobello Road is a narrow, winding, sealed road adjacent to the Otago Harbour running from Andersons Bay Inlet to the township of Portobello. From there it continues as Harington Point Road which runs to the lighthouse facility at Taiaroa Head. At points on this road, traffic speed is required to reduce dramatically to negotiate the corners. Highcliff Road is the alternative route to the township of Portobello and the southern side of the Peninsula. It runs along the top of the Peninsula hills is sealed and winding in nature and becomes very narrow at the top of its climb to the hills. The pavement and surface are in good condition and adequate for the low to medium traffic volumes it must handle.
Highcliff Road gives access to water reservoirs and radio station transmitter facilities around Camp Road and Sandymount.

Stuart Street Overbridge - Civil Defence

Service Access Roads

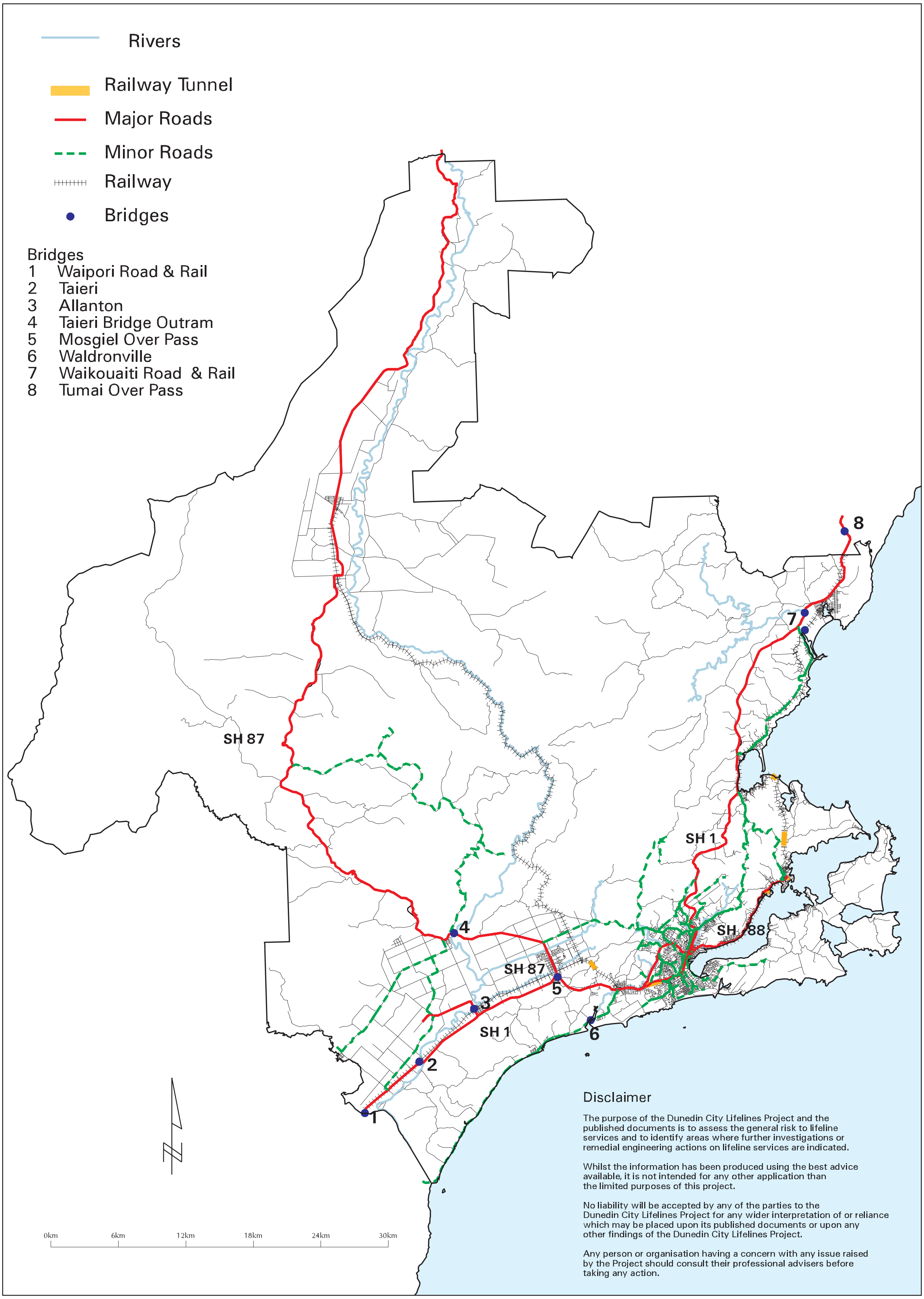
Some key lifelines sites are at remote locations serviced either by minor roads or specific access roads. These are generally narrow gravel roads which have little or no other purpose for being maintained. Typical of these are roads servicing Swampy Summit and Mount Cargill communication sites, the Mount Grand Water Treatment Station and the Southern, Ross Creek and Sullivans Dam water reservoirs. Other facilities are generally serviced by normal suburban roads.

City Bridges

A summary has been made of major bridge structures situated on arterial routes (other than State Highways) which may be at risk in the event of a major natural disaster. Arterial routes considered in this appraisal are:

- Stuart Street - Taieri Road.
- Brighton Road - Green Island to Brighton.
- Kaikorai Valley Road.
- Leith Valley Road.

Transport and Bridges (Rural Area)



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.

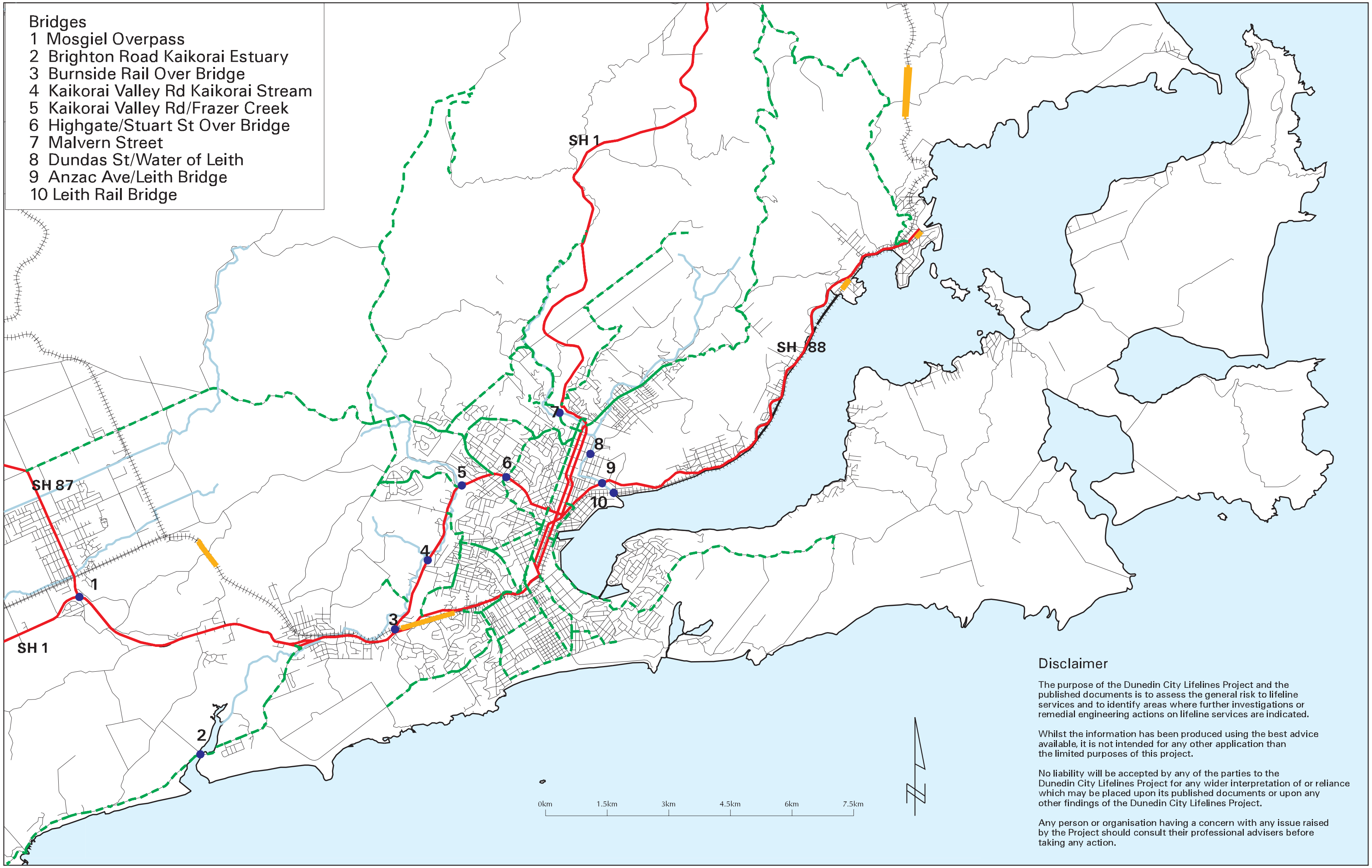
Whilst the information has been produced using the best advice available, it is not intended for any other application than the limited purposes of this project.

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
June 17, 1999

Transport and Bridges (Urban Area)



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.

Rivers

Railway Tunnel

Major Roads

Minor Roads

Railway

Bridges

City Consultants
June 17, 1999

ROADING - ASSESSMENT OF VULNERABILITY

State Highways

Assumptions used
A number of assumptions were made in carrying out the vulnerability analysis described in the section on methodology:

Assessment Item	Assumptions carried to Chart
Technology	Bulk fuel / gas storage sites assessed as posing a direct hazard through explosion damage to the highway structure. The effects of lack of fuel on transport following an event has not been considered.
Fragility	The "standard" to which roads are designed does not include for earthquake or liquefaction movement. Therefore sections prone to these effects have all been assigned 4 points for fragility. The design of bridges does allow for these factors and they are assigned points in accordance with their structural capacity. For flooding and landslides 2 or 3 points have been assigned depending on the perceived resilience to damage of the asset.
Redundancy	Parallel routes have generally not been assumed to provide full redundancy. Widespread events such as earthquakes are likely to affect parallel routes as well as the primary route.
Cost	Due to the expense of roading reinstatement and the funding policy where for any emergency event over $20,000 funding must come from the Transfund emergency fund we have made the assumption that all costs are "major impacts" where funding is sourced from external sources (i.e. Transfund). It may be argued for the highway that this is moderate impact where costs are funded by reprioritising of programmes.

State Highway 1 (City Area)
The section of SH1 through the city between Caversham and Pine Hill will be affected by:
- Liquefaction during earthquake events.
- Flooding of the Water of Leith.
- Tsunami where the highway is below the 5m contour level.

A prominent fault trace runs through the harbour and SH1 is vulnerable to being blocked by building collapse and landslip. Movement along this fault will invariably cause disruption along a significant length of highway with liquefaction and earthquake damage likely to affect water, gas, sewerage, power, and telephone hardware buried within the road. Effects of service failure are likely to impinge on road reinstatement and in particular washouts and flooding due to burst water pipes, will create serious disruption.

Should SH1 be incapacitated, there are numerous parallel routes through the city. It is likely, however that any event of sufficient size to affect the State Highway will also affect the alternative routes, so the security of this section of the route is very important.

State Highway 1 (North of City)
The Northern Motorway (Pine Hill to Waitati) will be affected by:
- Snow and ice during winter (short term closures only).
- Earthquake and rain generated landslides.

The long term effects of road closures due to snow are minimal but a larger scale event such as an earthquake will have extensive effects. While the Northern Motorway is supported by two alternatives (Mount Cargill

Road and Blueskin Bay Road), it is likely that one or both of these routes will be affected to a similar or worse degree than the State Highway. Bridge structures are also likely to be affected and this is covered separately in a section which follows.

Between Waitati and Waikouaiti, the road will be affected by:
- Tsunami.
- Flooding of the Waitati River.
- Flooding of the Waikouaiti River.
- Instability in the Kilmog area.

North of Evansdale the Coast Road offers an alternative route to Waikouaiti. This road is of low standard but would suffice as temporary access (should it remain usable) for light vehicles while State Highway 1 is being repaired. The Kilmog Hill is susceptible to landsliding and general slope instability. An earthquake, could trigger a major landslide (15m depth x 100-200m in length) over this section. Heavy rainfall or snow will also temporarily close the road on a regular basis.

Flooding of the Waikouaiti River between Merton and Waikouaiti occurs occasionally and a large flood will cause major scouring to the existing road and supporting embankments, with closures of greater than two days anticipated. Alternative routes between Dunedin and Waikouaiti include State Highways 85 and 87, although these involve detours of over 100km.

The section between Waikouaiti and Palmerston is expected to be relatively sound following an earthquake, although some minor slips can be expected. Flooding or tsunami damage to sections of the highway will cause disruption but is likely to be repaired reasonable quickly.

In the case of widespread flooding or snowstorms, equipment and human resources are likely to be stretched. This will have an impact on the time required to recover the serviceability of State Highway 1.

State Highway 1 (South of City)
Between Caversham and Milton, the road will be affected by:
- Liquefaction during earthquake.
- Landslides in the Green Island and Saddle Hill areas.
- Flooding on the Taieri Plains.

The overall vulnerability of this link is identified to be lower than for the section north of Dunedin. Alternatives routes between Dunedin and Mosgiel exist, with Three Mile Hill being the most obvious.

The flood free highway between Mosgiel and Waihola has improved the reliability of the route during flooding of the Taieri and an alternative low standard route exists along the coast.

A fault along the eastern side of the Taieri Plain could cause severe disruption to the road should a sizeable earthquake occur, although alternative routes exist along the western side of the plain.

The section through Fairfield is subject to settlement due to the presence of old mining works.

State Highway 87
Between Mosgiel and Middlemarch the road will be affected by:
- Flooding of the Taieri river near Outram.
- Liquefaction during earthquake.
- Snow and ice closures during winter.

Flooding of the Taieri River at Outram and Kokonga have caused closure of the State Highway in the past with a central section of the Outram bridge being washed away in 1981.

Snow and ice closures occur frequently between Outram and Middlemarch during the winter months but these are generally short term (1-2 days) and often occur during widespread snowstorms that also affect State Highway 85 and State Highway 1 north of Dunedin.

The State Highway 87 route links Dunedin with Central Otago. Alternative routes consist of State Highway 85 (Pigroot) through Ranfurly and State Highway 8 through Roxburgh. Closure of State Highway 87 would not be considered to cause serious disruption to the central Dunedin city area, although, combined with closure of State Highway 8 and State Highway 85, the effects would be substantially increased.

State Highway 85
State Highway 85 is technically outside the area being investigated by this project but closure of this link to Central Otago will have adverse effects on commercial and tourist activity in Dunedin. The highway is prone to snow closure during winter, generally for periods of less than 2 days and the Deadhorse Pinch landslip will fail in a sizeable earthquake closing the highway, potentially for several days. Alternative routes into Dunedin exist via State Highway 87 and State Highway 8.

State Highway 88
State Highway 88 will be affected by:

- Liquefaction during earthquake
- Tsunami
- Landslides
- Flooding

State Highway 88 is of significant importance as it provides the only means of access for heavy vehicles to Dunedin's main port. Closure of this link essentially cuts road access between the city and the port, although alternative access is available via Blueskin Bay Road. This road is of poor geometric standard and is unsuitable for commercial use and access by emergency vehicles should be possible, assuming the route has not been affected by the event which closes State Highway 88. Harbour transport could be used for emergency access if both routes are lost.

State Highway 88 follows the harbour coastline for the majority of its 13 km length. Steep slopes stand above the highway, many of which are supported by retaining walls in various conditions of repair. Seismic activity in the Dunedin area is likely to cause potentially large landslides to cross the highway. Sections are also retained at various locations below the highway directly adjacent to the harbour edge and failure of retaining walls and causeway support is likely to take several days or weeks to repair.

The potential for economic impact is considered to be high as a substantial amount of Dunedin's trade is routed through Port Chalmers. Loss of commercial access to this facility will undoubtedly affect the city's operation. The entire length of the highway is also within the high tsunami risk zone and effects of a large tsunami would cause similar disruption to a major earthquake.

Highway Structures

To the North of Dunedin
The Waikouaiti River bridge has unrestrained roller bearings at one end of the 3 spans and with a large seismic loading it is likely that one span would drop into the river.

The Waitati River bridge has piers with little ductility which is likely to lead to a pier failure from a large seismic loading. If necessary a temporary ford can be constructed.

The Patmos Avenue underpass has its north abutment founded on a slope which is likely to move with large seismic loading. The original bridge was lengthened to cope with earlier slope movement but further movement could cause the bridge to collapse. Failure of this bridge will only block State Highway 1 until the debris can be cleared.

To the South of Dunedin
The bridge over State Highway 1 at Otokia may be critical. Although it has linkage rods, they may not be strong enough to keep the bridge intact given the long length of the structure (370m) which could expose it to different phases of the earthquake wave. The current detour route via the old Henley bridge is out of service while the bridge is being brought back to a standard suitable for light vehicles and heavier vehicles still may not be able to use this detour in the future.

Deep Stream bridge on State Highway 87 has a masonry pier and approach fill at the southern end which has moved in the past. During a large seismic event either one of these deficiencies is likely to cause damage to the bridge.

The State Highway 1 Abbotts Creek bridge, which can be regarded as a critical bridge, is likely to have slumping of its approach fills during a large earthquake.

The Taieri River Bridge on State Highway 87 which was damaged during the 1980 flood has since been strengthened against both flood and seismic loadings.

Major City Connector Routes

The major arterial routes within Dunedin are under the control of Dunedin City Council and provide intra-linking between state highways and other major connectors.

Three Mile Hill Road is an alternative east-west link from the city to the Taieri and beyond. It is prone to adverse impact due to weather and fault proximity. During winter months the road is exposed to impact from ice and snow, which increases accident potential and reduces access by limiting the alternatives for vehicles travelling east to west. A fault trace crosses Three Mile Hill Road and could cause land movement and direct impact from the fault.
Loss of this link to the west leaves State Highway 1 as the only major route available to cope with larger traffic movements.

Kaikorai Valley Road is the link from Stuart Street to Green Island and hence is a major route from the city to the south and has a pavement structure consistent with its heavy volume of traffic.
The area of Kaikorai Valley Road has been identified as being subject to earthquake amplification and there have, in the past, been isolated incidents of land instability. The impact of earthquake activity is the highest risk, although there is a potential for flooding from the Kaikorai Stream all along the valley, particularly where the stream crosses the road at various points.
Kaikorai Valley Road is a strong link within the city's major connector network, providing access to an industrial area located at the southern end of the road. Loss of this link north of this point limits the access for industrial vehicles and requires use of the suburban hills for through traffic.

The alternate connector route that gives access to the south is Brighton Road / Taieri Mouth Road. Brighton Road is susceptible to amplification of earthquake intensity and to tsunami and flooding from the mouth of the Kaikorai Stream at the estuary. There is a fault trace off-shore from Brighton Road which gives potential for increased earthquake intensity and impact. The road surface itself is subject to pavement failure in places mainly due to heavy logging traffic use. The impact of a tsunami would be severe here as Brighton Road runs along the shoreline at a low contour interval (<20m) and is built on a sandy base which would not withstand the impact. A tsunami would adversely effect the whole area adjacent to the road as well as the road itself. Loss of this link north of Scroggs Hill Road would limit access to properties in Brighton and Ocean View, although alternatives are available through Scroggs Hill Road and McIntosh Road to the north and other links with Taieri Mouth Road to the south. The potential for flooding centres around the Kaikorai Estuary, which is the outlet for the Kaikorai Stream and in extreme flood conditions could undermine the banks and hence the structural integrity of the Brighton Road formation at this point. The bridge structure is also highly susceptible to enhanced shaking and flood damage due to its age and construction.

Taieri Mouth Road is the continuation of Brighton Road past the Brighton township, and is of the same basic pavement structure as Brighton Road with some recent upgrading and enhancements. The potential impact from tsunami and earthquake due to the proximity of a traced fault, are the greatest risks that are apparent. Taieri Mouth Road is located along the shoreline to the Taieri Mouth township from Brighton below a 20m contour level. It is built on a sandy base which would be susceptible to failure when exposed to large quantities of water. If Taieri Mouth Road were to be cut off it would leave the alternatives to the south as State Highway 1 from Mosgiel, and the other minor unsealed east-west links to the State Highway from the coast.

Suburban Link Routes

Suburban links to the north, other than by State Highway are Leith Valley Road from Malvern Street, North Road/Norwood Street to Mt Cargill Road and the Port Chalmers link by Blueskin Road to Waitati.

Leith Valley Road is at risk from proximity to a fault trace to the west, its limited formation depth and strength and to limited impact from surface water in heavy rains and /or storms.

From the Port Chalmers and West Harbour areas an alternative route north is by Blueskin Road from Port Chalmers, given that State Highway 88 is accessible. Blueskin Road climbs to near the top of Mt Cargill and is susceptible to weather extremes such as snow and ice.

Mt Cargill Road is narrow and winding and exposed to weather extremes such as snow and ice and at times may be impassable to traffic.

North Road and Norwood Street lead in to the Mt Cargill route to the north and are at risk from landslide and earthquake amplification due to the nature of the underlying soil types in the area which would place the carriageway formation at risk from subsidence and cracking.

In St Kilda and St Clair, roads that would be lifeline links adequate to carry larger volumes of traffic in an evacuation are King Edward Street, Forbury Road, Andersons Bay Road, Hillside Road and Victoria Road.

King Edward Street is located below the 2 metre contour on soils sensitive to liquefaction. In an earthquake of reasonable magnitude these soils will liquefy and become unstable with a tendency to flow and subside which will undermine the structural integrity of the pavement. A tsunami would have adverse effects on the link to the southern suburbs and limit access to the coast.

Forbury Road is on the boundary of unstable soils in South Dunedin and at the eastern end of the road is in an area of soils prone to liquefaction. It is below the St Clair cliffs and close to an inferred fault trace.
Loss of the Forbury Road link would leave other alternatives for access to the east, although these links are prone to the same adverse impact from tsunami and earthquake.

Victoria Road provides a north - south link from King Edward Street /Prince Albert Road to Forbury and basically follows the coastline. It is exposed to the same impacts from tsunami and earthquake due to being below the 2 metre contour and located on soils susceptible to liquefaction and amplification of earthquake intensity. This would lead to a degradation of the subgrade and failure of the road. The loss of this link leaves few north - south alternatives in the area with equal capacity for traffic.

Andersons Bay Road is an important arterial road which runs from St Kilda in the east to connect to the Southern Motorway near the Oval and is exposed to tsunami and increased impact from earthquake. It is also built on sensitive soils and could be prone to amplification of earthquake intensity.
Loss of Andersons Bay Road would leave other roads in the area as alternatives but as stated before all the roads in this area of South Dunedin have similar vulnerability characteristics from tsunami, liquefaction of soils and amplification of earthquake intensity. Andersons Bay Road is also built on what was the original coastline before reclamation of the foreshore area.

Hillside Road is a collector link in the road hierarchy and carries moderate levels of traffic with normal peak periods. It links the southern part of South Dunedin with the important arterial links from Forbury Road to Kind Edward Street. Although more inland than most roads in the area it is still exposed to sensitive soils and possible amplification of earthquake intensity. Tsunami is a real threat at the eastern end of the road. Loss of this link would increase volume on Macandrew Road or other more minor roads but Macandrew Road is exposed to the same extent as other roads in South Dunedin and is susceptible to liquefaction of underlying soils, earthquake amplification and tsunami.

The hill suburbs of Mornington, Maryhill and Maori Hill provide alternative links to major arterials that connect east to west in the city and give access to a large section of the residential housing in Dunedin.

The link from Princes Street to the west is High Street and Mailer Street. High Street is a very steep street but its vulnerability is not as extreme as others in the city. It has some risk from shaking and there are a number of historic buildings on its frontage but it would appear that the underlying strata will withstand reasonable impact. Tsunami is only an issue at the intersection with Princes Street. From the High Street/Mailer Street link is the Elgin Road/Mornington Road link which runs from Mailer Street to the intersection with State Highway 1 at Lookout Point. Both Elgin Road and Mornington Road are susceptible to amplification of earthquake intensity.

An alternate route to the south via Easther Crescent, Middleton Road and Blackhead Road to Brighton Road is sealed and recently upgraded but the route is steep in places and susceptible to landslips. Blackhead Road is in close proximity to an inferred fault trace but no other evidence of hazard amplification is apparent. The route is not at risk from tsunami as it follows the coastline at a sufficient height above sea level, and earthquake hazards are the same as most areas in Dunedin.

Two main routes to the western area of the city are State Highway 87 and George King Memorial Drive.
George King Memorial Drive starts near Outram and intersects the State Highway half way to Middlemarch.
At the southern end of the Drive some amplification of earthquake magnitude could occur.

Service Access Roads

Access to water reservoirs located off Townleys Road relies on Kaikorai Valley Road being open. The Kaikorai Stream is bridged by Townleys Road and is susceptible to severe flooding conditions.

Mt Grand Water Treatment Station can be accessed from Dalziel Road by Three Mile Hill Road or Brockville Road. This access does not appear to be at risk from hazards other than meteorological with snow and ice presenting major problems in this area.

Access to Ross Creek is via Malvern Street to Tanner Road. Malvern Street is located off George Street and is in the potential flood area of the Water of Leith. Alternate routes from Wakari and Maori Hill are subject to landslipping and to adverse weather conditions.

Highcliff Road on the Peninsula gives access to radio and telecommunication facilities. The major hazard is snow, ice and dense fogs that are common as well as landslip due is earthquake shaking.

The service roads for Swampy Summit and Mount Cargill are at high elevations and therefore exposed to extremes of weather which can render them impassable. They are generally not susceptible to earthquake but some land movement could occur.

City Bridges

Natural disasters which may impact on bridges are flood, earthquake and tsunami or storm surge.

Location of Structure	Damage expectation
Highgate/Stuart Street Overbridge	Loss of embankment, some structural damage in severe shaking with potential collapse over road.
Brighton Road - Kaikorai Estuary	Loss of embankment in flood or tsunami, structural damage in severe shaking and approach embankment subsidence.
Brighton Road/Otokia Stream	Flood or tsunami loss of right embankment, structural damage and failure of right embankment in severe shaking.
Kaikorai Valley Road/Kaikorai Stream	Flood loss of embankment in severe event, structural damage due to enhanced shaking in earthquake.
Kaikorai Valley Road/Frazer Creek	Flood loss of embankment and similar loss in earthquake.
Burnside Rail Overbridge	Some structural damage in severe earthquake shaking event.
Dundas Street/Water of Leith	Severe structural damage or failure in flood or earthquake.
Malvern Street/Water of Leith	Severe structural damage or failure in flood or earthquake.

ROADING - MITIGATION STRATEGIES

State Highways

Transit New Zealand has developed a comprehensive response programme to undertake remedial work immediately following a hazard event.

This has been adopted as the means of recovery rather than by initiation of direct mitigatory action because it has been found impractical to determine specific locations for expenditure of large sums of money on a cost effective basis.

The exception to this philosophy can be the bridging elements of the State Highways where, in some instances, effective work may be done on upgrading. Bridges frequently present barriers to movement which are difficult to circumvent and are not easy or cheap to replace or repair even on a temporary basis.
Neither in depth examination nor structural calculation have been made in the identification of mitigation works, but a number of bridges have been nominated for further structural analysis to determine the need for and aspects of mitigation. Among these bridges are:

- Taieri River Bridge SH87
- Deep Stream Bridge SH87
- Lee Stream Bridge SH87
- Waikouaiti River Bridge SH1
- Waitati River Bridge SH1
- George Street Overbridge SH1
- King Edward Street Bridge SH1
- Taieri River Bridge SH1

The bridges have been reviewed on the basis of hazard maps, bridge photos and the bridge descriptive inventory only. This data provides only a general review of the bridge and its foundation type. The bridge drawings were not available at this stage so information on linkage arrangements, pile sizes, inclination of piles (raking), number of piles, abutment widths, pier detailing and borehole logs etc, was not examined. These details have a major effect on the damage to any bridge and the strength of the individual elements. Consequently the type and extent of damage to the bridges is only guesstimated from a generic structural type and individual damage and strengthening requirements for any bridge may differ widely from that assumed.

For the majority of the bridges a site specific study is required together with a design review. This will determine understrength elements, the extent of probable damage and the most cost effective method of strengthening where required. For the small single span bridges and box culverts it may only be necessary to review the drawings.

Conclusions
General observation on pavements is that maintenance, as currently provided, represents the most cost effective solution to protection of the roading system.

Bridges, particularly those mentioned above, need further examination in detail to determine whether mitigatory work is appropriate and at what cost. Transit New Zealand has a current investigation budget which may permit such work to be undertaken.

Recommendations
Continue the well established general maintenance programme and review of critical structures on the State Highway network.

Major City Connector Routes

From the Vulnerability Analysis it is clear that the highest risk posed to the road network is on the southern coast (Brighton - Taieri Mouth Road), Stuart Street in and Three Mile Hill Road.

Measures to be used to minimise the effect of natural disasters are in themselves not enough to maintain the lifeline. Strategies must also include how to open the lifeline once disaster has struck. The previous stages of the lifelines project have identified alternative routes for most major connector routes and in particular those identified as having a high vulnerability.

Ongoing access and pavement upgrades and improvements are budgeted items and form part of the City Council 20 year strategic plan.

Mitigation Measures

- Review structural standards for all major city connector routes.
- Identify sources of plant and machinery for use in recovery operations. These are to be categorised by the nearest location to a vulnerable lifeline.
- Slip prone areas on the suburban hills, Abbotsford, Green Island, East Taieri are to be examined for the need for retaining structures.
- Identify strategically important service lines (power, water) buried beneath roads. Work with the service authorities to ascertain vulnerability.
- Review construction methods for services located within roads (pavements, overlays and backfilling) and examine their vulnerability. Prepare a remedial list of repair works for trenches and pavement upgrade.
- Overhead services can be hazardous in an event. Investigate expanding the 'undergrounding' program for power supply.
- Formulate a response strategy to a natural disaster. All plant, machinery, personnel, and materials that are required are to be defined and identified.
- Service roads to water and power supply operations shall be examined and upgraded in accordance with their vulnerability.
- Prepare diversion plans for key routes to avoid known hazard areas.
- Formulate debris clearance plans for Brighton Road, Kaikorai Valley Road, Stuart Street. The plan may also be applied to unforeseen damage to other roads in the network.
- At particular risk from snow storms is Three Mile Hill Road. Historically, clearing of this road has been difficult and measures should include a recovery plan for severe snow storm and for subsequent gritting.

Suburban Link Routes

From the vulnerability analysis, the most at-risk suburban linking routes and rural links are Portobello Road, Coast Road, King Edward Street, Portsmouth Drive, Macandrew Road, Victoria Road, Andersons Bay Road and Highcliff Road. There are others that have a moderate risk to natural disasters, but strategically these roads are of less importance.

The majority of the risk seems to be in the South Dunedin area and around the coastal fringe (liquefaction, shaking, amplification and tsunami). It is likely that the most at-risk areas would need to be evacuated in the event of a tsunami warning and would require extensive recovery resources in the event of a severe earthquake. Some risk is also seen on the hill suburbs but this is less severe.

Mitigation Measures

Tsunami or Storm Surge

- Give priority for recovery to Portobello Road, Portsmouth Drive, Macandrew Road, Victoria Street and Andersons Bay Road
- Formulate an evacuation route to the hill suburbs which takes account of numbers of residents in effected areas and the capacity of the roadway. One-way and intersection controls may need to be utilised.

Earthquake

- Clearing of debris and repair to roads are priorities.
- Formulate a recovery plan for effected areas and important lifeline roads.
- Investigate current lateral resistance of the underlying subgrade. This identifies the location of power sources, fuel sources and plant, emergency labour and machinery for recovery operations.
- Formulate a plan for crossing structures for failed road surfaces. Identify the location of resources for crossing structures and a methodology for placement.
- Prepare a recovery plan to be used to open alternate routes to State Highway or major connector routes if these are unable to be used. Prioritise sequence of work for road network lifeline recovery.

Service Access Roads

The majority of these roads consist of unsealed access for service providers and are themselves accessed from suburban connector or link routes. Because of their constant use by service providers they are generally well maintained but it is not possible to pre-determine the risk element which may impact on access, nor the location of damage because of the extensive route length involved.

Mitigation Measures

Mitigation strategy is largely based upon giving priority repair status to such damage as may occur to service access roads. While little pre-planning will be effective, identification of localities which may require disaster management is a valuable mitigation objective in itself.

Recognised as of particular significance are access routes leading to water supply and treatment works and to communication services.

City Bridges

All major city connector routes are exposed to some degree of risk by natural hazards. Some city bridges are likely to be significantly at risk from earthquake shaking, liquefaction and landslip. The extent to which this exposure can effect the loss of a lifeline is proportional to the mitigation of effects that Dunedin City Council needs to consider with respect to bridges and the routes they service.

Dunedin City Council has a bridge renewal and upgrading program that will implement many of the suggested investigations for the bridges contained in high priority lifelines.

Bridges at risk and mitigation strategies are:

Location of Structure	Mitigation
Highgate/Stuart Street	Examine strengthening of the embankment for lateral and longitudinal strength
Brighton Road/ Kaikorai Estuary	Stabilise embankment and protect footings from washout
Brighton Road/Otokia Stream	Examine options for upgrading right embankment for flood impact and slope failure from shaking
Kaikorai Valley Rd/ Kaikorai Stream	Investigate structural strength for lateral movement.
Burnside Rail Overbridge	Examine structural strength upgrade for lateral movement
Kaikorai Valley Road/ Frasers Creek	Investigate strengthening of footings and embankment against impact of flooding.
Dundas Street/ Water of Leith	Investigate structural integrity of footings and embankments for failure potential in severe flooding/ earthquake event.
Malvern Street/Water of Leith	Investigate structural integrity of footings, sub/super structure connections and embankment retaining for failure potential in severe flooding or earthquake event.

Mitigation Measures

- Investigate bridges on major city connector routes and identify alternative routes.
- Identify strategically important bridge structures and undertake a technical assessment of structures in accordance with vulnerability analysis of lifeline routes.
- Where appropriate strengthen structures for both lateral and longitudinal movement and stress.
- Examine bridge structure connections to road structure, columns and retaining structures and strengthen as required.

Conclusions

The Greater Dunedin City area is generally susceptible to earthquake hazard which makes it impossible to be cost effectively selective in mitigation of damage to the roading network whether this be state highways or other routes. While it is recognised that some routes are more susceptible to hazard damage than others it is considered more appropriate to manage any reconstruction measures to carriageways rather than commit large capital expenditure to mitigate in these areas.

Bridge structures are more readily identified as being at-risk, but modes of failure are particularly difficult to predict and it is considered that, while some strengthening may be undertaken, planning for restitution is, in many cases, the best course of action.

Asset managers are alert to the need for continual improvements of the overall transport network and the Lifelines project has enhanced awareness of the impact of natural hazards in general.

Recommendations

Both Transit New Zealand and Dunedin City Council propose to continue their existing management planning with ongoing pavement, bridge and general access improvement.

HARBOUR - DESCRIPTION OF SERVICE

Sea Channel

Entrance Channel to Port Chalmers

The entrance channel of length 4.2km terminates just inside the line of Aramoana Beach. This section is in an open seaway and extends through the coastal sand littoral drift system. The channel has a least depth of 13.2m and a minimum bottom width of 180 metres. Under the influence of Taiaroa Head on the south side and the rubble mound training wall or mole on the north side it is largely self scouring.

The lower harbour channel extends from Harington bend just inside the beach line to Port Chalmers, a distance of 8.7 km. This section is in sheltered waters and has a least depth of 12.2 metres and a minimum bottom width of 180 metres. A number of training walls hold the channel in position at Harington bend. From there to Port Chalmers the channel is effectively defined by the headlands to the bays. The lower harbour channel terminates at the 350 metre diameter swinging basin off the Port Chalmers wharfs. The bed of the channel is fine to medium sand and dredging is required to clear sand from the inside of the bends, sucked up the channel from the littoral drift system by tidal currents.

Inner Channel to Dunedin.

A short, deep 1.6 kilometre section of channel links Port Chalmers to the narrow passage between Goat and Quarantine Islands. The Victoria Channel (9.8 kilometres) extends from the islands to the 280 metre swinging basin off Victoria Wharf. Victoria Channel has a least depth of 7.5 metres and a minimum bottom width of 80 metres. Bed conditions are mostly sandy but with mud from Ravensbourne to Dunedin. As for the lower harbour, fine sands worked up the channel by tidal currents have to be dredged from the inside of bends. A half tide rubble mound training wall on the eastern flank assists with scour and prevents ingress of material to the channel.

Marine Control

The Taiaroa Head Signal Station is the controlling agent for shipping in the harbour. No ship can enter the harbour without the approval of the signal station which also acts as an observatory on sea and weather conditions for pilotage staff. It records and broadcasts hazards within the harbour and the immediate coastal zone. The signal station is extensively equipped with radio, radar and telephone communications equipment.

The Taiaroa Head lighthouse serves as a navigation aid for ships making coastal passages and the landfall tower (a spar buoy) located at the outer end of the channel is a homing beacon for ships approaching the harbour wishing to find the entrance channel and pick up a pilot.Once in the entrance channel, a sector light on Hautai Hill keeps ships on the channel centre line and within the harbour. Beacons on both sides mark the channel.

The Port Company has tide gauges at the harbour entrance, Port Chalmers and Dunedin with telemetric links to Taiaroa Head and wind gauges installed at Taiaroa Head, Goat Island and Victoria Wharf are also linked to Taiaroa Head. The information from both sources is needed to make pilotage decisions.

Navigation Beacons
In the lower harbour there are 29 beacons and a light on the mole end to delineate the channel. The beacons line both sides of the channel from 400 to 1,400 metres apart. All beacons are fitted with radar reflectors and lights for night passages. The lights are powered either by photo voltaic cells and batteries or by shore-based power. Some beacons are wooden piled dolphin type structures and others are a single steel tube pile. The channel from Port Chalmers to Dunedin is marked by 77 beacons, ranging from 600 metres to 250 metres apart.

Berthing Facilities

Container Terminal and Beach Street Wharf, Port Chalmers - Port Otago

Port Chalmers
The Container Terminal has two heavy duty reinforced concrete breastwork type wharfs, each accommodating cellular and multi-purpose vessels up to around 50,000 tonnes dead weight and 12.0 metres draught. A heavy duty paved back-up area of 10.0 hectares is available for cargo storage.

The Beach Street forestry terminal has two berths handling vessels up to 40,000 tonnes dead weight and 11.0 metres draught. The wharf is a reinforced concrete caisson, solid quay wall type structure. A heavy duty paved back up area of 10.5 hectares is provided for cargo storage.

Dunedin
A dedicated LPG import berth and storage facility has a dolphin type wharf structure for vessels up to about 10,000 tonnes dead weight.

An oil jetty for imported petrol, diesel, light fuel oil and bitumen products is also used for bunkering vessels with either diesel or light oil. The jetty structure comprises timber piles and substructure with a reinforced concrete deck. The jetty can accommodate vessels up to 30,000 tones dead weight and 8.0 metres draught and is linked to the storage facilities of each of the four major oil companies by a land based pipe line.

A dedicated fish import berth at Victoria Wharf (north), with cold storage facilities alongside is a timber breastwork structure with a reinforced concrete deck.

A general purpose berth at Victoria Wharf (south) is a solid quay wall structure of steel sheet piling and relieving slab. A heavy duty concrete deck is placed behind the sheet pile wall. The berth is equipped with wharf cranes and transit sheds.

Lay-up berthage is provided at Rattray Wharf which is an old timber breastwork wharf and a dedicated fish import berth at Birch Street wharf, with fish processing and cold store facilities alongside, is of timber breastwork with a reinforced concrete deck. The outer end is used as a lay-up berth for ship repair and servicing.

Elsewhere
At Ravensbourne there is an import fertiliser berth. The wharf which is adjacent to the channel is a timber piled and decked structure with a reinforced concrete steel pile supported frontage. The wharf is linked to the shore by an all timber access jetty. The wharf is dedicated to the fertiliser processing works ashore and vessels up to 30,000 tonnes dead weight and 8.0 metres draught can be accommodated.

Commercial inshore fishing berths and infrastructure are provided at Careys Bay.

Cargo Handling

Port Chalmers
At the container terminal there are two container handling gantry cranes for loading containers to and from ships. The cranes are capable of lifting up to 45 tonnes at a maximum outreach of 34 metres. They will handle containers up to 12.2 metres long. Internal cargo handling plant includes 10 straddle carriers, three full-container handling forklifts, and three empty-container handling forklifts. There are electrical power outlets to serve 938 refrigerated containers in two separate container stacks.

At Beach Street wharf, two level luffing wharf cranes with a lifting capacity of 5 tonnes at 22 metres maximum outreach are available. Bulk cargo storage is available in the form of Cargo Shed A with a floor area of 2,400 square metres. A further shed with a floor area of 6,000 square metres is presently under construction (Spring 1997). A woodchip storage facility of 40,000 tonnes capacity, comprising elevator, distribution gantry and towers is located at the inner end of Beach Street.

The stevedoring and log marshalling companies provide three to four large forklifts capable of handling containers or large wood packs, three to four large specialist log handling forklifts, three truck/trailer units for transporting logs and a number of log butting tractors.

Dunedin
The Victoria Wharf (south) general purpose berth is equipped with two 5 tonne level luffing electric wharf cranes with a maximum outreach of 22 metres. Under-cover cargo storage capacity is provided by two transit sheds, each with a floor area of 1,800 square metres. At the north end of the berth is a cement silo of 1,000 tonnes capacity.

The Victoria Wharf (north) fish berth has two cargo storage sheds each with a floor area of 1,800 square metres and a central cold store with an internal volume of around 4,500 cubic metres.
The Leith Wharf apple export facility has two large cool stores and one cold store alongside the wharf, each with a volume of around 20,000 cubic metres.

The LPG berth is fitted with specialist LPG unloading arms and a pipe line linkage to the storage tanks ashore.

The oil jetty uses rubber hose links for ship-to-shore transfers but there are permanent commodity pipe lines along the wharf and ashore which link with the inland storage tanks.

Cargo handling plant (forklifts etc) for Dunedin operations is not specifically provided by the Port Company but is hired on an as-and-when required basis from other sources including the Port Chalmers Container Terminal.

Elsewhere
The Ravensbourne Wharf is fitted with four wharf hoppers and a belt unloading conveyor extending right into the works. The nominal capacity of the conveyor is 600 tonnes an hour.

Buildings

Administration
The port as a whole is controlled and administered from the Port Company head office in Beach Street, Port Chalmers. The Port Company's management functions are carried out within its head office building which is also a home to the regional staff of shipping companies using the port and provides amenity facilities for cargo workers employed by the company. From this building the control of commercial shipping, including the company's own pilot launches, tugs and dredges is exercised.

An essential link in this process is the company's signal station at Taiaroa Head which communicates instructions to shipping. As well, Taiaroa Head provides a weather and sea information service and warning of any marine hazards within the port area.

There are a number of other administration buildings for port related activities on the waterfront. Otago Stevedores has a general office and cargo worker amenity building at Beach Street, Port Chalmers. Owens Services, the log marshalling company, has a similar building in Beach Street, Port Chalmers.

At Dunedin the Apple and Pear Board has offices adjacent to its cool stores on the Leith Wharf; Liquigas have an office and control centre close to the LPG wharf; Sealord have offices and amenities in Birch Street behind the wharf; and Milburn Cement have offices alongside the cement silo at Victoria Wharf (south).

Amenities
In addition to the amenity facilities provided as part of administration/office buildings there are a number of specialist amenity buildings, including an amenity block for cargo workers on the outer end of Beach Street Wharf, Port Chalmers; an amenity block for cargo workers on Ravensbourne Wharf; and an amenity block for cargo workers in S shed at Victoria Wharf (south) and G shed on Birch Street Wharf.

Garage/Workshop Facilities
A specialist straddle carrier repair facility and general plant repair facility is situated close to Macandrew Road in the container terminal, Port Chalmers. Also at the southern end of the terminal are located specialist refrigeration unit repair and testing facilities, container repair facilities and reefer container washing and drying facilities.

Owens Services has a log loader and plant repair workshops alongside A Shed in Beach Street, Port Chalmers and Sims Engineering has workshop facilities adjacent to the large slipway at the outer end of Birch Street Wharf, Dunedin.

Transport Links

Rail
A rail transfer facility is located in the Port Chalmers Container Terminal adjacent to Macandrew Road. It is capable of holding 29 wagons or 58 TEU. (containers), with rail tracks are provided on both the multipurpose and container wharfs and at the Beach Street forestry terminal a rail transfer siding has been installed at Back Beach. The siding has a holding capacity of 10 log wagons.

The Port Chalmers wharfs are connected from the Sawyers Bay yards through the Port Chalmers tunnel under Gray Street.

In Dunedin the Victoria Wharf south berth has three rail sidings on the wharf apron. The Victoria Wharf (north) berth has a siding behind the transit sheds. A rail siding with a holding capacity of 6 to 7 UK wagons is provided in the South Freight terminal close to the Leith Wharf. All the Dunedin sidings are fed from the Dunedin yards by the Wickliffe Street back shunt. The Ravensbourne fertiliser works has a rail siding.

Road
The Port Chalmers Container Terminal has a road entry point and gate house for documentation purposes at the end of George Street adjacent to the administration building. Queuing space for trucks awaiting clearance at the gate house is provided and a defined area of the terminal yard is set aside for road transfers.

At the Beach Street forestry terminal, road vehicles have a controlled entry point at Back Beach through a tally and documentation shed. The transfer of cargo to stack takes place alongside individual stack positions.

Access to Dunedin wharfs is generally by way of the Anzac Avenue or Cumberland Street overbridges. Road access to both the Victoria Wharf berths and the Leith Wharf is available and road access to Birch Street Wharf is possible but is strictly controlled. Road access is available to the LPG terminal but not the wharf. Road access to the Ravensbourne fertiliser works is available but not to the wharf.

Utilities

Fresh Water
Water is provided at all wharfs for fire fighting, ships bunkering and wharf cleaning purposes. All are fed directly from the City Council domestic water reticulation system. The main wharfs have back-flow preventers fitted at the point of connection to protect the city water supply from possible contamination from ships' bunkers.

Sewerage
Port administration buildings and amenity blocks toilets are connected into the city sewerage reticulation system.

Electrical
At Port Chalmers, 11,000 volt high tension power is taken from the substation on Cemetery Hill into the port's main incoming substation on Macandrew Road. From there power is reticulated to three other substations within the terminal and a fourth at Beach Street wharf. The high tension supply is used directly to power the container cranes, but otherwise is broken down to 400 volt three phase power which is used for the following purposes:

- Ships supply to avoid using ship generators in port.
- Refrigeration power outlets.
- Power for chip loader and stock pile elevator and gantry.
- Electrical machinery used on wharf frontage e.g. wharf cranes.
- Domestic power for amenities workshops etc.

Port users such as Otago Stevedores, Owens Services etc. have their own independent connection to the Dunedin Electricity network for their domestic power requirements.

At Dunedin, low tension 400 volt three phase power is taken at five points around the harbour and used for the same purposes as already described. Frequently port users are also connected to the same point of supply. The five supply points are:

• Birch Street outer	Supply slipway, wharf crane & Birch Street wharf
• Birch Street inner	Supply Dunedin office, marina and tug berths
• Rattray Street (S shed)	Supply Rattray wharf and sheds
• Victoria Wharf south (T shed)	Supply transit sheds, wharf and cranes
• Victoria Wharf north (X shed)	Supply transit sheds, Sealord cool store wharf supply, oil jetty and parts of Leith Wharf.

The Apple and Pear Board has an independent supply for its cool stores at Leith Wharf and the electrical power supply on the Ravensbourne Wharf is drawn from the fertiliser works substation.

Communications
Radio communication is vital to the operation of the port. The Taiaroa Head signal station is the main radio communication centre and is equipped with radar and marine band and VHF radio. As well as shipping control Taiaroa Head undertakes commercial radio calls to shipping on behalf of shipping companies, ships agents etc. Taiaroa Head has an automatic stand by generator should there be a power failure.

Most of the decisions in relation to shipping control are made by piloting staff in the Port Chalmers administration building or on the harbour tugs or pilot launches. There needs therefore to be good internal radio communication between administration, signal station and floating plant.

The company's tugs and pilot launches and the administration building have both marine band and VHF radio equipment and a vital element in the radio system is the aerial on Hautai Hill close to the signal station, which gives coverage of the whole harbour.

As well as the normal telephone links, including fax and E-mail to the administration building, the company operates an Air Time NZ two-way cell phone system which connects the company vehicles and floating plant with the company's telephone network. The operation of this system is dependent on Air Time NZ's transmitter on Swampy Summit.

Other Facilities

Floating Plant

The operation of the port is dependent on a number of items of floating plant owned and controlled by the Port Company. Two Schottel harbour tugs of 2,000 horsepower each are available to assist the berthing of ships and, when not in use are moored at Rattray Wharf, Dunedin. Two pilot launches are kept at a specialist berth at Boiler Point in Careys Bay and the company operates a small split hopper trailer suction dredge and a dumb barge grab crane dredge with attendant tug and spoil disposal barges. When not in use they are moored at Boiler Point, Careys Bay.

Bunkering for small vessels is available at the fishermen's wharfs at Careys Bay. Bunkering of large vessels is available at the oil wharf, Dunedin. At some of the Port Chalmers and Dunedin wharfs bunkering by road tanker is permitted.

Ship Repair and Servicing

The port owns a nominal 500 tonne slipway at the end of Birch Street Wharf, primarily for servicing its own plant, but also available for other vessels. Lay-up wharfage for ship repair is provided adjacent to the slipway at the Birch Street outer and Kitchener Street wharfs. The facility is leased to Sims Engineering, who operate it. Slipways and repair for smaller vessels are available at Miller and Tunnage's boat yards, Careys Bay.

HARBOUR - ASSESSMENT OF VULNERABILITY

Sea Channel

The vulnerability of the navigable channel to the port with respect to natural hazard is not great and it is difficult to conceive major disruption to the passage of vessels of modest draught for protracted periods. The worst scenario envisaged would likely be the shallowing of the channels due to earthquake shake, which may involve extensive dredging to re-establish sea bed profile and possible re-survey of existing beacon layout.

While there is little likelihood of damage to the Taiaroa Head lighthouse and the function which it performs, sector lights, beacons and the radio communications equipment associated with reception of vessels may suffer from derangement and need adjustment.

Otago Harbour is divided in two by the Halfway Islands - Goat Island and Quarantine Island and the possible effects of an earthquake on the beacons is different in each part of the harbour. The lower harbour from the landfall beacon to the channel between the halfway islands will be considered first.

The landfall beacon is a major structure, designed to remain in place during the worst storms that nature can produce, so it is possible that it will remain in place in all but the most severe earthquake or tsunami. The channel beacons, however, could easily be dislodged in an earthquake and the channel itself could be filled in by movement of the mainly sand and mud bottom of the harbour, resulting in obstruction or closure of the channel from Port Chalmers to the sea to ships of up to 12.5m draft and 260m LOA (length). Provided that one of the two pilot cutters "Potiki" and "Ototao", and work-boat "Kapu", survive the earthquake, the channel could be surveyed reasonably quickly and a navigable channel found. With modern equipment, one of these three vessels could guide and escort ships to and from Port Chalmers during daylight hours in reasonable weather, even if all the beacons had been dislodged or destroyed.

The loss of the channel beacons in the upper harbour would be a more serious matter, as the main channel in the upper harbour, Victoria Channel, is not a natural channel but is dredged, and has a training or restraining wall on the southern and eastern side for most of its length. In a major earthquake it is quite possible for this training wall to collapse into the Victoria Channel, taking some or all of the beacons with it. As this channel is narrow and shallow (ships using it are restricted to 8.0m draft, 29.0m beam and 185m LOA) a collapse of the wall could have serious repercussions and vessels would not be able to use it until it had been fully surveyed and dredged. Any ships at the wharfs at Dunedin and Ravensbourne, including tankers at the Oil Jetty, and LPG tanker at the Liquigas Terminal, could be effectively trapped until the channel is cleared. It is probable that the beacons marking the shallow-draft Eastern Channel would survive even a serious earthquake. This is a natural channel and can be used during daylight hours at or near high tide by small vessels with shallow draft.

Finally, one other part of the harbour where beacons could be lost in an earthquake is the swinging basin opposite the Port Chalmers wharfs. The edge of this basin has been dredged to just over 12.0m, with a very steep, almost vertical side and in an earthquake, this edge could tumble into the basin, taking beacons with it, which could greatly hinder the larger vessels such as container ships using the Port Chalmers wharfs.

Harbour access is likely to be limited until revised channel and sea bed profiles can be established.

Berthing Facilities

In terms of importance to the port, the Port Chalmers berthing facilities are seen to be at greater risk than those in the upper harbour. Because of the influence of filled ground and inferred proximity to fault lines running up the harbour, the container wharf, multipurpose wharf and outer Beach Street wharf are vulnerable to earthquake. The principal cause of failure in credible earthquake conditions would be due to settlement combined with sliding induced by liquefaction, which would, in turn, be influences upon mechanical equipment and underground services in the area. Repairs to these facilities, which represent vital economic assets to the port and city economy could be lengthy.

So far as the Dunedin wharfs are concerned, there is likely to be severe damage to the older piled wharfs due to settlement and horizontal translation of walls and fill beneath the structures. From an economic view, the Ravensbourne, LPG and Oil wharfs are especially important and will suffer from a limited amount of structural and mechanical failure in the same way as the internal Dunedin wharfs, but with the need for re-establishment being greater due to the unique nature of the services which they offer.

In all locations we must anticipate disruption of road access and hardstanding areas adjacent to wharfage due to settlement, liquefaction and heave. Particularly badly damaged areas are likely to occur in the old timber wharf areas of the extreme upper harbour, which will suffer from mechanical failure of piles, transoms and decking to an extent that repair would be difficult.

The ship repair slipway (Sims Engineering) is likely to suffer extensive damage in credible earthquake conditions and reinstatement will be required because of the unique nature of the facilities.

Cargo Handling

Examination of equipment used in cargo handling reveals a considerable risk to container gantry cranes, which may be damaged due to shaking combined with settlement of the wharf track upon which they run, or by direct overturning due to earthquake shake. It may be expected that buckling of crane legs will occur, with derangement of mechanical running gear and jib extensions being a major cause of severe damage in credible earthquake conditions.

Straddle carriers and other mobile equipment is at similar risk to the gantry cranes but, because of their numbers, the overall vulnerability is lowered.

Oil product storage tanks may be distorted by settlement and “slop failure” of the walls in earthquake shaking. Due to the configuration of storage, LPG storage should be less heavily damaged. Cement import facilities are potentially subject to damage due to settlement and wall failure and cold storage may suffer from panel dislodgement, foundation settlement (because of proximity to wharf frontage) and general mechanical derangement.

Tugs and dredges are thought to be reasonably secure from earthquake effects but may be subjected to damage due to falling equipment, wharf faces etc, and to the effect of tsunami.

Buildings and Hardstandings

Subject to vulnerability from earthquake shaking and liquefaction are the hardstanding areas of the container storage yard and the log stacking area. Because of the nature of the fill and location of these areas, settlement and liquefaction damage will occur and be more serious for the container hardstanding than for the log area because of its finished surface and drainage channel formation and the extensive underground electrical services in the refrigerated container area which will probably need to be relaid.

Newer buildings, designed for earthquake resistance, are likely to survive earthquake with some damage to the internal hardstanding. Older buildings, such as the Victoria and Birch Street wharf sheds, are likely to suffer considerable damage and may be irreparable, although operable in the short term.

Transport Links

Road access to Dunedin is likely to suffer from earthquake shaking, liquefaction and landslip along its length and other transport routes are likely to be in worse condition. The disruption is expected to be of relatively short duration, measured in days rather than weeks.

Rail traffic is likely to suffer in much the same way as the roading, but with more serious effect upon the track and grade. It is anticipated the disruption will be extensive due to faulting, shake, settlement and, in some instances, to liquefaction. There is also the prospect of some damage by tidal surge or tsunami, but with a low probability. Extensive rebuilding of the embankments which cross the various bays between Dunedin and Port Chalmers may be required.

Utilities

The supply of water, fuel, gas services and removal of waste water will be disrupted by earthquake and are deserving of careful individual appreciation.

Supply of electricity or standby facilities needs to be reviewed, as severing of cables and toppling of overhead supply will effectively close the port. Currently the port has no standby power facilities.

Operations such as container cleansing, maintenance of temperature (for reefer and other frozen cargoes) and repair facilities are matters for consideration as general derangement is to be expected unless special arrangements to prevent fracture or other mechanical failures is in place.

Communications networks are essential to the proper operation of the port and these are likely to be seriously disrupted by any significant seismic or tidal event.

Other Facilities

The floating plant is considered to be relatively secure, with widely dispersed locations and offering minimal risk from all hazard events except tsunami.

Ship repair and servicing facilities are subject to damage from earthquake and it may be expected that wharfs and mechanical equipment will suffer damage.

Electronic equipment installed in the signal station at Taiaroa Head will suffer from seismic shaking.

HARBOUR - MITIGATION STRATEGIES

Sea Channel

Because of the nature of the sea channel, it is considered that no commercially viable mitigatory work may be undertaken which might significantly increase the survivability of the dredged slopes. In the event of a major earthquake it would be necessary to dredge the channel to restore depth and this operation could extend over several months.

Loss of navigational channel beacons is probable in a severe earthquake event, but as with the channel slopes, it is not practical to undertake any mitigatory work. Rapid reinstatement following dredging would need to be managed, but inevitably the upper harbour would need the most urgent treatment if the fuel wharfs are to be kept open.

Berthing Facilities

There is likely to be only moderate and fairly superficial damage to the container wharfs which have been designed for earthquake impact, but the Victoria wharf in the upper harbour is likely to suffer extensively. No mitigatory action will be undertaken on either of the wharf systems; Victoria wharf on economic grounds and the container wharfs because they are already designed to high standards.

Cargo Handling

Consideration of potential damage to the two container gantry cranes from earthquake shaking leads to the conclusion that mitigation measures are likely to be largely ineffective and that the best method to adopt is management of repair work on a basis of urgency. The possible modification of cranes involving braking and holding-down improvements is currently under investigation. Similar policies relate to the straddle carrier fleet and other mobile equipment, with a number of minor items such as securing of tankage and further review of port installations underway.

Buildings

Newer buildings at Port Chalmers and in the upper Dunedin harbour area are not in need of further upgrading, but some older structures at the Victoria and Birch Street wharfs will be damaged but it is not considered that mitigation works would be cost effective.

External storage areas have been examined and mitigation in the form of managed repair after the event is the adopted strategy.

It is recognised that there will be extensive superficial damage to many port structures but it is impossible to determine location of inherent weaknesses with any certainty and expenditure on universal mitigation engineering would be prohibitive.

Transport Links

Damage occasioned by earthquake shaking, liquefaction and consequent settlement of both road and rail connections will be repaired following the event as it is considered to be impossible to cost effectively protect the systems by meaningful mitigation engineering. Track and roading within the port area will be restored in a planned exercise involving equipment owned by or leased to Port Otago Limited.

Utilities

Some disruption of services in the supply of water, fuel etc. and removal of waste products is expected as a result of earthquake shaking, but there is currently no guidance available as to where these services might be damaged and accordingly it is proposed to manage the reinstatement following the event.

Note has been made of potential for damage by settlement between piled wharf structures and filled ground and future design work will incorporate protective measures.

The supply of electrical power for refrigerated container outlets and motive power for the container cranes is a critical aspect of port working, so provision of an alternative power supply to assure a minimum supply for these activities is to be addressed as a priority.

Other Facilities

There are no mitigation activities planned for dredges, dumb barges and other floating equipment as it is believed these elements will survive most natural hazards without damage.

Ship repair installations at Port Chalmers and in the upper harbour at Birch and Kitchener Street wharfs will not have any further strengthening works carried out for economic reasons.

Examination of Taiaroa Head lighthouse leads to the conclusion that some work should be done in securing the essential communications equipment, which may be achieved at very modest cost. Planning towards duplication of signal station function should be considered and funding secured.

Conclusions

The study has indicated that there are a number of harbour and port assets which are vulnerable to earthquakes and other extreme events. The port area in Dunedin is older and more vulnerable than the newer facilities at Port Chalmers, but as it is only able to accommodate vessels of 8m draught or less, Dunedin is less critical.

Access to the berths from the sea as well as land will be crucial after a hazard event as many relief provisions will probably be brought in by sea. In this regard the areas of critical concern are the navigational channels, the container berth at Port Chalmers and the Victoria Wharf in Dunedin.

The interdependency of the port facilities with other services such as road and rail access, power, water and communications connections is crucial for the recovery of the city and region after a hazard event. These links and interdependencies need to be recorded and reinforced by regular meetings and re-evaluations.

Recommendations

It is essential that the port company designs for hazard events in all new facilities and that it be sensitive to the need for attention to the existing operations, structures and equipment. Of particular concern is equipment such as computers which is critical for the successful operation of a modern port. It is essential that such equipment is properly located and secured to ensure it is safe from all but the severest hazard events.

There is a need for continued review of potential structural weaknesses and development of improved contingency planning to deal with hazard events, the results of which are not predictable.

It is recommended that Port Otago Limited continue to be involved in all the meetings arranged by the Lifelines Project.

RAIL SYSTEMS - DESCRIPTION OF SERVICE

General Description

Dunedin is connected to the railway by the Main South Line which runs from Lyttelton to Bluff. There are two short branch lines in the Dunedin area, the Port Chalmers industrial line which runs from Sawyers Bay to Port Chalmers and the Taieri branch which commences at Wingatui. In Dunedin itself there are many private sidings, a large marshalling yard and the E Yard Freight Branch site on Strathallan Street.

Main Trunk Line - North

Track

The line running north from Dunedin follows the harbour edge on a man-made causeway to Sawyers Bay where it then climbs firstly over the hills to Waitati and secondly over the hills to Merton. There are crossing loops and storage tracks at several places en route, including Sawyers Bay, Waitati, Seacliff, Merton and Waikouaiti. The line runs at low level alongside Blueskin Bay between Waitati and Evansdale.

Bridges

Significant bridges north of Dunedin are over the Leith Stream, Waitati Stream, Waikouaiti estuary and the Shag river beyond Palmerston.

Tunnels

There are five tunnels between Dunedin and Oamaru:

- Tunnel 8, Roseneath Tunnel (320m) between Sawyers Bay and St Leonards.
- Tunnel 7, Mansford Tunnel (200m) at upper Port Chalmers.
- Tunnel 5, Mihiwaka (1300m) between Purakanui and Sawyers Bay.
- Tunnel 4, Cliffs Tunnel (280m) between Waitati and Purakanui.
- Tunnel 2 at Otepopo (220m) between Hampden and Waianakarua.

and one other on the Port Chalmers branch.

Main Trunk Line - South

Track
The line south of Dunedin runs through Caversham to Green Island, then to Wingatui, Mosgiel and over the Taieri Plains to Milton. The track follows an easy route through Caversham Valley, the Caversham Tunnel to Burnside, then east of Fairfield, through the Wingatui Tunnel to Wingatui. The track then generally follows the State Highway to Milton. There are connections to Hillside workshops, and storage or crossing tracks at Burnside, Green Island, Mosgiel and Milton. The Taieri branch connects at Wingatui and this then joins to the Taieri Gorge Railway.

Bridges
There are few significant bridges on the Main Trunk Line - South with the exception of the Taieri and Waipori River bridges near Henley.

Tunnels
The Caversham Tunnel (1,400m) from Caversham to Burnside is cut in sandstone and is unlined. It was built as a two track tunnel but is now only one track. The Wingatui Tunnel (900m) is cut through schist rock, is brick lined and was built to carry two tracks, now reduced to one.

Rail Operations

Railway Yards
There are three main concentrations of yard tracks in Dunedin:

- The passenger yard track at the Railway Station - primarily used for storage.
- The marshalling yard - used exclusively for making up and breaking up main line trains and shunts.
- The freight branch yards - used for loading and unloading freight and containers into or onto wagons.

There is also siding space at Sawyers Bay, Port Chalmers, Burnside and Mosgiel.

Local rail operations are controlled from the Dunedin Operations Terminal. There are two levels of control; all local shunt movements are directed by local Operations Controllers and all main line movements (shunts and main line trains) are controlled by Train Control. Dunedin Train Control coverage extends from Oamaru to Bluff, including all branch lines. Many aspects of train management, ie equipment allocation, are organised in Head Office in Wellington.

Locomotive Maintenance Depot
The Cumberland Street Locomotive Depot is used for servicing (fuelling etc), maintenance and repair of locomotives. It has two servicing tracks in the fuelling bay and three tracks in the repair depot, two of which are elevated, allowing easy access to underframe componentry.

Mechanical Maintenance
There are maintenance staff located at the depot on Cumberland Street and at the crane depot on the freight branch site. In addition there is a mobile wagon maintenance team which travels from siding to siding checking and repairing wagons. This team has heavy lifting traversing jacks available for use in rerailing locomotives and wagons. Hillside Workshops on Hillside Road, constructs new wagons and carries out heavy repairs. Major locomotive repairs are carried out in Christchurch.

Track, Structures, Signals and Communications
Staff responsible for track, structures, signals and communications maintenance are located at the Locomotive Department on Cumberland Street. There are also track maintenance gangs located at Balclutha and Waitati which use hi-rail trucks, some equipped with machinery for cutting and bolting rails.

Tranz Rail has an Ericsson telephone exchange located at its Operations Terminal and operates its own telephone network nationwide. It also has a radio network for train control and for use by shunters and maintenance staff.

Freight Handling Facilities
The E Yard Freight Centre has several large warehouse-type buildings and is fully equipped with a forklift fleet varying in capability from 2 1/2 tonnes to 30 tonnes capacity and a fixed gantry for transferring containers. Tranz Rail has an owner/driver truck fleet.

Administration Buildings
The area is run from the Area Office at 27 Wharf Street with Operation Control located in the Terminal Building at 1 Strathallan Street. The freight branch is controlled from the Strathallan Street E Yard offices.

RAIL SYSTEMS - ASSESSMENT OF VULNERABILITY

General Description
The railway network is inherently susceptible to disruption due to the need to maintain well conditioned "line and level" over considerable length in locations which are particularly prone to hazards of one type or another.

Main Trunk Line - North

Track
Much of the line running north from Dunedin Railway Station lies upon filled ground and will suffer from distortion and settlement due to shaking and/or liquefaction during earthquake. In particular, the length from the station through to Port Chalmers is likely to suffer settlement in those sections on causeway and some lengths are susceptible to land slipping. Bearing in mind the (as yet unconfirmed) probability that there is major active faulting running down the harbour parallel to the line, this particular length is highly likely to suffer severe damage and the area around the Leith Bridge crossing particularly so.

The climb from Sawyers Bay to Mihiwaka Tunnel, and thence down to Waitati is not expected to suffer greatly from distortion due to shaking, but it is expected that there will be many slips which will require engineering work.

The line from Waitati through to Waikouaiti traverses low-lying ground and beyond Warrington rises on poor grade slip country, making this length susceptible to shaking, liquefaction, slip and possible tsunami effect. Some lengths of the high country line present a major damage potential due to slipping. At Cherry Farm there is a high potential of flooding and liquefaction settlement.

From Waikouaiti onwards to the city boundary, the line runs through country which is prone to slipping, but apart from short sections alongside Hawkesbury Lagoon this should not be a significant problem.

Railway Bridge over Water of Leith - Civil Defence

Bridges
The Leith Stream Bridge is close to a fault line and is likely to suffer settlement damage which, because of the short span may be readily reinstated unless the beams fail under lateral movement. There will be disruption to communication and signalling services, but it should be noted that this bridge also carries a number of other lifeline services.

The rail-over-road bridge at Sawyers Bay is considered to be at risk from earthquake shaking which may cause the box structures of the way-beams to slip from their supports, closing the line to the north.

The older road-over-rail bridge at Borlases Road may collapse across the track and the upper Port Chalmers rail bridge, located below the Scott Memorial, is also subject to damage by earthquake, though these are considered to be low risk events.

Bridges at Waitati and Warrington are of timber construction and may also be damaged by shaking, but are likely to be readily restored.

The structure at the Waikouaiti Estuary will present more serious problems for reinstatement in view of the length of crossing and its vulnerability to shaking, liquefaction effects and flooding. Slips will occur on both approaches so access may be difficult and repair work extended. Similar problems will be encountered at the Shag River bridge which lies further north.

Tunnels
Tunnels are expected to suffer damage to portals and internal failure of linings at points of weakness. Portal damage is expected to be particularly severe at the Mansford Tunnel and the Port Chalmers branch access tunnel, with lesser damage at Roseneath. Damage to Mihiwaka Tunnel is expected to be relatively minor.

The Cliffs Tunnel is most likely to be affected by rock falls blocking the line.

Main Trunk Line - South

Track
The line running south from Dunedin Railway Station is at risk from earthquake shaking and liquefaction effects in the area lying beyond Green Island, and considerable damage to line alignment and some settlement is expected.

Beyond Green Island to the city boundary, the line will be subject to derangement due to shaking and is also susceptible to flooding at certain locations. Through the hilly terrain from Green Island to Mosgiel, there are areas of potential slipping at cuttings.

Bridges
In the central city area, the Cumberland Street overpass is a modern construction which is expected to survive enhanced earthquake impact and, though it is anticipated that there may be carriageway damage to the bridge, this is unlikely to cause more than minor temporary interruption of rail services.

Close to the city, the Andersons Bay Road rail-bridge has been strengthened in recent years, but presents a possible risk of damage due to earthquake in view of its proximity to a fault line. Possible lateral displacement of the heavy steel support beams could cause failure. A similar risk applies to the Glen overbridge, which is within 500 metres of an active fault line. Neither bridge is considered to present a very high level of risk, but both are subject to damage in credible earthquake conditions because of enhanced shaking and are both critical to rail operations to the south.

The rail bridges over the Taieri and Waipori rivers are both substantial and are expected to survive earthquake shaking and flood with minimal damage.

Several road over-rail-bridges exist, which may cause temporary disruption to rail service in the event that they collapse on to the track. In general, they are likely to cause obstruction due to abutment displacement and consequent collapse of spans in locations such as Kaikorai Valley Road, Abbotsford, South Road, Caversham and possibly at Wingatui. The more modern bridge over the rail at Allanton is likely to be slightly damaged at beam connections, but is considered unlikely to collapse on to the track.

Tunnels
The tunnels at Caversham and Wingatui are expected to cope reasonably well with the effects of earthquake, although the proximity of a fault line through Kaikorai Valley may induce severe damage to the portals of the Caversham tunnel and slipping adjacent to it. Wingatui Tunnel will probably suffer less damage, but some linings may be dislodged. Both tunnels should be readily re-instated.

Rail Operations

Railway Yards
All of the yards within the centre city area, together with those at Sawyers Bay, Port Chalmers, Mosgiel and Burnside, will suffer from distortion of the track due to earthquake and, in the event of high intensity shaking, areas of liquefaction will cause ground settlement. Disruption of services in these areas may be extensive, though the reinstatement time will not be great if access can be achieved.

Mechanical Maintenance/ Locomotive Maintenance Depot/ Freight Handling Facilities
Similar effects to those experienced in the railway yards will occur at these facilities, with disruption of services due to toppling of gantry structures and derangement of cranes likely to cause problems for maintenance.

Damage to pavement areas will affect the operation of forklift trucks and other freight handling equipment, seriously disrupting operations. Depending upon the priorities established for repair, this may not result in prolonged incapacity.

Damage to the locomotive turntable and diesel storage tanks will cause significant operating difficulty and the earthquake effect upon the turntable structure and alignment of rotational gear may be extensive and time consuming to repair.

Flooding of many of these areas is possible as most of the land is low-lying and possibly prone to tsunami.

Administration Buildings/ Hillside Workshops
All of these lie within an area which is susceptible to enhanced earthquake shaking and liquefaction, which is likely to cause some structural damage to buildings, particularly with respect to services and much inconvenience with respect to general access, storage etc. Heavy equipment in workshops will be damaged by misalignment and overturning and will take major restoration effort.

RAIL SYSTEMS - MITIGATION STRATEGIES

General Description

Tranz Rail New Zealand has adopted a high standard maintenance operation over their system throughout the southern area of New Zealand and believes that management of reinstatement of hazard damage presents the most economical and efficient means of mitigation.

There are a number of predominant at-risk elements within the system and strenuous efforts have been made, and continue to be made, to eliminate the worst of these with a view to shortening any periods of closure.

Vulnerability analysis has provided a good review of the potential weakness in the system components, but it is recognised that the extent of the required mitigation measures is not practical or likely to be cost effective.

Main Trunk Line - North

The track to the north is potentially the most susceptible part of the system because it encompasses steep gradients, tight curvature, tunnels, coastal causeways and areas of ground susceptible to landslip.

Typical of elements which require constant review and which may be progressively improved upon are:

- Leith rail bridge crossing structure.
- Mihiwaka tunnel portals/linings.
- Track stability from Mihiwaka tunnel to Waitati/Warrington.
- Kilmog track stability (continuing mitigation).
- Waikouaiti rail bridge.

These elements form the basis of current mitigation review.

Main Trunk Line - South

Generally at less risk than the northern route, there are elements which are susceptible to flooding. Much effort has been put into the control of flooding on the Taieri but it is unlikely that any measure by Tranz Rail other than total elevation of the track would be more effective than the work already carried out.

Examination of the Caversham tunnel portals and linings and the bridges over the Taieri and Waipori rivers may reveal minor elements of these structures which would benefit from mitigation.

Rail Operations

It is considered that any work on rail yards within the city area is likely to be ineffective and costly. Accordingly, any damage done to track and surface would be repaired after the event.

Reviewing the stability of buildings which control rail operations and securing of control systems is an ongoing function of operational staff and may be given greater prominence, particularly with reference to the principal office which stands on landfill prone to enhanced shaking and liqefaction.

The communications system operated by Tranz Rail represents a very important function in control and emergency contact. Accordingly, this element of the railway system should be critically reviewed and any mitigation designed to protect equipment and signalling functions.

Conclusions

Tranz Rail has a good preventative maintenance system in operation but intends to review elements of the "vulnerability analysis" to establish if more can be done to protect systems whilst maintaining cost effectiveness.

Recommendations

Continue the current maintenance programme and undertake progressive review of system weaknesses in respect of hazards.

AIR TRANSPORT - DESCRIPTION OF SERVICE

Dunedin Airport

General Description
Dunedin Airport is a public airport owned and administered by Dunedin Airport Limited and situated 11 nautical miles west of Dunedin City.

Runway
The runway is a modern sealed surface some 1,900 metres long and 46 metres wide, capable of accepting heavy, jet engined aircraft. Normal services can handle Boeing 767 aircraft and in emergency conditions larger aircraft can be accommodated.

Terminal Building and Offices
The terminal building has a ground floor area, first floor administration offices, two first floor air bridges, serving commercial airlines and the new international departure lounge.

Buildings have been developed since the original construction in the 1960's and consist of a steel frame, with timber and steel faced walls, which are substantially braced. Recent developments have added the international departure area and a separate modern single-story building for international arrivals and customs. Other buildings within the airport area are:

- Tower annex (Airways Corporation)
- Rescue fire garage and offices
- Three hangers
- Control tower/technical workshop (Airways Corporation)
- Power centre (Airways Corporation)
- Water treatment building
- Sewerage plant

Power
Mains supply is via two separate lines; one from Berwick the other from Outram. These services are overhead lines which terminate at a transformer point located about 200 metres from the main terminal. There is no standby power available, other than for the Airways Corporation building and facilities associated with air traffic control. The terminal building switchgear is in the power centre.

Water
Mains water is supplied from the West Taieri Rural Water Scheme. This is supplied as treated water which is distributed to the terminal building and other locations by a pneumatic pressure system. The water is pressurised and pumped electrically and a standby diesel pump is located in the pumphouse for firefighting and back-up domestic service. The pumphouse is located some 200 metres from the terminal building and is contained in a block wall and concrete structure. All pipe work is in steel.

Sewerage
Waste water is treated on site at the airport sewerage plant located some 500 meters north-west of the terminal building. Sewerage from the airport village is also processed here. Treatment involves primary settlement and oxidation pond retention, with sewage pumped electrically from pumping sumps located close to the airport buildings.

Drainage
Surface water within the airport boundary is collected by gravity drains which run parallel to each side of the runway into a collection channel which runs at right angles to the runway halfway along its length. This surface water is removed by pumping from an intake structure which delivers directly to an Otago Regional Council open channel to the west of the airport. Pumping is by five electric pumps which are served by the general power supply and which have no standby power.

Further drains collect run off from the north and south ends of the runway and discharge by gravity to the open drainage channel on the west.

Rescue Fire
Two Unipower rescue fire vehicles are permanently based at the airport with three dedicated staff. No other emergency services are based at the airport, but local services are on call.

The terminal and hanger buildings are protected by sprinkler systems connected to the water supply. The water supply can be supplemented from that held in concrete tanks adjacent to the pumphouse.

Fuelling and Servicing
Supplies of aviation fuel are available from a modern tank and pumping system located some 200 metres south-west of the control tower building. Tanks and pumping equipment are protected by a concrete bund and provide Jet A1 and Avgas to aircraft by direct pumping or by tanker. Servicing and storage facilities for light aircraft are at the northern end of the complex.

Communications
Telephone lines service Dunedin Airport Limited, Mainland Air, Air New Zealand, Ansett New Zealand, and Flightline Aviation.

A public address system within the terminal building and UHF radios are operated by Dunedin Airport Limited and Airways Corporation of New Zealand Ltd.

Ground to aircraft radio communication is operated by Airways Corporation Limited.

Other Landing Facilities

Taieri Airfield
This is a non-certificated private airfield operated by Otago Aero Club Inc. and situated six nautical miles west of Dunedin City on the northern boundary of Mosgiel township. There is no runway lighting and no night flying is possible without using flare canisters. The grass runway can accommodate machines of capacity up to and including Group 7 aircraft.

Dunedin City Heliport
A non-certificated heliport operated by the Dunedin City Council is situated at Kitchener Street, adjacent to the harbour.

Dunedin Hospital Heliport
A recent development has been the construction of a heliport on the roof of Dunedin Hospital.

Fuelling and Servicing
Limited supplies of Jet A1 and Avgas fuel, along with general service facilities are available at Taieri Airport, but neither the Dunedin City nor Dunedin Hospital heliport have fuel or servicing capability.

Communications
Taieri Airfield and both helipads use the standard unattended aerodrome procedures on VHF radio frequency 119.1 MHz.

Airways Control System

General Description
Dunedin Air Traffic Control, operated by Airways Corporation of New Zealand Limited, supplies aerodrome and approach control services within its associated CTR (Control Zone) and TMA (Terminal Approach Area).

Control Tower and Other Buildings
The control tower, situated at the southern end of the main terminal building, is constructed of reinforced concrete on a floating foundation. It is some 20m high in four levels. The tower cab is the operational control position, the second and third levels are offices and the ground floor is the technical centre. Located to the south west of the tower building is an annex housing the airport caterers.

Power Centre and Standby Power
The main electrical distribution centre and the standby generator are in the power centre adjacent to the control tower. Standby power is available immediately and automatically on the failure of both mains power sources. All on-airport navigational aids, airfield lighting and essential operational data processing are provided with emergency power. Standby battery power is available to the Mosgiel and Henley NDB navigational aids and to essential circle guidance lights.

Runway Lighting
The runway and approach lighting is arranged in two separate circuits, each of which is capable of giving adequate night operational capacity. Runway and taxiway lighting may be operated by remote ground control.

Communications
Communications to the control tower is by telephone and by radio for aviation control, using the following frequencies:

120.7 MHz (long range).
122.4 MHz (short range).
119.5 MHz.

AIR TRANSPORT - ASSESSMENT OF VULNERABILITY

Dunedin Airport

General Description
Located on the flood-plain of the Taieri, the airport has some history of flooding and notwithstanding major engineering works designed to alleviate this particular hazard, there remains a probability of recurrence.

The airport and the approach roads lie within an enhanced earthquake shaking area and there is some possibility of liquefaction if the shaking intensity exceeds MMVIII on the Modified Mercalli scale.

Runway
The runway is constructed on Taieri Plain alluvium with a substantial asphaltic sealed base course.

The flooding of 1980 was observed to do little damage to the pavement and the surface survived well. The generally high water table is persistent and prevention of inundation is dependant upon pumping and open channel flow and these elements of drainage are particularly susceptible to hazard damage.

Because of the generally uniform alluvial strata of the Taieri Plain and the form of construction of the runway, it is considered that flooding will cause little surface deviation or settlement.

The effect of earthquake shaking and liquefaction settlement associated with high intensity earthquake may be more selective, but it is again expected that there will be minimal differential settlement of the runway. Some cracking of asphaltic runway surface may be expected, but repair is likely to be relatively easy and the runway will not be out of service for lengthy periods.

Hardstanding Areas
The hardstanding areas in front of the buildings and at the hangers will possibly suffer from more damage than the runway in an earthquake, principally at expansion jointing and in the surrounding areas where

fuel systems are built into the sub-grade. These vulnerabilities are not seen as having a long-standing effect on air transport.

Terminal Buildings and Offices
The airport terminal buildings and offices are subject to flooding which will render them inoperative. This is likely to be of relatively short duration and, though destructive, will not be excessively costly to the structural fabric.

The building is likely to survive earthquake shaking but with some internal damage to services, drainage and communication equipment. Damage to the upper office levels due to shaking will be confined to displacement of equipment and probably destruction of glass in windows etc. The air-bridge system may be damaged and the electrical services made inoperable for a short term following an earthquake.

Vulnerability to meteorological hazard is well understood by airport administration and appropriate operating procedures are already in place, with closure of the airport as the ultimate solution in most cases. Damage has historically been relatively light and there appears to be no significant improvement to structures which might be made to enhance survivability of the service. Random damage by windstorm, cessation of service due to snow and ice and the incidence of heavy rainfall are all likely to be of short duration and readily repaired.

Other Buildings
The main hangers, international arrival building, water treatment building and sewage disposal system are all expected to suffer minimal damage due to flood or earthquake. Reticulation systems will be fractured in some building connections and will require repair before operating. In all cases, the damage will be repairable in the short term.

Power Supply
Both electrical substations which service the airport are subject to flooding and pole mounted electrical equipment is liable to damage by shaking due to earthquake.

Water and Sewerage Systems
The principal damage to the water supply system is likely to be caused by earthquake effect upon the pipeline delivering treated water to the airport, with the length of supply line being essentially non-redundant, raising the vulnerability. The three storage tanks for raw water supply are below ground level and therefore reasonably secure against shaking, but are expected to settle, causing damage to inlet and outlet pipework. Flooding may pollute the water system.

Domestic water supply and fire fighting system pumps are in the same building and are likely to survive earthquake. Pumping may be provided to the domestic system by the firefighting diesel pump system in the absence of mains power, with pumping dependent on continued diesel fuel supply.

Sewage disposal to the airport treatment plant will be subject to earthquake damage at pipe junctions with the buildings and may suffer from some joint failures due to enhanced shaking of the pipeline to the treatment plant. Major damage to the treatment plant itself is not expected, but there may be some derangement of the equipment which will require adjustment.

Airport Drainage
There is expected to be little damage from earthquake to the open drainage system which serves the airport area. Some displacement of drain crossings may occur and there are likely to be minor bank face slippages due to shaking. The pumping station at the south end of the collector system and gravity drains are likewise susceptible to damage by shaking.

Other Landing Facilities

Taieri Airfield
Operation of this airfield may be impossibnle for limited periods due to either flooding from the Silverstream or enhanced earthquake shaking.

Access to the airfield may be made difficult due to flooding or displacement of the access bridge, but the overall period to re-establish services may be short. Generally speaking, the use of the airfield by helicopters and fixed wing aircraft will be easily re-established provided road access is available.

Dunedin City Heliport
This is on filled ground, subject to enhanced earthquake shaking and potential liquefaction. Located on the foreshore, it is an area which may also be at hazard from tsunami.

Dunedin Hospital Heliport
The Dunedin Hospital helipad is of robust construction and designed to seismic standards. It is however particularly vulnerable to short term meteorological influences.

Airways Control System

General Description
The control system oversees most normal operations at Dunedin Airport and the surrounding area, but in an emergency situation it's vulnerability does not restrict airport use, which can be continued under manual control.

Control Tower
Robustly constructed, the control tower is expected to be resistant to earthquake effects, though there is likely to be some minor damage to the reinforced concrete at a number of locations. Worst effects are likely to be due to equipment damage through insecure fixings and damage to glass.

Standby Power
Most buildings in the Airways Corporation control system are expected to suffer only minor damage in an earthquake with the worst damage being due to unrestrained movement of plant. In this respect, particular importance is directed to the standby generator and automatic start-up equipment which controls the emergency power supply.

Battery standby power for NDB navigation aids may be lost due to shaking, though reinstatement should be readily achieved provided access is available to the sites.

Runway Lighting and Navigational Aids
These are subject to dislocation of cable jointing and derangement of approach lighting from earthquake shaking. Re-alignment of navigational equipment will be required and close examination of all circuitry made before recommissioning of service, as it is expected that some cable damage may occur between building and exterior runs.

Particular recognition needs to be given to landing aids at Swampy Summit and approach lighting masts which are at risk of being affected by earthquake, flooding and severe weather conditions. Although much has been done to protect these installations, some damage is expected and, because of poor accessibility it may be difficult to reinstate services quickly.

AIR TRANSPORT- MITIGATION STRATEGIES

Dunedin Airport

Earthquake
The primary function of the airport depends upon the ability to land fixed wing aircraft on the runway and provision of an operable hardstanding area for parking and loading. Both the runway and hardstanding areas are of good quality flexible construction on consistent sub-grade and there is no evidence that differential settlement is probable. The nature of earthquake impact is likely to be uniform over these areas, with any effects due to settlement being unlikely to inhibit use. There is a possibility of some random surface deformation which would cause relatively short term closure, but it is impossible to determine where this might occur and the resulting problem would need to be addressed following impact. No meaningful mitigation work is likely to effectively improve survivability.

The buildings at the airport have been examined and although they may suffer some superficial damage to the fabric (including loss of glass and ceiling fittings), it is not expected to be of major consequence to operations , as repair work would be readily achieved. The building would continue to service the principal purpose of the airport but to a reduced level of convenience pending repair. The fittings and fixtures associated with passenger handling, communications, air conditioning and fire prevention are likely to suffer most by shaking and, as these are relatively cheap to secure, this work should be undertaken as soon as possible (if not already completed).

There is expected to be damage to connections of water supply, sewage and power in the airport terminal caused by differential settlement between the buildings and the external connections and it may be possible to provide flexible joints to reduce loss of service. Securing pumps, meters, header tanks and hot water cylinders will be of considerable advantage. A more detailed examination of these systems is necessary in order to determine where cost effective work may be undertaken.

Flooding
Susceptibility to flooding remains a serious hazard consideration to airport operation but is a difficult and costly event to mitigate.

The incidence of heavy rainfall over a prolonged period is likely to cause concern because of the inability to rapidly and effectively drain the very considerable area of flat land outside the airport boundary. The airport area is capable of being drained by existing pumping systems but problems arise from back-flow when the external catchment is saturated. The solution of providing an enclosed airport peripheral bund is considered unacceptable on cost grounds, when related to the level of incidents, and in consideration of the relatively brief period of disruption usually involved.

The flood risk has been partially addressed by Otago Regional Council since the floods of 1980, but probably the best protection to the airport from flood is to ensure that all on-site drainage channels are kept clear and power supply for the pumps being made secure by installation of a standby generator.

Meteorological Effects
There are no effective mitigation strategies for wind or snow hazard on buildings, so it maybe expected that some damage will occur to doors, canopies and the like from time to time, which will be dealt with by normal repair procedures. Items such as transmission aerials, lighting masts and the air bridges should be re-examined critically and strengthened where necessary against wind storm and snow loading damage. These facilities are not essential in the operation of the airport and incidental damage may be managed as repair work.

Technological Hazards
Examination of the airport area has not exposed any significant technological hazards which might seriously affect the operation of the service and incidental matters of security, protection of gas cylinders and fuel lines are regularly reviewed and adequately policed. The relatively isolated location and constant presence of security and operating staff ensure that limited opportunity exists for sabotage, and no further mitigatory action appears necessary.

Other Landing Facilities

Taieri Airfield
There is little which may be done to mitigate earthquake or flood damage to this airfield. In the event of earthquake it may be necessary to repair the undulations which could occur, but there is no way of assessing the extent of damage, nor where this may happen. Drainage runs naturally towards the Silverstream and mitigatory sub-surface drainage is not warranted in terms of cost effectiveness for this secondary airfield.

Dunedin City & Dunedin Hospital Heliports
In major emergency circumstances, alternative sites which are in less exposed locations will be used for helicopter operations. There is no cost effective mitigation warranted at either site.

Airways Control System
A review has been undertaken of the effects of the principal hazards of earthquake and flooding upon the functions of control. The impact of meteorological conditions and technological incidents are already part of the overall security system covering operational aspects of area control. As a result, there are no major physical mitigatory actions to be taken with respect to the control building, contents and standby facilities, all of which are expected to be adequate to resist earthquake and flooding hazards. Regular checks of seismic restraint of equipment are recommended.

Loss of airfield lighting, predominantly to the runway and hardstanding areas, has been identified as being temporarily correctable by the use of runway flares held at Taieri aerodrome and no further action is necessary in mitigation.

Termination of the two independent power supply lines to the airways control system at a common point on the south west edge of the airport administration area makes this location vulnerable and consideration should be given to separating the services to provide redundancy.

Conclusions

Examination of landing facilities, cargo handling and passenger processing has revealed that few practical mitigation measures need to be added to those currently in place.

Due to earlier experience with reference to flooding, a great deal has been learnt and measures put in place to reduce the impact of this hazard in the future.

Building systems and operational equipment, together with services such as water and sewage disposal may need improvement against earthquake shaking and this should be progressively undertaken following a physical review.

Power input and the provision of standby power supply needs review, particularly with reference to stormwater pumping.

Loss of access by road through Allanton, Outram and Henley may be a significant impediment to airport operations and should be reviewed.

Recommendations

In order to facilitate progress towards mitigation of earthquake and flooding hazards Dunedin Airport Limited intends to prepare a schedule of activity and commission a review of:

- Duplication of power supply to the airport area in general.
- Establishment of standby emergency power generation, with particular reference to stormwater pumping.
- Water supply and sewage system security against earthquake and flooding.
- Security of computer, control equipment, passenger handling and luggage systems, audio and visual equipment etc. with reference to earthquake shaking damage.
- Fire system, alarms, air conditioning and mechanical services for security from earthquake and flood.
- A schedule of spare component holdings and emergency lighting facilities within the terminal.

Dunedin Airport Limited has an existing emergency services plan which should be re-visited in respect of the findings of this review. Particular reference should be made to arrangements for testing and recovery of the runway and hardstanding facilities following earthquake or flood.

PUBLIC TRANSPORT/HEAVY HAULAGE - DESCRIPTION OF SERVICE

Introduction

The movement of people and goods is a critical function during and after a disaster. The availability of resources for this function are therefore considered as lifeline services.

Passenger Services

Dunedin has a range of passenger transport vehicles operating and available for the transfer of people from any hazard area. There are approximately 120 buses and 160 taxis operated by five bus companies and a number of small passenger services in the city. With minimal warning a range of vehicles can be made available for the collection and transfer of people within the emergency area.

Capacity of buses ranges up to a maximum load of about 70 passengers but difficulty may be experienced in cases where people have mobility problems. In this case the use of ambulances or specialist vehicles could be required. Where high water or ground clearance is required, there are trucks available in the local fleet to meet the need.

Taxis companies operate radio dispatch communication systems to all their vehicles but bus operators tend to have more limited contact with their vehicles.

Heavy Haulage

In the Dunedin city area there are approximately 220 vehicles classed as heavy vehicles, ranging from one-tonne utilities through to 'B' train truck and trailer units up to 44 tonnes. Rigged trucks, articulated trucks and 'B' trains are the most common.

Because of the mobile nature of their use, it cannot be pre-determined where any operator's vehicles will be at the time of an emergency, although it can be assumed that a percentage will be at operators' depots and further percentage will be on main roads either north or south of Dunedin.

Heavy Vehicle Fleet Maintenance

Garaging
Most operators of heavy vehicles have their own yards which are located throughout the industrial areas of Dunedin. There is sufficient space in most to cater for extra vehicles so that problems in one area that might affect depot or vehicle availability can be addressed by sourcing or storing vehicles at another site. Not all sites have covered storage for vehicles but most have access to administration areas and workshop space.

Servicing of Vehicles
Servicing facilities are maintained by most operators with pit or hoist access on most sites. Comprehensive facilities that can cope with large numbers of vehicles are to be found in the industrial areas close to transport operators bases with easy access to the main vehicle thoroughfare. Parts availability, because of the different makes of vehicles, may not be easy, given the trend towards smaller stock holdings and the reliance on nationally centralised parts supplies. General servicing can be done by most competent diesel mechanics and there is a co-operative approach to problem solving in this industry that would see most vehicles back on the road in a relatively short time. Fuel supplies are available at recognised truck shops, service stations and operators yards.

NZ. Army Facilities
Transport under the control of NZ Army is not always available due to the exigencies of the service. The Bridgeman Street barracks is an ageing brick-built structure which is susceptible to enhanced earthquake shaking and may also be liable to flooding, due to the low lying surrounding ground and high water table

PUBLIC TRANSPORT & HEAVY HAULAGE - ASSESSMENT OF VULNERABILITY

Passenger Services

Services are geographically dispersed throughout the city and it is not anticipated that hazard impact will seriously deplete the stock of buses or taxis. The principal factors which will affect use of the fleet will be their dependence upon serviceable roads and a sufficiency of fuels.

A secondary factor which increases operational vulnerability is the loss of servicing facilities due to collapse of servicing structures from earthquake or isolation during flooding.

The Citibus Newton depot is just outside the enhanced earthquake area and probably less susceptible to flooding than other garages. Green Island, Mosgiel and Sawyers Bay depots are likewise reasonably secure from enhanced shaking and the overall picture is one of low vulnerability due to widespread resources.

Heavy Haulage

The vulnerability of some specialist vehicles, including cranes, to earthquake and flooding risk appears to be higher than the passenger service vehicles and other heavy haulage vehicles due to the fact that they are generally resident in the industrial areas of the city which have a larger exposure to enhanced earthquake shaking, liquefaction and flooding. The overall risk, however, is still considered to be relatively low.

Heavy Vehicle Fleet Maintenance
Maintenance centres are well dispersed throughout the city, although some of the principal heavy haulage garages are in the industrial area where the effects of earthquake and flooding will cause greater damage to structures and to gantry cranes. An example of this is the heavy railway workshop in Hillside Road, but in general we would expect damage to be of low impact upon maintenance of fleets, with many reciprocal service arrangements in place.

PUBLIC TRANSPORT AND HEAVY HAULAGE - MITIGATION STRATEGIES

Passenger Services
Protection of passenger vehicles from the impact of hazard events in order to ensure their availability for evacuation purposes and transportation of workers in the period immediately following disaster depends largely upon location. The diversity of parking locations, will by itself, offer immunity from total loss of service and, as many vehicles are parked outside, there is little which may be done to mitigate damage. Consideration might be given to parking away from trees and structures such as high walls etc, which may collapse on vehicles and avoiding locations where flooding is known to occur.

There is a possibility of risk to fleet vehicles due to building or retaining wall collapse and there may be some mitigation measures which might be undertaken to upgrade workshops and the control systems involved in the operation of passenger services.

Fuel supply systems, particularly where overhead tanks are involved, should be re-examined for seismic restraint and, where gas or diesel heaters are installed in garages, the security of fixtures reviewed and strategies for protection from loss by fire should be considered.

Heavy Haulage
The wide diversity of garaging and location of working haulage vehicles make them less likely to be at risk by other than random hazard events. Because of the probable shortage of special use vehicles such as heavy cranes, crawler tractors, pumping vehicles etc, particular care is recommended with respect to their parking locations. Flooding maybe of more concern than earthquake in some locations.

Heavy Vehicle Fleet Maintenance
Owners have advised, through their assessment of vulnerability, that there is a wide distribution of locations at which maintenance is carried out and that the greatest risk to their facilities lies in enhanced earthquake shaking causing damage to buildings used for maintenance purposes with the worst feature being loss of gantry craneage and associated collapse upon vehicles. Owners should examine the stability of their buildings and incoming services.

Conclusion
Diversity of garaging location and maintenance depots renders the vehicle fleet at relatively low risk from natural hazards.

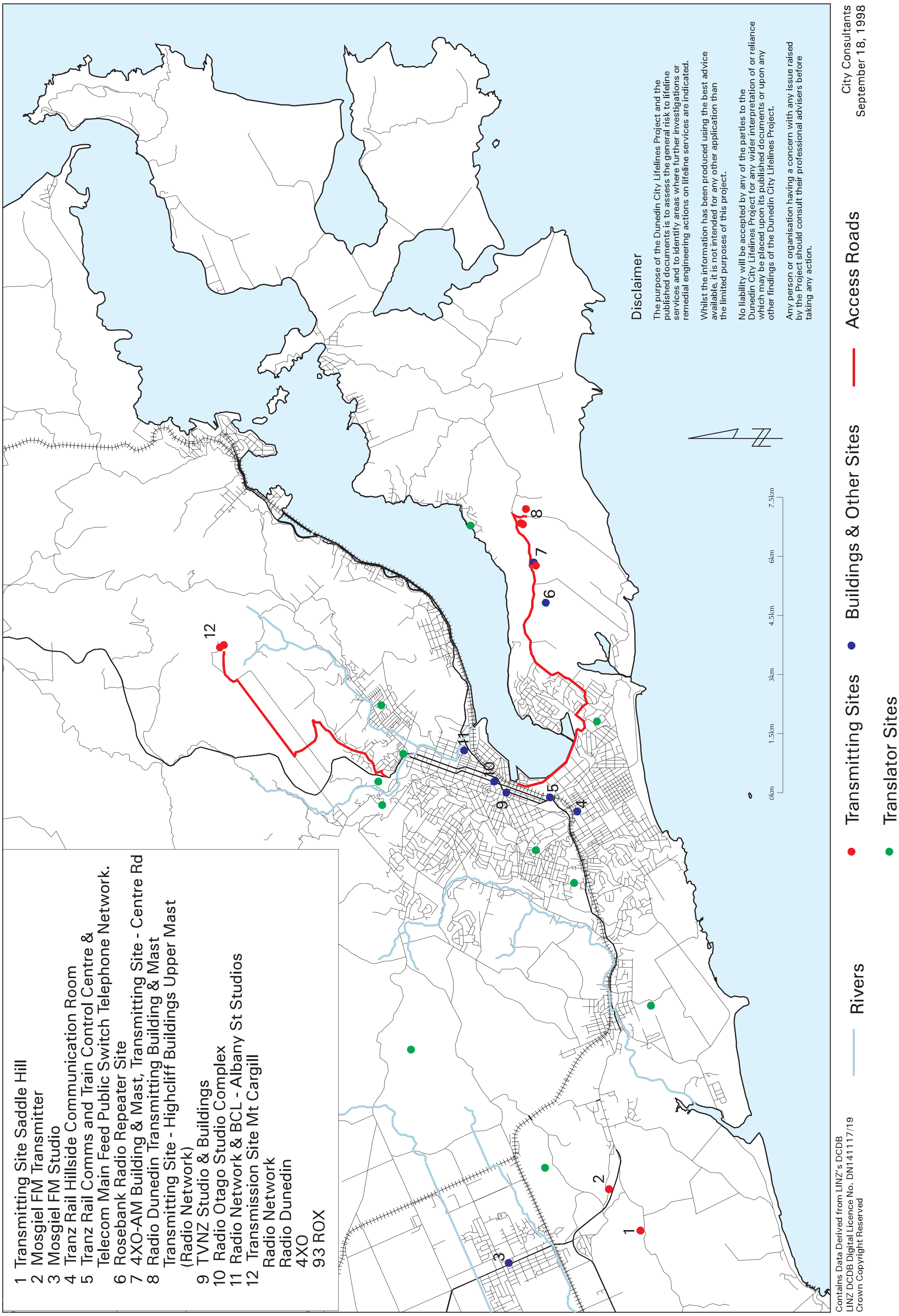
Matters which should be examined for mitigation are building structures, fuel supply tanks, cranes, operating systems and spares.

So far as has been reported by owners, mitigation action is likely to be centred upon a wide range of relatively minor expenditure on these elements. Transportation facilities remain vital to recovery of the city and surrounding area within an acceptable time scale and will contribute markedly to this being achieved.

Recommendations
Individual owners should review their operations and take appreopriate steps to protect vital transportation resources from hazard events.

CHAPTER 7. COMMUNICATIONS - CONTENTS

Telecommunications and Broadcasting



TELECOMMUNICATIONS - DESCRIPTION OF SERVICE

General Description

All participants provide telecommunication services to the greater Dunedin area, including telephone traffic, computer based data traffic, television and radio signals. Some provide access to public networks while others are private. These networks consist of both copper-cable and fibre-optic cable landlines and, to a more limited degree, radio systems which utilise the most up-to-date technologies and are extremely robust. Some have such diversity that on the failure of one system they can be switched to an alternative system with little apparent interruption to the user.

Generic description of this highly complex technology has been prepared to cover the broad spectrum of communications in the Dunedin/Otago area and relies upon contributions from:

- Telecom New Zealand.
- Tranz Rail Ltd.
- Broadcast Communications Limited.
- Clear Communications Ltd.

Technologies

The technologies and methods employed to connect the various assets of each service provider are:

Fibre Optic Cable

High capacity underground fibre optic cables carry the majority of telephone and data traffic to and from Dunedin. Within the city this cabling is used to link service providers with high speed interconnection.

Copper Cable

This older technology is used to provide the majority of urban and suburban telephone/data links. There is still some overhead cabling but underground cable more common and is used extensively throughout the city. Modern electronic circuitry allows copper cabling to be used beyond its original range and capacity.

Microwave Radio

Microwave systems utilise radio waves to provide interconnection between two locations and a number of systems are used within the city and to the north, central and south. Most of these systems are used as a back-up to fibre optic cable for telephone and data traffic. Microwave is also used where cabling is uneconomic to install.

Mt Cargill and Swampy Summit are the primary microwave transmission sites, providing connection to sites to the north and south for telephone, data, television and radio. A number of other sites are used for local linking within a participant's system and to one or more of the major transmission sites. An extensive microwave network carries television transmissions from the Mt Cargill site north to Mt Studholme, south to Kuriwao and Hedgehope and central to Obelisk as well as linking sites within Dunedin.

VHF/UHF Radio

These technologies include cellphones, land mobile despatch services, trunk-dispatch radiotelephones and radio-paging systems. Minor uses include cordless telephones and wireless private in-house telephone exchanges.

Cellular

There are many cell-sites within Dunedin City and its surrounds which provide cellphone coverage. Sites vary from hilltops to building faces, which allows tailoring of the coverage area to be served by each site. All these sites are linked, either by microwave radio or cable to the telephone network. If the link to the telephone network is broken, the cellphone transmitter/receiver cannot operate. The density of cellphone sites is determined on the basis of expected usage for the area.

Dispatch Service

This service provides for mobile radio communication which is effected by transmission through a repeater station located on a hilltop, either to another mobile radio or to a base radio. This service can be connected to the telephone network but more commonly stands alone or is connected to another repeater by a radio link.

Trunk Dispatch
This service is provided at several sites in Dunedin and is similar to the dispatch service except that the channel used is allocated by the repeater currently being used. It is a dynamic process and allows better use of mobile radio frequencies. The repeaters can operate in 'stand-alone' mode if linking to the telephone network fails, allowing limited operation.

Radio Paging
To provide a calling and messaging service to customers, paging transmitters are located on hilltops and tall buildings and each must be connected to the telephone network to function.

Safety Radio Services
The MSA (Maritime Safety Authority) operates a VHF marine safety service on the marine channels 16 and 71 from Mt Cargill. This is available for public use and is connected via a telephone network to a Maritime Operations centre at Avalon. The Otago Maritime VHF Association also operates a Marine Repeater at Hautai Hill.

Port Otago operates an HF (High Frequency) and VHF radiotelephone service from the marine station at Taiaroa Heads.

Airways Corporation operates a VOR (VHF Omnidirectional Radio) and DME (Distance Measuring Equipment) at Swampy Summit and NDB's (Non-directional beacons) at Swampy Summit and Henley. This equipment can operate independent of the telephone network.

Systems

The public switched telephone network (PSTN), with its computer controlled exchanges, provides customer connection, through the various technologies described above, to other customers locally, nationally and internationally. Exchange types include:

- Remote line units (RLU)
- Local exchanges (LX)
- Tandem exchanges (TX)

Telephone exchanges are located at strategic points in the networks and when failures occur, rapid reconnection or restoration of service can be made depending on the severity of the failure. Failures or network problems are able to be diagnosed quickly and telephone traffic control measures can be implemented rapidly

The PSTN is structured to provide alternate routing of traffic should failure of certain exchanges, trunks or junctions occur. Excepting customers connected to the affected exchange, any such failure would result in impaired service, not total loss. Total loss of network access generally requires the simultaneous loss of several exchanges trunks, junction routes and links which are not duplicated.

Since the introduction of stored programme control exchanges, service providers have been able to monitor customer behaviour on a real-time basis and experience has shown that small scale local events can considerably increase calling rates, resulting in network congestion in a local area. This causes difficulties for the affected customers when originating and completing calls but leaves the rest of the network operating normally. More widespread events can cause a general network blockage, with a collapse of the network's ability to function through overloading. Traffic management systems are used to control these situations by restricting the ability to originate calls. It is vital that public broadcast by radio and television be made to discourage unnecessary use of the telephone network following a major disaster. Failure to do so means that load shedding will have to be activated with a resulting risk of disallowing emergency calls.

The cellular network could suffer even greater overloading if many of its cells are out of service, as occurred during the Edgecumbe earthquake where, because of high levels of calls coming into the area, it was necessary to apply 100% restriction to calls from selected exchanges such as international and Auckland for several days after the event. This method of control can be expected in any civil emergency.

Cable Networks

Each participant uses one or more of the above technologies in providing links to their fixed assets. The telephone network consists of:

Local Access Networks

Typically these consist of multi-paired copper cables connecting customers to the exchange. To extend the range or capacity of copper cables, various technologies are employed, usually involving electronic circuitry of some kind. This can be powered over the cable itself or by a remote power feed. Rural subscribers may be connected via a radio system to the cable network.

Junction Links

These are circuits or links provided between exchanges within the Dunedin area.

Trunk Links

These are circuits which extend beyond the Dunedin area. They consist of high-capacity fibre optic cables or digital radio systems.

To the north and south, fibre optic cables are laid alongside the railway line and State Highway One; to Mosgiel, the cables follow both the railway line and State Highway to Mosgiel junction.

A fibre optic cable provides the link between the Dunedin BCL base in Albany Street to the BCL communications facility in Dowling Street. It will ultimately be used to provide interconnection between a telephone/data service provider and a digital microwave network.

Microwave Networks

A communications centre at Strathallan Street utilises a microwave link to Cargill House to provide interconnection between service providers.

Swampy Summit and Mt Cargill are the major microwave sites to and from the city and both sites have fibre optic cables connecting them to the local Dunedin networks. Mt Cargill also has local circuits to the TVNZ facility in Dowling Street to carry television programming. There is a further link to the BCL base in Albany Street carrying telephone and data traffic for the Maritime Safety Service, which has facilities located at Mt Cargill.

Microwave Transmission Site, Swampy Summit - Telecom

Radio Networks

Cellphone sites vary from hilltop sites to various buildings and structures in the urban area and all require connection to the cellphone switch via trunk links to remain operational.

There are dispatch repeaters and trunk dispatch repeaters at many sites in and around Dunedin. Swampy Summit is the main site for these repeaters, some of which are linked to other sites within Dunedin, including Rudd Road, Signal Hill, Corstorphine, Rotary Park, Saddle Hill, Mt Cargill, Heywards Point and Mt Hyde.

Paging transmitters are located at four sites in Dunedin.

Transmission Buildings and Exchanges

There are a number of local and tandem exchanges in the Dunedin area, each housed in its own building. One service provider operates a digital exchange at its communications centre in Strathallan Street and another at the Hillside Workshops.

New cell site structures are continually being added to the cellular network to provide additional coverage.

All land mobile radio and microwave transmission sites have purpose-built buildings and masts or towers. Because of their exposed locations, these masts and towers are built to stringent requirements to enable directional antennae to remain in position in periods of abnormal conditions.

Power Supplies

The primary source of power for all service providers is the Dunedin Electricity network but all telecommunication sites have some degree of standby power.

The Mt Cargill facility operates from a three phase 11kV overhead line up Cowan Road to the carpark where it terminates and is fed underground to a transformer outside the rear of the building. The site also has two standby diesel generators which together are capable of running the entire site and all its equipment or individually can be configured to run most services, but at a reduced level. Essential services such as analogue and digital linking equipment and the communication equipment have battery back-up to provide uninterrupted service and to allow some continuation of service should the standby generators fail.

Most trunk dispatch repeaters and dispatch repeaters have either limited battery back-up to provide a few hours operation or are located at sites where standby generators are provided.

The communications centre in Strathallan Street uses a 6.6kV feed from Andersons Bay Road with back-up provided by a standby generator and UPS (Uninterruptable Power Supply).

Clear Communication’s John Wickliffe House site has 24 hour battery back-up and the Dowling Street site has 20 hour battery back-up.

Access Routes

Access to all telecommunication sites , via public and private roads, is possible using two-wheel drive vehicles in dry conditions but 4WD is usually necessary in wet conditions. Many sites are of sufficient size to allow helicopter access if necessary.

TELECOMMUNICATIONS - ASSESSMENT OF VULNERABILITY

Telecom New Zealand Ltd

Landlines

Vulnerability to Earthquake

Local reticulation (exchange to customer) is mainly by underground cables using copper conductors. By its widespread nature this reticulation is susceptible to damage, with certain types of cables (now obsolescent) more likely to give problems. Any cables affected by significant differential ground movement caused by changes in soil types or liquefaction, are likely to be severely damaged and bridge crossings would be especially vulnerable. Widespread damage to copper cables between the customers and the exchange may result from water penetration through cracks in the sheathes of lead sheathed cables.

Cabling between exchanges (junctions and trunks) is by a combination of fibre optic cables installed in ducts and microwave radio systems. Cables are vulnerable in areas subject to significant ground movement, eg. crossing a fault, in areas subject to liquefaction, or where a landslide carries both ducts and cables with it. Little damage is expected (except at some bridge crossings) to the route-diverse fibre optic junction cable system, and hence there will be low loss of junction links although there may be some reduction in junction capacity.

Radio systems may be subjected to support structure failure or antennae misalignment. Where ducts and cables enter buildings in areas subject to liquefaction or settlement damage may occur due to differential movement between the surrounding ground and the building. Aerial systems for microwave radio could become misaligned even if the supporting structures remain intact, although modern systems are reasonably tolerant of movement.

Restoration of lead sheathed cables may extend over many months, but virtually all other elements of the PSTN may be restored to full capacity within one week.

Vulnerability to Flood
Buried cables are designed to function in wet environments, so flood effects on them should be minimal. Higher surface water levels will increase the static water pressures on cable sheaths, in some cases resulting in water penetration causing faults within one to two days of the flood. These will be randomly distributed in flooded areas and should only affect a small proportion of customers.

Cabinets are almost always located in the road reserve at the fenceline and flood levels up to 200mm in the cabinet will have no affect. Beyond this, customers will lose service progressively.

Pillars are located in the road reserve at the fenceline and typically only contain 1 to 4 customer lines. Flood levels up to 400mm will normally have no affect but beyond this level, faults may occur.

Roadside equipment enclosures may be flooded and water penetration of critical components will cause total failure of the installation.

Any connectors in pillars, connection blocks in cabinets, telephone sockets in houses, and internal house wiring that have been immersed will probably have to be replaced. Associated cabling and mounting hardware will have to be hosed down to remove silt, sand etc. and then dried.

Repair of cables broken due to scouring of roadways and bridge abutments may have to wait until repair of the road is sufficiently advanced. Customers' service affected by either immersion of plant or cable breaks should be progressively restored over a period of two days to two months after the flooding subsides.

Vulnerability to Landslip
Buried cables are particularly vulnerable to landslip or subsidence. Cables are installed using a number of different methods.

Major urban cables are often installed in duct systems. Early installations comprised earthenware ducts, laid in sections approximately 1m in length and are particularly vulnerable to collapse in the event of ground movement. Newer installations are in PVC ducts, either glued or rubber-ring jointed. A mixture of other duct materials has been employed, including asbestos cement and cast iron. The cables conveyed in these duct systems generally have either a lead or plastic sheath. Plastic sheathed cables are more tolerant of minor displacement than lead sheathed cables which are susceptible to sheath cracking in the event of any movement.

Minor urban and rural cables are generally direct buried with the two predominant cables being lead and plastic sheathed.

The effect of cable damage will vary from small numbers of isolated customers without service, to widespread loss of service affecting many or all Telecom services. Major routes have diversity, so the failure of any one will precipitate the rapid restoration of services onto other routes.

Vulnerability to Snow Storm / Wind Storm
Overhead wires (aerial service leads) to many customers will be lost through the weight of snow or tree branches overloaded with snow falling and breaking wires, or telephone poles being broken. These customers will be scattered in pockets around the city but as the programme to convert to underground leads progresses this will become less of a problem.

Although aerial service leads are relatively easy to repair, it will take some time to repair all connections if damage is widespread. Most telephone poles support power service leads from the opposite side of the road, as well as telephone service leads. The priority that the replacement of broken telephone poles is given may be dictated by the need to restore power to houses, rather than the need to restore telephone service.

Exchanges and Radio Installations

Vulnerability to Earthquake
All telecommunications equipment is critically reliant on power supply so standby power generation equipment (to provide an essential supply) is installed at most locations. The adequacy of fuel reserves at individual sites is being reviewed, giving consideration to the possibility of a prolonged power outage and likely difficulties in obtaining access to the sites for refuelling. This underlines the interdependence of lifelines and the need for mutual understanding of both resilience and expectations.

Switching equipment is reliant on air conditioning to ensure the temperature does not exceed certain levels. While air conditioning equipment is not operating, temperatures need to be monitored to ensure they do not rise to damaging levels. Air conditioning equipment is reliant upon power and, in some cases, water supply (for replenishment only), and requires adequate seismic restraint of all fans, ducting, pipework and chillers.

The telecommunications network makes good use of diversity by means of alternative physical routes and alternative media but there are still some parts of the network where improvements can be made.

All exchanges in the Dunedin area are stored program control, which has resulted in some centralisation of switching operations, with remote lines units being dependent upon their hosts for switching of calls. The operation of some telephone exchanges may be unstable due to congestion caused by repeated re-dialling attempts. Dial tone may be slow to appear.

The majority of exchange buildings and equipment is expected to suffer little damage and, due to diversity, disruption to customer services from any damage that is incurred should be minimal.

Vulnerability to Flood
Exchange equipment will be at risk as soon as flood levels rise more than 50mm above the exchange floor level and five Telecom exchanges are at risk. If the equipment is powered up at the time, irreversible damage could occur, requiring replacement of the immersed equipment and possibly other equipment as well. If the equipment is powered down before immersion, it is expected that once the flood levels have subsided the immersed equipment can be successfully salvaged and restored to full service within days.

Exchange cable wells will be affected by high water levels in Telecom ductlines/manholes causing exchange cable wells to fill with water at a rate faster than the permanently installed sump pumps can handle. In many cases, the sump pump outlet pipe discharges into a gully trap below the potentially highest flood level and will be ineffective. If the water level rises to within one metre of floor level in many of the exchanges this could result in unfilled, unpressurised plastic cables, installed between the air dams in the cable well and the main distribution frame on the floor above, becoming partially submerged. Faults affecting many customers could result.

Vulnerability to Landslip
The vulnerability of exchange and radio buildings to landslip is considered low, although smaller installations serving pockets of customers may fail as a result of land instability.

Vulnerability to Snow Storm/Wind Storm
Many windows would be blown in or be broken by flying objects, then rain or snow would be able to enter buildings through the broken windows and damage equipment. Broken glass would have to be extricated from equipment during the clean-up after a windstorm. This would pose a risk to the availability of the network as, during the work, equipment could be accidentally disturbed. Most critical network sites either do not have windows or windows have been filled in.

Traffic overloading frequently results during a windstorm or snowstorm. It is expected that the telephone network will be very busy, but shouldn't be catastrophically overloaded. Some exchanges may experience minor load shedding. Loss of some cell sites may increase traffic on other cells, but since most of the PSTN will still be functional, this should not be a problem.

Toll links north may be lost or only partially available and many customers with aerial service connections will lose service. They will be relatively easy to repair once the winds have died down but it will take some time to repair these connections if damage is widespread.

The roofs at all Telecom sites are expected to carry snow loadings, although the strength of those at some radio station buildings need to be reviewed.

Mobile Radio Services

Vulnerability to Earthquake
The cellular and paging networks for most of the South Island are completely dependent on the central switch and failure of this switch or the links to it would completely disable these services.

The Fleetlink trunked dispatch service is normally dependent on a central switch but failure of this switch or the links to it would merely disable the linking between repeater sites and many users would be unaware of such a switch failure. Loss of all physical links to the radio stations would result in the loss of access to the PSTN for Fleetlink users. Congestion may occur on Fleetlink channels, but can be overcome by installing extra shared channels (within say two days).

There is likely to be significant cellular network congestion for the first two hours after an earthquake with some relief after three to six hours (as service demands are reduced through individual cellphone batteries depleting and the probable lack of mains power for re-charging). Disruption of service will result at some cell sites due to the depletion of battery reserve following the loss of mains power to sites and others will be disrupted by the loss of their fibre optic cable links to the cellular switch. Little effect is expected on the equipment and masts at the cell sites or on the connection of the cellular network to the PSTN or the trunk network, and the cellular network should be restored to virtually full capacity within four days.

In recent major international disasters cellphones have proven to be an extremely useful and speedy way for utilities to augment their communications systems and accordingly the management of Cellular network congestion by Telecom should be in favour of utility and emergency organisations. Restriction of other Dunedin cellular customers should be considered, to establish that preference.

Mobile radio services can expect up to 10% loss of service providing the timber masts at hilltop radio stations do not fail. There will be little effect on the land mobile radio equipment at these stations and little disruption due to traffic congestion.

Loss of the entire Otago radio paging network could result from all trunk links north being lost, or loss of valuable cable links between the paging switch and the hilltop radio stations. The paging network should be fully restored within 2-4 days by using temporary radio links.

Vulnerability to Flood

Two of the Dunedin cellular network cell sites could suffer from flood immersion to varying extents, but loss of both these sites would only have a minimal effect on the coverage and service level of the surviving cellular network.

Land mobile radio, Fleetlink and paging networks should be completely unaffected. Since all paging signals are broadcast from all the transmitters, loss of one landline access will only result in the Dunedin paging coverage being slightly decreased.

In common with all of the scenarios, some initial congestion on the telephone, cellular and Fleetlink networks is expected. During a flood it is expected that the telephone network will be very busy but shouldn't be catastrophically overloaded. Some exchanges may be subject to minor load shedding and loss of some cell sites may increase traffic on other cells, but since most of the PSTN will still be functional this is not expected to be a problem.

If it is assumed that all Telecom sites in, or near the flood plains lose mains power, the only sites affected are those that do not have their own engine alternator set mains back-up.

Road access to some sites may be impassable for virtually all vehicles and others may only be accessible by high wheel base vehicles such as 4WD's or trucks. This should not present any great difficulties to the Telecom repair effort, so long as there remains access across rivers.

Vulnerability to Landslip

Some radio based services rely on landlines for interconnection with the central switch (cellular, paging, etc) and services may be interrupted due to landslip but diverse routes are available to most critical sites. Restoration of services is dependant on access to failed sites and is therefore reliant on road access being available.

Vulnerability to Snow Storm / Wind Storm

Towers and masts are expected to survive the storm because of their combined snow and wind rating, but some dipoles and other antennas on these masts could be damaged. This means that the land mobile, paging, and trunked dispatch networks may be partially disrupted.

Most cell sites do not have standby generators and many could lose their mains power supply. Those that do will fail completely after the battery reserve has been used, unless a portable engine alternator is connected to the cell site. As Telecom has a number of portable engine alternator sets in Dunedin it should be possible to keep most cell sites functional unless road access is blocked by snow drifts.

Tolls

Vulnerability to Earthquake
Toll links out of Dunedin comprise a combination of fibre optic and radio technologies, with all links vulnerable to the effects of earthquake. Cable routes may fail as supporting structures fail and radio systems are vulnerable to building and support structure failure. Toll failure will initially cause widespread disruption to services until priority traffic is re-routed. Some services will automatically restore almost immediately.

Vulnerability to Flood
Toll services will be minimally impacted by flooding. Where supporting structures fail, services will be lost until traffic can be restored using alternative routes.

Vulnerability to Landslip
Cables carrying toll services which traverse unstable ground will be vulnerable to failure although complete failure of a cable will not necessarily result in the complete loss of services. Alternative routes will be employed for service restoration.

Vulnerability to Snow Storm/Wind Storm
Toll links carried on radio bearers could be affected by a windstorm but there will be little impact if only one link is lost.

Area Vulnerability to Disaster Events
For the purposes of describing Telecom's asset vulnerability to various events, the area has been subdivided into the following geographic zones:

- Harbour Basin and low lying areas, comprising the Leith Valley and North East Valley, harbour periphery, reclaimed land areas and South Dunedin/St Clair/St Kilda. This zone extends along the south coast to Taieri Mouth.
- Hill suburbs, comprising Maori Hill to Mornington and Corstorphine, Halfway Bush, Brockville and the Peninsula.
- Taieri Plains, comprising the entire plain.
- Northern approach, comprising the area north of the Leith Valley.

Harbour Basin and Low Lying Area Vulnerability
Landlines in this zone are vulnerable to earthquake shaking effects, particularly to lead sheathed cables and to flooding where water levels reach about 400mm above ground level.

Exchanges are vulnerable to flooding and, to a lesser extent, to earthquake shaking.

Mobile radio installations are built to new building codes and are not considered particularly vulnerable to shaking. Flooding may become an issue if water levels reach approximately 1m about ground level.

Cellular coverage in this area is provided by several transmitters with overlapping service areas but localised congestion may result if any one site is unusable.

Hill Suburbs Vulnerability
Landlines are vulnerable to localised land slumping, with effects ranging from inter-exchange lines being lost to small pockets of customers without service.

Exchanges are not particularly vulnerable to any event as all equipment is secured to adequate seismic standards and the majority of buildings are of recent construction.

Cellular services are housed in modern containerised structures although towers and masts may fail from shaking.

Taieri Plains Vulnerability
The major effect on the Taieri Plain is flooding, when exchanges will fail if water levels reach approximately 500mm above ground level and area isolation may occur as roadside equipment cabinets become inundated.

Landlines will fail randomly throughout the area, with the failure profile based generally on age and cables will eventually fail if left immersed in water, particularly at higher than normal static pressures. Fault location and repair will extend over some months.

Exchanges and landlines on the Taieri will be subjected to the effects of enhanced shaking.

Northern Approaches Vulnerability
The northern approach is characterised by land instability and any cables traversing unstable ground will be subjected to a variety of failure mechanisms ranging from sheath cracking due to land creepage, through to catastrophic failure due to large scale landslip.

Exchanges and radio sites are minimally exposed to landslip but mains power supply vulnerability and dependability is of primary concern. Most sites (excepting cellular service) have back-up AC and DC power sources.

Landlines in low lying coastal areas, including Blueskin Bay and the Waikouaiti River estuary, may be subject to the effects of tsunami.

High level radio sites will be subjected to the effects of snow and wind storms, although they are self-contained and essential services will survive for some period. Access during such events will be restricted, and may be for days afterwards.

Clear Communications Limited

Landlines
Clear Communications Limited provides a telecommunications service via microwave and fibre optic circuits from Dunedin, northwards. The fibre optic follows the railway line.

Dunedin to Ravensbourne
This landline is a fibre optic and is vulnerable to earthquake shaking, liquefaction and from flooding and tsunami in the lower Leith area. The probable cause of failure from earthquake is derangement or severance of the fibre at bridge crossings due to lateral movement.

Ravensbourne to Purakanui
Earthquake and landslip may lead to severance or derangement of the fibre, with the sections most vulnerable to earthquake shaking being bridge crossings.

Purakanui to Warrington
Earthquake is less of a risk here but the fibre optic is more exposed to the effects of a tsunami. If little movement occurs the optical fibre is less susceptible to water ingress than is conventional copper cable.

Microwave
Mt Cargill
See the Broadcasting section for detail.

Tranz Rail Limited

Landlines
Tranz Rail's telecommunication network is very dependent on local cabling and the supply of its network services by Telecom in the form of three 2Mbit/sec links. These are supplied by landline to the communications centre in Strathallan Street, which is Tranz Rail's most vulnerable site because of its fault line proximity and possibility of flooding. The cause of failure under earthquake conditions is likely to be severance of cables at jointing and derangement of switchgear within the building. Flooding is likely to cause cable faulting and probably presents a more frequent hazard impact though of less severity to the system. The mains power supply to this area is equally vulnerable.

Exchanges
Tranz Rail has two digital switches in Dunedin. The main switch is located on the ground floor of the communications centre in Strathallan Street, which is a building approximately 17 years old and of timber construction. Derangement of switchgear is likely to cause interruption of service in earthquake conditions and flooding damage to the exchange will be similar to that occurring to cable junctions etc.

The building itself is likely to suffer severe damage due to enhanced shaking and the liquefiable nature of the land upon which it is built. As a consequence, equipment located within the building is considered to be highly vulnerable.

Mobile Radio and Telephone Communication
Tranz Rail links its train control from its Network Centre in Wellington to repeaters in the Otago and Southland areas through it's building in Strathallan Street.

Access to hilltop and remote trackside repeaters appears to be reasonably good.

Tranz Rail is also dependent on mobile radio and cellular telephone services from Telecom.

Train Signalling
A centralised traffic control (CTC) signalling system is used in the Dunedin area for the safe and efficient running of trains. The Dunedin rail yard and five remote sites are controlled from the Train Control Centre in Strathallan Street using data circuits provided by Telecom as well as Tranz Rail landline circuits. In addition to this, a computerised track warrant system is used to ensure the safe running of trains between these remote sites. This information is conveyed to the locomotive engineer by radio communication.

In the event of a CTC system failure, set procedures are put into place and information authorising train movements is conveyed to the engineer by radio.

Signalling systems are particularly susceptible to disruption of trackside circuitry which is expected to be deranged or cut in many locations following a credible earthquake. In particular areas such as those immediately surrounding the Dunedin City shoreline to Port Chalmers and through the South Dunedin area, both track and communication lines will be most seriously displaced.

TELECOMMUNICATIONS - MITIGATION STRATEGIES

Introductory Note
A number of participating organisations in this study have no staff in the Dunedin district, making the defining of mitigation strategies difficult. Of those participants who have been able to provide information most do not have direct control over expenditure on this important feature. Some participants have already taken part in Lifeline studies in other locations and have mitigation strategies in place, while others explain their reason for limited strategies in their introductions.

All telecommunications service providers have similar strategies as the technologies used are similar.

Telecom New Zealand Limited

Introduction
The mitigation strategies outlined in this study draw heavily on the experiences of other areas, in particular Wellington and Christchurch, where lifelines studies have been completed and appropriate mitigation strategies developed.

Many strategies identified in these studies are already being implemented in other areas including Dunedin. The result is a series of strategies which may seem to be common sense, but which contribute to the survivability of the telecommunications networks.

Mitigation Strategies Common to all Areas
The following strategies are common to all geographic areas and some are already commonly practiced:

- All new or reworked installations to conform to company seismic control standards.

- All building refurbishment to conform to appropriate controls, particularly fire protection and hazard mitigation policies (internal).
- Back-up copies of critical network databases to be held off-site, and where possible, in electronic media.
- Good housekeeping policies and practices in key sites, including proper restraint of movable objects (desks, computer terminals, bookcases, etc) and removal of rubbish and packaging immediately to reduce the risk of fire.
- Enhanced security.
- Pressurisation of critical cables to prevent the ingress of water.
- Identify cables at higher risk of sheath fracture.
- Provide diverse network feeds to key installations where appropriate.
- Provide robust back-up systems at key sites.
- Enhance survivability of engine alternator sets and associated fuel systems.
- Analyse long term power outage probabilities and assess fuel requirements.
- Analyse battery back-up performance and robustness.
- Analyse key support systems such as air conditioning plant.
- General robustness designed into new and reworked networks.

Mitigation Strategies Relating to Specific Geographic Areas

Harbour Basin Low Lying Areas and Taieri Plains
Analyse the general preparedness for flooding events, including the provision of sand-bag materials and develop strategies to eliminate water ingress to key sites for extended periods. The main problem with this type of event is the disposal of unwanted water and silts.

In extreme events, power will be removed from key elements to enhance their survivability and hence lessen restoration times.

Hill Suburbs and Northern Approach
Mitigation strategies for this area revolve around expeditious route selection. In general, cable routes closely follow road alignments.

Tranz Rail Limited

Mitigation Strategies Policy Statement
The following strategies are common to all areas:

- All sites conform to company seismic standards.
- All major buildings conform to local building requirements.
- Good housekeeping and safety practices are actively encouraged within the company.

Provision of Back-up and Alternative Circuits
Where possible back up circuits are provided by use of:

- Standby generators and UPS for power requirements.
- Dial-up circuits for data and signalling.
- Dial-in back-up equipment to intercept radio links in the event of a network failure.
- Dial-out via dedicated lines in the event of a Telecom 2Mbit/sec link failure.
- Dial-out back-up using cellular link units.

BROADCASTING - DESCRIPTION OF SERVICE

Participants

Participants in this section were:

Broadcast Communications Ltd (BCL)
BCL is a wholly owned subsidiary of TVNZ which, in the context of this report, operates one broadcast site in Dunedin as well as maintaining other sites in the Dunedin area. Much of the technical information relating to the Mt Cargill site was provided by BCL.

The Radio Network (TRN)
TRN is a private sound broadcaster which operates what was previously the Radio New Zealand Commercial Division.

Radio New Zealand (RNZ)
RNZ is a SOE operating the non-commercial divisions of the previous Radio New Zealand.

Radio Otago
A private sound broadcaster owned by Radio Otago Ltd.

Television 1 and 2
TV1 and TV2 are owned by Television New Zealand, a State Owned Enterprise (SOE).

Television 3 and 4
TV3 and TV4 are owned by a private broadcaster, Global Television NZ Ltd.

Channel 9
A private television broadcaster owned by Allied Press Ltd

General Description

Each participant provides either 'information communications' in the form of broadcasting or, in the case of BCL, a technical service function to the broadcaster.

The broadcasting spectrum can be split into three distinct areas, each of which provides differing coverage:
- Sound radio - AM broadcasting
- Sound radio - FM broadcasting
- Television broadcasting

Owing to the nature of broadcasting spectrum licensing, the number and ownership of both sound and television broadcasting stations depends on market forces. Broadcasting spectrum is allocated by an auction process in which the highest bidder obtains the right to use a frequency. These frequencies can then be used, held, leased or sold. This has resulted in a continuously evolving industry and changing technologies which makes description difficult.

Television Broadcasting

There are eleven television channels available in Dunedin City, with six of these being free-to-air.

Both terrestrial and satellite technologies are available in Dunedin, although the majority of viewers receive their signals from terrestrial sites. The main television transmission site is located at Mt Cargill.

Currently analogue transmission only is used, with video information using AM (amplitude modulation) and sound information using FM (frequency modulation). Transmitted power levels vary from less than one watt from some translators to 300 kW from primary sites.

Sound Radio Broadcasting

Presently there are nine AM broadcast and ten FM broadcast transmitters as well as three FM repeaters. Of these, three are government owned (a SOE), with the balance being private stations.

The AM broadcast band covers the frequency range 550kHz to 1,600kHz and provides a generally larger coverage area than FM transmissions of the same power. The FM broadcast band presently covers 89MHz to 100MHz.

The AM frequencies currently used in Dunedin are:

621 kHz	Radio Rhema	Three Mile Hill site
693 kHz	Radio Sport Network	Highcliff site
810 kHz	National Radio	Highcliff site
900 kHz	Parliamentary broadcasts	Highcliff site
1044kHz	Newstalk ZB	Highcliff site
1125kHz	Classic Hits (re-transmits 89.4FM)	TRN Centre Road site
1206kHz	4XO-AM	Highcliff site

1305kHz	Radio Dunedin 4XD	Centre Road site
1575kHz	Hills AM (Access radio)	TRN Centre Road site

The FM frequencies currently used in Dunedin are:

89.4 MHz	Classic Hits	Mt Cargill site
90.2 MHz	Light FM	Mt Cargill site
91.0 MHz	Radio One	Mt Cargill site
92.6 MHz	Concert FM (+ 2 repeaters)	Mt Cargill site
93.4 MHz	C93	
95.4 MHz	Mosgiel FM	Chain Hills site
95.8 MHz	96ZM	RNZ Highcliff site
96.6 MHz	Radio Pacific	Mt Cargill site
97.4 MHz	4XO-FM	Mt Cargill site
98.2 MHz	More FM	Mt Cargill site

Microwave Networks

The services provided in Dunedin are both network programmed and locally programmed. Programme is brought to Dunedin by all types of telecommunications networks.

Three bi-directional analogue bearers in a 2+1 configuration provide programme links from Mt Studholme in the north which are used for incoming TVNZ and RNZ Concert FM programme distribution and contribution. One outgoing analogue link carries TV3 programme to Mt Studholme for re-broadcast in the Timaru and Waimate areas.

Further links are provided to Kuriwao in South Otago and to Obelisk in Central Otago. These are analogue bearers in a 2+0 configuration and carry television and RNZ Concert FM programme to Invercargill, Alexandra, Wanaka and Queenstown. There is also a digital 34 Mbit bearer to Kuriwao.

Within the city there are two bi-directional digital links from Mt Cargill to the TVNZ facility in Dowling Street. A passive reflector on Consultancy House is installed to reflect the signal to Dowling Street which is not in line-of-sight to Mt Cargill. Two further digital bearers link Mt Cargill to the BCL maintenance base in Albany Street carrying mainly data and telephone traffic.

There is an unidirectional microwave link from the Allied Press building in Stuart Street to their television transmission facility at Cowan Road.

A 9 metre satellite receiving antenna located adjacent to the Mt Cargill building receives the BBC news signal for HPTV which is routed to the Dowling Street studio by one of the analogue microwave links.

Television Repeaters

There are many television translators which repeat the TVNZ and TV3 transmissions to pockets within Dunedin where primary coverage is poor.

Landline Networks

Apart from those described in the Telecommunication - Description of Service section there are a number of Telecom provided landlines from studios to transmission sites. They are:

- Albany Street studio to Highcliff, 2 circuits - Radio Dunedin, 4YC.
- Telecom to Highcliff, 1 circuit - 4YA.
- Prince Albert Road to Centre Road, 1 circuit - Access Radio.
- The TV3 and SKY television programmes are received by fibre optic cable from the north.

VHF/UHF Networks

All FM transmitters at the Mt Cargill site are provided with programme via VHF or UHF Studio to Transmitter Links (STL's) which are radio links relying on directional antennae at each end. Some of these are dual-mono (to provide a stereo broadcast) and thus provide a degree of redundancy. STL transmitters are located at Radio Otago's Cumberland Street studio, The Radio Network studio in Albany Street, the University of Otago Student Union building and the BCL Maintenance base in Albany Street. UHF links provide programme to the Peninsula sites.

Transmission Facilities

Mt Cargill Site
All transmitters are contained within one building and all antennae are on the one lattice tower.

Building
The building at the summit of Mt Cargill is a poured concrete, partially cantilevered, single storied, flat roof structure divided into four operational areas:

- FM transmitters.
- Television transmitters.
- Antenna combiner.
- Service area.

The building has its own water and sewerage systems so is not reliant on external services.

Transmission Mast
The transmission mast is a self supporting steel lattice structure 105m high which carries the majority of the microwave and radio linking antennae as well as the radio and television antennae.

Antennae
Antennae consist of a single FM band antenna for all FM transmitters and three separate antennae for television transmission. These comprise a band 1, band 2 and a UHF antenna. These are divided into upper and lower stacks and fed with separate feeder cables and while normally operated as a combined antenna, each stack can operate independently. The antennae are connected to their transmitters by coaxial cables which are carried in two covered trenches.

Maintenance Access
Access is via Pine Hill Road and Cowan Road. Cowan Road is particularly subject to harsh weather during winter and may be closed for days and 4WD vehicles are usually required. A sealed carpark adjacent to the building may be used as a helipad.

Power Supply Systems
Power is provided by Dunedin Electricity through an 11kV 3 phase overhead line terminating at the carpark, with the final 200m underground. A transformer is located outside the rear of the building. Two standby diesel generators are available.

Highcliff Site

Buildings
The principal building is of 1930's era, constructed in concrete, and houses five AM transmitters, service areas and limited workshop facilities. Three small huts at the base of the masts house the antenna coupling units and two FM transmitters.

Transmission Masts
There are two lattice type stayed masts which, an earlier study has indicated, are more likely to survive an earthquake than the self supporting type. The 155 metre tall mast is substantially constructed, with a 3 metre wide plinth base, and the 125 metre tall mast has an equally substantial cross-section with a wide footing. Neither is likely to collapse. These masts are in themselves the antennae or radiators, with the antenna coupling units located in huts at the base of the masts. An FM antenna is also located on the upper mast.

Maintenance Access
Access to the masts and buildings is from Highcliff Road and Karetai Road, both of which are public roads and 2WD vehicles normally suffice, winter or summer.

Power Supplies
Power is provided by Dunedin Electricity from an 11kV 3 phase overhead line terminated at a transformer inside the main building. Power is reticulated underground from the building to both transmission masts and the FM hut. An automatic diesel generator provides standby power to all facilities on site and has a fuel tank above ground holding sufficient capacity for 3 days' operation.

Centre Road sites (Radio Network / Radio Otago)
There are three AM transmitters at these sites.

Buildings
There are two relatively small buildings of concrete block construction.

Transmission Masts
There are two stayed masts of steel lattice construction and a coupling unit which allows three AM transmissions on one mast.

Maintenance Access
Access is either from Highcliff Road to Centre Road or Tomahawk Road to Centre Road. As Centre Road is difficult in wet weather, 4WD is often necessary.

Power Supplies
An 11kV overhead line brings power to a pole transformer in Centre Road. An automatic back-up diesel generator is on each site, with sufficient fuel for 1 week stored in a tank above ground.

Chain Hills Site
This site and Saddle Hill are FM repeater sites only. Equipment is cabinet mounted at Saddle Hill and in a building at Chain Hills. Power is supplied by the normal 230V reticulation and access to both sites is by public road.

Studio Buildings
There are radio studio facilities for Radio New Zealand and The Radio Network at Albany Street; Radio Otago Ltd has three studios at it's Cumberland Street building and one at Mosgiel; Hills AM studio is in South Dunedin; and Radio One is in the University Union building, Castle Street. Channel 9 has television studio facilities in the Allied Press building in Stuart Street.

Power Supplies
All studios are dependent on reticulated power supply, but the Albany Street studio has an automatic back-up generator which can provide power for up to 1 week. .

Transmission Equipment
Each studio has STL facilities to its transmitters at Mt Cargill, Highcliff or Centre Road and Radio Otago has an STL from its Mosgiel studio to the Chain Hills transmitter.

BROADCASTING - ASSESSMENT OF VULNERABILITY

Sound Radio Broadcasting

Studio Buildings

Albany Street Studios (Radio Network/Radio New Zealand)
This is a single level reinforced concrete and concrete block building, structurally very strong but on unstable, partly reclaimed land with one corner of the building on solid ground. Its proximity to the Leith and relatively low level makes it vulnerable to flooding and possibly to tsunami.

Cumberland Street Studios (Radio Otago)
This is a relatively modern building on reclaimed land with its basement and access vulnerable to tsunami and possible liquefaction from shaking.

Mosgiel Studios (Radio Otago)
Subject only to extreme flooding.

Prince Albert Road (Southern Community Broadcasters)
The studio occupies the ground floor of an older two storey concrete building which is at risk from earthquake shaking and possible liquefaction. There is also some risk from flooding.

Transmission Buildings

Highcliff (Radio New Zealand)
This is an old reinforced concrete building, with substantial ligh-tweight roofing spans. Earthquake may cause severe damage to its roof and walls with subsequent damage to transmitting equipment.

Centre Road (Radio Network)
This is a concrete block building, subject to possible cracking of walls and with a light-weight roof likely to collapse during an earthquake.

Centre Road (Radio Otago)
Constructed in concrete block, this building will probably suffer cracking to walls during earthquake.

Saddle Hill (Radio New Zealand)
This is simply a steel cabinet on a concrete plinth and is unlikely to be damaged during an earthquake but the land upon which it stands is vulnerable to slipping.

Chain Hills (Radio Otago)
This is a concrete block building with light- weight roof, built upon land susceptible to slip.

Mt Cargill
See the section in Broadcasting which describes this buildings' vulnerability.

Transmission Equipment and Masts

Highcliff (RNZ)
This site has two separate transmission masts with FM transmission antennae on the larger mast.

The smaller mast is the most likely to survive an earthquake although the coaxial feeder cables could be vulnerable to derangement or severance.

The multi-coupling networks at the base of both masts are highly vulnerable to damage if either of the coupling buildings, located at the base of each mast, is damaged. The lower mast coupling building is timber framed and hence likely to survive an earthquake but the upper mast coupling building is concrete block and will be vulnerable to cracking.

The FM transmitters are in a small concrete block building which is vulnerable to cracking from earthquake and severe damage or destruction if the upper mast falls on it. The FM aerials are located on this mast which is vulnerable to high winds and severe earthquake shaking which may cause lateral displacement at the base insulators. The transmitters themselves are small and mounted in a strong rack.

Centre Road (Radio Otago)
This is a light-weight stayed mast, with the FM antenna mounted at the top of the AM mast. It is vulnerable to severe earthquake shaking.

Centre Road (Radio Network)
This is a lightweight mast that will be vulnerable to shaking and high winds although damage is likely to be minimal. There are three transmitters located at the base of the mast.

Saddle Hill (Radio New Zealand)
This wooden self-supporting pole and steel cabinet is at risk only from severe earthquake or slip.

Chain Hills (Radio Otago)
This is a stayed timber pole at risk only from severe earthquake or slip.

Mt Cargill
See Broadcasting section for details of transmission facilities.

Landlines

Albany Street to Highcliff
This Telecom line is vulnerable to earthquake, flooding and landslip at various locations. Derangement or cutting of the cable may occur along its length.

Telecom to Highcliff
This Telecom service is vulnerable to earthquake, flooding and landslip at various locations by a derangement or cutting of the cable, which may occur along its length.

Cumberland Street to Centre Road
This is another service provided by Telecom and is vulnerable to earthquake, flooding and landslip at various locations with derangement or cutting of the cable possible along its length.

Microwave and UHF
The following UHF radio links are vulnerable to misalignment of their aerial and co-axial feeder systems by earthquake shaking and possible damage to building structures:

- Cumberland Street to Centre Road
- Albany Street to Mount Cargill
- Cumberland Street to Mount Cargill
- Cumberland Street to Highcliff
- Mosgiel to Chain Hills
- Albany Street to Highcliff

Power Supplies

Centre Road and Highcliff
Mains power supply for the three AM transmission sites on the Peninsula is fed from the Andersons Bay Substation on the same feeder at 6.6kV. Supply runs from Silverton Street via Tomahawk Road to Centre Road. An alternative supply running along the harbour side of the Peninsula can be tied in at Marion Street, Macandrew Bay but this feeder crosses unstable land. All services are vulnerable to flooding, earthquake and landslip at various locations.

Saddle Hill Transmissions
This site is supplied by 11kV overhead lines with some vulnerability from weather, earthquake and landslip but easily repaired.

Mt Cargill
See the Broadcasting section which covers supply to this facility.

Standby Power Supplies
At the following sites, automatic starting diesel generators have been installed. The greatest risk to all of these is building failure or loss of the fuel tanks due to earthquake shaking:

- Highcliff.
- Centre Road (Radio Otago).
- Centre Road (Radio Network).
- Albany Street (Radio Network).

Television Broadcasting

Studio Buildings

Dowling Street Studio
This building is solidly constructed of bluestone but has an extensively modified interior. It is vulnerable to shaking from earthquake, although the risk is low due to founding on basement rock. There is a minor risk from tsunami

Albany Street Maintenance Centre
This is a modern single storey building built on a concrete pad but the site is on low lying reclaimed land close to the Water of Leith. Consequently it has a risk from flooding, shaking, liquefaction and tsunami.

Many radio and landline services pass through the site with few redundancy options and hence the building and contents are at high risk. Typical damage will involve settlement of foundations, wall cracking and roof derangement, with cable input to the building and underground ducts severely damaged and the building possibly rendered unoccupiable. Overall the loss of this building would represent a major impact on broadcasting systems.

Allied Press Stuart Street
This is an old multi-storey building of brick construction and is at risk from shaking, liquefaction and tsunami. The building houses the Channel 9 Studio and transmission equipment and typical damage will be cracking of walls and settlement of foundations. Though damage may occur to services entering and leaving the building, the impact is reduced by the availability of standby power.

Transmission Buildings

Mt Cargill Transmission Building
This is a poured concrete cantilevered building at approximately 600 metres above sea level and is at only moderate risk during earthquake due to foundation on bed-rock and there is no risk of flooding or liquefaction. The highest risk to this building is the weather as the site is subject to high winds and snow storms. Although there is no alternative to this building, many of the services within it could be restored relatively quickly using temporary accommodation.

Cowan Road
This is a steel framed, iron clad building with frames set in a concrete foundation. The greatest risk to this structure is from windstorm.

Transmission Equipment and Masts

Mt Cargill
The most vulnerable part of the transmission equipment is the tower and associated antenna system. The tower is a self supporting lattice structure and is subject to the severe weather conditions at this site. The primary risks are high winds, and snow and ice loading. There is a lesser risk due to shaking during an earthquake. The tower is engineered to withstand expected weather conditions but individual antennas can have a lower resistance. Earthquake shaking may damage the base of the structure which, whilst not damaging the building to any great extent, may cause failure of the tower base hold-down bolts. This may result in severe lateral force when combined with weather impact. There is a measure of redundancy within the antenna system but if the tower fails so will most transmission services. The equipment within the building is less vulnerable as long as the integrity of the building is maintained.

Cowan Road
Weather is the factor which will have the greatest effect on service from this site. High winds could cause misalignment of the microwave antenna of the linking transmitter, rendering the service temporarily unusable.

Landlines
The Albany Street to Dowling Street landline is situated in low lying land, much of it reclaimed and subject to liquefaction and settlement due to earthquake. Cable junctions may fail due to the ingress of water exacerbated by earthquake shaking fracturing cable covers. This fracturing may also take place at building inlet and exit connections. The cable is also subject to the effects of flooding and tsunami.

Some alternate landlines are available, but these are subject to the same risks. Given the loss of this landline, alternative equipment could be obtained at short notice to restore at least some services but it should be noted that the Albany Street Maintenance Centre is subject to similar risks and that loss of these facilities together would extend the risk significantly.

Microwave and UHF

Albany Street to Mt Cargill
The Albany Street end of the circuit is on low-lying reclaimed land and is at risk from shaking, liquefaction, tsunami and flooding while the Mt Cargill end is at approximately 600m above seal level and at risk from severe weather conditions. The greatest risk is to the antenna system and supporting tower. There are some redundancy options and alternative equipment could be obtained at short notice to restore most services.

Dowling Street to Mt Cargill
These circuits face similar risks to those at the Dowling Street studio and the Mt Cargill transmission building.

Allied Press Building to Cowan Road
The main risk to this circuit is from earthquake shaking at the Stuart Street end and from extreme weather at Cowan Road. The most vulnerable equipment would be the antennae which could be misaligned.

Telecom Central Automatic Exchange to Mt Cargill
Refer to the vulnerability of exchanges and radio installations.

Power Supplies

Mt Cargill/Cowan Road
The upper sections of this 11kV line are primarily affected by severe weather conditions and isolated sections are vulnerable to landslip and shaking failure. Damage is likely to be relatively minor and easily repaired.

There are emergency power supply systems at Mt Cargill in the event of a failure but there is no standby power supply at Cowan Road where complete reliance is placed on the 11kV overhead line to the transmission site.

Standby Power supplies

Mt Cargill
The standby power source consists of two diesel generators each of which is able to supply at least part of the site services. The building housing them is robust and to be at low risk from all but extremes of weather and earthquake.

Allied Press Building
There is a standby generator available in this building to maintain supply in the event of a mains failure. Whether this would serve the transmission equipment in the event of an earthquake or tsunami would depend on the degree of damage suffered by the building.

Access Routes

Mt Cargill (Cowan Road)
This road rises to a height of approximately 600 metres above seal level and the most serious risk to access is due to weather conditions. In the past the road has been closed for several weeks at a time due to snow. Many of the functions at this site are remotely controlled and are therefore less affected by road closure but fault maintenance may become difficult.

BROADCASTING - MITIGATION STRATEGIES

Sound Radio Broadcasting

Studio Buildings
The modern computer based technology is easily transferred to an alternative site and if the digital equipment is destroyed, alternative or replacement equipment is readily available.

No measures other than secure installation of the technical equipment is taken to preserve the integrity of the existing studios.

Because of network programming and providing the toll network remains available, normal programme can be sourced from outside the local area.

Transmission Buildings
The following locations have been examined in respect of damage anticipated in the vulnerability analysis and consideration given to minor mitigatory measures:

- Highcliff
- Centre Road
- Saddle Hill
- Chain Hills
- Cowan Road

Due to the age and nature of construction of all buildings, little can economically be done to mitigate construction weaknesses and no current programme of upgrading is proposed. As most buildings currently have adequate room for future service additions, there is little likelihood of building upgrades being required for expansion.

Highcliff and Centre Road require the standby fuel supply storage tanks to be additionally braced for seismic security.

All RNZ and TRN sites have been undergoing a programme to remove surplus/redundant equipment and any additional equipment is being securely seismically mounted.

Transmission equipment and masts
Consideration has been given to possible mitigation work associated with the transmission sites at Highcliff, Centre Road, Saddle Hill, Chain Hills andCowan Road.

The AM masts are all primarily vulnerable to earthquake damage or destruction. They are required to sit on fragile insulators at ground level and because of the varying base mounting systems, some masts are more vulnerable than others. In the short term, there are unlikely to be any economically feasible upgrades that can be carried out.

Any FM radiators on AM masts are robustly mounted and FM feeders and radiators, which are vulnerable, are easily and quickly substituted.

Transmission equipment is generally securely bolted to the structural floor and any further mitigation to protect equipment is dependant on building design or upgrades.

Microwave and UHF Linking
UHF links are easily replaced by alternative or spare equipment from redundant or low priority services and lower quality communication gear is readily available for emergency replacement links should the primary system be lost. A low power linking or FM transmitter can be located at some suitable central location and be received at most transmission sites to provide a common programme on most AM/FM transmitters.

Television Broadcasting

Introduction
BCL owns and operates a number of broadcast and communication sites consisting of buildings, towers, antennas and support facilities such as standby power generator sets and ventilation systems etc. BCL also owns a number of microwave and fibre optic linking circuits in and out of these sites but does not own the individual transmission equipment within the building which belongs to client operators such as TVNZ, TV3 and Radio Otago.

The majority of BCL's mitigation strategies are already in place or part of an ongoing policy, centred on the assets it owns and not on the client owned equipment, although obviously the continued operation of this equipment relies heavily on the integrity of BCL's infrastructure.

Mitigation Strategies Common to all Areas
BCL has three principal parts to its mitigation strategies:

- Measures to preserve the integrity of the equipment and its services.
- The provision of back-up or alternative means to continue service.
- A disaster recovery plan.

Each site and service has a mix of the above strategies depending on the nature of the equipment and the risks to which it is exposed.

Measures taken to ensure the integrity of equipment:
- Where physically possible, BCL has opted for total compliance with the appropriate current NZ standards.
- All equipment, including non-fixed equipment, is seismically secured to NZ standards.
- Regular building and infrastructure inspections are undertaken by qualified inspectors, using the current standards and data available. All major installations are upgraded where there are shortcomings due to changed hazard data or improved standards.
- All installation and alteration work must conform to rigorous BCL standards and the appropriate current NZ controls. Every change or addition passes through a BCL control process.
- All sites are routinely checked and required to conform to BCL's rigorous "image" standard with emphasis on storage, cleanliness and other health and safety issues.

The provision of back-up or alternative systems includes:
- Where possible, all critical on-site equipment and equipment subject to potential failure is duplicated. This includes such at-risk equipment as antennas and feeders as well as the provision of duplicate back-up power supply generators.
- The provision of physically and environmentally secure fuel supplies.
- Where duplication of critical equipment is not appropriate, alternatives are used, i.e. the provision of alternative network feeds to critical sites.

Mitigation Strategies for Specific Sites or Systems
Mt Cargill (including building, tower and antennas etc.)
This site is subject to severe weather which can result in physical damage to site infrastructure, loss of conventional power to the site and restricted access. The general strategies detailed above apply with an emphasis on preserving the integrity of the equipment. Specific mitigation strategies are:
- Considerable weather data has been gathered and continues to be gathered for the site and the building and external infrastructure are engineered to withstand the expected conditions.
- All changes or additions are subject to a BCL change process and take into account the above data.
- Ongoing engineering consultancy to ensure building integrity against wind, water and snow damage.
- Dual standby generators are provided, each of which can maintain all of the services in the event of a power failure.
- Dual fuel storage and delivery systems are installed.
- Full remote control and supervision of all systems if access is impossible.
- Duplication of critical elements such as antennas and feeders.
- Critical equipment has a no-break battery back-up power supply.
- External equipment subject to the ingress of water is pressurised with dry air.
- Alternative network feeds to the site for those services which require it.
- An extensive disaster recovery plan is being developed.

Dowling Street Studio
This building has a low risk from flooding and shaking. Since the study began the studio complex and the building have been sold and are now no longer owned by TVNZ. There is still a network distribution node within the building and BCL general mitigation strategies apply only to the node. Specific (BCL) mitigation strategies are:
- The provision of alternative routes for critical services.
- The provision of no-break battery power for critical equipment.

Albany Street Maintenance Centre
This building is at risk from shaking and tsunami and BCL's general mitigation strategies apply. Specific mitigation strategies concentrate on:
- Providing alternative network feeds.
- The provision of alternative routes for critical services.
- The provision of no-break battery power for critical equipment.
- Generator standby power which can run all services in the event of a power failure.

CHAPTER 8. BUILDINGS & SERVICES - CONTENTS

BUILDINGS - INTRODUCTION

University of Otago

Selection of Buildings for Study

Buildings identified for this part of the study were limited to those considered to be critical in the period immediately following a disaster for emergency relief, continuing avoidance of risk to health, and for assembly and shelter, and also in the intermediate period for risk abatement. A few key industrial buildings were identified as important economic recovery.

The list was originally longer than that adopted, but the time required to individually survey each building was constrained. The list should also have included residential complexes, including halls of residence, buildings important to the image of Dunedin, such as its heritage buildings, and additional buildings that are important to the ongoing economic viability of the city. Expansion of the range of buildings examined is a worthwhile objective in continuation of the project.

Earthquake Assessment Adopted

For vulnerability assessments, it was decided that the only issue that need be specifically addressed was earthquake. Landslide and storm damage, including flooding, are likely to be common to an area, and any buildings within that area would be readily identified from the vulnerability studies of other groups and directly from the hazard analyses. Earthquake damage to a building, on the other hand, will depend on its structural form, materials, design standards, construction standards, and on siting and foundations.

Seismic Event Selection

The seismic event chosen for this study was one with an intensity measured on the Modified Mercalli (MM) scale at a level of MM IX on firm ground, or up to MM X on the softer gound in parts of the city. The MM intensity isoseismals for firm ground that were adopted were those estimated by Professor Richard Norris which are described and mapped in the chapter on hazards. The estimated recurrence interval of the event that produces these intensities is about 7,000 years (5,000 - 10,000 years) according to the assessment made there. They are associated with the maximum credible event of a Richter Magnitude 7.0 on the Akatore Fault or parallel fault. Other estimates are for at least 2,000 years recurrence interval for a MM IX intensity on firm ground when all sources, including remote events, are considered.

Smaller recurrence intervals were considered but dismissed. Elsewhere in New Zealand, recurrence intervals as short as 150 years have been used for similar studies. However, Dunedin is located in one of the more tectonically stable parts of the country and such an event, approximated by MM VII intensity would have little effect on most of the identified buildings. A recurrence interval of 150 years is likely to form the basis of intended modifications to the provisions in the Building Act relating to “earthquake prone” buildings. Collapse under such an event is likely to be defined by the relative vertical separation of adjacent levels.

An event with a recurrence interval of 450 years would have significant effect, consistent with MM VIII intensity. It is the event used for basic strength assignment for new structures. The longer period was adopted because it is associated with the maximum credible event identified in the hazards chapter and because it tests in a meaningful way the vulnerability of the infrastructure and support facilities of Dunedin.

Assessment Method Discussion

It has become customary to assess building response through an acceleration response spectrum, which is then scaled to account for building form and ductility and for risk. Approximate assessments for the effects of softer sites are also made. While this may be suitable for the design of new buildings, use of an acceleration spectrum is not necessarily suitable for the assessment of existing ones. Even for the assessment of the response of building parts and services, the spectrum must be modified in some way to account for resonant effects and the direct participation of ground accelerations, not directly modelled in the spectrum which is therefore not a true indicator of maximum likely accelerations.

Current international trends are towards a displacement-based approach which is likely to be included in the next generation of structural design standards. It produces more consistent results and has the beneficial effect of focusing attention onto the key issues that are related to building distress and collapse i.e. the strains in the materials, and the influence of deflection on the stability under displaced gravity loads (the so-called P-delta effect).

Traditional static analyses do not provide an accurate picture of the likely effects of earthquakes. More detailed analyses, while providing better assessments, can not usually be applied with confidence to older buildings because of difficulties in modelling the structure and material properties and uncertainties about ground interaction. However, where the maximum relative displacement can be estimated and the resulting effects determined, then an adequate picture of the effects of the earthquake can be gauged.

This study has primarily used a more heuristic approach based on the known performance of various types of buildings in past earthquakes. Indeed, it is as well to recall that the majority of data used for the seismic risk assessment produced by the New Zealand National Society for Earthquake Engineering was drawn from historic reports of MM Intensity and the attenuation relationships that were implied.

The Modified Mercalli Intensity Scale itself is defined in part by the effects of seismic events on buildings of various loosely defined types. Assignment of a type to a building should therefore provide a measure of the vulnerability of the building to an event that produces a chosen intensity level. Although rather tautological, this is essentially the method used in this vulnerability assessment. It is similar to, but cruder than, the "attribute score" or "penalty score" method often used for roughly assessing vulnerability from a visual survey.

Building Standard Used

For this purpose, the definitions proposed by Andrews et al were used. These were partially reported in the chapter on hazards, but the types mentioned in the MM definitions were not reported in the papers. For completeness, these are:

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 reinforcement, 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.

Anticipated Effects Based on Modified Mercalli Intensities

The effect of a MM IX earthquake is likely to be:

- Very poor quality 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.

The effect of a MM X earthquake (the same event as before, but the effects determined for soft sites) is likely to be:

- 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 of Type IV have moderate damage or permanent distortion.

Method of Assessing Vulnerability

Each identified building was assigned a type, taking into account mitigating factors (such as greater depth and thickness of masonry). The likely effects on the buildings were at first assessed from this type assignment, and then tempered by knowledge drawn from experience of more detailed assessments of similar buildings. Not all buildings have been analysed mathematically or surveyed in any detail, but many have been. Several have been analysed by the displacement-based approach described above. The willingness of those who have undertaken those past assessments to share the resulting information is appreciated. Considerable effort was required to correlate these assessments and the preliminary assessments of the identified buildings with actual numerical calculation.

A building was assessed as vulnerable if it would suffer loss of essential function due to damage to the building fabric. This does not necessarily imply collapse. Damage to services in buildings may also lead to loss of function, and it is thought that this cause is likely to be that most commonly leading to loss of function of facilities when the services are reviewed at a later time.

BUILDINGS - DESCRIPTION AND VULNERABILITY

Infrastructure Owners' Buildings

Water

Mount Grand Treatment Plant (Mixed Vulnerability)
The building was constructed in 1974. The reinforced masonry treatment building and mixer tanks support the chlorine/drum store. Filter tanks are reinforced concrete as are the pipes used as retention loops.
The contact tank was built in 1969 using precast post-tensioned prestressed concrete wall panels and reinforced masonry inner walls.

Southern Reservoir Treatment Plant (Mixed Vulnerability)
The chlorination building was constructed in 1954 using reinforced concrete frames with cavity masonry panels (250 mm). The micro-strainer building is of similar construction and was completed in 1969. Neither structure is vulnerable.
The Number One contact tank, constructed in reinforced concrete in 1954 is vulnerable. The Number Two tank, built in 1969 using post-tensioned precast concrete wall panels and reinforced masonry inner walls is marginally vulnerable.

Booth Road Treatment Plant (Not Vulnerable)
This building was constructed in 1963 of reinforced concrete frames with cavity masonry walls. The reservoir and micro-strainer tanks are of reinforced concrete. The reservoir has post-tensioned concrete roof units.

Mosgiel Bores and Treatment Plant (Not Vulnerable)
The reinforced masonry buildings were upgraded in 1995. Aeration towers are of reinforced concrete pipes.

Midland Street Yard (Not Vulnerable)
These buildings were constructed in 1965. The heavy store has steel portals, encased to crane rail height, and masonry infill panels. End wall frames are of reinforced concrete. Other buildings have reinforced concrete frames with masonry infill wall panels.

Sewerage and Stormwater

Tahuna Waste Water Treatment Plant (Not Vulnerable)
Constructed in 1977, the building has reinforced concrete walls and frames, and precast prestressed roof units and cladding.

Musselburgh Pumping Station (Generally Not Vulnerable)
This building was constructed in 1958 and extended in 1997. The original building has steel portal frames with brick infill panels on the street, and precast reinforced concrete roof units. This roof has the potential to collapse in a severe earthquake. The building configuration is compact. The extension has steel portal frames, metal roof and cladding, with brick cladding on the street.

Portobello Road Stormwater Pumping Station (Not Vulnerable)
Built in 1962, the building has reinforced concrete frames with brick cavity walls (275mm) and precast reinforced concrete roof units post-tensioned after placing.

Electricity

Transpower Substations (Not Vulnerable)
Halfway Bush substation building is sited on clays and silts overlying volcanic rock. It was built in the 1950's and was upgraded in the 1960's. Except for the north wall of the crane building, which may be prone to earthquake damage, the building is unlikely to be vulnerable.

The South Dunedin substation building is more recent and designed to provisions of PW 81/10/1, and therefore effectively meets present-day requirements. It is piled. Settlement in the foreshore is evident around it.

The Three Mile Hill substation building is also designed as for the South Dunedin building to PW 81/10/1.

The small Berwick switchyard building is of light timber frame construction. Piles below floors are well braced.

Dunedin Electricity Ltd Headquarters (Not Vulnerable)
Vulnerable parts of this complex were secured when it was recently remodelled. This work included construction of an intermediate reinforced concrete floor within the previous double-height spaces. Other buildings, though not detailed to contemporary standards, are dominated by design criteria other than earthquake (wind, crane surge), leading to a high inherent strength.

Major Dunedin Electricity Ltd Substations (Vulnerability varies)
All substations are subject to a current seismic assessment study with some seismic strengthening to be constructed as a result. At present seven of the substations have been assessed with various degrees of strengthening recommended. All transformers and important switching gear is likely to be on shallow reasonably stiff raft-type foundations.

Substation buildings are as follows:

- Andersons Bay. Pitched reinforced concrete roof on a combination of reinforced concrete walls and frame with concrete masonry infill. Shallow foundations on deep soils. Constructed 1960.
- Berwick. Lightweight timber truss roof on single storey reinforced concrete masonry walls. Shallow foundations on deep soils. Constructed 1987.
- Corstorphine. Lightweight roof on structural steel portal frames. Concrete masonry cavity walls with the internal 150mm wythe reinforced and solid filled. Shallow foundations on intermediate depth soils. Constructed 1972.
- East Taieri. Lightweight roof on parallel chord rafters. Cavity concrete masonry walls with bond beam at top and reinforced pilasters. Shallow foundations on deep soils. Constructed 1973.
- Green Island. A reinforced concrete roof on reinforced concrete walls in transverse direction. Nominal frame action in longitudinal direction. This building is to be strengthened with the addition of some buttress walls in the longitudinal direction. Shallow foundations on deep soils. Constructed 1957.
- Halfway Bush. Lightweight roof on single storey reinforced concrete walls in both directions. Shallow foundations on intermediate depth soils. Constructed 1986
- Kaikorai Valley. Lightweight roof on truss construction. Reinforced concrete columns with cavity concrete block infill. Internal wythe of block appears to be reinforced and solid filled. Shallow foundations on deep soils. Constructed 1977.
- Mosgiel. Office building is constructed of lightweight timber framing with brick veneer. Light roof on timber framed roof structure. Continuous concrete perimeter foundation wall with internal piles. The substation is constructed with a light roof on cavity concrete block walls. There is likely to be a bond beam to the top of the walls with several reinforced pilasters. Shallow foundations on deep soils. Constructed 1964
- Neville Street. Reinforced concrete roof on a combination of reinforced concrete walls and frame. The structure is two storeys high with high stud heights. Foundation construction consists of a shallow stiff raft slab on deep soils. Constructed 1951
- North city. Light roof on single storey reinforced concrete block walls. Shallow foundations on deep soils. Constructed 1975.
- North East Valley. Light truss roof on reinforced concrete block walls. Shallow foundations on deep soils. Constructed 1994.

- Outram. Heavy tile roof on a combination of single storey reinforced concrete walls and frame. Shallow foundations on deep soils. Constructed 1964.
- Port Chalmers. Reinforced concrete roof on single storey reinforced concrete walls. Shallow foundations on deep soils. Constructed 1953.
- Smith Street. Pitched reinforced concrete roof on reinforced concrete walls in the transverse direction and a reinforced concrete frame in the longitudinal direction. Brick infill to the reinforced concrete frame. Shallow foundations on deep soils. Constructed 1958.
- South City. Partial two storey building with a light roof to the upper storey sections. There is a combination of reinforced concrete walls and structural frame in both directions. There is a large internal blast screen constructed from cavity brick with the cavity solid filled and reinforced. The foundation is a tapered compensating type raft foundation used as a basement. The building is constructed on reclaimed ground. Constructed 1971.
- St. Kilda. Light roof on single storey concrete block walls. Shallow foundations on deep soft soils. Constructed 1979.
- Ward Street. Light roof on structural steel trusses. Two-storey high reinforced concrete frames with solid in-situ concrete infill. Reinforcement consists of individual bars and rolled steel sections. Deep piled foundations through reclaimed harbour land. Constructed 1937.
- Willowbank. Reinforced concrete roof on cavity brick construction. There is likely to be a bond beam at the top of the walls and reinforced pilasters distributed around the structure. Concrete raft type foundation on deep soils. Constructed 1963.
- Halfway Bush Supply. Light roof on timber framing. Reinforced concrete block walls. Shallow foundations on intermediate depth soil. Constructed 1988.
- South Dunedin Supply. Light roof structure on 100mm cavity concrete block walls. There is a bond beam at the top of the walls and reinforced pilasters at mid point of each longitudinal wall. Shallow foundations on deep soft soils (reclaimed harbour). Constructed 1972.

Gas Production

Gas Production Plant (Not Vulnerable)
The main production building is a two storeyed reinforced concrete building with unreinforced brick veneer. It is compact in configuration and should respond well even though it has not been designed to current standards.

Roading

Ward Street Yard (Marginal Vulnerability)
Built in 1962, the building has reinforced concrete frames and cavity masonry infill walls. Some structures have precast reinforced concrete frames.

Communications

Telecom Central Exchange (Critical Parts Not Vulnerable)
This five-storey reinforced concrete building, completed in 1975, was designed as a ductile frame using the draft code provisions of the time. Security of engineering systems has been subsequently improved to the provisions of NZS 4219.

Telecom Maintenance Depot (Vulnerable)
All buildings on this site are reasonably new. The main buildings are constructed from structural steel portal frames with reinforced concrete block infill to windowsill level. These building are essentially lightweight in construction on shallow strip foundations. There are several secondary buildings, which are not currently in service. The remainder of the site consists of a large chip seal paved yard for parking of maintenance vehicles. The assigned vulnerability has been assessed from the location and the limited access that would be available after a major seismic event.

Dunedin Postal Centre, Strathallan Street (Possibly Vulnerable)
These buildings consist of three large portal frame structures with light cladding and a two-storey steel and timber framed office building. All foundations are shallow strip foundations on previously existing hard fill. The site has very soft deep soils (reclaimed harbour) and a major storm water drain passing under the building. Constructed in 1997.

Radio

Albany Street (Generally Not Vulnerable)
This building is of well detailed reinforced concrete and masonry construction with steel framing for roofs however, part of the floor is built on reclaimed land and may be subject to differential settlement.

Transmission Towers (Generally Not Vulnerable)
Included in this group are the Peninsula towers and the Mount Cargill tower. They are well anchored, adequately detailed and are well maintained.

Television
Forsyth Barr House (Not Vulnerable)
Although not well proportioned for ductile response, the building possesses high lateral resistance. Recent alterations removing several structural walls have not diminished the intrinsic overall strength.

Broadcasting House, Dowling Street (Part Vulnerable)
The principal building, though of unreinforced masonry, is only mildly vulnerable. Most deficiencies are related to past inappropriate remodelling and interior alterations. The adjacent building, however, is vulnerable, particularly in the studio area.

Administration
Civic Centre (Not Vulnerable)
This block excludes the Municipal Chambers, and the conference and entertainment facilities of the Town Hall complex. It houses the central administration of the City Council. Constructed in reinforced concrete to present day standards, it is well founded on a rafted system on sound clays. Weaker subsoil areas near the Moray Place Post Office (now ANZ Postbank) were backfilled with concrete.

Contractors' Facilities

Fulton Hogan, Fairfield (Low Vulnerability)
The Fulton Hogan main office building is constructed with post tensioned reinforced concrete frames with precast floor systems and some concrete block infill. This building was built within the last 25 years and will have been designed for a reasonable level of earthquake load. There are further single and two storey office buildings of light timber frame construction that should be designed to the non-specific design codes of the period. The latest timber frame office building is designed to be portable and has been constructed to modern standards. The remaining buildings are generally single storey, high stud buildings constructed from structural steel portal frames or timber with light-weight cladding. All foundations are expected to be shallow strip type. There are old underground coal mine shafts in the vicinity of Fairfield which will result in various levels of vulnerability to ground stability during a major earthquake. The remainder of the site consists of yard space for vehicles and plant. The main area of vulnerability stems from the possibility of the yard becoming isolated due infrastructure failure.

Works Civil Construction (Critical Parts Not Vulnerable)
The depot comprises a number of single storey buildings, developed since around 1975, that house office and workshop facilities. Construction is a mix of light timber framing, steel portals and reinforced concrete masonry.

Naylor Love (Vulnerable)
All Naylor Love subsidiaries (Construction, Structural Steel, Aluminium, Building Services) are housed in buildings with unreinforced masonry walls and unreinforced partitions between the building parts. Roof construction is often of timber trusses only notionally tied into the walls. The administration building (completed 1997) would remain functional, but the critical support facilities would be severely damaged, some collapsing. Recovery of large timbers from the yards and storage areas for shoring and the like would be possible, but the facility as a whole would be inoperable.

Critical Facilities Buildings

Civil Defence

Headquarters (Not Vulnerable)
This is housed in the lower parts of a car parking building that is of substantial reinforced concrete construction in good repair. The building has a high intrinsic strength, and has been detailed in a way that should provide ductile response. Column dimensions are substantial, inhibiting instability even if materials fracture. Some improvement to access paths is desirable for security of access.

Hospitals

Dunedin Hospital (Critical Areas Not Vulnerable)
Critical facilities are housed in buildings of reasonably modern construction. Although not all are detailed for ductile response, they possess large strength. These buildings include the main Ward Block (including lecture theatres), Oncology and Clinical Services.

Vulnerable areas include Psychological Services (part of the original hospital), Children's Pavilion (four storey reinforced concrete building of frame-like proportions) and the complex housing Physiotherapy, Prosthetics, Orthotics and Occupational Therapy. These buildings are more particularly vulnerable due to the widespread use of single wythe unreinforced masonry partitions along main interior access routes.

Wakari (Major Use Areas Not Vulnerable)
Buildings that were remodelled when Psycho-Geriatric and other psychological services were recently moved to the site are not vulnerable. These include the Forensic (Safe Care) Unit (new building), Long Stay (former nurses home), and Intellectually Handicapped Unit (former radiotherapy building).

The main part of the original building is vulnerable. It includes single wythe unreinforced clay tile, brick and coke breeze masonry partitions, and the frames are not well detailed. Principal shear walls are not well positioned (lack of gravity stabilising loads, and dubious connections to floors). The kitchen is housed in the part-basement of this block, but it may escape serious damage and is accessible from the exterior.

The two wings that extend to the north from this block are, however, likely to be satisfactory and are seismically separated from the main block.

Mercy and Marinoto Clinic (Not Vulnerable)
Except for the original homestead building, which is classed as non-essential, all buildings are of recent construction and are well proportioned and detailed.

Fire Stations

Central (Vulnerable)
This building, although including reinforced and steel elements, is essentially of unreinforced masonry. It is likely to suffer severe damage appliances housed within the building may be damaged or trapped. There is also a risk to personnel.

Dunedin Central Fire Station - Civil Defence

Though the vulnerability of the building is recognised by the NZ Fire Service and there are contingency plans for control of emergencies from elsewhere (St John Ambulance, Central Police Station), the security of this facility itself is nevertheless critical.

Suburban (Not Vulnerable)
Several buildings (St Kilda, Roslyn, and Willowbank) are of a similar design using timber framing (glue laminated timber frames to the roof) and split block veneers. Some veneers may fail, but this is unlikely to prevent rapid use of the facilities and appliances.

Lookout Point station has substantial reinforced concrete frames and floors. Some infilled unreinforced masonry walls may fail, but the station should remain operational.

Police Stations & Prison

Central (Not Vulnerable)
The five-storey reinforced concrete building completed in 1994 was designed to remain fully operational following a 500-year seismic event. A risk factor of 1.3 was applied and the foundations were piled to firm gravels for the main building. Systems are designed to be operational for isolation from utilities for a period of three days.

Suburban (Not Vulnerable)
Dunedin South and Dunedin North Community Police Stations are recently constructed.

Prison (Vulnerable)
The three storey brick building was constructed before the turn of the century and although in good condition for this age and type of building, it is nevertheless vulnerable.

Ambulance

Order of St John Regional Headquarters (not vulnerable)
The operational sections of this building were substantially upgraded to a higher standard of seismic resistance in 1995. The building is piled and the overhanging ground immediately behind the garage is considered stable in view of the bedrock exposed.

Community Buildings

Halls, Stadiums and Raceways

Dunedin Town Hall Complex (Not Vulnerable)
Although appearing to be constructed of unreinforced masonry, this building is well framed with steel and reinforced concrete. It may suffer damage, but would be useful for shelter and similar uses.

The Glenroy Auditorium, including the Harrop Street Link was substantially rebuilt in the recent redevelopment.

The Municipal Chambers were secured and largely strengthened (though not to contemporary standards) when it was upgraded. It may be damaged, but the substantial thickness of the masonry walls should ensure its stability. The building houses non-essential facilities.

Edgar Stadium (Vulnerable)
The building is well constructed, with steel framing and precast concrete walls well connected to the frames, though the support to the end walls is questionable (ineffective bracing elements). The roof is lightweight. The site has suffered considerable settlement (not related to usage) and is prone to liquefaction. While damage is likely, the building would remain useful for storage of materials not requiring shelter from the weather. Reliance for shelter for persons might be imprudent in view of the likely difficulties of access to the site, and probable poor weatherproofness.

Dunedin Stadium (Not Vulnerable)
Like the Edgar Stadium, this building is well built and robust. Any liquefaction of the underlying uniform sands is unlikely to render the building unusable. Blocking of surface soils brought about by liquefaction of sands at depth may present access difficulties, but the building is likely to remain operational and suitable for shelter for persons and as an assembly point (subject to access).

Badminton Hall (Not Vulnerable)
The limited amount of masonry is well contained by encased columns. Remarks for the Dunedin Stadium are applicable here.

Forbury Park (Members Stand Not Vulnerable; Rest Vulnerable)
The main (members) stand is framed in reinforced concrete and steel, and is piled to firm strata. Flexibility of the ground may produce resonant effect from remote earthquakes, and ground settlement may impair usability, but the facility should remain operational and suitable for personal shelter or assembly.

Other buildings on the site (Stewards, including administration area, and Public stands) are substantially of unreinforced masonry in poor repair, with settlement damage and are likely to be severely damaged or collapse. Debris is unlikely to impair access, however.

Schools
Schools were not separately surveyed. However, integrated schools have a programme of improvement that is a condition of their integration agreement. Most (all in the case of Catholic schools, the majority of integrated schools) have completed this upgrading. All public non-integrated schools are the subject of a nation-wide survey to be conducted for the Ministry of Education. A pilot study is being undertaken in Wellington, and this will be followed for the rest of the country, probably in 1998. The information will be reviewed when available.

Commercial Buildings

University of Otago (Mainly Not Vulnerable)
Most critical facilities are in new buildings, well designed, built, and maintained. Those designed even before the advent of modern codes of practice (c 1976) were required to comply with PW 81/10/1 which is roughly equivalent to the later codes.

Buildings which are exceptions are those identified in a recent survey as vulnerable and listed in their order of priority for strengthening work suggested by the survey: Geology, Registry, Allen Hall, Former Mining School (Computer Sciences), Lindo-Ferguson, Staff Club, Home Science, Marama Hall, Professorial Houses, Scott Building, St Margaret's College, Selwyn College, Zoology, Union Court, Works and Services, Botany Annex. The survey excluded Knox College Halls of Residence, School of Physical Education, and the Survey School and Botany Department Building.

The Survey School (original Queen Mary maternity hospital) was checked under "change of use" provisions of the Building Act and found to be adequate. Hazardous elements (for example unreinforced single wythe partitions) were removed.

Cadbury Confectionery (Mixed Vulnerability)
The bulk store was constructed in the early 1990's to present-day standards. In the 1960's, two levels were added to a 1940's building immediately to the south of the bulk store. That original building has been assessed by the designers of the additions as having reasonable seismic resistance. Other buildings, dating from before and about the Second World War, and are constructed in a fashion typical of that period. Although some have frames of substantial wall-like proportions and have floors tied in to walls, they are assessed as somewhat vulnerable, with, perhaps, one-quarter of them losing function in a MM IX event.

Transtec (Railway Workshops) (Not Vulnerable)
Except for some non-essential facilities constructed from unreinforced brick (eg original foundry), all buildings are of lightweight construction. Principal framing to the industrial use spaces is steel and/or timber with properly engineered connections. Foundation conditions consist of indifferent overburden overlying sound strata at 8-10 m depth, and critical items such as presses and mills are piled to these strata. There may be some damage to weatherproofing, especially to the large glazed areas of some walls, but the buildings would remain functional. The administration areas are also largely of timber framed construction and would remain functional.

Scott Technology (Not Vulnerable)
This is a structural steel building with only lightly reinforced blockwork infill walls. Infills should survive. Other blockwork (end walls) may be distressed, with minor failure although the building as a whole should remain functional.

Farra-Dunedin Engineering (Vulnerable)
There are three main areas, the foundry, the steel fabrication shop and the sheet-metal/pattern shops.
The street walls of the foundry are of reinforced concrete in a poor state. The concrete is permeable and reinforcement is rusting. Past concerns about this have led to duplicate steel columns for support of the

roof. The roof structure is of both steel trusses and portals tied to the walls. Extensive damage is probable but collapse unlikely.

The steel shop is of similar construction but with unreinforced masonry walls. Columns, probably sufficient to prevent collapse, buttress these. The main transformer is in a vulnerable, otherwise disused part, failure of which may render the building inoperable.

The sheet metal building is largely vacant. Pattern store has unreinforced hollow core cavity concrete walls and indefinite structure and is likely to collapse. The sheet metal shop may survive, but may not be functional. The whole site is on firmly compacted fill which may aggravate the problem.

Wickliffe Press (Low to Moderate Vulnerability)
The Wickliffe press plant is made up of several different buildings added to and altered as the plant expanded. The buildings adjacent to Albany Street are constructed from a reinforced concrete frame with Oamaru stone infill and large windows. These buildings are over 40 years old and as such will not be designed for any significant earthquake loads. A majority of the remaining buildings are structural steel high stud portal frame buildings with lightweight roof cladding and precast concrete exterior walls. These are relatively recent buildings constructed over the last 15 years. The main office building is of structural steel frame and concrete floors and was constructed around 1993. All foundations are likely to be shallow strip foundations on deep soils.

Allied Press, Cumberland and Stuart Streets (Moderate Vulnerability)
The Allied Press buildings consist of several buildings of varying construction. The main wings (Evening Star Building) on Cumberland and Stuart streets are four storey reinforced concrete buildings constructed over 30 years ago. The design will have allowed for only nominal earthquake effects. These buildings have been subject to concrete repairs within the last 10 years. They generally house the offices and editorial departments and also the local television network. The press building is currently under construction and has been designed to modern standards. The distribution and old press hall are of modern construction, structural steel and lightweight cladding. There are several unreinforced masonry buildings on the site but these are not critical to the operation of the newspaper or television. The new press building is constructed on piles. All major items of plant have been constructed on deep raft type or pile foundations.

Fisher & Paykel, Taieri (Not Vulnerable)
The whole facility on the Taieri industrial estate is relatively new. It is built on ground that is known locally as "Milners Pit", which is less prone to the large deformation or slumping likely to characterise sites further south. Construction is structural steel in the main, with the older administration building of in-situ reinforced concrete panel construction. The building would survive even an extreme event.

Buildings

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.

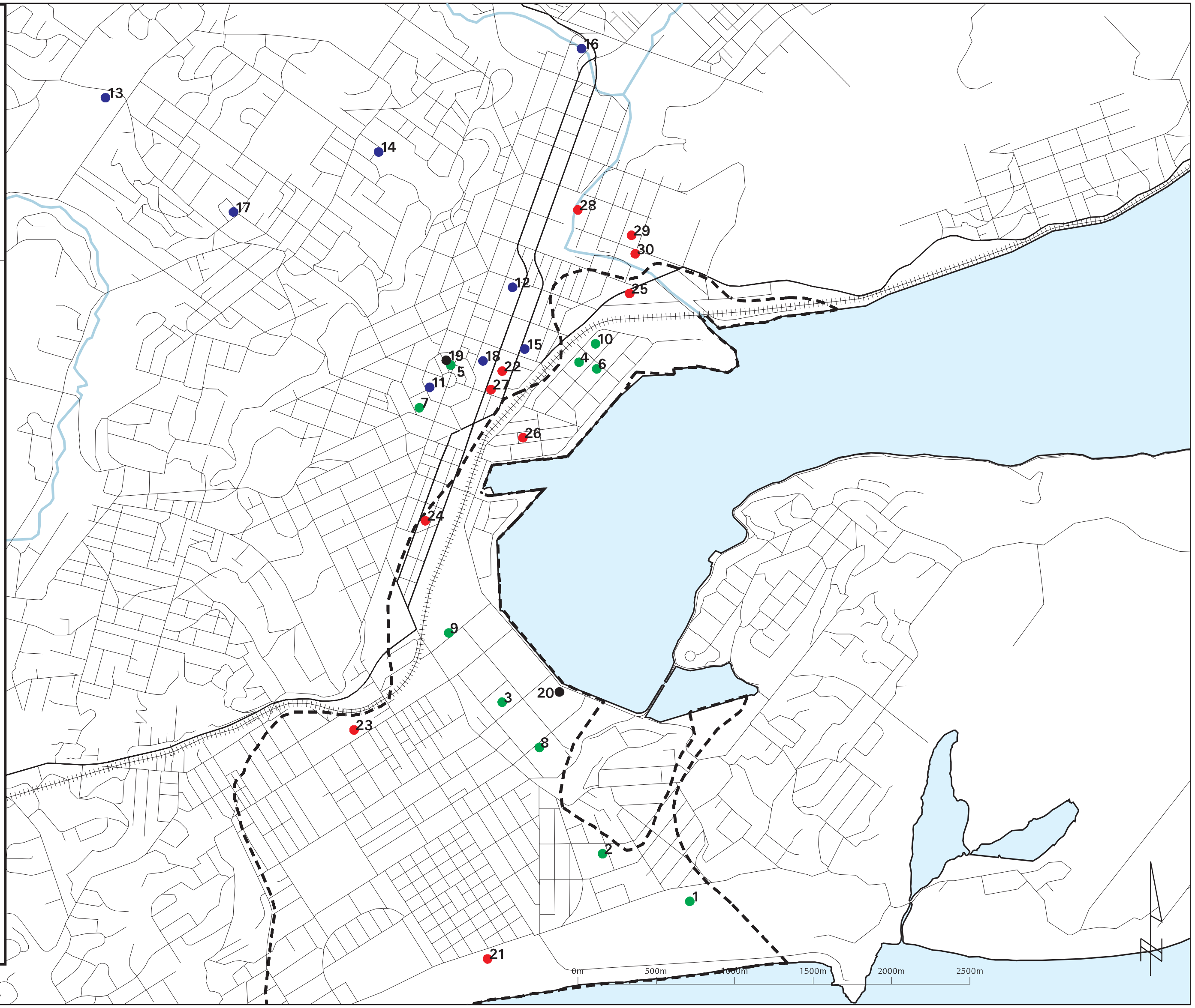
Any person or organisation having a concern with any issue raised by the Project should consult their professional advisers before taking any action.

● INFRASTRUCTURE OWNERS BUILDINGS
1 Tahuna Treatment Plant
2 Musselburgh Pump Station
3 Midland Street Yard
4 Ward Street Yard
5 Civic Centre
6 Dunedin Electricity Ltd
7 Telecom Central Exchange
8 Telecom Maintenance Depot
9 Dunedin Postal Centre
10 Naylor Love

● CRITICAL FACILITIES
11 Civil Defence
12 Dunedin Public Hospital
13 Wakari Hospital
14 Mercy Hospital & Marinoto Clinic
15 Central Fire Station
16 Willowbank Fire Station
17 Roslyn Fire Station
18 Central Police Station

● COMMUNITY BUILDINGS
19 Dunedin Town Hall
20 Edgar Sports Stadium
21 Dunedin Stadium & Badminton Hall

● COMMERCIAL
22 Cadbury's
23 Transtec
24 Scott Technology
25 Wickcliffe Press
26 Farra Dunedin Engineering
27 Allied Press
28 University of Otago
29 Otago Polytechnic
30 Dunedin College of Education



Rivers

Boundary of Soil Types Susceptible to Liquefaction

● Infrastructure Owners
● Critical Facilities
● Community Facilities
● Commercial

City Consultants
September 18, 1998

BUILDINGS - MITIGATION STRATEGIES

Owners' Involvement

In this part of the report, some suggestions are made for mitigating the effects of earthquakes on the buildings reported upon under the preceding section. General suggestions are made that are relevant to all buildings, but specific suggestions are made only for those buildings identified as possibly vulnerable.

It is recognised that this report does not include all important structures and that it adopts a "broad brush" approach to statements made on vulnerable elements of buildings.

The requirement to mitigate the effects of a major disaster event will fall on the building owner. This may be driven from several influences:

- Legislative.
- Territorial Authority encouragement for improvement of building stock.
- Insurance—and the inability to secure finance for buildings construed as earthquake risks.

It is noted that the cost to building owners of forced mitigation may prove prohibitive in the current economic climate. Nevertheless owners are advised to consider the impact of hazard damage on their building assets and further investigate vulnerability on a voluntary basis.

The Building Act and Proposed Changes.

A proactive approach by the Territorial Authority to identify earthquake risk structures and to formulate a strategy for their management is considered the most prudent approach. This will enable gradual improvement of the building stock to a given standard to be achieved over a controlled period of time. This is notwithstanding any legislative change that might require upgrading in a programmed way.

The vulnerability of a building can be measured in both the probable effects to the structure of the building and also to the contents of the building. This also applies to modern "earthquake proof" non-vulnerable buildings. Significant improvement to the recovery times after a disaster event can be made by prudent investigation and securing of critical items of plant, equipment and stocks of spare parts.

There should be an awareness, especially among building owners, that the provisions of the Building Act that relate to "earthquake prone" buildings are likely to be amended. Existing provisions are contained in section 66 of the Act.

In section 66, an earthquake prone building is defined as one that would suffer catastrophic collapse in a moderate earthquake and thereby present a risk to persons through death or injury or cause damage to adjoining property. For this purpose, a "moderate" earthquake is defined as one that would subject the building to forces one-half as great as those specified in NZS 1900, Chapter 8:1965. This definition uses NZS 1900, even though that Standard has been revoked for the design of new buildings and replaced with NZS 4203:1992. The provisions apply to all unreinforced concrete or unreinforced masonry buildings other than those used for some forms of domestic accommodation.

If a building is determined by the Territorial Authority to be earthquake prone, the Authority may serve notice on the owner of the building to remove the danger, either by demolition or by strengthening.

Present proposals for amendment of the Act suggested by the Building Industry Authority include redefining a moderate earthquake as one with a return period of 150 years. The notion of collapse is, however, preserved. All buildings, of whatever construction, would be covered by the amendments, although some forms of domestic buildings may yet be exempt. Territorial Authorities would be required to survey all affected buildings within a specified period and may (i.e. optionally) then serve notice on owners of buildings found to be earthquake prone (though the use of that term seems likely to be discontinued).

An earthquake with a return period of 150 years in Dunedin is only slightly greater in intensity than Modified Mercalli Intensity VII. Peak ground acceleration from such an earthquake could be expected to be about one-half that applicable to the design of new buildings. An average value of this fraction for the whole country is about two-thirds. As the presently used notion of collapse is to be retained, conventional design methods may not be directly applicable. Designers may therefore wish to derive reduced peak ground acceleration for which conventional design methods could be used. This is roughly equivalent for many buildings to a return period of 50 years, and implies a further reduction from the levels used for new buildings of some 30%, typically.

It is possible that a two-tier approach may be introduced. A threshold level would be used for assessment of vulnerability and another level would be used for the design of strengthening methods. A suggestion has been made that the return period for the threshold level is set at 50 years, and the return period for strengthening is set at 150 years. Both would be used against the criterion of collapse.

The levels of strength associated with the likely revisions to the Building Act are significantly above those presently used for the definition of earthquake proneness. The actual ratio depends on the form of the building and its materials of construction and detailing. For buildings expected to remain elastic, present strength criteria for determining earthquake proneness are roughly 1/8 of those applicable to new buildings, whereas the proposed criteria increase this to about 1/3–1/2.

Recommendation to Owners

With these amendments in mind, owners of buildings contemplating renovations or other remodelling should consider upgrading their buildings for earthquake resistance at the same time. This would effect a progressive improvement of the building stock without the sort of disruption that would inevitably arise from compulsory improvement.

In many cases, considerable improvement of the response of the buildings in earthquakes can be achieved with minimal cost and intervention. Mostly, improvement of inter-connection will suffice to radically improve performance of the building and securing of contents will also mitigate against loss.

Experience shows that damage to buildings in earthquakes is greater where maintenance has been improper or inadequate. Well maintained, unstrengthened buildings have survived large earthquakes better than fully strengthened buildings in poor condition. A maintenance schedule is therefore a necessary part of proper building management. It should be prepared regardless of whether or not restoration or redevelopment work is being carried out.

It is highly desirable that owners form contingency plans for rapid assessment of damage to buildings and for appropriate security measures in the event of a damaging earthquake. In the event of isolation, alternative access routes should be identified and back-up communication installed.

Infrastructure Owners' Buildings

Water

Mount Grand Treatment Plant (Mixed Vulnerability)
A detailed survey of this facility should be undertaken during current upgrading activity, particularly with respect to contact and dosing structures.

Southern Reservoir Treatment Plant (Mixed Vulnerability)
The contact tank structures should be examined and upgraded as part of the general Dunedin City Council water improvement strategy.

Sewerage and Stormwater
There are a number of relatively minor items mentioned in the Civil Services section of the study which should be tackled under general maintenance provisions. Amongst these is the precast roofing at Musselburgh Pumping Station.

Roading
The Ward Street Yard has marginal vulnerability and the building as a whole, but particularly the cavity masonry infill walls should be reviewed and secured. Use of steel stiffener posts for the walls would be effective.

Electricity

Transpower Substations (Not Vulnerable)
Dunedin Electricity Ltd Headquarters (Not Vulnerable)

Major Dunedin Electricity Ltd Substations (Vulnerability Varies)
Dunedin Electricity has taken reasonable mitigation measures for their buildings. This has involved the assessment of the seismic performance, and upgrading as recommended by the engineering consultants involved.
In addition to mitigation measures for buildings, further measures may be required to mitigate the effects of a major disaster event by securing building contents and equipment, such as stock items of switching and isolating gear. The lead time to procure these items is significant and any breakage due to poor securing would have a large impact on the ability of this organisation to function after a major event. There are several items of equipment found in typical switching yards that require securing, such as electronic switching gear and back-up battery banks. The securing of these items is simple and inexpensive.

Communications

Telecom Central Exchange (Critical Parts Not Vulnerable)

Telecom Maintenance Depot (Vulnerable)
The major hazard relates to isolation in the event of a major emergency and it would be prudent to survey the facilities to determine measures to secure the building contents and any specialist stock and plant.

Dunedin Postal Centre, Strathallan Street (Possibly Vulnerable)
The location would suggest that the area might become isolated in a major event with disruption to the infrastructure elements in the area. Securing of the contents would be prudent.

Television
Broadcasting House is vulnerable. A change of ownership of the company has presented the opportunity to review the building and its functions and a general strategy for improvement has been adopted which will be worked through as opportunities present themselves.

Contractors Facilities

Fulton Hogan, Fairfield (Low Vulnerability)
The worst effect is that this contractor might be isolated from the Dunedin area due to the location of base operations their securing of basic facilities such as communications systems would be a major mitigating factor.

Works Civil Construction (Critical Parts Not Vulnerable)

Naylor Love (Vulnerable)
The continued function of these buildings after a major seismic event and the ability to recover shortly afterwards needs examination. A program of replacement and upgrading of most of the buildings on the site should be considered.

Critical Facilities Buildings

Hospitals

Dunedin Hospital (Critical Areas Not Vulnerable)

Wakari (Major Use Areas Not Vulnerable)

Fire Stations

Central (Vulnerable)
Though the vulnerability of the building is recognised by the NZ Fire Service and there are contingent plans for control of emergencies elsewhere (St John Ambulance, Central Police Station), the security of this facility itself is nevertheless critical. Recent removal of the control room to Christchurch may have eased one problem but not necessarily improved the ability to respond effectively to a major disaster in Dunedin.

It is suggested that the main front vehicle bay be secured to prevent collapse of the overlying structure into it and onto the street.

Suburban (not vulnerable)

Police Stations & Prison

Central (not vulnerable)

Suburban (not vulnerable)

Prison (Vulnerable)
The suitability of this building for continued use as a prison should be reviewed.

Ambulance

Order of St. John Regional HQ (not vulnerable)
All operational parts of the building have recently been strengthened and no further work appears necessary at this time.

Community Buildings

Halls, Stadiums and Raceways

Edgar Stadium (Vulnerable)
If there is low reliance on the facility for relief work then little need be done. Upgrading work should address the identified weaknesses in the structure and identify alternative routes to and from the facility should be undertaken.

Forbury Park (Members Stand Not Vulnerable; Rest Vulnerable)
As high reliance on this facility is unlikely, progressive structural upgrading as part of other works should be sufficient mitigation.

Schools
Vulnerability and mitigation strategies are part of a national study being undertaken by the Ministry of Education. The study is due for completion in October 1998. In general, except for isolated buildings, not part of the main blocks, most schools are not vulnerable. Nothing further need be recommended to accelerate the mitigation of risk.

Commercial Buildings

University of Otago (Mainly Not Vulnerable)
Establishment of the vulnerability of buildings not included in this study, and a program for their improvement should be progressed. These include selected buildings from the following list: Geology, Registry, Allen Hall, Former Mining School (Computer Sciences), Lindo-Ferguson, Staff Club, Home Science, Marama Hall, Professorial Houses, Scott Building, St Margaret's College, Selwyn College, Zoology, Union Court, Works and Services, Botany Annex, and all Halls of Residence.

Cadbury Confectionery (Mixed Vulnerability)
Older buildings should be reviewed. It is likely that improvement of building inter-connection would be effective in reducing vulnerability to acceptably low levels. Security of plant, equipment and building services should be reviewed.

Farry-Dunedin Engineering (Vulnerable)
All buildings should be reviewed. Continuation of buttressing of walls with steel columns is encouraged, at least as an interim measure. Consideration should be given to protection of critical plant, particularly main transformer and switch areas.

Wickliffe Press (Low to Moderate Vulnerability)
The most likely difficulty will be distributing product to customers and receiving incoming supplies. To ensure that business can be re-established at the earliest time, mitigation measures should include the securing of critical plant and stocking of sufficient spare parts and stock.

Allied Press, Cumberland and Stuart Streets (Moderate Vulnerability)
Basic mitigation measures are securing critical items of equipment such as computer and communication systems.

Assessment and strengthening is advocated because the local television network is housed in the buildings this may become a vital link in the communications systems immediately after a major event.

BUILDING SERVICES & CONTENTS - DESCRIPTION

Introduction

Building services and contents have not been extensively surveyed as part of the Dunedin Lifelines Project partially because of the considerable resource required to make subjective assessments on the widely varying content and the belief that this and building structural surveys are essentially the owner's direct responsibility, best handled by the engagement of qualified persons.

Traditionally, most attention has been placed upon the building itself which is either constructed to the appropriate standard of seismic resistance or strengthened to achieve this. While this is crucial to minimising human and material losses from a major disaster, the building function otherwise is solely to keep personnel and contents productive and protected from the elements .

Should the services and equipment become inoperable during and/or following a major disaster, the building is no longer able to carry out the function(s) it was intended for. Examination in previous studies has found that much damage has been done within seismically adequate buildings and they therefore become totally unusable due to the complete upheaval caused by the contents of the buildings being dislodged and rendered inoperable.

In the past, once the structure of the building has been completed, mechanical and electrical contractors have often installed the building services with little input from suitably qualified engineers and as a result have failed to ensure an appropriate level of seismic resistance being incorporated.

If consideration had been given to seismic effect, this would often be at a level of 0.1g (0.1 times the acceleration due to gravity). This compares with accelerations in excess of ten times this being experienced at the top of some buildings during moderate to severe earthquakes.

Seismic Standards

The services and contents of more recently constructed buildings should comply with the current New Zealand Standards, NZS 4219 "Seismic Resistance of Engineering Systems in Buildings" and NZS 4104 "Seismic Restraint of Building Contents". However, it has been observed that this is not always the case.

BUILDING SERVICES & CONTENTS - MITIGATION STRATEGIES

Building Services

Service failures during earthquake may be many and varied in so many different ways that examination on a property to property basis is the best way to generate practical mitigation options.
It is recommended consideration be given to the following service systems within buildings:

- Heating and Ventilation — Fans, motors, ducting, pipework and vents.
- Electrical — Emergency batteries, switchboards, light fittings and fans.
- Fire Protection — Header tanks, pipework, batteries and control boxes.
- Plumbing and Drainage — Water storage, pipework, hot water cylinders.
- Lifts — Hoist motors, controls.
- Security Systems — Controls, video cameras etc.
- Communications — PABX racks, controls generally, speakers etc.
- Refrigeration — Compressors, cabinets, pipework.

Many of these more sophisticated building services are now incorporated in private homes and should similarly be considered by home owners.

Building Contents

Building contents are frequently given even less consideration than services, with various owners and tenants installing all manner of equipment and furniture without any concern for the effects of an earthquake.

Examples of frequently seen loose standing contents in commercial buildings and private homes which should be restrained are:

- Tall bookshelves (and contents if important).
- Key communication equipment ie PABX, fax, etc.
- Key computing/data access equipment.
- Large partitions.
- Drawings and file storage.
- Hot water cylinders (good supply of emergency water).
- Emergency generators, header tanks, fuel tanks, supply lines, start batteries and cabinets.

Conclusions

While structural retrofitting of a building may be a costly though vital operation, mitigating the risk of injury to people and loss of function of a building due to unrestrained building services and contents can often be easily carried out at relatively little cost.

The payback in both instances can be substantial, resulting in little or no loss of function allowing the service, utility or business to continue operating and providing a commercial benefit to owners, operators, service providers, businesses and the wider community.

Recommendations

It is strongly recommended that building owners and mangers examine the services and contents of their buildings to assess the potential loss due to natural hazard and consider mitigatory actions which might be taken now to increase survival of these assets. Systems have been developed that enable a broad-brush but methodical risk assessment to be undertaken economically.

Standby power may be a crucial element in the operation of certain critical buildings and particular attention should be given to protection of existing systems, with installation of standby power as an alternative supply in some cases.

Compiling a register of potentially vulnerable system assets, commencing seismic restraint work and preparing recovery plans for use after events are highly desirable mitigatory actions which may be started now.

CHAPTER 9. HEALTH & EMERGENCY SERVICES - CONTENTS

HEALTH & EMERGENCY SERVICES - INTRODUCTION

Approach Taken

Some city lifelines are primarily service providers rather than owners and operators of infrastructure networks. Their critical assets tend to be their expert staff, supported by specialist buildings and plant.

In many cases these lifeline providers are dependent upon the continued availability of the infrastructure of other lifeline services to enable them to carry out their full operational functions.
Lifelines considered in this chapter are:

- Medical Health - Dunedin Hospital, Mercy Hospital, The After Hours Doctors, General Practitioners, Civil Defence Emergency Medical Units and Ambulance Services.
- Public Health - Dunedin City Council Environmental Health Unit and Healthcare Otago Public Health Unit.
- Emergency Services - NZ Fire Service, NZ Police and Dunedin City Civil Defence.

As these services are not primarily owners and operators of infrastructural services, the main focus of this study was on the effect of the loss of other lifeline services on their essential functions. Vulnerability is therefore considered against the loss of each lifeline service.

HEALTH & EMERGENCY SERVICES - DESCRIPTION & VULNERABILITY

Water

Medical Health
Dunedin Hospital uses around 300,000 litres of water a day for drinking, sanitation and production of steam for heating. This is fed in to the hospital through a number of supply points. The boilerhouse has storage for 20 days of essential operation, while other areas hold 200,000 litres, which is less than one day at normal consumption rates and not all of the stored water is potable. In the event of rupture of water mains near to or within the hospital premises, flooding of the lower basement could threaten the power distribution controls, emergency generators and PABX equipment.

Mercy hospital has water storage on site for 24 hours of operation.

The After Hours Doctors centre has only four hours supply of stored water, while general practitioners and emergency medical units are all dependent upon continued mains water supply but could continue to function for a limited period without mains supply.

Ambulance operators are not dependent upon water supply for their primary functions.

Public Health
The primary impact on public health services would be the need to monitor and advise on hygiene measures in the absence of water or if water could not be properly treated.

Emergency Services
The NZ Fire Service places a high reliance on the availability of water mains for fire fighting water supplies, although untreated water is suitable and some other sources can be used for fire fighting.

The Central Police Station has sufficient stored potable water for at least 72 hours and also has a 200,000 litre static supply suitable for fire fighting.

The Civil Defence Headquarters has only limited stored water and ward headquarter sites are reliant on mains water supply, although the lack of water does not critically inhibit the essential functions of these sites.

Sewage Disposal

Medical Health
Dunedin Hospital discharges its sewage directly to the reticulated sewerage system, apart from that from the lower ground floor which is at a lower elevation than the sewers and relies on pumped discharge.

Mercy hospital and most emergency medical unit sites are elevated and so are unlikely to be affected by sewer discharges but will be restricted in how they dispose of their wastes.

General practitioners would expect to have patients presenting with illnesses from those who may become exposed to sewage contamination.

Public Health
Public health authorities would be involved in assessing risks from sewage discharges, with advice to the public on hygienic disposal methods and to engineers on alternative treatment and disposal options. If sewage is discharged to the harbour or waterways, there will need to be careful monitoring and warnings to the public to avoid recreational activities in these areas.

Emergency Services
The Fire Service may be limited in their use of alternative sources of fire fighting water where there is possible contamination from sewage discharges.

The Central Police Station has sewage holding tanks sufficient for three days of normal use.

All civil defence sites are fully reliant on reticulated sewage disposal.

Stormwater Disposal

Medical Health
Dunedin Hospital could experience flooding of its below-ground levels if stormwater reticulation is inoperative.

Mercy Hospital and other medical treatment sites should not be unduly affected but the Ambulance Service may experience access difficulties due to flooded roads and scouring caused by water flows.

Public Health
Advising people not to come into contact with potentially contaminated flood waters would be the main issue arising from damage to the stormwater system.

Emergency Services
The primary concern for all emergency services would be restrictions on access through surface flooding and road scouring.

Refuse Disposal

Medical Health
Dunedin Hospital fills a refuse skip in two days. Some of the waste generated is medical waste requiring special disposal procedures.

Mercy Hospital, general practitioners and emergency medical units and the Ambulance Service also generate medical wastes.

Public Health
The main public health concern is over difficulties in disposing of contaminated (flood water) or spoiled (refrigeration failure) foods from the 700 food outlets in the City and from domestic fridges and freezers. If collection and disposal at the landfill is not possible severe health effects could result.

Emergency Services
None of the emergency services generates refuse of a nature or quantity to cause problems.

Electricity Supply

Medical Health
Hospitals are highly reliant on electricity supplies and both Dunedin and Mercy hospitals have back-up generator capability.

The Dunedin Hospital generator will supply critical areas and minimal lighting in other areas and has fuel for thirty hours, while the boilerhouse generator has fuel for four days.

The Mercy Hospital generator provides 80% of the hospital's requirements.

General practitioners and emergency medical units can operate at about half their normal level during daylight without electricity. Some medical centres have wiring to enable a portable generator to supply their needs but don't have dedicated generators.

St John Ambulance has a generator with around 100 hours of fuel. This supplies operational but not administrative parts of their premises.

Public Health
Loss of access to computer records would be the only direct effect on public health authorities, but loss of refrigeration for foodstuffs could have serious public health consequences.

Emergency Services
Fire alarm systems are supposed to be fitted with 12 hour back-up batteries but after these run down alarms will not work. The Fire Service has a number of portable generators and a generator for the central Fire Station. Failure of power to their radio repeater sites will affect communications once back-up batteries become exhausted.

The Central Police Station has 72 hours of fuel for its back-up generator and the North Dunedin and South Dunedin stations each have around 12 hours of generator fuel.

The Civil Defence Headquarters has a generator with 72 hours of fuel and all vital equipment has battery back-up. The Civil Defence Emergency Communications Unit has full battery back-up and a portable generator. Ward headquarters sites have full back-up battery for their radio communication systems, which can also operate from car batteries. The premises themselves have no back-up power but basic battery and chemical lights are available for use at these sites.

Gas Supply (Fuel and Medical Gases)

Medical Health
Neither hospital is fully reliant on reticulated gas and Dunedin Hospital holds seven to nine days of LPG gas.

Both hospitals, general practicioners and the Ambulance Service use medical gases and supplies of bottled medical gases could easily be transported to Dunedin under all but the most severe circumstances.

Emergency Services
The primary concern with the reticulated gas supply would be getting it shut down rapidly to prevent fires or explosions from gas leaks.

Liquid & Solid Fuels

Medical Health
Dunedin Hospital uses steam from the coal-fired boilers for heating and cooking. Stored coal is sufficient for eight days of operation in summer but only three to four days in winter.

Mercy Hospital holds seven to ten days of boiler fuel.

St John Ambulance has a 10,000 litre underground tank of fuel for its ambulance fleet. The fuel pump runs from the generator but fuel can be pumped by hand in the last resort.

Emergency Services
The primary requirement is for vehicle fuels and all services rely on refuelling at normal service station facilities.

Transportation

Medical Health
The primary issues for all medical treatment sites is isolation from staff, patients and medical supplies. While the Ambulance Service has some four wheel drive ambulances and access to helicopters for moving patients where access is difficult, the number able to be moved this way would be relatively limited. Dunedin Hospital has a helipad and Mercy has large grounds which would provide landing space for helicopters.

Air transport is relied on for just-in-time delivery of many medical supplies so the operation of and access to the airport is critical.

Sea transport of medical supplies and medical evacuees would depend on the port being operational and the harbour navigable.

Loss of road and rail links into the city could create difficulty for delivery of medical gases and other supplies as well as for the medical evacuation of patients.

Public Health
The majority of public health functions require health personnel to operate in the field and restricted movement would hinder operations.

Emergency Services
Most emergency services rely on vehicular movement around the city to carry out their functions and any limitations on road transport would hinder this. While the Police and Civil Defence have access to four wheel drive vehicles, the Fire Service is reliant on its fire appliances which are not suited to off-road operation.

Loss of transport links into the city would limit the movement of supporting personnel and resources from other areas.

Communications

Medical Health
The Dunedin Hospital PABX is considered to be vulnerable, but fifty lines are hard-wired to default telephone positions in the hospital. The telepaging system operates on the generator power supply and the hospital is linked to the Ambulance Service radio-telephone system.

Mercy Hospital has hand-held radio equipment for communications on their own site but are reliant for all other communications on the public telephone system, as are general practitioners.

St John Ambulance has a full radio-telephone system which has a number of back-up operating modes and power supply options.

Public Health
Public health agencies have no communications other than the public telephone system.

Emergency Services
Police, Fire Service and Civil Defence all have full radio-telephone systems connecting their key sites and mobile vehicles as well as quantities of portable radio equipment including portable repeaters. The primary repeaters for all services have back-up power systems.

The Civil Defence Headquarters telephone exchange has tie-lines to the Police, Dunedin Hospital, St John Ambulance and a number of other organisations. If the public exchange is unable to switch calls between these organisations, the civil defence telephone exchange is capable of doing so if the lines remain intact.

The Civil Defence Emergency Communications Unit has radio communications equipment for all emergency agencies and is fully self-contained for field operations. The Police and Fire Service also have dedicated mobile command and communication units.

A remote radio broadcast facility at Civil Defence Headquarters enables simultaneous public information broadcasts to be made over the main Dunedin radio stations.

The 111 system is reliant on the public telephone system and any disruption to this has severe implications.

Emergency services place little reliance on cellular telephone networks due to their dependence on toll circuits and the ease with which the systems can be overloaded.

Buildings & Services

Medical Health
The Dunedin Hospital ward block is built to withstand over 2 metres of sway in an earthquake but the equipment and chemicals in the building are generally not seismically secured. The boilerhouse chimney may be vulnerable to earthquake, leading to a loss of steam production.

Mercy Hospital was built in the 1960's and has been extended over the years to prevailing seismic codes.

The After Hours Doctors Centre is in a relatively modern building but their equipment is not secured to withstand earthquake shaking and the wide spread of general practitioners' facilities throughout the city spreads the risk of major losses.

The operational part of the St John Ambulance building is of recent construction and of a seismically resistant design.

Public Health
Apart from access to equipment, health authorities are not particularly reliant on their buildings.

Emergency Services
The Central Fire Station is likely to suffer structural damage in an earthquake but other fire stations are more robust. Apart from access to fire appliances, the buildings themselves are not critical.

The Central Police Station is of recent seismically resistant construction.

The Civil Defence Headquarters was designed to withstand earthquake shaking. Many of the ward headquarters sites are in school buildings which have been assessed as being relatively safe.

HEALTH & EMERGENCY SERVICES - MITIGATION STRATEGIES

Water

Medical Health
Dunedin Hospital is supplied from a number of supply points, reducing the risk of complete water loss. Tankered water can be pumped into the main Dunedin Hospital tanks and from there pumped to other parts of the hospital.

Hospitals and medical treatment sites will have high priority for re-instatement of water supply through mains supply or temporary supply systems but all would have to implement water conservation procedures.

Public Health
Civil Defence Headquarters is equipped with a remote broadcast facility for local radio stations and this would be critical in getting public health information messages broadcast, but is dependent on the radio stations themselves remaining operational (see the chapter on Communications for details).

Emergency Services
The NZ Fire Service has identified a number of alternative fire fighting water supply sources, including Moana Pool and Speights Brewery (water supply). In the re-development of the Moana Pool complex, the desirability of a fire connection point for easy access to the pool water has been requested to be included in the design. In the event that water sources are scarce, fire control methods other than bulk water may have to be used. If all fires are brought under control, Fire Service resources will be available to assist with temporary water distribution.

Civil Defence Headquarters can be served by a rural fire trailer tanker brought into the carpark building. As this will not be immediately available and may not be potable water, a stored water supply is being investigated to serve the initial period of an emergency.

Sewage Disposal

Medical Health
The sump pump for the lower ground areas of Dunedin Hospital could be used to pump effluent from the hospital system into tankers for disposal, so long as road access is available and there is power to run the pump.

Mercy Hospital and the majority of other medical treatment sites are elevated and if necessary would have to continue discharging waste into damaged sewers.

Emergency Services
Alternative waste disposal for Civil Defence Headquarters is being investigated.

Stormwater Disposal

Medical Health
Protection of the Dunedin Hospital from excess stormwater entering lower areas will be a priority task, as a number of critical hospital systems are threatened by this. It is not practical to consider moving the large generators from this area, but future changes to the PABX system and electrical control systems should review their current vulnerable locations.

Emergency Servic es
The Civil Defence Headquarters has a raised floor to protect against excess stormwater affecting operations.

Refuse Disposal

Medical Health
Dunedin Hospital will establish a secure refuse disposal area and store waste until normal disposal is available again.

The After Hours Doctors centre will also use this facility and other medical health agencies will hold their own refuse in as secure a manner as possible.

Public Health
To reduce the volumes of foodstuffs perishing and needing to be disposed of, plans are in place to provide refrigerated containers for food storage and public health authorities will supervise disposal of unsafe foodstuffs.

Electricity

Medical Health and Emergency Services
The primary mitigation measure is ensuring ongoing fuel supplies for generators and refrigerated container units (see the chapter on Fuels).

Liquid & Solid Fuels

Medical Health
The Dunedin Hospital boiler can be run on coals other than those normally used although the resource consent does not allow for this. Steam will be limited to essential uses to conserve fuel.

Emergency Services
Emergency services, other than Ambulance, are totally reliant on the petroleum industry for the supply of vehicle fuels and will be among priority users if fuel stocks are limited. Petroleum supply companies are taking action to ensure that fuel from their bulk tanks can be accessed for this type of use.

Transportation

Medical Health
Rapid reinstatement of primary road and air transport links will be critical for medical health agencies for both access for staff and patients and supply of medical stores. Use of four wheel drive vehicles or stretcher teams may be the only way of transporting patients to other areas.

Communications

Priority re-instatement of telephone services to medical and emergency services sites is planned through the civil defence telephone re-connection priority lists.

Emergency services radio telephone systems are engineered and maintained to high standards and portable equipment is held to augment the main systems.

Buildings & Services

All health and emergency services are encouraged to survey their premises and secure critical stores and equipment against earthquake shaking.

The NZ Fire Service has plans to construct a new Central Fire Station.

CHAPTER 10. INTERDEPENDENCE OF LIFELINE SERVICES AND RECOVERY TIME ESTIMATES- CONTENTS

INTRODUCTION

No lifeline service can function wholly independently of one or more other lifelines.

While the primary focus of the vulnerability assessment phase of this project was on each group of lifeline services and the individual assets within it, the effects of interdependence can have a critical impact on service provisions and on recovery times.

The levels of interdependence are increased by the trend towards the use of contracted services for maintenance and recovery of damaged assets. In many cases, several lifeline services may rely on the same contractor.

Thus an assessment of the level of interdependence of lifelines became a key component of the vulnerability phase of the project.

To ensure that appropriate consideration was given by each individual service to dependence upon other services for reinstatement, recovery or ongoing daily operation, members were asked to identify the dependence of their particular service on others.

RESULTS OF INTERDEPENDENCE ASSESSMENT

In the assessment of interdependence, no attempt was made to define the extent of damage other than to state that it was widespread, random and disabling to all systems in some way. The dependence of each service on other lifelines is summarised in the tables appended to this section of Chapter 10.

When considering the interdependence of all lifelines, including fire, ambulance and police, the dependence of all services on each other was assessed to be:

- Roading (access) — Greatest dependence of services on this lifeline ↓
- Fuels
- Communications
- Electricity Supply
- Buildings & Structures
- Water
- Stormwater
- Sewerage
- Airport
- Rail
- Harbour — Least dependence of services on this lifeline

When, however, the results are analysed further, the priorities are somewhat different. For example dependence of infrastructure services such as water, sewerage, and stormwater on other lifelines becomes:

- Electricity — Greatest dependence of services on this lifeline ↓
- Roading (Access)
- Fuels
- Communications
- Buildings — Least dependence of services on this lifeline

For services such as police, fire and ambulance which are dependent on access and movement, the priority changes to primary dependence being on roading, fuels and communications, with some dependence on their buildings and water supply.

Individual agencies need to concentrate in the areas defined as of greatest dependence to them to ensure that their particular network and operation is protected against loss of these services for what could be lengthy periods. Conversely those services identified as being of greatest dependence for others need to review their networks and operations to ensure that a robust system is offered and the likelihood of loss of services to others who depend on them is minimised.

LIFELINES INTERDEPENDENCIES SCORING TABLE

AFFECTED LIFELINE	DEPENDENT LIFELINE Water	Sewer-age	Storm-water	Elec-tricity	Fuels	Roading	Rail	Airport	Har-bour	Comm's	Build-ings	Police	Fire	Ambu-lance	Hos-pital	TOTAL
Water	-	1	1	1	4	1	1	1	3	1	4	4	4	2	4	32
Sewerage	1	-	1	1	4	1	1	1	2	1	4	1	1	4	4	27
Stormwater	2	3	-	1	2	3	1	2	1	3	2	2	2	4	3	31
Electicity	4	4	4	-	4	1	2	2	4	4	3	2	2	4	4	44
Fuels	2	3	3	4	-	4	4	3	4	1	3	4	4	4	4	47
Roading	3	3	3	3	4	-	3	3	4	2	4	4	4	4	4	48
Rail	1	1	1	1	1	1	-	1	4	1	1	1	1	3	3	21
Airport	1	1	1	1	4	1	1	-	1	1	1	2	3	3	3	24
Harbour	1	1	1	1	3	1	2	1	-	1	1	1	1	3	1	19
Comm's	2	2	2	2	4	3	3	4	4	-	4	4	4	4	4	46
Buildings	4	2	2	1	1	2	3	2	3	4	-	1	4	2	4	35
Police	3	2	3	3	4	1	4	4	1	2	4	-	-	-	-	31
Fire	3	2	3	3	4	1	4	4	1	2	4	-	-	-	-	31
Ambulance	1	1	1	1	1	1	1	1	1	3	3	-	-	-	-	15
Hospital	1	1	1	1	1	1	1	1	1	3	3	-	-	-	-	15
TOTAL	29	27	27	24	41	22	31	30	34	29	41	26	30	37	38	-

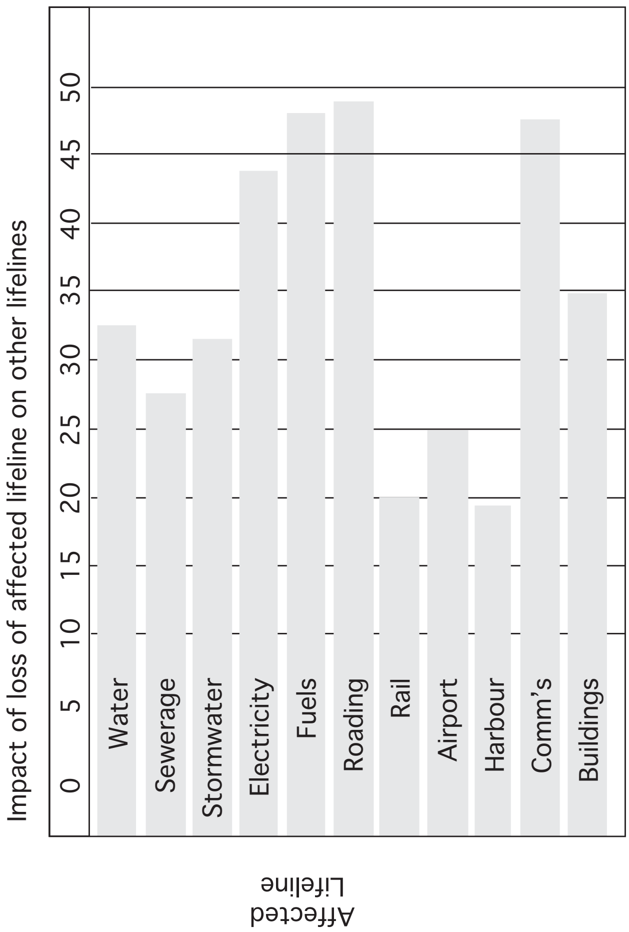
INTERDEPENDENCE RATING

Significant Minor

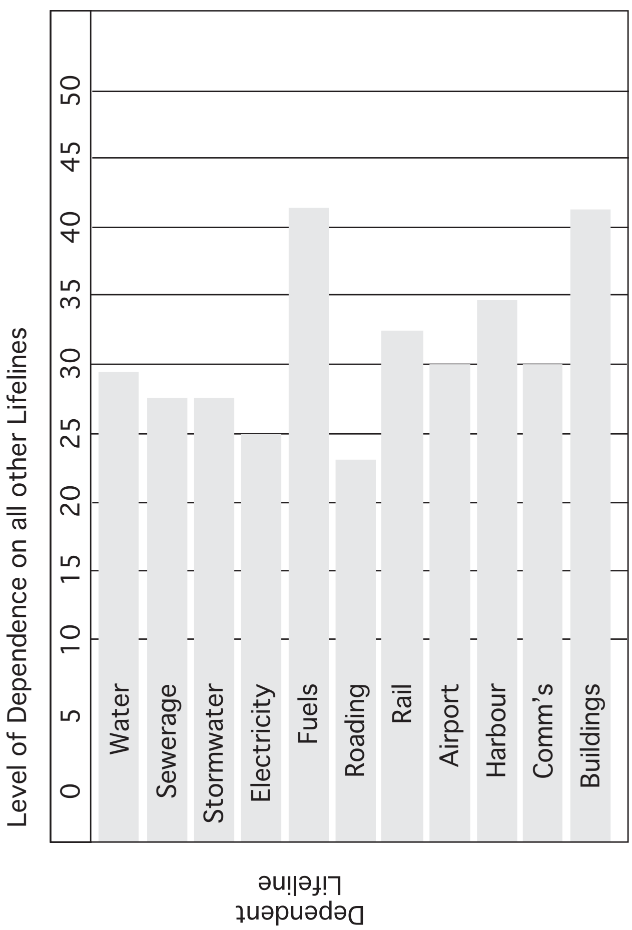
4 3 2 1

LIFELINE INTERDEPENDENCIES

Impact of Loss on Other Lifelines



Comparative Dependence on Other Lifelines



Health & Emergency Services

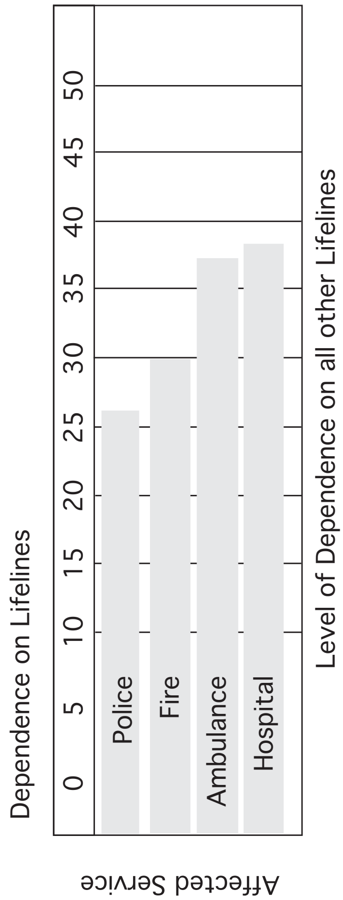


Table Here

THE RECOVERY PERIOD

Introduction

A scenario-based review of typically expected loss of lifeline services throughout the greater city area from seismic events (including liquefaction and earthquake induced landslip), flooding, tsunami, meteorological and technological events was produced to approximate the likely services losses and recovery times which may be expected.

Because of the uncertain nature of hazard impacts, detailed and accurate losses and recovery times cannot be determined.

The purpose of producing these assessments is to provide a simple measure against which other agencies may develop planning to operate without the lifeline concerned, or implement mitigation strategies to provide alternative service.

Water Supply Scenario

Seismic Events

- Raw water intake will be reduced by 60% and restoration of supply will take between 30 and 120 days.
- Treatment of water is likely to be disrupted for between 7 and 14 days with 40% loss of capacity if Mt Grand is disabled and up to 120 days if the Taieri Bridge is out of commission.
- Reticulation will be damaged in numerous places with restricted supply for 3 to 4 weeks over 20% of the city. Worst affected areas are likely to be South Dunedin, St Kilda, Kaikorai Valley, Mosgiel, Peninsula. However supply tothe Central Business District is likely to be satisfactory.
- Storage capacity will be critical in some areas which are serviced by isolated installations such as Montecillo, Fairfield and at Southern reservoir where a 15% loss of city supply may take 2 to 4 weeks to restore. The Peninsula storage is likely to be disrupted for a slightly longer period.
- There will be negligible damage to the water supply depots. Restricted supply (particularly to hill suburbs) may be needed to facilitate work repair to pipeline fractures or reservoir damage. This may continue for several weeks.

Flooding, Tsunami, Meteorological or Technological Events

- Raw water supply pipes damaged by flood and settlement or landslip:
  - Deep Creek and Deep Stream 20% disability estimated for 1 to 3 weeks.
  - Taieri Plain pipelines only 5% disability for 3 to 10 days.
  - Taieri Bores could be 100% unserviceable for 28 days.
- Treatment and storage facilities will have limited damage due to meteorological conditions causing operating difficulties but no significant functional loss.
- City reticulation could be damaged in numerous localities due to pipe settlement or wash aways, slips etc but generally only 10% system loss of function with reinstatement in a 1 to 3 week period. Principal localities at risk are South Dunedin, St Kilda, Kaikorai Valley and North East Valley, the Peninsula and Fairfield.
- Water supply depots will generally be unaffected.
- There is always a possibility of vandalism and more serious deliberate tampering with the water supply function and product. In the light of historical record, it is not possible to offer a calculable probability of disability to the system.

Sewage Scenario

Seismic Events (including liquefaction and induced landslip)

- Damage to pumping stations could result in the loss of 60% of capacity to drain the city area, and dependent upon the extent of damage to pumps and screens, will take from 8 to 26 weeks to repair (the latter time if damage occurs to the rising main).
- General reticulation damage will occur in the lower lying areas of the city with many collar breaks in Andersons Bay, South Dunedin, St Kilda and around the University and lower Central Business

District. It is estimated that 25% loss of service to city reticulation will take from 3 to 8 weeks to repair.
- Treatment plant and ocean outfalls are expected to suffer a 20% disability and require 2 to 8 weeks to reinstate.
- During the immediate and short term recovery period there is likely to be a need for discharge of untreated sewage to the harbour which will pose a health risk.

Flooding, Tsunami, Meteorological or Technological Events
- Expected damage to main sewers is caused by settlement, landslip and considerable infiltration placing a strain upon the reticulation and pumping system within the city area. There is likely to be a 10% loss of overall function which will require 7 to 14 days to reinstate. Localities principally at risk are in lower lying areas of South Dunedin and St Kilda.
- In the outlying districts the major pipeline and pumping mains associated with Mosgiel and Green Island sewage treatment plants are at risk from settlement, landslip and surcharge of lines as within the central city area. The loss of function is likely to be about 10% of the overall system but repair may take slightly longer due to access difficulties and take say 1 to 3 weeks to recover.

Stormwater Scenario

Seismic Events
- It is estimated that there will be an overall disability of disposal service of the order of 15% with an estimated repair period of between 4 and 8 weeks. This lengthy time will be the result of prioritising work.
- Damage is likely to be wide-spread with surface run-off carried to natural water courses and this may cause damage to underground services (power, telecommunications, gas etc) from infiltration and scour.
- Roading is certain to be damaged and open channels will suffer from blockage due to landslip.
- Pumping stations are expected to suffer minimal damage but service disruption will occur owing to power losses and pipework damage. An estimated 15% overall loss of service for a period of 7 to 14 days is possible.

Flooding, Tsunami, Meteorological or Technological Events
- Trunk stormwater pipework, pumping stations and open channel watercourses are likely to suffer damage through landslip, overcharged pipework, settlement and collar breakages, debris transmission and wash-outs. It is estimated that 7.5 to 10% of the city system will be affected and recovery will take 1 to 3 weeks.
- Outlying districts will suffer less from flooding with the exception of Mosgiel which tends to flood in lower areas of Owhiro Stream.

Refuse Disposal Scenario

Seismic Events
- There is expected to be little loss of function on the various landfill sites around the city. Possible damage may occur to the leachate pumping system at Green Island, but the overall disability to all sites is likely to be negligible and any repair work will be carried out as a non-urgent activity within 3 to 7 days.
- Roading damage will cause disruption to domestic rubbish collection.

Flooding, Tsunami, Meteorological or Technological Events
- Little damage should occur to the refuse disposal system apart from accessibility. The advent of tsunami may (in extreme conditions) cause more prolonged inundation of the Green Island disposal area and possibly damage to the leachate system but damage is expected to be minimal and recovery will take 3 to 7 days at worst.

Electricity Scenario

Seismic Events
- Because of extensive diversity it is expected that there will be no major loss of power supply, but

intermittent power outages will occur over the entire area for a period of between 1 to 3 weeks after the event.
- The principal cause of outage will be failure at sub-stations, due to building and equipment damage, and loss of pole mounted transformers throughout the city. (Some 75% of supply is overhead.)
- Load-shedding and repair outages will be commonplace at this time and it is anticipated that some 30% of the area supply system will be affected in some way.
- South Dunedin and the harbour commercial areas are likely to be the worst affected.

Flooding, Tsunami, Meteorological or Technological Events
- Periodic, but short term loss of high voltage supply due to weather conditions is generally unpredictable and not preventable. It is assessed as a 10% loss of service of not greater than 24 hours.
- Physical damage by weather to high voltage lines and towers, transformers and sub-stations is perceived as being minimal with 10% loss of service function on a broadly based and well diversified system, with reduction of supply being recovered within 3 to 7 days in all cases.
- Flooding and landslip are likely to be damaging to underground cables particularly in areas of South Dunedin, St Kilda, Kaikorai Valley and North East Valley, with some damage from washout. A general loss of 5-10% of systems in these areas, with restoration within 1-3 days is the anticipated worst case.
- Landslip causing damage to lines, transformers and pole mounted units will result in 5% losses of service for 1-3 days.

Gas Scenario

Seismic Events
- Total shut-down of the network for safety reasons may take 6 weeks to restore.
- Damage to the gas holder at Kensington will cause major disruption.
- Damage due to water infiltration may result in considerable delays in restoring supply.
- Fracture to pipes will cause pockets of explosive gas with considerable danger of serious fire damage.

Flooding, Tsunami, Meteorological or Technological Events
- Flooding, weather and technological hazards will cause serious loss of service for several reasons:
  - Full loss of gas production at the landfill site for 1-3 weeks.
  - Infiltration of water to gas lines following landslip, requiring replacement and purging, may cause 100% loss of service for 1-3 weeks.
  - Damage to the system by vandalism could require whole or partial close down of the system for purging, taking up to a week to reinstate.

Liquid and Solid Fuels Scenario

Seismic Events
- Distribution of stock in bulk delivery should not pose a problem if road transport and road surfaces permit. Tankage is likely to survive, but some delivery pipes may be damaged and cause a 10% disability of service for a period of 7 days.
- Delivery of new stock (both liquid and solid fuels) will be inhibited by damaged road access (particularly from the north) and any disruption to the harbour channel and berthing facilities. An estimated 50% loss of the oil wharf facility may extend for up to 6 weeks, requiring road transport servicing of bulk fuel supplies if road access is available.
- Loss of the oil wharf facility will necessitate rationing, as road transport supply can only transfer limited quantities of fuel. This would impact upon services dramatically if the hazard event was close to the time of a tankship call when stocks were at low level.

Flooding, Tsunami, Meteorological or Technological Events
- Re-supply of fuel stocks from north and south may be delayed. This disruption does not appear to be too serious, provided that adequate stocks of liquid fuel and coal are maintained in the city.
- In extreme conditions, solid fuels may be delivered by sea.
- Distribution may be inhibited by flooding and general road conditions but generally such events will be of short duration, affecting supply for 3 to 7 days at worst.

Roading Scenario

Seismic Events

- State Highway 1 to the north could be closed from between 3 to 7 days with damage to bridges, landslip and road surface heave. Particular areas of damage are expected at Tumai Overpass, Kilmog and Northern Motorway.
- State Highway 1 southwards is expected to remain open with some loss of function due to surface heave. Repairs are likely to be extended up to 30 days as non-priority activity.
- State Highway 88 to Port Chalmers will be unusable for 3 to 7 days and may severely inhibit port operations.
- Major city roads will be affected by surface heave, debris and surface flooding from burst water mains. Disruption to major city roads such as Portsmouth Drive and Kaikorai Valley Road may involve 20% of the routes and may not be fully restored for up to 30 days.
- Approximately 20% of all secondary and general roading will be disabled due to surface damage, collapsed structures, burst pipework damage, fallen trees etc and prioritising will be necessary to secure recovery of certain essential service roads, ie communications, power access. Full recovery may take up to 30 days.
- Bridges, both on the state highway system and throughout the city, are likely to be disabled by failure at the abutments and in some instances slipping of deck structure. The probable order of loss of function of city bridges is placed at 15% of stock, with an extended repair period of between 4 and 5 weeks.

Flooding, Tsunami, Meteorological or Technological Events

- State Highway 1 north may be closed for 1 to 3 days by major landslip, generated by weather or flooding/tsunami, involving 100% loss of service during reinstatement.
- State Highway 1 south may be closed for 1 to 3 days by major flooding and damage to bridges, with 100% loss of service.
- State Highway 88 to Port Chalmers may be disabled by weather causing slips or by tsunami damage and may be closed for 1 to 3 days pending repair.
- Major city roads will not be significantly damaged except for the following which are likely to experience 100% loss of service for the periods stated:
  - Portsmouth Drive - tsunami wash-away 3-7 days
  - Kaikorai Valley Road - flood from Kaikorai Stream 1-2 days
  - North East Valley Road - flood from Lindsay Creek 1-2 days
  - Kaikorai Estuary - tsunami and flood (bridge damaged) 3-7 days
- Secondary roads and access routes will be disabled by flood or slip for relatively short periods assessed at 3-7 days, depending upon priority of re-working. Generally only 10% of all stock will be affected in this way.
- Bridges are not expected to be significantly damaged, except for that over the Kaikorai Estuary and some minor structures in low-lying areas. These represent 5% of bridges, which could be closed for 2-3 days.

Harbour Scenario

Seismic Events

- Damage to the entrance channel from Taiaroa Head to Port Chalmers and onward to the Upper Harbour is likely to be in the form of collapse of the sides of the dredged channel and loss of navigation beacons. This may restrict berthing of larger vessels at both locations.
- Channel dredging will be needed and service restricted by 30%:
  - Taiaroa Head - Port Chalmers 14-30 days.
  - Port Chalmers - Upper Harbour 30-120 days.
- Smaller vessels are likely to be able to operate in daylight within 3 days, berthing at both locations. There will be uncertainty about LPG bulk supplies arriving by sea for up to 4 weeks because of vessel size.
- Port Chalmers facilities, craneage and general port operations are likely to suffer a 30% disability for a period of between 30-120 days depending upon severity of damage to non-redundant equipment.
- Some service pipework and electrical services will be damaged and hard standing areas will become

unsafe for container operations.

Flooding, Tsunami, Meteorological or Technological Events

- No serious damage is expected, but tsunami is likely to damage wharf protection works and weather may cause landslip damage. This damage is unlikely to cause significant loss of service and should be in effect for no more than 3 days.

Rail Systems Scenario

Seismic Events

- Track to the north is likely to be disabled 100% for a period of 3-10 weeks, dependant upon slip damage and bridge/tunnel conditions.
- Track to the south will be subject to reduced service, pending repair to anticipated track settlement. There will be bridge abutment damage and minor tunnel damage, but this will only represent 30% disability for a period of 1-3 weeks.
- The Dunedin to Port Chalmers line is expected to be affected in the same way as the track to the south and in roughly the same range of disability, possibly 50%.

Flooding, Tsunami, Meteorological or Technological Events

- Track to the north may be disabled 100% by slips and is subject to tsunami damage at several locations. The period of closure will vary greatly, but probably lies at 3-10 weeks.
- Track to the south could well be disabled 100% by flooding which could also damage bridge abutments and embankments. Slips may also occur. The period of reinstatement may vary from 1 to 3 weeks.
- The Dunedin to Port Chalmers line will probably close due to grade slipping but for a relatively short period of 3 to 7 days.

Air Transport Scenario

Seismic Events

- Dunedin Airport is expected to suffer minimum disruption at 15% disability on normal service. The runway is expected to remain operational for daylight operations only for a period of 3 to 7 days, pending re-calibration and restoration of navigational systems. The buildings will be damaged and suffer a greater loss of function, probably 25% disability, for 4 to 6 weeks, but will remain operational.
- At Taieri Airport and Dunedin Hospital Helipad no disruption is expected.

Flooding, Tsunami, Meteorological or Technological Events

- Historically, the most serious event which may recur is flooding. Any flooding of the runway will effectively stop aircraft movements at Dunedin Airport, but access to the airport may become difficult even if the runway is operational. Probably 100% loss of service will occur for a period of 2-3 weeks if the runway is covered and 3-7 days in localised flooding of airport access.
- Taieri Airport may be rendered 100% non-operational by extended bad weather for 3-7 days.
- The Hospital Helipad may experience shut-down for short periods due to weather condition (particularly strong winds), usually not exceeding 3 days.

Road Passenger Transport / Heavy Haulage Scenario

Seismic Events

- Some loss of vehicle stock is expected due to building collapse, with loss of maintenance facilities. The expected overall stock/maintenance loss of 10% will be recoverable in 7 to 10 days.
- There will be disruption of city services due to road conditions and possibly fuel shortages for a period of 7 to 10 days.
- Heavy demand will be placed upon heavy haulage vehicles for repair work and these may be subject to travel restrictions due to road damage.
- Haulage of goods from the north will require substantial deviations of route for 3 to 7 days.

Flooding, Tsunami, Meteorological or Technological Events

- Vehicle losses will be negligible, although there will be some loss of operating efficiency and choice of routes.
- Some service centres could be affected by flooding or tsunami effect, with general loss of service of no more than 5% for a period not exceeding 5 days.

Communications Scenario

Seismic Events

Telecommunications

- There will be severe disruption of service with a 25% disability on all services for the first 3 days and overloading of circuits in particularly badly affected areas. Exchange buildings will suffer minimal damage but microwave systems will require re-calibration, which should be readily achieved. Damage will be caused to landline cables by ingress of water from burst mains. The railway signal system will require re-calibration but should be readily restored.
- Toll links will offer limited service for 3-7 days.
- Local calls will be disrupted for 7-14 days.
- The Cellular network will be disrupted for 3-7 days.
- Full service restoration expected to take up to 3 weeks.

Broadcasting

- Only 10% loss of overall function is anticipated, with principal disability occurring on the first day and full service reinstatement will take up to 3 weeks, dependent upon availability of spare equipment and technicians.
- Loss of power supply, landline cable connections, and damage to buildings will be responsible for major service disruption.

Flooding, Tsunami, Meteorological or Technological Events

Telecommunications

- General meteorological conditions may cause some operational difficulties in normal circumstances but extreme conditions will cause service disabilities of the following orders and for similar reasons to the seismic events:
    - Toll links with limited service for 1-2 days.
    - Local calls disrupted 1-3 days.
    - Cellular net disrupted 1-2 days.
- Overall service disruption due to cable damage, winds, snow etc is estimated to affect only 15% of the system and in many instances alternative routing may be available.
- Railway landlines may be more severely damaged by slips and might need additional repair times of 1-3 weeks, depending upon severity.

Broadcasting

- Services are estimated to suffer 10% loss of function and be repaired in 1-3 days.
- The most significant problem will be power supply loss, but generally this outage will affect the system for no more than 24 hours.
- Full service restoration is dependent upon the availability of technicians and replacement equipment.

Buildings and Services Scenario

Seismic Events

Structures

- Modern commercial buildings will generally survive with only minor damage to glazing and peripheral structures.
- Pre 1960 (or thereabouts) commercial buildings will suffer more damage, with an anticipated 5% loss of function on the building stock. Typical failures will be due to collapse of retaining walls, infill panels, brickwork, canopies and glazing. Street access may be impeded by debris and, while some buildings may warrant demolition, most will be suitable for repair and upgrade. The period for recovery of building damage is difficult to assess but is likely to lie between 3-12 weeks before re-occupancy.
- It is estimated that there will be damage to 30% of domestic housing stock, but probably only 5% will be unsuitable for occupancy and then only for 3-12 weeks. Structural performance of buildings is

strongly related to age, with more modern buildings offering better security against damage.

Internal Services and Fittings

- Connections of water supply, waste services and power may be severed, with probably 20% of building stock damaged in this way. Header tank leakage, hot water tanks being shifted and connections broken, misalignment of lifts and activation of fire sprinkler systems will cause internal damage.
- Internal fittings and cabling will be damaged, including suspended ceilings, doors, security systems and furnishings will be broken and computer equipment may be damaged.
- Items on open shelves will fall.
- Up to 5% of commercial buildings may be unoccupiable for a period 3-4 weeks.

Flooding, Tsunami, Meteorological or Technological Events
Structures

- Generally there will be no loss of buildings other than from wind damage. Some glazing damage will occur from time to time and roofing will be blown away. Anticipated loss of service from events in this category is likely to be below 5% of all types of buildings, with unsuitability for occupancy being of the same order. Repair periods will naturally vary but will usually average 1-3 weeks.

Internal Services and Fittings

- Almost always the most susceptible element is content damage from meteorological conditions with approximately 5% of buildings suffering services and fittings damaged in worst events.
- It is particularly difficult to assess the degree of service loss and the time required for repair or reinstatement but it is clear that certain areas of the city such as South Dunedin and St Kilda are particularly vulnerable and reinstatement from the effects of flood could be lengthy.

Summary of Recovery Periods

A summary of indicative anticipated recovery periods from serious hazard impacts is presented in the table below.

Summary of Recovery Periods

Utility	Basic Service	Full Service
Water	2-3 weeks	4 months
Sewage	3-6 weeks	4-6 months
Stormwater	2-3 weeks	2-3 months
Refuse Disposal	3-5 days	5-7 days
Electricity	1 week	3-4 weeks
Gas	1-3 weeks	6 weeks
Liquid/Solid Fuels	1-2 weeks	5-6 weeks
Roading	3-7 days	5-6 weeks
Harbour	1-2 weeks	4-6 months
Rail Systems	1-3 weeks	3 months
Air Transport	1-2 days	3-4 weeks
Road/Passenger Transport	3-5 days	2-4 weeks
Communications	1-3 days	3 weeks

The times indicated assume that the resources needed to restore a particular service will be available as required, although the reality in a major event will be that priorities will have to be established and the periods in the table will be the minimum likely to be experienced.

Should major hazard impact extend to other cities or districts, the periods of recovery may extend beyond those given, due to loss of availability of skilled personnel, equipment and materials normally expected to be supplied from outside Dunedin.

Basic service means service for shortened hours or where considerable inconvenience is experienced by users, or where rationing of the service commodity is needed. Safety considerations may involve total closure.

Full Service is when supply or service is largely restored to pre-event condition, although some general work of a non-essential nature may be ongoing.

REDUCING THE LEVEL OF DEPENDENCE

Actions need to be considered which will make each lifeline more robust. The following factors need to be considered:

Reduction of Dependence on Other Lifelines for Basic Services

In the initial response period the ability to get about and get to facilities is likely to be critical, and this is recognised in the priority of dependence identified earlier in this chapter. Road access and availability of fuels will be critical for most lifelines and resources are likely to be concentrated on addressing these issues initially.

With resources to reinstate lifelines being scarce or limited for some period, each lifeline operator needs to consider what they can do to protect their lifeline from dependence on potentially disrupted services. For example:

- Water, sewerage and stormwater need to consider the use of emergency generators for critical facilities, the structural integrity of their buildings and the services mounted within them and their communication systems so that they are functional and available following a hazard event.
- Police, fire and ambulance need to ensure that they have access to sufficient fuel and that their communications networks are robust and functional without the need for extensive restoration effort. They should also consider the need for 4WD vehicles for movement on damaged roads.

Robustness of Services to Critical Facilities

Some critical facilities are highly dependent on other lifelines. For example:

- Dunedin Hospital depends on water, sewerage, electricity, fuels for heating, road access, communications and their specialised buildings.
- The sewerage system relies on power supply to pumping stations and treatment plants (although the main installations at Musselburgh, Tahuna and Green Island have, or soon will have, emergency generators).
- The water system depends on power supply to pumping stations, treatment plants and control valves.
- The electricity supply companies require the availability of fuel to enable restoration works to be facilitated.

As part of their mitigation measures, each lifeline should review the dependence others have on their service at critical facilities and address how the supply of this service can be made more robust, avoid hazards or provide for alternative supply sources. Conversely, each lifeline should address how it will cope with failure of services on which it depends and, where possible, have appropriate mitigation strategies in place such as provision of emergency generators, adequate emergency storage of water, access to fuel and alternative communication facilities.

Coping With Limited and Rationed Resources

Dunedin is a small city and, in the case of a significant event causing widespread damage, a lot of work will be required to restore lifelines to even basic operation. Over the initial period resources will be limited and it is likely to be some days before significant resources (in terms of materials, equipment and skilled labour) will be available from outside the City.

Any shortage of resources will result in conflicts, particularly where those resources are provided by contractors with commitments to a number of different lifeline operators, including those outside Dunedin in a wider emergency event.

As asset managers develop their mitigation and response strategies, it will be essential that material and parts requirements are assessed and either adequate stocks held or able to be accessed at short notice. Appropriately skilled personnel need to be provided for through contracts, mutual support agreements or other arrangements.

Civil Defence should facilitate pre-planning with regard to identifying the priority to be afforded to particular facilities and services under emergency conditions.

Flexibility in Planning and Mitigation Strategies

Inevitably there will be a need to establish priorities appropriate to any emergency or event but there will always be some uncertainty as to the actual form, scope and impact of a particular hazard event. Arrangements must therefore be flexible and allow for some fluidity as to what may need to be done and when. Mitigation strategies need to reflect the possible delay in access to resources - perhaps through more physical mitigation measures at key facilities which will provide a higher level of security in the event of an emergency. Planning could provide for shut-down in a fail-safe way to conserve what could be a scarce resource. Earthquake-activated shut-down valves on reservoirs are an example of this approach.

CONCLUSIONS

All lifelines depend on others and each operator must not only address how they can make their own service more robust and able to be restored as soon as possible, but must also address how they can contribute to making other lifelines which depend on their service more robust, particularly the critical facilities.

With resources likely to be limited in the event of a significant impact, consideration needs to be given to planning for such an event with a view to establishing the priority for reinstatement of facilities and services. Civil Defence is probably the best agency to facilitate such planning since the earliest decisions needed in an event are likely to be in their hands.

CHAPTER 11. PROJECT CONTINUATION- CONTENTS

MONITORING AND REVIEW

Monitoring Implementation of Lifelines Mitigation Strategies

This lifelines project has been the first step in what will be an on-going exercise - particularly by asset managers. Vulnerabilities have been identified, priorities for reduction of the vulnerable components have been established, straightforward mitigation measures have been identified and tasks for the future set out.

Progress towards implementing the recommended lifeline mitigation strategies to make Dunedin City less vulnerable needs to be monitored on a continuing basis and priorities reviewed and altered as necessary.

The Dunedin City Council has agreed to sponsor the monitoring and review of lifelines mitigation strategies through annual meetings of lifeline providers, facilitated by Civil Defence.

Review of Lifelines Project Report

Following the fifth annual review of lifeline mitigation strategy implementation, consideration will be given to the need for a full review of the hazards, the vulnerability of lifeline services and the mitigation strategies as currently defined in this report.

If it is determined that significant review is warranted, a new project brief will be developed and agreed by the lifeline services involved.

ADDITIONAL PROJECT AIMS

With the completion of the primary aims of the Dunedin City Lifelines Project, it is recommended that two additional aims be pursued.

Using the hazard information and the estimates of damage and loss of service provided in this report, it should now be possible to examine in some detail the potential economic effects on the City of damage scenarios and also to consider the ongoing planning implications which may arise.

Economic Impact of Lifelines Disruption

While the functional effects of lifeline disruption have been clearly defined in this project, the economic impacts on the community arising from lifeline disruption have not thus far been addressed. In considering priorities for resources in the protection and post-disaster recovery of lifeline services, the economic implications must be understood and taken into account. It is of little use, for example, protecting or rapidly restoring services to purely residential areas while leaving industrial areas without adequately protected services. Residents are generally able to improvise for their requirements at home but are entirely dependent upon the continuation of their employers' facilities for their economic survival.

The City, as a whole, depends upon the success of its commercial activities for its continued viability, so there is a significant incentive to ensure that services to them are as robust as possible or that alternative means of supply are planned for.

Once assessed and determined, critical economic factors should be taken into account in the annual review of lifeline mitigation strategies and may impact upon currently established priorities. It would be expected that any future review of the lifelines project would adopt a methodology which incorporates economic issues.

It is expected that identifying key economic impacts will further encourage commercial enterprises to assess what planning they should engage in to ensure continuation of their business, even if primary utility services are lost. Strategies will vary from arrangements with businesses in other areas to meet their production requirements to having back-up services and suppliers arranged.

Planning Implications of Hazard Vulnerability

One of the issues which has repeatedly caused anguish in the recovery from emergency events has been the conflicting desires of the regulatory authorities to change planning criteria to avoid recurrence of hazard losses and those of the affected parties wishing to reinstate assets to pre-emergency locations and standards of construction. In Australia, following both Cyclone Tracey (Darwin) and the bush fires near Melbourne, local authorities encountered strong resistance to proposals to regulate for more hazard resistant planning and building requirements.

Early consideration needs to be given to known areas of significant hazard, for both the adequacy of current planning provisions and what special provisions may need to be in place to ensure appropriate re-development following any hazard impact. If these are widely known and explained, public resistance to them may be lower than that experienced in Australia.

Special planning provisions for areas of high hazard vulnerability may, in turn, influence the priorities given to the protection or re-instatement of elements of lifelines servicing such areas.

Planning measures are, in themselves, a mitigation tool which can prove very effective. An example of the level to which this has been used elsewhere is in the USA, where entire communities have been relocated away from flood plains.