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WATER SUPPLY AND EARTHQUAKES: DEVELOPING A MULTI-AGENCY APPROACH

David BRUNSDON[1] & John L MORRISON [2]

SUMMARY

Lifelines engineering projects and related activities over the past decade in New Zealand have prompted the improvement of earthquake resilience of water supply networks in the Wellington metropolitan area. The bulk water supply to the metropolitan area (population of approximately 360,000) crosses the Wellington fault in six locations over a distance of approximately 50km from three source locations.

The formation in February 2002 of a multi-agency planning group has sharpened the focus on the full range of mitigation and preparedness measures for these networks. This group comprises emergency managers as well as water supply managers from each of the five local authorities involved, along with health sector, fire service and research representation. A multi-agency five-year strategy and action plan has been developed to focus and co-ordinate the range of activities, which include public communications messages to raise the level of stored water in individual households, medical centres and other essential community facilities.

INTRODUCTION

The importance of an adequate and reliable water supply in sustaining modern communities is universally accepted. However the vulnerability of water supply networks to earthquake actions, particularly permanent ground deformation including fault rupture, is not so widely appreciated outside of the scientific and engineering arena.

The network supplying water to the Wellington metropolitan area features such vulnerability. Efforts to mitigate the effect of earthquake impact on both the bulk water system and local distribution networks (which are separately operated and administered) has focused on aspects such as the interconnection of zones, structural upgrading of reservoirs and addition of automatic shut-off valves, along with the progressive upgrade of brittle water mains. For some of the major fault crossings, attempts have been made to articulate and isolate adjacent sections of the bulk main.

[1] Kestrel Group Ltd, Wellington, New Zealand (db@kestrel.co.nz)
[2] Greater Wellington Water, Wellington, New Zealand (John.Morrison@gw.govt.nz)

Greater emphasis has recently been placed on response preparedness, with particular reference to the development of repair strategies and the distribution of emergency water supplies to meet community needs following a major earthquake.

This paper outlines the multi-agency emergency water supply strategy that has been developed for the Wellington Metropolitan Water Supply area (refer Fig 1), and backgrounds the aspects of the New Zealand Civil Defence Emergency Management Act that relate to lifeline utilities.

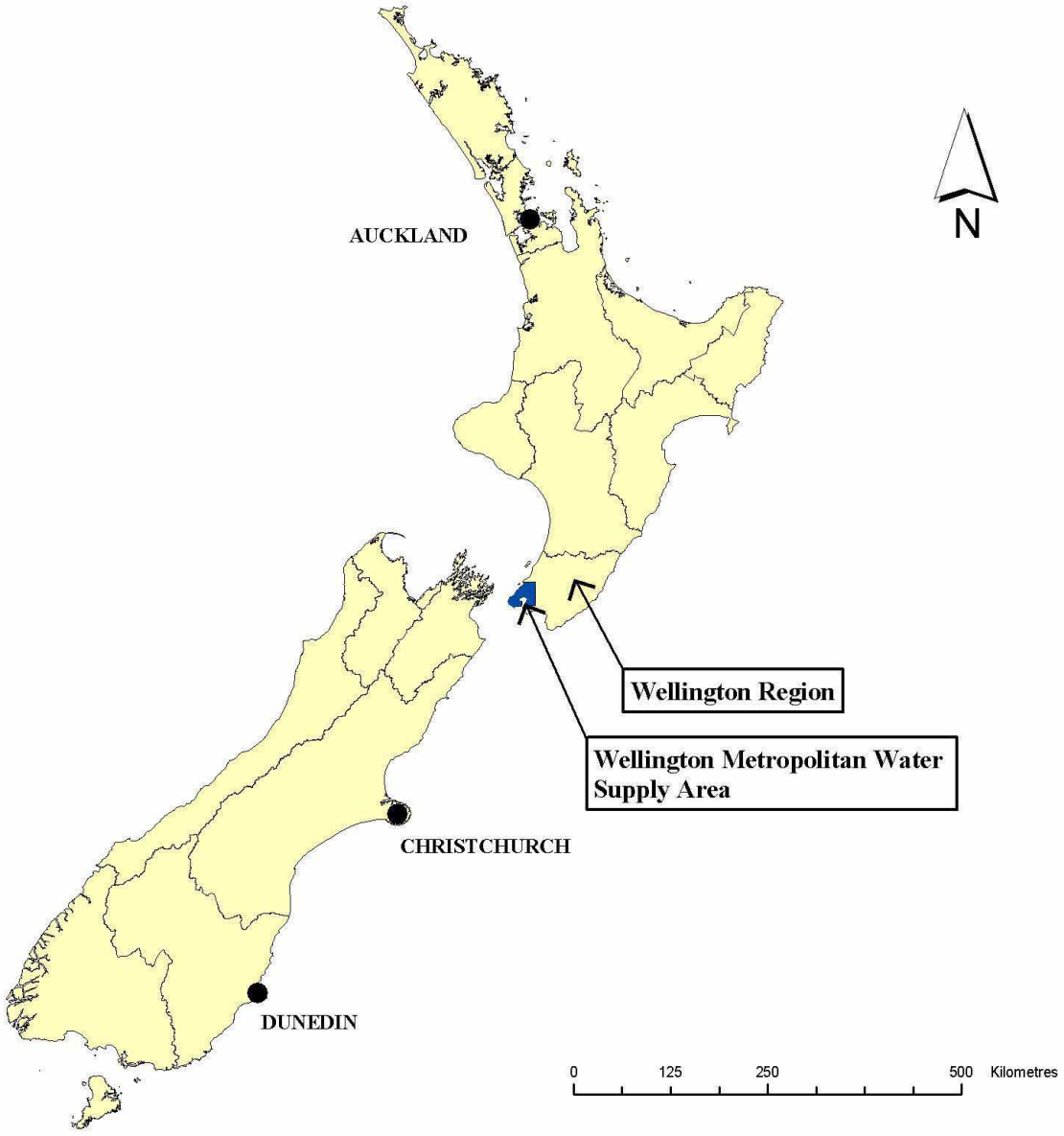

Fig 1: Map of New Zealand showing the Wellington Metropolitan Area and regional boundaries

LIFELINES ENGINEERING IN NEW ZEALAND

The focus of lifelines engineering work in New Zealand is on ***regional scale events*** that are beyond the ability of individual organisations to respond to and control. The responsibility however for taking appropriate mitigation and preparedness steps remains with the individual utility organisations. While Lifelines Engineering in New Zealand had its origins with earthquake, subsequent work has extended to address all hazards. Earthquake hazard has nevertheless been found to present the most significant hazard to utility systems in virtually all of the regions studied to date.

The regionally-based multi-disciplinary Lifelines engineering model has expanded to involve Lifelines Projects in each of the 16 regions of New Zealand (refer Fig 1). This model is based on the application of the principles of the international Risk Management Standard AS/NZS 4360: 1999 (SA & SNZ [1]) via a collaborative process. Through this process, the vulnerability of many of New Zealand's utility and transportation network operators has been reduced.

There has been a range of physical mitigation measures undertaken by the various utility sectors over the past decade (Brunsdon [2]). Typical water supply projects range from the seismic upgrading of individual elements such as reservoirs through to the creation of medium-term (10 to 20 year) mitigation programmes integrated with Asset Management plans. While some of this work was or would have been initiated by the respective individual utility asset management plans, the lifelines process has provided a sharper focus and often a greater sense of urgency in the 'toughening' of networks. The extent of physical work undertaken to date has however varied between organisations depending on the level of priority assigned by senior management.

The key to the success of Lifelines studies in New Zealand lies in its ability to portray the wider view of seismic risk. The main product of this work has been the generation of a much clearer picture of what the real situation is likely to be following a major earthquake. A balanced but informed scenario is a fundamental tool in seeking community involvement, and is a key linkage with other disciplines such as emergency management.

The New Zealand Lifelines engineering process represents a very effective regionally-based collaborative model which draws extensively on a combination of voluntary and time-in-kind input. These inputs come from hazards researchers, emergency managers, engineering consultants and planners in addition to utility asset managers. This process is viewed by other sectors as a model framework for integrating technical processes with community considerations.

CIVIL DEFENCE & EMERGENCY MANAGEMENT FRAMEWORK

One important factor influencing the growing activity in the Lifelines Engineering field in New Zealand is the recent passage of new Civil Defence Emergency Management (CDEM) legislation. This internationally unique legislation requires Lifeline utilities to become actively involved in regional and national emergency management planning, and to be able to ensure service continuity to the fullest possible extent following emergency events, including earthquake.

Under the CDEM Act [3], CDEM Groups will form across each region (refer Fig 1) to integrate and co-ordinate hazard risk management planning and emergency management activity. CDEM Groups are essentially a consortia of local authorities, emergency services, lifeline utilities and others delivering emergency management within regional boundaries.

The CDEM Act features the requirement for Lifeline utilities to actively engage with the emergency management sector in the development of regional and national plans. Implicit in this is the need for Lifeline utilities to give equal consideration to responding to and recovering from major emergencies as well as prior physical mitigation.

The Act defines lifeline utilities as key agencies, including airport authorities, port companies, gas production, supply and distribution companies, electricity generators and distributors, providers of networks for water and waste-water, telecommunications, rail and road, and producers or distributors of bulk petroleum energy products. The Act does not impose new business requirements or alter responsibility for risk, asset and emergency management. The emphasis is on providing continuity of operation, particularly where their service supports essential CDEM activity (e.g. a hospital).

The duties of Lifeline utilities under the Act have been interpreted within a set of Director's Guidelines (MCDEM [4]) and supplementary Best Practice Guide (National Lifelines Engineering Committee & MCDEM [5]) as expectations for lifeline utilities which include:

- Planning for and being able to implement procedures to ensure continuity of business and service to customers – making clear to utility managers that it is not an option to be unprepared. This includes understanding the full range of hazards that could impact an operation and considering external risks such as dependence on utilities from other sectors and outsourcing/contractor arrangements.
- Establishing planning and operational relationships with CDEM Groups (local government and emergency services – Police, Fire, Health) and other external agencies.
- Communicating and planning across their sector to optimise service during emergencies.

To meet the requirements of the Act, there will clearly need to be greater emphasis by lifeline utilities on and commitment to the key elements of earthquake preparedness across the 4Rs of *reduction*, *readiness*, *response* and *recovery*.

Traditional Civil Defence messages relating to emergency water have referred to the need to store 3 litres per person per day for 3 days at household level. This amount however only covers direct drinking water needs. Each person requires an additional 10 to 20 litres of water per day for personal hygiene requirements and food preparation. Understanding and communicating the implications of this requirement is fundamental to being able to meet the CDEM objective of maximising the continued habitation of people in their homes following a major earthquake.

THE WELLINGTON REGION

Seismicity and Surface Geology

There are a number of active faults present in the Wellington region, along with challenging surface geology which features areas of high susceptibility to associated permanent ground deformation due to fault rupture, liquefaction and landsliding (WELG [6]).

The greatest threat to water supply in this area comes from the Wellington fault, which runs from Cook Strait, through Wellington, the Hutt Valley and north to the Bay of Plenty. At approximately 420 km long, it is part of one of New Zealand's longest onshore faults. It has a probability of rupture of approximately 10% in 50 years, with a mean recurrence interval of 600 years. The time since last rupture for the Wellington segment is assessed as being 340 to 490 years. The physical ground movement associated

with this event is of the order of 5 metres of horizontal movement along the fault and up to 1 metre vertically.

Bulk Water Network

The Greater Wellington Regional Council is responsible for the collection, treatment and distribution of bulk water to Wellington, Hutt, Porirua and Upper Hutt cities. The respective city councils are responsible for distributing the water to the individual users.

The Greater Wellington Regional Council (Greater Wellington) is responsible for providing potable water to Wellington, Hutt, Upper Hutt and Porirua cities. Greater Wellington Water collects and treats bulk water and distributes it to major supply points within each city, from where the respective city councils distribute it to consumers.

Regional bulk water is sourced from three run of the river intakes in two surface water collection areas, two off river storage lakes and an artesian aquifer. There are four water treatment plants, 15 pumping stations and 180 kilometres of trunk pipelines. Costs are recovered by means of a levy on the four customer councils, allocated in proportion to each city's annual water consumption.

Greater Wellington Water supplies about 150 million litres of water on an average day, peaking to about 200 million litres in summer, to meet the demand of 360,000 people.

Figure 2 shows the layout of the bulk water network, and highlights that the bulk network crosses the Wellington fault in six locations over a distance of approximately 50km from three source locations. The level of damage to the water supply networks across the Wellington region resulting from a rupture of the Wellington fault has been assessed at NZ$48 million (Hopkins & Shephard [7]).

THE WELLINGTON METROPOLITAN EMERGENCY WATER SUPPLY PROJECT

Background & Establishment

During the 1990's, considerable 'toughening' of the metropolitan water supply networks was undertaken. This work was influenced by the Wellington Lifelines Project (CAE [8]), and observations made in relation to major overseas earthquakes during this period.

In 1994, the Wellington Lifelines Group undertook a project to promote improved response planning for the immediate response phase, using water supply as a case study (WELG [9]). The work that followed saw automatic shut-off valves installed at a number of key reservoirs across the region and an improvement in the short-term water storage at these reservoirs.

Discussions during 2001 between the territorial authorities involved highlighted that a potentially significant supply gap still remained in the event that repairs to the bulk water network in some locations took an extended period of time. Furthermore, the responsibilities and functions of the organisations and key individuals were not fully integrated. This applied to firstly the respective organisations involved in supplying water and secondly the water supply managers and emergency managers for responding to such a situation.

These concerns led to the establishment of the Wellington Metropolitan Emergency Water Supply Planning Group in February 2002. This informal group involves the water supply managers and emergency managers from each of the local authorities of the Wellington metropolitan area (Wellington City, Hutt City, Porirua City, Upper Hutt City and the Greater Wellington Regional Council, along with representation from public health agencies, the New Zealand Fire Service and the Institute of Geological and Nuclear Sciences. This group is co-ordinated by Greater Wellington Water, with the first author being the contracted project manager.

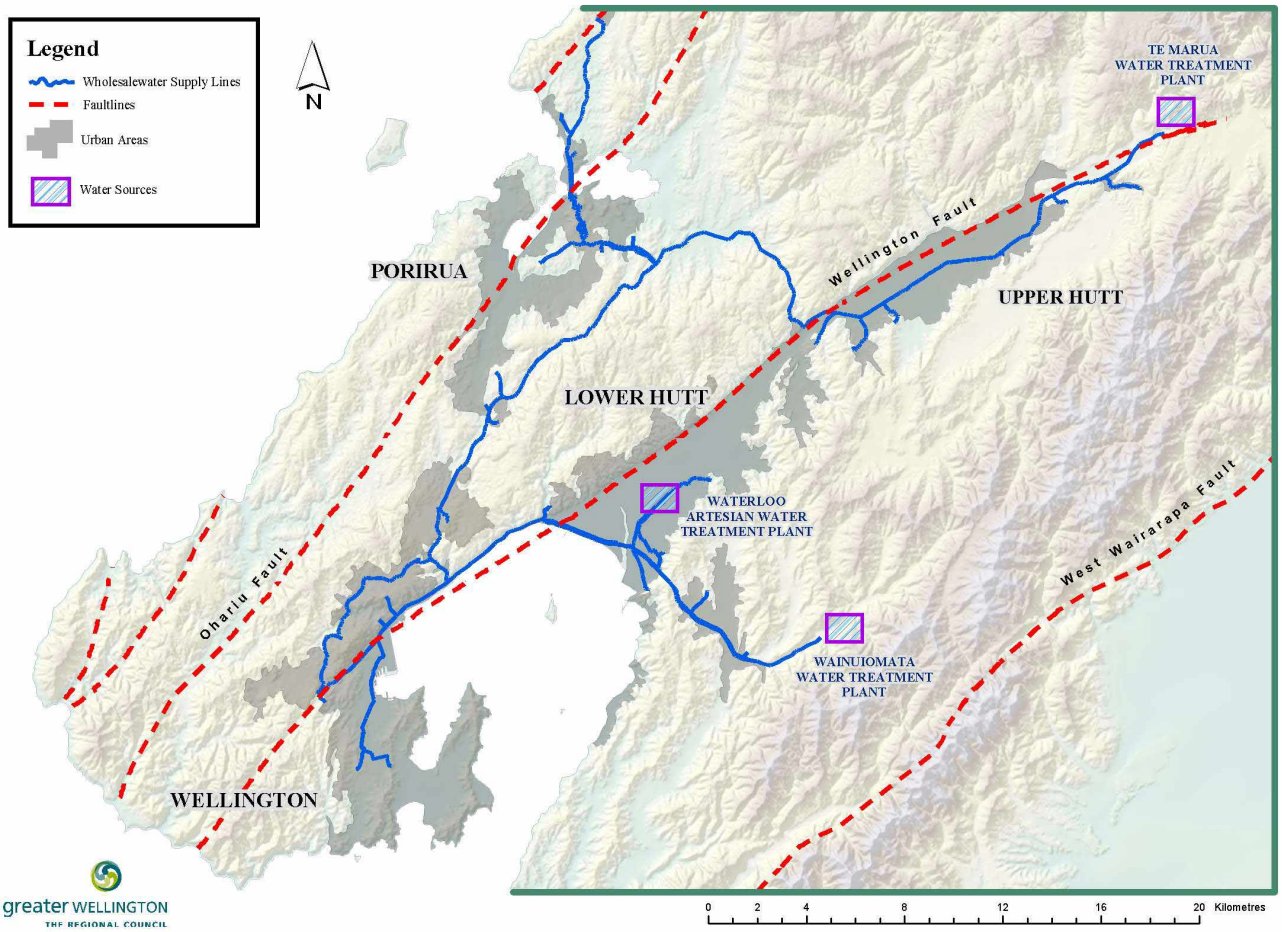

Fig 2: Map of Wellington Bulk Water Network showing key faults in the Wellington region

Objectives and Target Outcomes

The principal objective of the Planning Group is to establish an agreed approach to the mitigation and preparedness activities that are of common interest to the water supply asset managers and emergency managers of the five local authorities involved.

The wider target outcome that is sought is an increase in the level of preparedness activity by all sectors involved in the supply of water following a major emergency, and an increase in awareness of personal responsibility to be carried by end users.

The functional restoration of water supply to all households following the 1995 Kobe earthquake took 82 days, noting that full repairs extended well beyond this time period (Kameda [10]). Later analysis showed that 15 days was the critical time frame beyond which the public of Kobe became extremely impatient. Kobe City subsequently established restoration targets which aim at an average supply of 250 litres/ person/ day within four weeks of a major earthquake (Nojima [11]). This is considered to represent a very demanding target, and an impractical form of expression for the Wellington metropolitan area given the organisational separation of the bulk transmission and local distribution components.

The process of restoring mains water supply following a major earthquake involves in the first instance the availability of water in the network, and subsequently the progressive improvement of the quantity and quality of the water. These steps can be characterised in terms of the restoration of a *basic* supply and a *functional* supply, defined as follows:

- *Basic supply* – untreated water available through mains to individual consumers that will require boiling, and may be restricted in volume and subject to frequent disruption
- *Functional supply* – treated water available through mains to individual consumers with intermittent outages for local repairs, and some capacity constraints.

The underlying philosophy adopted for restoring water following a major earthquake can be summarised under the headings of short-term focus and medium-term focus as follows:

Short-term focus *(individual responsibility)*	• People use their own emergency water supplies • When these run out, they will need to go to community supply points
Medium-term focus *(water supply authorities)*	• Progressively re-livening the trunk mains and moving the community supply points down towards the centres of the affected populations • Restoration of a *basic supply* to individual consumers, followed by a *functional supply*

There are a number of planning implications for the local authorities and their communities arising from this philosophy. The general public needs to upgrade their household supplies to between 10 and 20 litres per person per day (ie. making allowance for hygiene requirements as well as basic potable needs) for at least three days. Indications from assessments made under this project are that a longer period of storage

is needed for residents of Wellington City due to their physical distance from the bulk water supply sources, older and more vulnerable mains and access difficulties.

Strategy

The Wellington Metropolitan Emergency Water Supply Planning Group has developed a strategy to reduce the 'gap' between emergency supplies and the restoration of bulk water. The key elements of this strategy (WMEWS [12]) can be grouped into the following areas:

- ***Reducing the duration of loss of bulk supply***
  - Continuing with mitigation programmes to reduce the physical vulnerability of the bulk water network
  - Developing specific repair strategies to address the access and resource challenges
- ***Improving the level and duration of effective local city water storage***
  - Raising the level of dependable local city storage by continuing the programmes of improving the seismic resistance of local reservoirs constructed prior to the mid-1980s
  - Developing effective plans for councils to distribute retained water in a controlled way, and over an extended period of time in some areas
  - Investigating alternative water sources and means of treatment and distribution
- ***Raising the level of household, key facility and workplace water storage***
  - by communicating the need for different sectors of the community to significantly increase the level of stored water

Action Plan

A programme of mitigation and preparedness activities corresponding to the strategy outlined above to be undertaken over the next 5 years has been developed by the Group [12]. This action plan involves individual and collective reduction and readiness activities necessary to achieve an effective response and recovery, as summarised below:

- ***Reduction***
  - Identify priority major asset mitigation measures and incorporate them into medium and long-term financial plans
  - Systematic incorporation of seismic considerations within asset renewal programmes
  - Review the settings/ triggers for automatic shut-off valves
  - Research on consequences and operational impacts
- ***Readiness***
  - Develop an integrated communications plan which addresses both pre-event and post-event messages to the community
  - Establish hierarchy of critical community supply points
  - Ensure appropriate national arrangements and mutual aid agreements are in place
  - Identify alternative water source options and develop plans for their use including minimum local treatment requirements.

- Upgrade water supply response plans, placing emphasis on local and regional water distribution arrangements, and specialist technical resources needed for initial assessment and repairs
- Hold exercises to test the preparedness and effectiveness of the councils' response

The objective of these activities is to achieve an effective ***response*** in which each organisation is clear on their roles with a minimum of overlap, particularly for the following key aspects:

- Reconnaissance and reporting locally and regionally
- Resource deployment
- Communication with each other, other sectors and the public

and to have a platform established from which the ***recovery*** can be managed efficiently.

A ***Public Communications Group*** has been established to progress *communications* issues, as these typically involve more than one organisation or sector.

Implementation and Monitoring

Implementation of the mitigation and preparedness strategy and action plan is the responsibility of each council working individually and collectively as appropriate. While the plan outlines the strategy and defines collective activities, the specific individual actions to be followed are to be determined and undertaken by each council.

The Wellington Metropolitan Emergency Water Supply Planning Group meets at approximately six-monthly intervals in order to provide an information exchange framework and to monitor overall progress.

CONCLUSIONS

The new Civil Defence Emergency Management Act for New Zealand requires that lifeline utilities place greater emphasis on and commitment to the key elements of earthquake preparedness across the 4Rs of *reduction*, *readiness*, *response* and *recovery*.

A project was established in February 2002 to improve existing response and recovery strategies for the delivery of water to end users following a major earthquake. The Wellington Metropolitan Emergency Water Supply Planning Group involves the water supply managers and emergency managers from each of the local authorities of the Wellington metropolitan area. The Group provides co-ordinated inputs from the water sector to the regional Civil Defence Emergency Management Group.

The unique feature of this group is the co-operative model that it operates under, using the collaborative interagency Lifelines Group model that has become established over the past decade in New Zealand. The specific work being undertaken involves the integration of core *asset*, *risk* and *emergency* management functions. While the activity elements themselves within each of these strands are regarded as being standard items, the integration of them both within and across organisational boundaries requires the strategic and innovative co-ordination approach outlined in this paper.

A strategy and corresponding programme of mitigation and preparedness activities to be undertaken over the next 5 years has been developed. The focus of the activities in this action plan is to improve the level of emergency water supplies available to key sectors of the community following a major earthquake. The

action plan supports the mitigation measures being undertaken by the councils as part of their asset management programmes.

The short-term priorities include ensuring key community facilities such as hospitals, local medical facilities and rest homes, schools and emergency operations centres have appropriate volumes of on-site stored water, and the establishment of new public education messages to emphasise "more stored water for longer" for households and workplaces.

References

1. Standards Australia and Standards New Zealand. “Risk Management” AS/ NZS 4360, Sydney and Wellington, 1999.
2. Brunsdon D R. “Lifeline Engineering in New Zealand: A Decade of Collaboration and Achievement.” Proc. Wellington Lifelines Group International Workshop, Wellington Regional Council, ISBN 0-909016-771, Wellington, New Zealand, 2001.
3. Civil Defence Emergency Management Act 2002 (obtainable at www.legislation.govt.nz), Wellington, New Zealand 2002.
4. Ministry of Civil Defence and Emergency Management. “Working Together: Lifeline Utilities and Emergency Management.” Director’s Guidelines DGL 3/02 www.civildefence.govt.nz Wellington, New Zealand, 2002.
5. National Lifelines Co-ordinating Committee & Ministry of Civil Defence and Emergency Management. “Lifeline Utilities and CDEM Planning.” Best Practice Guide (BPG 1/03), ISBN 0-478-25456-3 Wellington, New Zealand,2003.
6. Wellington Earthquake Lifelines Group. “1993 Report.” Wellington Regional Council, ISBN 0-909016-09-7, Wellington, New Zealand, 1993.
7. Hopkins D C & Shephard R B. “The Great Wellington Quake – Reconstruction Challenges.” Proceedings of Wellington Lifelines Group International Workshop, ISBN 0-909016-77-1, Wellington, New Zealand, 2001.
8. Centre for Advanced Engineering. “Lifelines in Earthquakes - Wellington Case Study.” Project Summary and Project Report, Centre for Advanced Engineering, University of Canterbury, Christchurch, New Zealand, 1991.
9. Wellington Earthquake Lifelines Group. “1994 Report.” Wellington Regional Council, ISBN 0-909016-22-4, Wellington, New Zealand, 1994.
10. Kameda H. “Engineering Management of Lifeline Systems Under Earthquake Risk.” Proc 12WCEE, Paper No. 2827, Auckland, New Zealand, 2000.
11. Nobuoto N. “Towards the New Era of Lifeline Earthquake Engineering.” Proceedings of Wellington Lifelines Group International Workshop, ISBN 0-909016-77-1, Wellington, New Zealand, 2001.
12. Wellington Metropolitan Emergency Water Supply Planning Group. “Mitigation and Preparedness Strategy and Action Plan.” www.gw.govt.nz Wellington, New Zealand, 2003.