LIFELINES IN EARTHQUAKES
A CASE STUDY BASED ON WELLINGTON

D. C. Hopkins[1], J. L. Lumsden[2], J. A. Norton[3]

ABSTRACT

This paper outlines the 1990 Centre for Advanced Engineering project which considered the vulnerability to earthquakes of all lifelines, including building services, in the Wellington region. A case study approach was used involving representatives from service companies, consultants, academics and technical specialists.

Five task groups considered various aspects of lifelines services, including definition of earthquake hazards in the region, descriptions of the services, analysis of vulnerability and identification of mitigation measures. Results of this work are outlined.

Specific conclusions were reached on recommended mitigation measures and, through wide involvement of service company engineers and managers in the project, further work is continuing in Wellington and the methodology is being adapted for use elsewhere.

1. INTRODUCTION

Lifelines, those services which support the day to day life of our communities, have become increasingly important in recent years as technological developments lead us to greater and greater dependency on them.

Wellington's lifelines were recognised as uniquely vulnerable in earthquake, but had received little attention. Not only is the city and region susceptible to earthquake shaking, it is crossed by several major active faults. In addition, being New Zealand's capital city it is the seat of government and the centre for much of the country's commercial activities. The region contains steep hills of solid rock as well as flat areas of weak soils. Water, gas, electricity and telecommunications traverse the region, crossing faults and areas of unstable soil. Road and rail transport lead only to the north, reducing the redundancy available from alternative access routes. The city's airport is sited on an area subject to uplift and the harbour mouth is constricted. Large areas have been reclaimed for commercial development of the city and the port.

Thus within a small area most, if not all, factors affecting lifelines in earthquake are present in a city and region of manageable size. The aerial view of the Wellington region shown in Figure 1, with the Wellington Fault clearly visible, highlights the vulnerability of the city.

The Centre for Advanced Engineering at the University of Canterbury initiated the idea of reviewing Wellington's lifelines and provided significant funding for implementation of the project which was carried out between late 1989 and early 1991.

General objectives of the project were to:
- assess the vulnerability of lifelines
- identify mitigation measures
- raise awareness of the importance of lifelines amongst service providers in both Wellington and elsewhere in New Zealand

2. SCOPE

All major lifelines were considered:
- Water
- Sanitary Drainage
- Stormwater Drainage
- Gas
- Electricity
- Telecommunications
- Transportation (road, rail, sea and air)
- Building Services

While most attention has been paid to regional and major city distribution networks, critical aspects of local networks were also considered in some cases. Two important restrictions on the scope of the project were vital in keeping work to manageable and comprehensible limits:
- The specific aspects of Wellington's lifelines were addressed with no attempt to generalise or draw parallels.
- The focus was on vulnerability assessment and engineering mitigation measures, as distinct from issues of general preparedness and response planning.

1 *Principal, Kingston Morrison, Limited, Wellington (Fellow).*
2 *Projects Director, Centre for Advanced Engineering, University of Canterbury.*
3 *General Manager Works, Lower Hutt City Council (Member).*

3. APPROACH

A unique and important feature of the project was the wide involvement of engineers and managers in key positions with the local authorities and service companies. This proved invaluable in meeting all three major objectives, particularly the raising of awareness, with the prospect of practical implementation.

A Steering Committee consisting of CAE representatives, consulting engineers, university staff and service company personnel, provided overall guidance and direction. This committee was also responsible for fundraising and publicity.

Key personnel in the technical direction were project director David Hopkins, project manager John Norton and CAE Projects Director John Lumsden. Refer Figure 2.

The work on the project was spread among five task groups co-ordinated and managed by the project manager reporting to the project director. The task groups were:

- Geology and Geomechanics
- Civil Services and Gas
- Electrical and Telecommunication Services
- Transportation
- Building Services

4. SEISMIC HAZARDS IN THE WELLINGTON REGION

The Task Group on Geology and Geomechanics comprised leading authorities on geology, geotechnical aspects, seismology and engineering seismology, with special emphasis on the Wellington region. They brought together all existing information and after some debate settled on the two earthquake types against which assessments were made.

The Maximum Credible Event, or Wellington Fault Event, which caused displacement along the Wellington Fault and local peak ground accelerations of 0.9g. The probability of such an event is about 10% in the next 50 years.

The Design Level Event, or Moderate Regional Event, was a regional earthquake, with an undefined epicentre but which gave a peak horizontal acceleration in bedrock of 0.3g.

Figure 1: Wellington City and Adjacent Region

Briefly the group's work consisted of:

- Preparation of a geological map of the region with emphasis on seismic hazards such as active faults, low strength sediments, unstable slopes and reclamations.
- Description and analysis of the geological setting.
- Reviewing records of past earthquakes, the characteristics of ground shaking, attenuation models for various deep and shallow earthquakes, nature of ground surface deformation and tsunami effects.
- A commentary on likely effects of the two earthquakes on various sections of the lifeline routes.

Principal considerations were:

- A worst case scenario giving movement of 4 metres horizontally and one metre vertically on the Wellington fault, which passes through the cities of Wellington and Lower Hutt.
- Extensive areas of potentially liquefiable soils adjacent to the harbour at Petone and Seaview, in parts of the airport and elsewhere.
- Steep unstable slopes along the line of the Wellington Fault and around the waterfront.
- The existence of large areas of reclamation of varying quality, especially in Wellington City and at the port's container terminal.

Figure 3 is a map of potential earthquake hazards. Likely impacts for the Wellington Fault earthquake and for the lesser regional earthquake are tabulated. Ground acceleration contours for the fault earthquake are plotted as an envelope of effects compiled by considering the fault movement at sections along the fault.

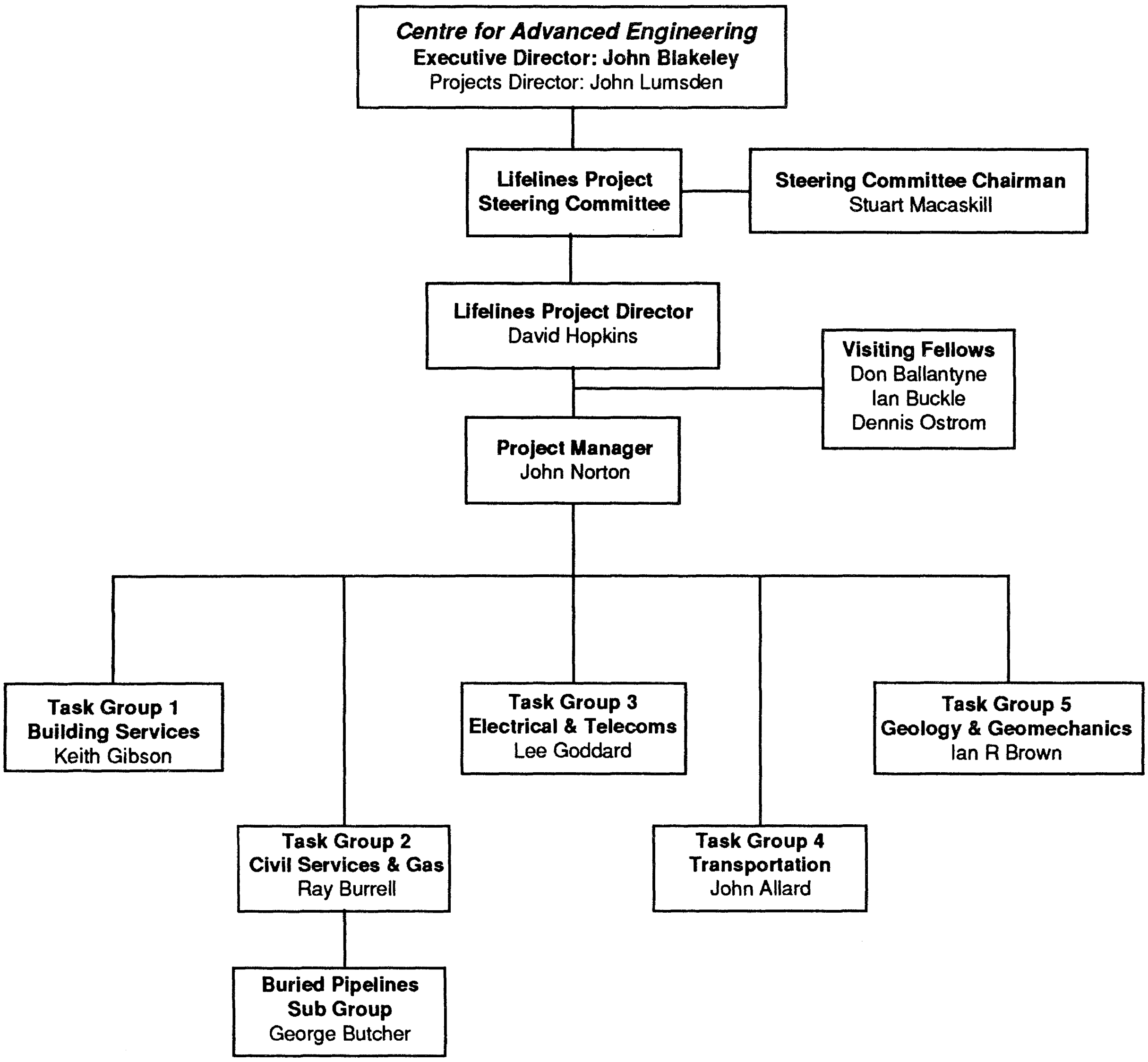
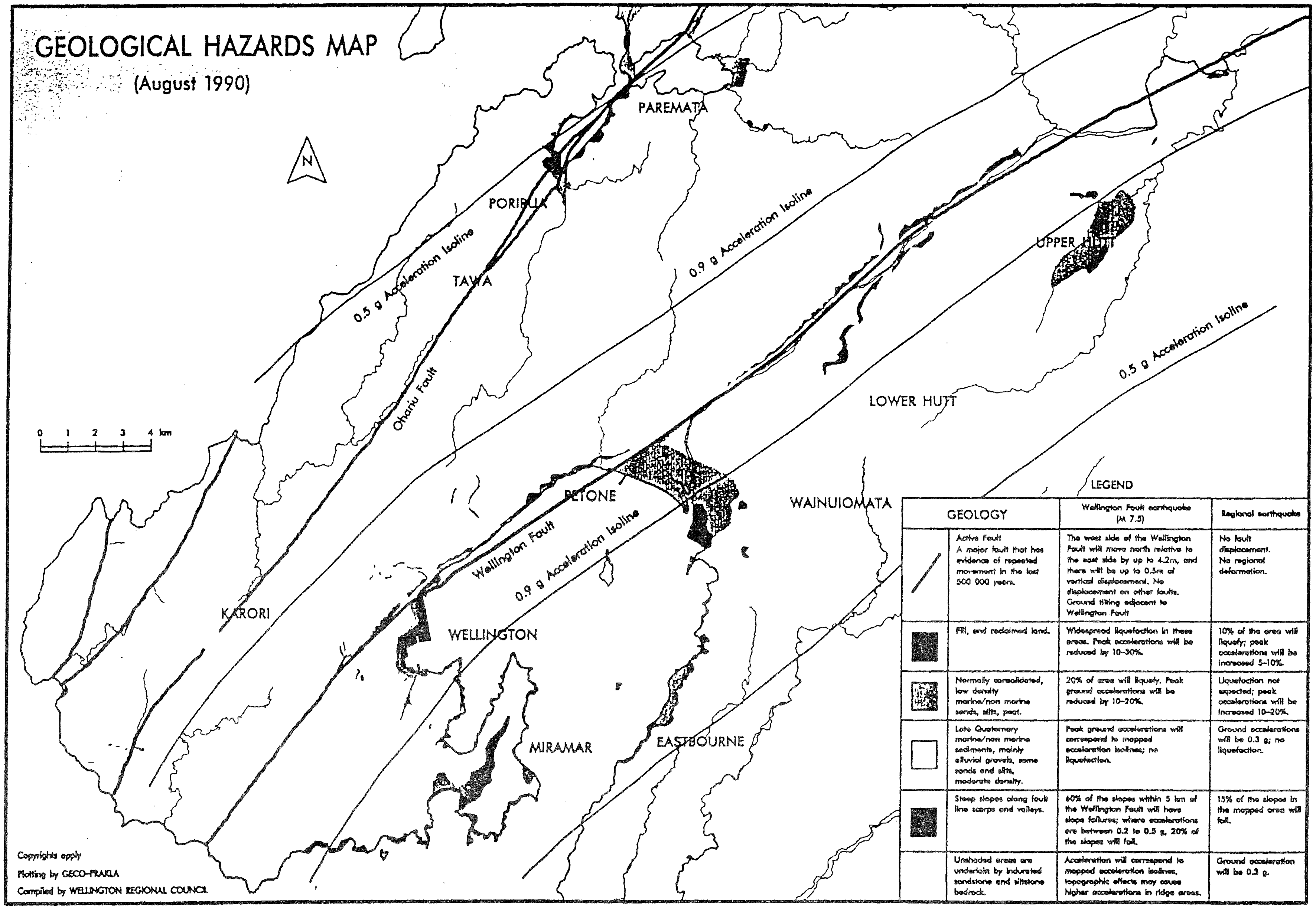


Figure 2: CAE Lifelines Project Organisation Chart



GEOLOGY		Wellington Fault earthquake (M 7.5)	Regional earthquake
	Active Fault A major fault that has evidence of repeated movement in the last 500 000 years.	The west side of the Wellington Fault will move north relative to the east side by up to 4.2m, and there will be up to 0.5m of vertical displacement. No displacement on other faults. Ground tilting adjacent to Wellington Fault	No fault displacement. No regional deformation.
	Fill, and reclaimed land.	Widespread liquefaction in these areas. Peak accelerations will be reduced by 10–30%.	10% of the area will liquefy; peak accelerations will be increased 5–10%.
	Normally consolidated, low density marine/non marine sands, silts, peat.	20% of area will liquefy. Peak ground accelerations will be reduced by 10–20%.	Liquefaction not expected; peak accelerations will be increased 10–20%.
	Late Quaternary marine/non marine sediments, mainly alluvial gravels, some sands and silts, moderate density.	Peak ground accelerations will correspond to mapped acceleration isolines; no liquefaction.	Ground accelerations will be 0.3 g; no liquefaction.
	Steep slopes along fault line scarps and valleys.	60% of the slopes within 5 km of the Wellington Fault will have slope failures; where accelerations are between 0.2 to 0.5 g, 20% of the slopes will fail.	15% of the slopes in the mapped area will fail.
	Unshaded areas are underlain by indurated sandstone and siltstone bedrock.	Acceleration will correspond to mapped acceleration isolines, topographic effects may cause higher accelerations in ridge areas.	Ground acceleration will be 0.3 g.

Figure 3: Lifelines Project Hazards Map

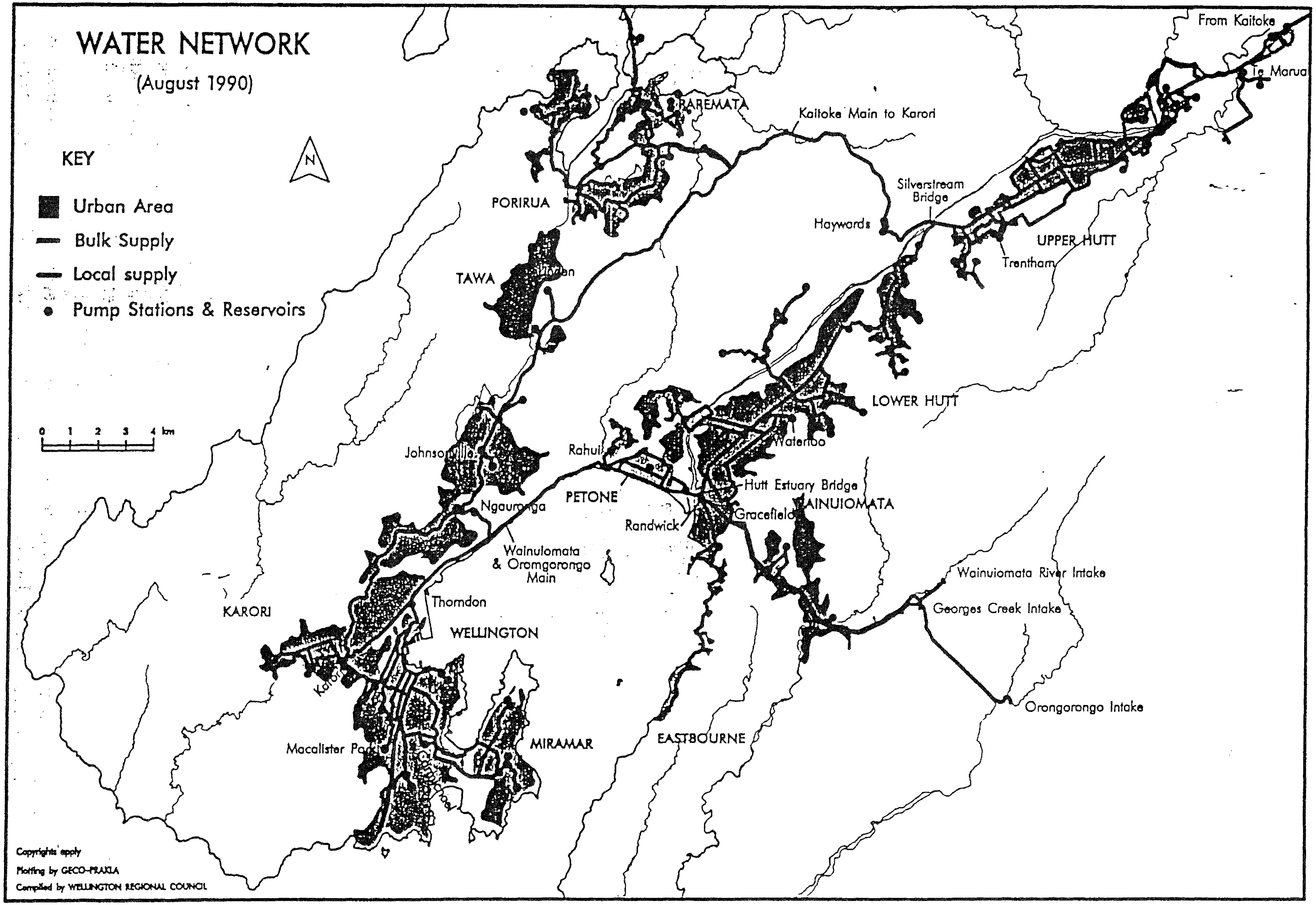


Figure 4: *Water Network*

This map and accompanying commentaries were used by the Task Groups to assess the vulnerability of each lifeline network.

A physical description of each network was compiled from which each was divided into components for assessment of vulnerability. Components needed to reflect elements of common importance and common susceptibility to damage. Some components were discrete elements - e.g., a reservoir, a substation, a river crossing, while others were sections of network between discrete elements. The choice of elements was important to define the nature and logic of the network. In the study a relatively coarse set of elements was used to keep the size of the exercise manageable. In critical areas a finer set could be assessed for more detail - e.g., subcomponents of a substation, junction segments of a section of pipe network or change in pipe size. The components were tabulated on to the vulnerability charts.

Each network was overlaid on the geological hazard map and each component was assessed for its susceptibility to damage from the given earthquake event. Hazards considered were:

- fault movement
- ground shaking
- soil liquefaction
- landslide
- ground uplift or submergence
- ground settlement
- tsunami and seiche

5. LIFELINES DESCRIPTIONS

5.1 Water Supply

As an example of the network map prepared for each lifeline, the water network is shown in Figure 4. There are four sources of water supply for the region:

Kaitoke - The Kaitoke source from the Hutt River to the north of the region (50% of the region's supply). Major earth-constructed reservoirs, concrete flumes, two tunnels, a 900mm diameter steel main, three pumping stations and 19 service reservoirs are involved in water storage and reticulation, much of which is close to the Wellington Fault. The main reservoirs at Te Marua contain 30 days supply.

Wainuiomata - Wainuiomata River (15%) to the east of the region. 750mm cast iron and 1100mm steel pipes take water to Wellington City via a tunnel through the Wainuiomata Hill and the Petone foreshore. Generally it is gravity fed, but pumping stations are involved in providing alternative supplies and interconnection to the Hutt Valley artesian system. There is no primary storage.

Orongorongo River - Orongorongo River to the east of the region (10%). This follows a similar route to Wainuiomata and is gravity fed. There is no primary storage.

Hutt Valley - Hutt Valley Artesian, centrally located (25%). A major pumping station services reservoirs on the surrounding hills.

To service district and local networks, supply is taken from the service reservoirs by the local authorities for distribution and reticulation to consumers.

Service reservoirs are generally dome-roofed reinforced concrete or prestressed concrete structures of around 1 million litres capacity. While some are recently constructed, most are about 30 years old, with a few in Wellington city up to 80 years old. Typically they hold a day's local supply and take about 15 hours to fill from empty.

Each authority is responsible for its own network, the form of which varies from authority to authority.

5.2 Sewage Disposal

Several district systems manage the collection, treatment and disposal of sewage in the region. The district systems are centred on the Hutt Valley, Wainuiomata, Porirua and Wellington. Each system is independent and managed and operated by the appropriate local authority.

Hutt Valley - The Hutt Valley system serves the cities of Upper Hutt and Lower Hutt and comprises local collection networks, a main trunk collection network, a central milliscreen treatment plant and a main pressure line to a shoreline ocean outfall. Pipes are generally reinforced concrete.

The system includes 21 pumping stations dating from the 1920s to the 1970s, none of which have standby power supply. Monitoring and control of the system is from the main pumping station and milliscreen plant at Seaview, with many stations connected by telemetry.

Wainuiomata - The Wainuiomata system consists of four pumping stations connected with asbestos cement mains terminating at a treatment plant. Construction dates from 1957 to 1977.

Porirua - The principal district mains in Porirua comprise tunnels of in-situ concrete, rising mains of concrete-lined steel (1972) and ductile iron (1989).

Rising mains from Tawa and Porirua East of reinforced concrete (1956 to 1979) are joined in the Porirua centre by rising mains from Pukerua Bay/Plimmerton/Paremata of asbestos cement rubber ring-jointed pipe (1965 to 1982). Pumping stations which serve the rising mains, date from the same period.

Disposal is by treatment at a new (1989) plant at Titahi Bay.

Wellington City - The Wellington City sewage system is centred on a main gravity interceptor line which runs from Ngauranga in the north, through the western side of the central city to a short coastal outfall at Moa Point. For the most part it is a single line. Generally, the interceptor is fed by gravity lines from the western side and by rising main and pump stations from the eastern side, including the central city area. Parts of it date from 1890 and are brick-lined while other parts from the 1930s and the

1970s are concrete-lined. There are short sections of trenched pipe, and one line is trenched cast in-situ concrete with a slab top. There is an aqueduct across the Ngaio Gorge.

A newly constructed pumping station and milliscreening plant near Moa Point discharges into a short outfall at this point.

The local network comprises many rising mains, some of cast iron with lead joints, tunnels of in-situ concrete and trunk mains of earthenware mortar-jointed pipes, reinforced concrete with rubber ring joints and some asbestos cement.

Numerous pumping stations dating from the 1950s onwards serve the rising mains and are dependent on mains electricity supply - there are no backup power systems.

5.3 Stormwater Disposal

In the Hutt Valley, various culverts and pipelines of rubber ring-jointed reinforced concrete collect runoff from local areas for discharge into the Hutt River, which provides the central disposal system.

In the Porirua area, the Kenepuru, Porirua and other streams provide the collection system for discharge into the inner Porirua Harbour. Connecting pipe systems are of reinforced concrete with rubber ring joints.

In the Wellington city area, brick culverts dating from 1880 onwards and some in-situ concrete tunnels comprise the main trunk system. The Horokiwi, Ngauranga, Ngaio and other streams discharge into the harbour through culverts under the Hutt Road.

5.4 Gas

Gas is supplied into the Wellington region by the Natural Gas Corporation to two local supply authorities - the Wellington Gas Company for Wellington and Energy Direct for the Hutt Valley and Porirua.

The Natural Gas Corporation has two separate welded steel lines entering the study area from the north through a major control gate on the inland Paekakariki Hill Road, which is fed from the Kapiti coast.

The western line feeds through a control gate at Pauatahanui through Waitangirua to the Tawa city gate for the Wellington Gas Company supply. The eastern line feeds to the Belmont Hill control gate and has a cross connection to the control gate at Waitangirua. Energy Direct takes supply from Belmont and Waitangirua. Both lines are welded steel pipe. The western line is 20 years old and the eastern line is approximately 10 years old.

5.5 Electricity Supply

The electrical distribution system comprises a regional supply from the national grid to two district distribution networks. The supply is through the Trans Power New Zealand Limited national grid network, which feeds the Supply Authority networks operated by MED Capital Power and the Energy Direct. Electricity comes from the south via a 500kV DC link to the South Island and from the north via 220kV and 110kV lines.

The main Trans Power distribution station in the region is the Haywards Distribution Station, which is connected to Bunnythorpe to the north, and to Benmore in the South Island. Haywards is the major interconnection point for the 220kV, 110kV and HVDC systems and distributes power to Bunnythorpe and the local Trans Power stations at 110kV AC for on-supplying to the Supply Authorities.

The second major Trans Power station in the region is Wilton, which is connected by one 220kV AC circuit to Bunnythorpe and one 220kV circuit to Haywards. Wilton interconnects the 220kV and 110kV systems and is the major station supplying the Wellington City area via the Central Park substation.

There are no generating facilities in the region.

5.6 Telecommunications

Public telecommunication services in the Wellington Metropolitan Area are provided by Telecom Corporation of NZ Limited. The telephone service is provided by a network of telephone exchanges at twenty-seven sites in the Wellington area. These exchanges are grouped into four geographical areas, each served by a major tandem exchange. Tandem exchanges are located at Wellington Central, Courtenay Place, Lower Hutt and Porirua.

The majority of junction (circuit) routes in the Wellington area are provided using Fibre Optic Transmission Systems (FOTS). The fibre optic cables are drawn into PVC ducts and terminal equipment is located at each exchange to serve the junctions required.

The tandem exchanges at Wellington Central and Courtenay Place are interfaced with the Toll Network, providing access to the rest of New Zealand and overseas via the International Exchange in Auckland. Major trunk routes from Wellington use either microwave radio or fibre optic systems.

In general, the junction network is structured to provide alternative routing of traffic should failure of exchanges, trunk or junction routes, occur. Although some exceptions still exist in the network, these are progressively being eliminated.

The mobile radio network provides facilities for communication between fixed sites and portable radio equipment, which can either be mounted in vehicles or hand held. It does not normally provide access to or from the public telephone network.

The cellular radio network provides facilities for communication between the public telephone network and the portable telephones, or between portable telephones. Radio equipment, comprising both transmitters and receivers, is provided for the cellular radio service at five sites in the Wellington region.

5.7 Broadcasting Network

Broadcast radio facilities in the Wellington region are provided by State and private organisations, originating from studios in Wellington city. Radio transmitter sites are located about the Wellington metropolitan area as dictated by technical considerations.

Television facilities are also concentrated in the Wellington area, with local and national studio facilities provided. Transmitter sites are distributed about the area and some are common to radio, with microwave network links to other parts of the country sharing some common facilities.

Radio New Zealand and private radio rely on the transmitter at Mt Kau Kau and on Telecom circuits. Programme feed for some FM stations is by UHF radio link. One of the AM stations, RNZ's 2ZB, is designated as the primary local region broadcast information station for Civil Defence. All studios and transmitters are equipped with standby power generators.

The primary television transmission facility in the Wellington region is located at Mt Kau Kau, with major television production studios located at Avalon in the Hutt Valley.

A high-power transmitter facility on Mt Kau Kau uses a 122-metre steel tower and concrete transmitter equipment building equipped with standby power. Some sixty low power repeater transmitters, which obtain their programme feed from the main signal transmitted from Mt Kau Kau, are located about the region . No standby power facilities are provided at these repeater sites.

There are presently three national television networks broadcasting in the region, all transmitting from the facility at Mt Kau Kau. Programme feeds for all three networks normally originate from Auckland. The national network Transmission Control Centre is located at Avalon, where national network communications are supervised. A national news production facility is located in Wellington City.

Programme links to Mt Kau Kau from Auckland are via macro-high microwave linking station, as are links to Avalon, to the city news production facility and to the South Island.

5.8 Transportation Systems

Roading - Two major highways, State Highways 1 and 2 provide roading access into the region from the north and the north-east. These highways join at Ngauranga to form the motorway leading to Wellington City. State Highway 1 provides the principal access to and from the central North Island and enters the region from the north-west coast. State Highway 2 provides access to and from the Wairarapa region, 70kms to the north-east across the Rimutaka Ranges.

Railway - The railway system serving Wellington comprises two major lines and two minor lines. The North Island Main Trunk Line enters Wellington down the west coast serving the major freight flows (including those to the inter-island ferries), the minor inter-city passenger flows and the busy commuter services, which run as far north as Paraparaumu some 48kms north of Wellington. The second main line runs from Wellington north-east through the Hutt Valley into the adjoining Wairarapa sub-region, and from there links to the remainder of the system at Palmerston North. The line now carries only very local freight but is heavily used by commuter traffic in the Hutt Valley. Minor passenger flows from the Wairarapa to Wellington occur in the morning and evening peak periods.

The North Island Main Trunk Line runs over reclaimed shore platforms, along an embankment close to Porirua Harbour, over Paremata Bridge and across the fault at this location. The line also runs in tunnels at the foot of an unstable cliff south of Paekakariki, over swampy land south of Paraparaumu and over major river bridges at Waikanae and Otaki.

The Wairarapa line follows the Wellington Fault adjacent to the harbour at the foot of a steep fault scarp. At Petone it is crossed by a concrete road overbridge, and it crosses both the Wellington Fault and the Hutt River three times in passing through the Hutt Valley. Through the Wairarapa region the line crosses five major river bridges.

Wellington railyards are on reclaimed land astride the Wellington Fault.

Sea Transport - The Port of Wellington forms a major link in the movement of cargo through the country and to and from the adjacent region. The port provides inter-island freight with regular services to two South Island ports and has direct links with overseas lines. Facilities include a two-berth container terminal operating with three container cranes and a back-up area of 24 hectares. Road and rail transfer is available within this area and there are several berths immediately adjacent for conventional cargoes at Aotea Quay and Glasgow Wharf, many with access to wharf cranes and to wharf sheds within the port security area. Much of this port infrastructure is on reclaimed land.

A roll-on passenger and freight ferry service operates to the South Island with up to six sailings daily. The berth lies directly on the Wellington Fault Line.

The major bulk liquid terminal is located at Seaview Oil Terminal Wharf at Point Howard. It has an associated major storage tank farm adjacent.

Air Transport - The Airport lies towards the eastern end of the Wellington Peninsula on land formed when the seabed rose in previous earthquakes. The airport is the hub of the New Zealand system with the second largest number of movements in Australasia, second only to Sydney. International flights are confined to trans Tasman with the largest aircraft normally used being the Boeing 767.

5.9 Building Services

Building Services may be regarded as the end users of major lifeline supplies. They vary in quality and extent as much as buildings themselves.

Buildings were categorised into commercial, industrial and public buildings, and electrical; heating, ventilating and air conditioning (HVAC); plumbing; fire protection; vertical transportation; security; communications and processes services were examined.

A starting point was a review of the rate at which major lifelines could be restored following the scenario earthquake events.

Commercial buildings were split into three subcategories: high, medium and low quality, where quality essentially refers to the likely performance of its building and its services in earthquake, and takes account of initial specification, maintenance, the function and its position in the market.

Likewise **industrial** buildings were categorised according to function: petrochemical, warehousing, construction industry, heavy engineering, light engineering, chemical/pharmaceutical, food processing, automotive repair, light manufacturing, high technology manufacturing and research facilities.

Public buildings were split into two broad categories:
- government, transport and emergency buildings
- hospitals

By splitting the building stock into these categories, it was possible to make general assessments of the vulnerability and performance of building services in the chosen earthquakes.

Analysis of each service was made to assess dependence upon lifelines on the one hand, and ability to recover to receive services on the other.

6. VULNERABILITY HIGHLIGHTS

Having described the services in the Wellington region that form the various Lifelines and assessed the seismic hazards, it became possible to readily identify the vulnerable sections of each service. During this process the vulnerabilities were prioritised.

Note: Statements refer to the Wellington Fault Event unless otherwise stated.

6.1 Water Supply

- Te Marua Lakes are located near the fault, but are designed for the effects of fault movement.
- The Wellington fault runs between Te Marua Lakes and the treatment plant, intersecting the main supply pipes.
- Major pipes cross old bridges that are located on or near the fault.
- The main from Te Marua is vulnerable in other places where it crosses the fault, and to landslips.
- Paremata Bridge which carries the main is vulnerable to liquefaction and ground settlement.
- The Wainuiomata main is subject to liquefaction along the Petone foreshore, and to settlement of the Hutt Estuary Bridge.
- The Karori Reservoir is on the Wellington Fault.
- The Wainuiomata-to-Thorndon pipeline would be broken by movement of the Wellington fault.
- Junctions between original and reclaimed land pose a threat to water pipes and other buried services.

6.2 Sewage Disposal

- Pumping stations have no back-up power supply.
- The Ngaio Gorge aqueduct is likely to fail in strong shaking.
- The main interceptor drain adjacent to the hospital is in an area subject to liquefaction. It is 6 metres deep and would take two months to repair.
- Overflows discharge into the stormwater system which if functional would discharge sewage into Wellington Harbour. If not, contamination of streets and basements would occur.

6.3 Stormwater Disposal

- Older drains particularly brick culverts in potentially liquefiable soils are at risk. Failure will result in serious flooding and subsidence of buildings.
- The Horokiwi, Ngauranga and Ngaio streams are vulnerable to landslide which could result in disruption of main road links.

6.4 Gas

- The main supply line to both Wellington City and Lower Hutt crosses the Wellington Fault.
- The supply line to Wainuiomata crosses the Hutt River estuary bridge and passes through potentially liquefiable areas in Seaview.
- Tsunami could affect lines in low lying areas.
- The cast iron/lead jointed system south of Wellington CBD and around the waterfront will be badly affected by ground shaking.

6.5 Electricity

- A complete loss of power to Wellington City would most likely occur.
- Transformers are susceptible to toppling.
- Spare cables and parts are not adequately supplied
- Damage in principal older substations will be up to 100% in the Wellington Fault Event.
- Repairs to the system would take over one year to complete.
- Concentration of substations at Haywards, close to the Wellington fault increases the vulnerability of the network.
- The Wellington Fault earthquake would cause extensive disruption to major equipment and buildings.
- 33kV lines serving the city cross the Wellington Fault, mounted on the Molesworth Street Bridge.
- Between 50% and 75% of MED Capital Power's network would sustain damage in the Wellington Fault Event.
- Up to 90% of the Energy Direct system would be affected in the Wellington Fault Event.

6.6 Telecommunications and Broadcasting

- The Moderate Regional Event would cause interruption of service for several days at the most.
- Many cables cross the Wellington Fault, some on vulnerable bridges.
- Equipment and buildings at exchange sites are critical. (Sites are currently being reviewed in detail).
- Broadcast transmitters and aerials are subject to failure.
- Broadcasting House, a focal point of the Radio New Zealand system, is located close to the Wellington Fault.
- Resumption of normal services after a Wellington Fault Event would take several months.
- There would be loss of power and structural damage to the Mt Kau Kau transmitter, the Transmission Control Centre at Avalon ad the Makara Microwave Station.

6.7 Transportation

- The common section of State Highways 1 and 2, immediately north of Wellington City is likely to be closed by landslips, ground displacement and possibly flooding.
- All routes from Wellington to the rest of the North Island would be closed.
- Fault movement, liquefaction and landslips would render railways inoperative, and railyards would suffer extensive damage.
- The Port of Wellington would be severely affected with the Wellington Fault passing through the ferry terminal. Reclaimed areas would settle causing building and crane damage.
- Significant parts of the airport runway are prone to liquefaction.
- Thorndon, where road, rail and ferry traffic meet, is a particularly vulnerable area, being partly reclaimed land, and sited on the Wellington Fault.

6.8 Building Services

- Building Services have a heavy dependence on external services from lifelines, particularly electricity and water.
- Equipment is particularly vulnerable to shaking, and a significant amount is inadequately secured. Mitigation measures would be cost-effective.
- Fuel supplies for standby power are important.

7. INTERDEPENDENCE OF LIFELINES

Some original analysis of the interdependence of each lifeline upon the others was made. Assessments of interdependence were made for:

- the first week after the earthquake
- the first month after the earthquake

Table 1 shows assessed times to recover for each lifeline, made independently.

Table 2 shows the analysis of interdependence for the first week after the earthquake. Adding across gives a measure of importance, adding down gives a measure of dependency. The overall priority for attention can be gauged from the interdependence quotient.

The analysis highlighted the fundamental importance of roading, equipment (of all kinds), standby power, fuel supply and telecommunications, together with the high dependency of building services, air transport and broadcasting on other lifelines.

The methodologies developed to derive estimates of importance, dependency and rate of recovery can be applied to lifelines in other cities.

The analysis of interdependence is a new concept and the work done on the project is believed to be the first of its kind. It proved to be a most important technique for developing an understanding of the likely effects of earthquake. Many service providers were able to analyse their own vulnerability and assess consequences, but when the implications of the effects on others, on which they depended, were analysed and discussed, new and important factors came to light. For example, the dependency of radio and telecommunications remote sites on access roads to supply diesel to standby power generators. As a result, the need to increase the capacity of holding tanks was identified. A small but vital item, but it is not difficult to imagine similar situations.

The analyses made during the project were invaluable for the cross communication required. The actual numbers obtained should be interpreted in a general way only, with particular emphasis on relative importance.

The recently formed Wellington Earthquake Lifelines Group has set up a Task Group to further develop the assessment and application of interdependence analyses of lifelines. This should result in a more in-depth understanding of the subject that can be used to identify applications in risk assessments, in formulating response plans, and in compiling proposals for mitigation measures.

8. MITIGATION MEASURES

Mitigation measures have been identified in outline only. Resources did not permit close examination of detailed and comprehensive measures. Rather, the value of this project has been to raise the awareness of all service providers and to highlight those parts of their services that are most at risk from seismic hazards. Most are planning to or are carrying out more detailed reviews under their own management.

Some of the specific mitigation measures recommended were:

- Provide standby power plant at pumping stations as a matter of urgency.
- Installation of tie bolt couplings on the water main where it crosses the Wellington Fault.
- Installation of isolation valves.
- Review of alternative sources of water.
- Decommissioning of Karori's reservoir.
- Pinpointing of likely trouble spots in gas lines. Isolation and ready response is planned.
- Bracing of zone transformers and older models of switchgear.

Table 1: Recovery of Service - A Preliminary Assessment of Time to Recover Following a Major Event (Wellington Fault)

THESE ARE DEPENDENT ← ON THESE ↓	Water Supply	Gas Supply	Sanitary Drainage	Storm Drainage	Mains Electricity	Standby Electricity	VHF Radio	Telephone Systems	Roading	Railways	Sea Transport	Air Transport	Broadcasting	Fuel Supply	Fire Fighting	Building Services	Total Importance
Water Supply		•	1	•	•	•	•	•	•	•	•	•	•	•	3	3	7
Gas Supply	•		•	•	•	•	•	•	•	•	•	•	•	•	•	2	2
Sanitary Drainage	1	•		•	•	•	•	•	•	•	•	•	•	•	•	3	4
Storm Drainage	•	•	2		•	•	•	•	•	•	•	•	•	•	•	1	3
Mains Electricity	2	1	2	2		•	3	3	•	2	•	3	1	•	•	2	21
Standby Electricity	3	1	2	2	•		3	3	•	•	•	3	2	2	•	3	24
VHF Radio	3	3	3	2	3	•		3	2	2	2	2	2	•	3	•	30
Telephone Systems	2	1	1	•	1	1	•		•	•	•	1	3	1	2	1	14
Roading	2	2	2	2	3	2	2	2		2	3	3	2	2	3	1	33
Railways	•	•	•	•	•	•	•	•	•		1	•	•	•	•	•	1
Sea Transport	•	•	•	•	•	•	•	•	•	•		•	•	1	•	•	1
Air Transport	1	1	•	•	1	•	•	•	•	•	•		1	•	•	•	4
Broadcasting	2	2	2	•	•	•	•	1	1	•	•	•		•	1	•	9
Fuel Supply	3	1	1	1	•	3	1	1	3	2	•	1	1		3	1	22
Fire Fighting	•	2	•	•	•	•	•	1	•	•	•	2	•	1		1	7
Building Services	•	•	•	•	•	•	•	2	•	•	•	1	1	•	2		6
Equipment	3	3	3	2	3	3	2	3	3	3	3	3	3	2	2	3	44
TOTAL DEPENDENCE	22	17	19	11	11	9	11	19	9	11	9	19	16	9	19	21	
PRIORITY FACTOR	29	19	23	14	32	33	41	33	42	12	10	23	25	31	26	27	

Note: 3 = High Dependence
2 = Moderate Dependence
1 = Low Dependence
• = No Dependence

Priority Factor = Importance + Dependency

Table 2: Interdependence of Lifelines - First Week After Earthquake

UTILITY	RECOVERY OF BASIC SERVICE OR CONTROL	PROVISION OF 50% SERVICE	PROVISION OF FULL SERVICE	COMMENT
Water	Up to 2 days	2 weeks	12 months	Access and equipment. Pipe structures. Treatment plant. Radio communications.
Drainage: • Sewerage	Up to 2 weeks for control	12 weeks minimum	24 months minimum	As for water. 6 months min for inspection - CCTV.
• Stormwater	2-3 days	12 weeks	12 months	Important for early sewerage control
Gas: • Welgas	Up to 3 days	3 weeks	6-12 months depending on sleeving programme	Local shutdowns only as necessary Inspection needed to reinstate a service
• HVEB	Less than 3 days	3 weeks	6 months	As for water.
Electricity: •Regional	Up to 3 days	2 weeks	9-12 months	Radio communication. Access and equipment. Transmission towers.
• District	Up to 3 days for control. 1 week for service.	4 weeks	12 months	Sub stations. Cable structures
Telecom: * VHF Mobile	Up to 4 hours	2-3 days	2-6 months	Access and equipment. Standby fuel.
• Local Telephone	Up to 2 days	3-6 weeks	12 months	Buildings. Line structures.
• Tolls	Up to 5 days	4 weeks	12 months	Transmission towers.
• Cellular	Up to 5 days	4 weeks	2 months	Switching units. Transmission towers
Broadcasting	Up to 6 hours	2-3 days	2-6 months	Access and tower realignments. Standby power. Telephone link.
Roading	3-5 days - some Vehicular access to most areas. 2 weeks access to region	3-4 weeks	18-24 months	
Rail: • Wellington	2-3 months	2-3 months	12 months	Track alignment. Buildings. Signalling. Slips.
• North from Upper Hutt	1 day			
• North	Up to 12 months	12 months	18 months	Depends on extent of slips at Paekakariki hills.
Ports	1-2 days	6-8 weeks	12-24 months	Access. Power
Airport	1-2 days if plant immediately available, 4 days otherwise	6 weeks	6-12 months	Access & earthmoving plant. Asphalt plant. Controls and navigation aids.
Definitions	Ability to provide a basic manageable service for priority use.	Provision of general service to most areas. Some queuing or overload. Temporary fixes in place.		

- Review required spare parts and cables to ensure reinstatement of electrical supply is not unnecessarily delayed.
- Pay closer attention to seismic issues for extensions and new equipment.
- Increase awareness and effectiveness of mitigation measures through staff training.
- Review key telephone exchanges for seismic integrity.
- Investigate more closely the useability of the Port of Wellington and the airport following an earthquake.
- Increase redundancy as roading system is developed.
- Review performance of important bridges.
- Make a closer and more detailed analysis of the Thorndon region and the motorway overbridges. Take steps to improve this vital area.
- Increase redundancy in the Cook Strait ferry service.
- Investigate the use of shut-off valves in buildings for gas.
- Encourage businesses to review the earthquake integrity of their operations, equipment and stock.

These and other actions will form the basis of action by the service providers affected.

9. CONCLUSIONS AND RECOMMENDATIONS

The project has been successful in raising the awareness of many affected people, and in providing a data base of information about Wellington's lifelines and hazards they face.

One of the most successful features has been the involvement of a wide range of professionals from the scientific, engineering and service authority backgrounds. They have communicated well together and came to realise the need for further action by each service authority.

An exceptional amount of valuable information has been brought together on both the Hazards and the Lifelines in Wellington. The very fact that it has been brought together in a succinct form is certain to prove beneficial in future. No ready reference was previously available.

Many issues were highlighted through the course of the Project, notably the definition of overall hazards and their effects on lifelines and the variation of performance with soil and topographical situations.

The value of engineering input at all levels i.e. management, concept design and detailed engineering, was highlighted. All three are required in order to achieve effective mitigation measures. This input should extend beyond management to the political level, and the project brought to light the need for engineers to describe proposed mitigation measures in terms that can be understood by elected councils in the context of their overall responsibilities.

Many service authority engineers involved in the project welcomed the wider view of seismic risk which the project encompassed. They were accustomed to seeing almost all effort directed to buildings and structures.

Analysis of whole systems was seen as beneficial, as was the analysis of interaction of lifelines with one another.

The use of vulnerability assessment charts proved invaluable in identifying key areas of concern. The application of a grading system required considerable judgement, and although no great precision is claimed, the process of review and assessment of grading numbers was in itself valuable.

The analysis of interdependence of lifelines also involved the award of grading numbers; but again, the value was as much in the process of assessing the degree of interdependence as in the resulting numbers. Some surprising interdependencies emerged only after discussion among all personnel concerned with the various affected lifelines.

Movement on the Wellington fault was, of course, important but many other significant hazards were identified that are associated with earthquake shaking. These included landslides and liquefaction. The assembly of the Hazard Map provided service authorities with a comprehensive appreciation of the nature and extent of earthquake-induced effects. Many representatives of lifeline service authorities were unaware, prior to the project, that such hazards existed.

The bottle-neck situation at Thorndon was dramatically highlighted, particularly in discussion at the Workshop where the importance of this area became clear as Groups compared conclusions. Vital road and rail transport pass through the area, with access to the ferry terminal.

Principal recommendations resulting from the project include:

Other cities with significant earthquake risk should undertake similar studies targeted at their particular lifelines. Lessons for other regions include:
- Involvement of key people in examination of safety issues in earthquake will lead to effective and sensible action.
- The approach and methodology used on this project can be drawn upon and adapted in other regions. Even though major earthquake faults may not always be present in other areas, the project clearly showed that there are many other earthquake-related hazards which can adversely affect lifelines.
- Many of the key issues identified in this project are common to other centres.

Service companies should carry on where this project leaves off. Individual companies should address their particular vulnerabilities and establish a formalised approach to mitigation. This includes issues involving:
- Disaster response planning
- Asset management and planning
- Conceptual design of lifeline networks
- Detailed engineering
- Interdependence of lifelines

Companies should make risk management and lifeline earthquake engineering an integral part of their operations.

The importance of implementation of mitigation measures must be given due recognition. Data exists for sensible review of options and costs. Each lifeline service company should use it to review their vulnerability and cost-effective mitigation measures.

10. DEVELOPMENTS SINCE PROJECT COMPLETION

Those concerned with the project considered it vital that an on-going forum for sharing experience, knowledge and concerns is established on a New Zealand wide basis. A means considered likely to achieve this involved the setting up of a new Steering Committee with the support of key service companies with affiliation to the New Zealand National Society for Earthquake Engineering, and through them to Lifeline Earthquake Engineering organisations overseas.

It was considered that such a committee would be responsible for promoting Lifeline Earthquake Engineering issues with the objective of reducing earthquake risk while recognising financial and resource limitations.

Since completion of the project such a committee has been established in Wellington to promote lifeline earthquake engineering mitigation work among service providers.

Further, other communities are beginning to use the methodology of the project to consider hazard assessment in their own regions. A project has now been established in Christchurch supported by regional and local authorities and all service providers. This project will adapt the methodology to consider those natural hazards to which the region is considered vulnerable, namely earthquake, flooding, rain and wind storm action and tsunami.

There is also interest in both Auckland and New Plymouth to consider vulnerability of these cities to volcanic activity.

11. ACKNOWLEDGEMENTS

The project was notable for the wide support from individuals and organisations. Most of the input by technical groups and committees was done on a voluntary basis, representing a significant and much appreciated contribution. Financial support from the Centre for Advanced Engineering and the major sponsors, Earthquake and War Damage Commission, Natural Gas Corporation, Ministry of Civil Defence, Trans Power NZ Limited, Transit New Zealand, Wellington Gas Company Limited, Hutt Valley Energy Division, MED Capital Power, Telecom Wellington Limited, Port of Wellington Limited, The Wellington Regional Council and Lower Hutt City Council, is gratefully acknowledged.