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Wellington's Lifelines in Earthquake Project

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WELLINGTON'S LIFELINES IN EARTHQUAKE PROJECT
An Outline of a Major Review

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Abstract

This paper outlines a project involving a major review of all lifelines including building services in the region of Wellington, New Zealand. A case study approach was used involving representatives from all service companies, as well as consultants, academics and technical specialists.

Background to the project, its scope and objectives are briefly described.

Five task groups worked on various aspects 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 attention and implementation is expected.

For presentation purposes the paper has been split into three sections.

SECTION A
LIFELINES, HAZARDS AND METHODOLOGY

1. INTRODUCTION

Lifelines, those services which support the 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 (Refer Figure 1) susceptible to earthquake shaking, it is crossed by several major active faults. In addition it is a major port, New Zealand's capital city and lies at the southern extremity of the country's North Island. The region contains steep hills of solid rock as well as flat areas of weak

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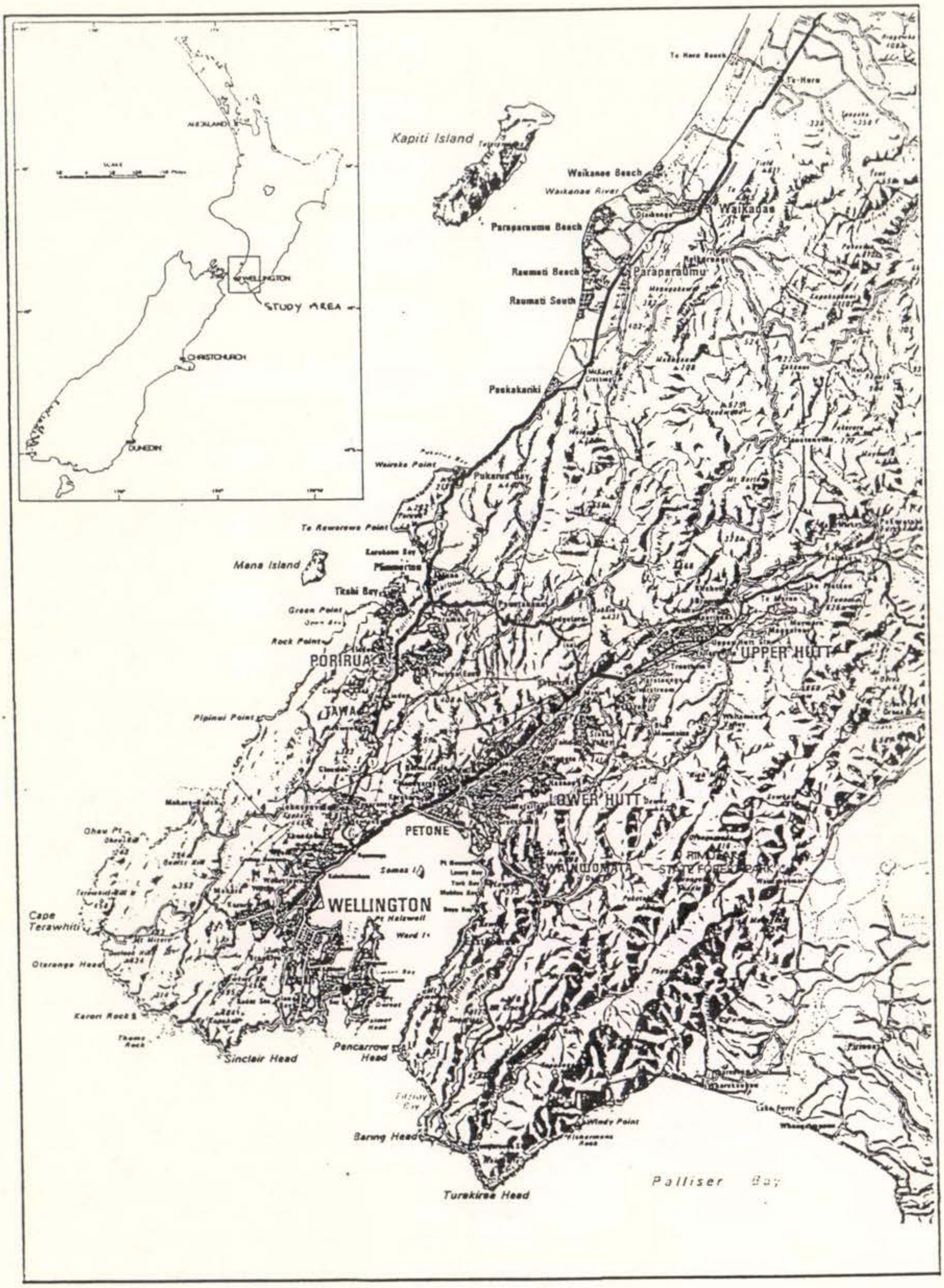

FIGURE 1: Locality Map

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 of reclamation have been created 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 Centre for Advanced Engineering at the University of Canterbury promoted 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:

- assessment of vulnerability of lifelines
- identification of mitigation measures
- raising of awareness amongst service providers both in Wellington and elsewhere in New Zealand.

2. SCOPE

All major lifelines were included:

- Water
- Sanitary Drainage
- Stormwater Drainage
- Gas
- Electricity
- Telecommunication
- Transportation - road, rail, sea and air
- Building Services

The definition of the Wellington region varied with each, depending on the location of the main elements of the network.

Most attention has been paid to regional and major city distribution networks. Critical aspects of local networks were considered in some cases.

Two important restrictions on the scope of the review were to prove vital in keeping work to manageable and comprehensible limits:

- The specific aspects of Wellington's lifelines were to be addressed with no attempt to generalise or draw parallels with lifelines in other cities.

- The focus was on vulnerability assessment of Lifelines, as distinct from issues of civil defence preparedness and response planning.

It was felt that the benefits of the study to other cities would be greater for having addressed specific lifeline details.

3. APPROACH

A unique and important feature of the approach has been the wide involvement of engineers and managers in key positions with the service authorities and companies. This has proved invaluable in meeting all three major objectives, particularly the raising of awareness, with the prospect of practical implementation being effected by the 15 utility organisations involved.

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

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

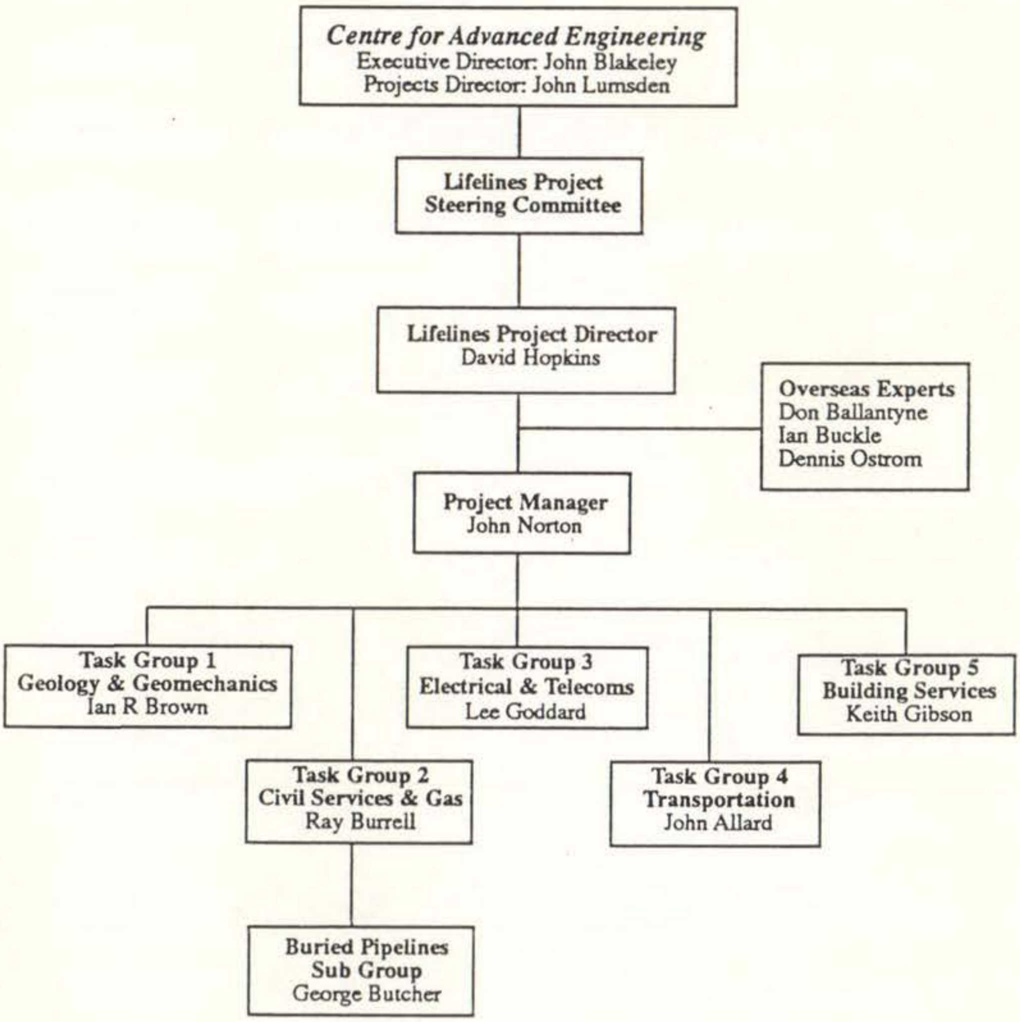

FIGURE 2: CAE lifelines Project Organisation Chart

The work on the project was spread among five Task Groups, co-ordinated and managed by a project manager reporting to a project director. Task Groups were formed to cover:

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

The Geology and Geomechanics Group were charged with the task of defining the seismic related hazards in the region in a form suitable for use by the other Groups. Each of the other Groups was given a written brief which outlined their tasks:

- Definition and description of each lifeline network and its components.
- Assessment of vulnerability to various identified earthquake hazards.
- Consideration of consequences of failure.
- Identification of engineering mitigation measures from a management concept design and detailed engineering perspective.

Assessment of vulnerability was made for two levels of earthquake, representing a 'design' event and a 'maximum credible' event. The design earthquake was one which produced peak ground acceleration of a 0.3g (MM8) and had a 50% probability of occurrence in 50 years. The maximum credible earthquake, involved movement on the Wellington Fault causing peak ground accelerations up to 0.9g (MM10) and had an assessed probability of occurrence of 10% in 50 years.

For each earthquake and each lifeline system, vulnerability assessments were made for each of three separate periods:

- immediately after the earthquake
- the period following the earthquake
- during return to normality.

Both the likelihood of failure, and overall importance, were assessed.

In determining practicable mitigation measures, considerations of the consequence of failure was essential. Items which could be readily restored to service if they failed, clearly have a lower priority than items which would take longer to restore. Thus an iterative procedure involving considerable judgment was required.

In considering the consequences of failure, or time to restore, a wide view of 'lifeline' was taken. Specifically, the view was taken that restoration of services to, say, a factory or building was of little use unless it too was capable of operation. Quite apart from physical readiness, people with the necessary skills needed to be available. In this context Task Groups were encouraged to seek out the 'weak links' which could be critical in delaying resumption of service, and a return to normal conditions.

Throughout the project, the Task Groups met individually on a regular basis, guided by the project manager. Co-ordination of technical effort, and interaction between Groups was achieved at regular meetings of the Task Group leaders, attended by selected members of the Steering Committee. With up to 15 people in each Task Group, a wide range of engineers had first-hand involvement.

To enhance the value of the project to participants generally, involvement of overseas experts in lifeline earthquake engineering was sought. Three lifelines experts from USA were invited to contribute directly to the project by commenting on work outputs, and through attendance at a special three-day Workshop in Wellington in September 1990. Other experts provided comment by correspondence. The Workshop provided an excellent forum for discussion and generated considerable enthusiasm and practical response from the 100 attendees. Through this means, one of the principal objectives of the Centre for Advanced Engineering was achieved - transfer of technology to practicing New Zealand engineers.

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.

In outline the group's work consisted of:

- Preparation of a geological map of the region defining seismic hazards - active faults, low strength sediments, unstable slopes, reclamations.
- Description and analysis of 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:

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, at the port's container and ferry terminals.

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.

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

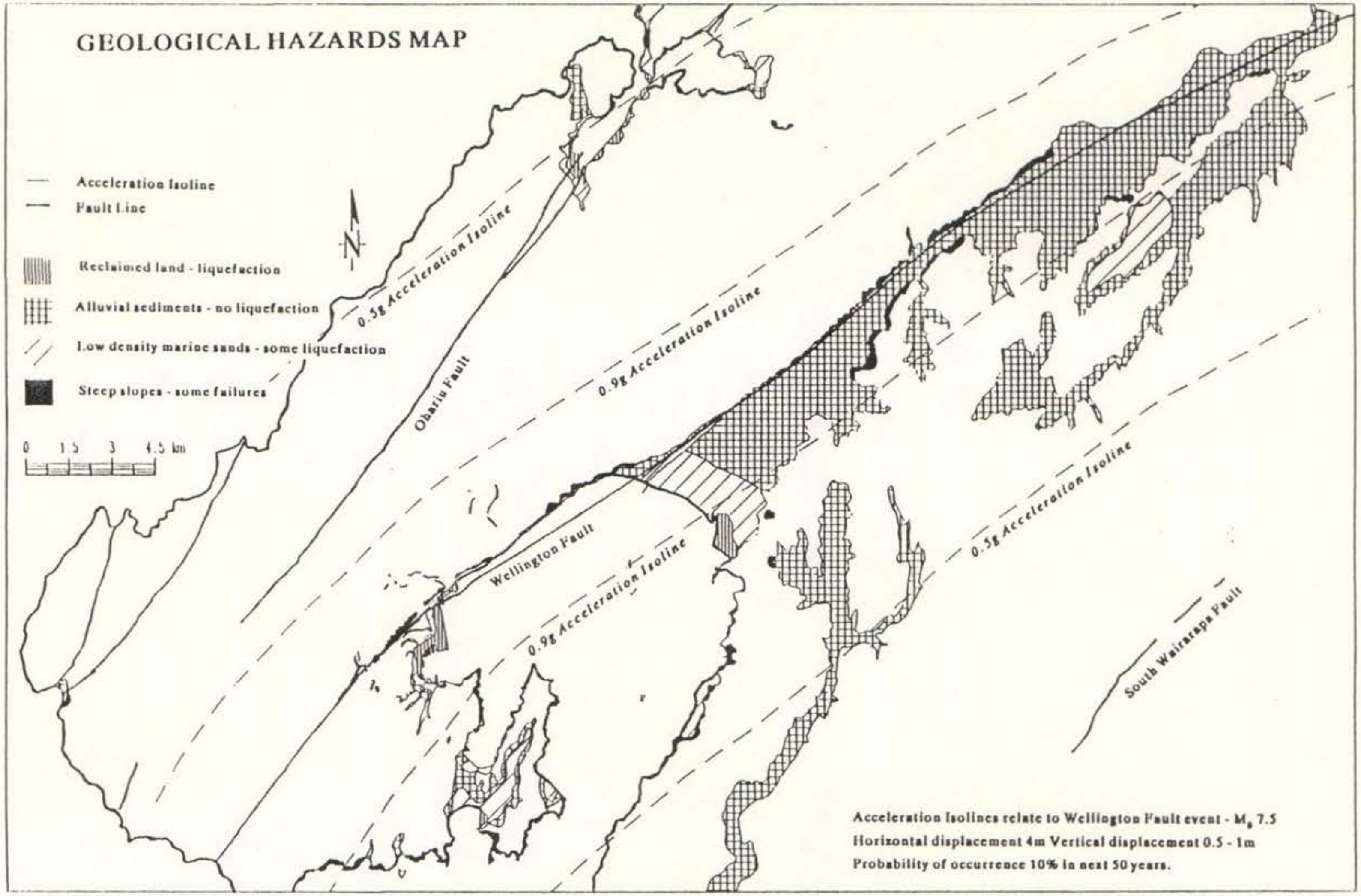

FIGURE 3: Lifelines Project Hazards Map

5. LIFELINE DESCRIPTIONS

5.1 Water Supply

There are four sources of water supply for the region:

- 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 the storage and reticulation, much of which is close to the Wellington Fault. The main reservoirs at Te Marua contain 30 days supply.

- 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 in the system.

- Orongorongo River to the east of the region (10%). This follows a similar route to Wainuiomata and gravity fed through 525mm diameter steel pipes, passing across two bridges and through a tunnel. There is no primary storage.

- 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 up to 80 years old in Wellington city. Typically they hold a days 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.

Figure 4 shows the layout of main water supply lines and reservoirs.

5.2 Sewage Disposal

Sewage in the region is managed by several district systems for its collection, treatment and disposal. 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.

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.

The section from Upper Hutt to Silverstream railway bridge is a gravity system of twin reinforced concrete pipes with rubber ring joints. Pipes vary in diameter from 380 to 1370mm and date from 1956 to 1979.

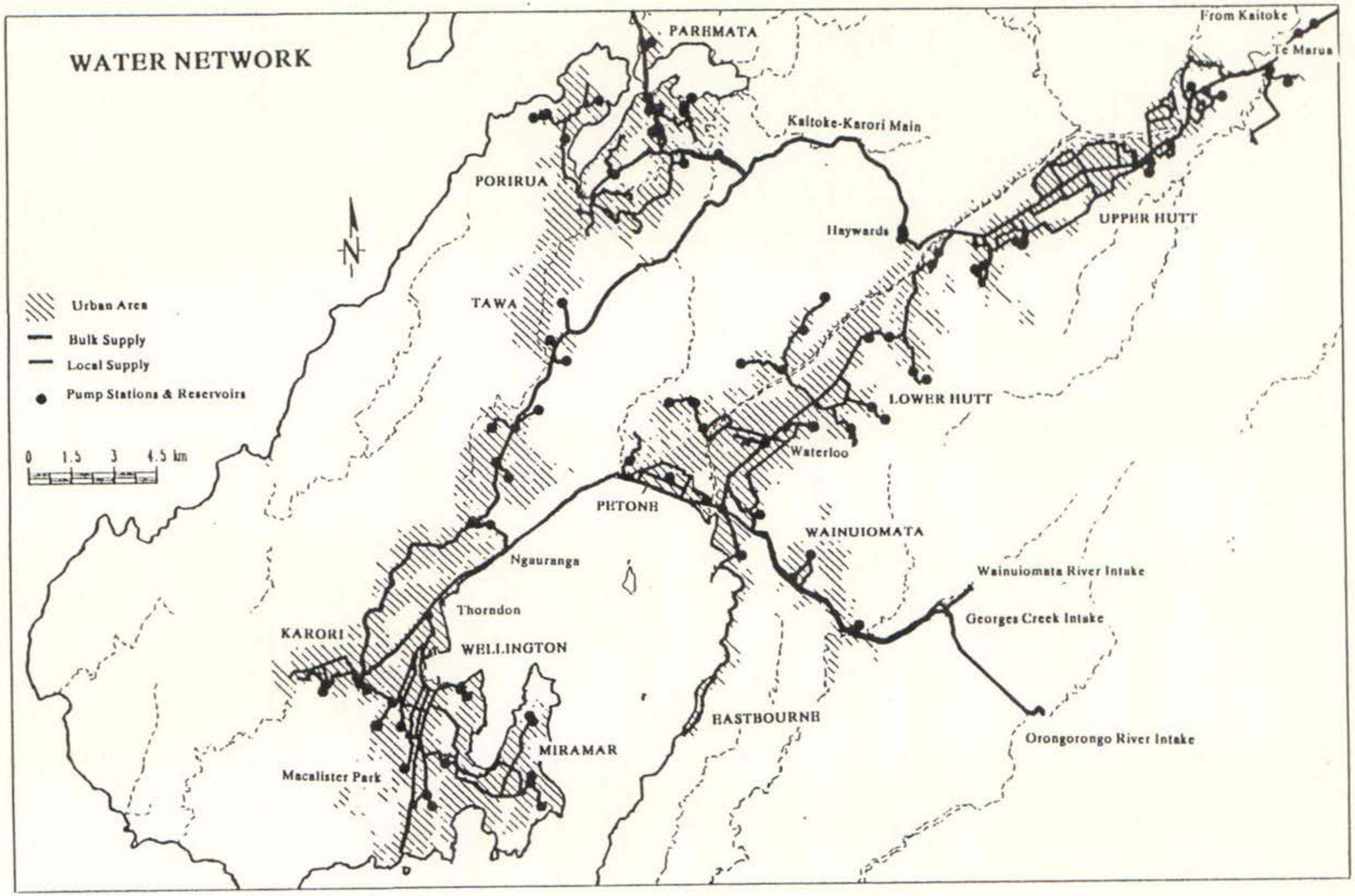

FIGURE 4: Location of Water Supply Lifelines

At the eastern bridge the twin pipes join for a short single pipe section along the eastern Hutt Road to the start of the Lower Hutt section. This single pipe section varying from 1065 and 1370mm diameter is of reinforced concrete rubber ring pipe dating from 1974. South of the Silverstream bridge the pipe branches each side of the Hutt River, leading to two pumping stations, at Ava Street and Barber Grove, from which pressure lines connect to the main pumping station and milliscreen plant at Seaview. A prestressed concrete pressure line 1295mm diameter outfall follows the coast to Pencarrow Head.

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

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

The principal district mains in Porirua comprise 1.8m high oval shaped tunnels of in-situ concrete, rising mains of 685mm diameter concrete lined steel (1972) and 625mm diameter ductile iron (1989).

Rising mains from Tawa and Porirua East of 300 to 850mm diameter reinforced concrete (1956 to 1979) are joined in the Porirua centre by rising mains from Pukerua Bay/Plimmerton/Paremata of 300 to 525mm diameter 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) treatment plant at Titahi Bay.

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, past the Hospital, through Lyall Bay and around to a short coastal outfall at Moa Point. For the most part it is a single line with twin sections from Willis Street to the Hospital and from Lyall Bay to Moa Point.

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.

Typically the interceptor is an oval or egg shaped lined tunnel 1.2 to 1.8m high. Parts of it date from 1890 and is brick lined while other parts from the 1930's and the 1970's are concrete lined. There are short sections of trenched pipe and around Lyall Bay, where 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. Typically 50% of this network would be 150mm diameter earthenware pipe with mortar joints, 30% would be variously asbestos cement, concrete or pitch fibre and 20% would be larger than 150mm diameter.

Numerous pumping stations dating from the 1950's 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.

Brick culverts of 900mm diameter dating from 1880 onwards service the Wellington City area with some in-situ concrete tunnels completing the main trunk system. The Horokiwi, Ngauranga, Ngaio and other streams discharge into the harbour through culverts under the Hutt Road.

Figure 5 shows the layout and principal elements of the sewage and stormwater drainage systems.

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 the Hutt Valley Energy Board for the Hutt Valley and Porirua. Refer Figure 6.

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 20 year old, 200mm diameter western line feeds through a control gate at Pauatahanui through Waitangirua to the Tawa gate for the Wellington Gas Company supply. The 10 year old, 300mm diameter, eastern line feeds to the Belmont control gate and has a cross connection to the control gate at Waitangirua. The Hutt Valley Energy Board takes supply from Belmont and Waitangirua.

5.5 Electricity Supply

The electrical distribution system comprises a regional supply from the national Trans Power grid to two district distribution networks operated by Wellington MED Capital Power and Hutt Valley Energy Board. The main Trans Power NZ Limited distribution station in the region is at Haywards, which is connected to Bunnythorpe to the north, and to Benmore in the South Island. Refer Figure 7.

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.

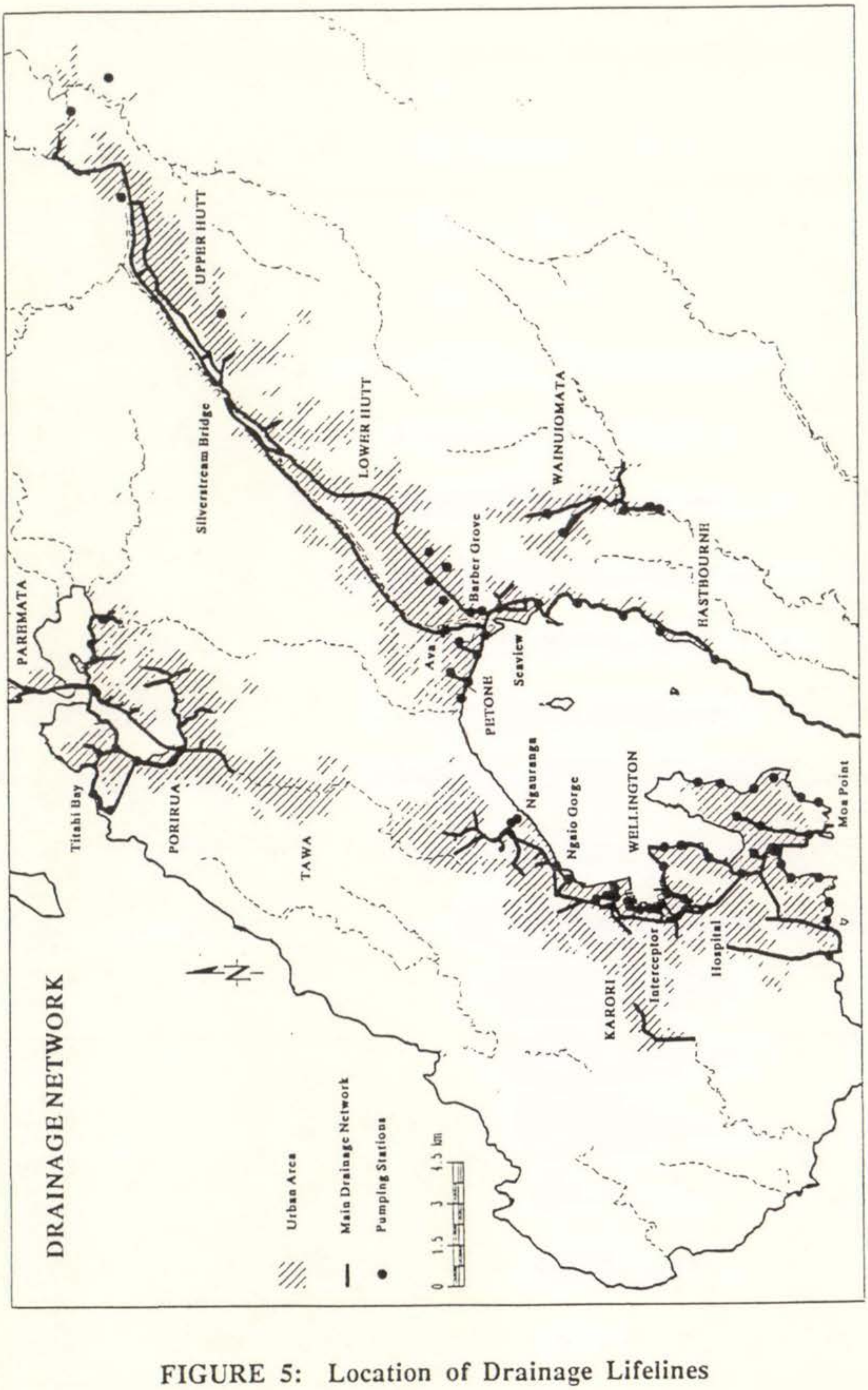

FIGURE 5: Location of Drainage Lifelines

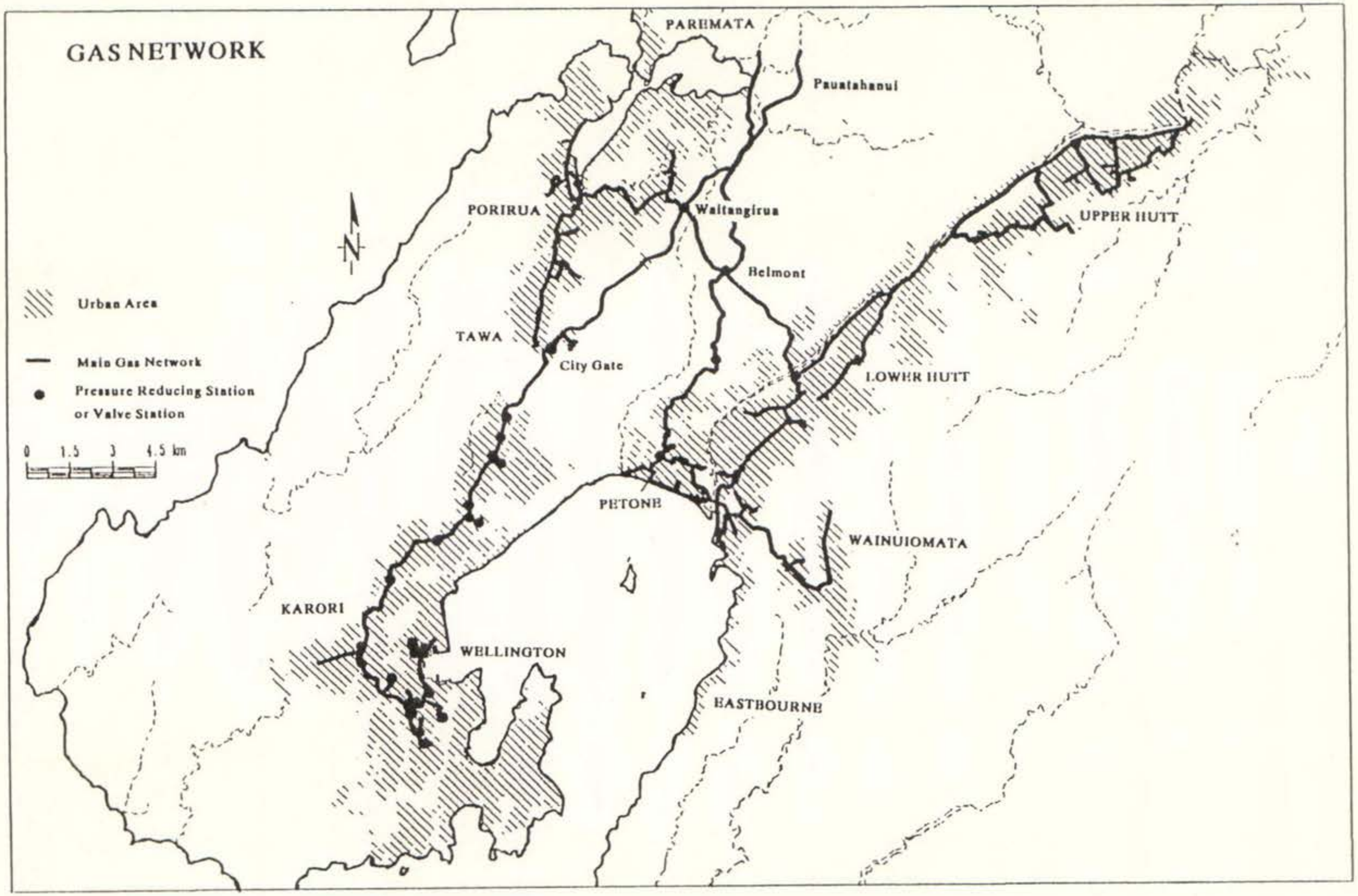

FIGURE 6: Location of Gas Lifelines

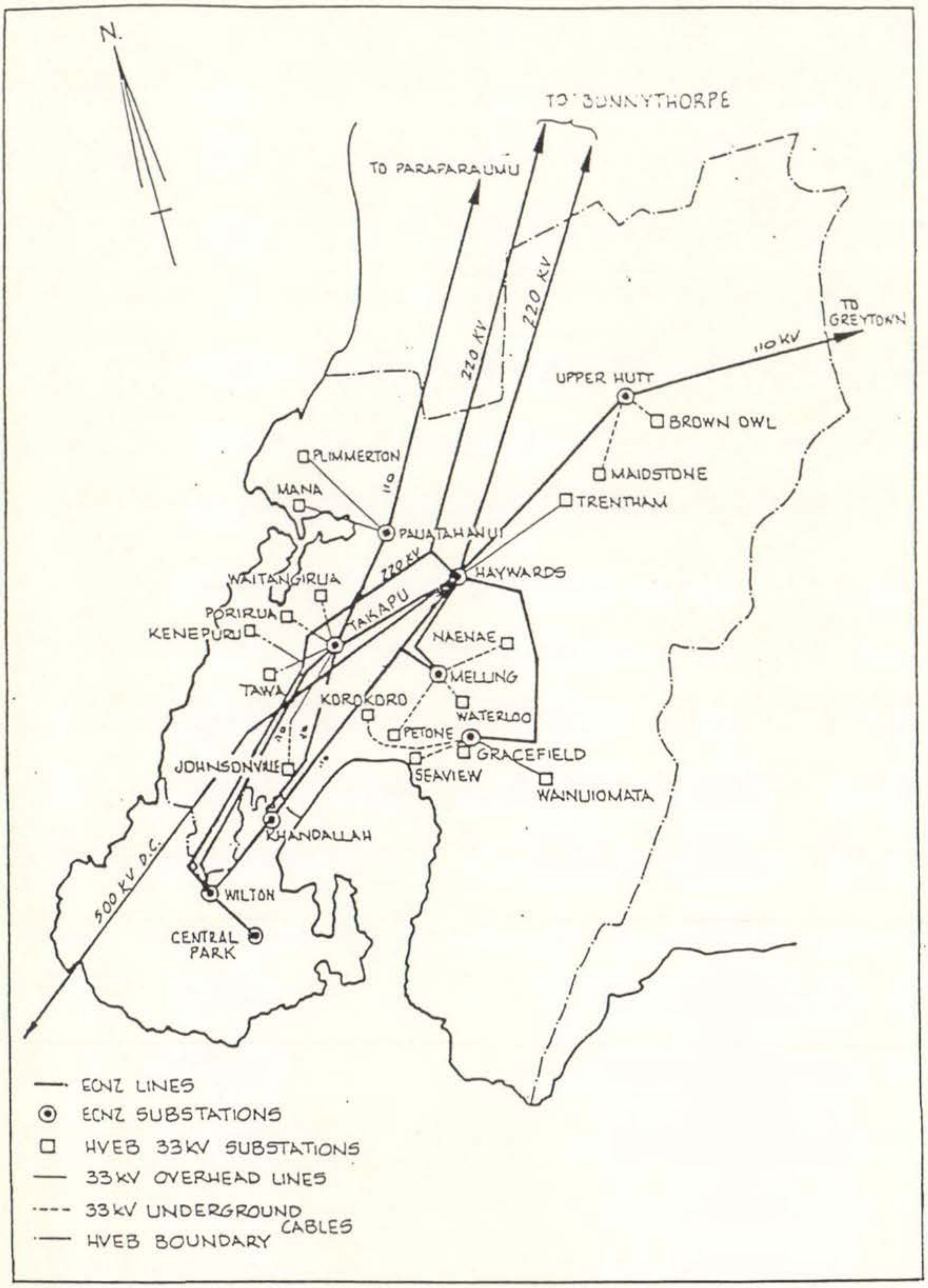

FIGURE 7: Electrical Supply Schematic Diagram

Figure 7 shows the location of major supply lines in the region.

MED Capital Power operates a 33kV sub-transmission distribution system with ten zone substations supplied from two Trans Power stations, Central Park and Wilton. The 33kV network comprises twin parallel circuits radially connecting the Trans Power station and each zone substation, by underground cable. There is no 33kV interconnection between zone substations but interconnections can be provided by using available 11kV circuits.

At each 33kV/11kV substation, up to 12 11kV feeder circuit breakers distribute supply to the local area using predominantly underground cable. All central city 11kV feeders are ring cables with differential protection. Suburban 11kV feeders are a mixture of ring protected and radial circuits. All 11kV substations on the ring system automatically trip on fault detection.

MED Capital Power has an extensively interconnected local distribution system with approximately 750 ground mounted fully enclosed 11kV/400V substations. All 11kV circuits are underground except for some rural overhead lines in the Makara area. In the central city all 11kV and 400V circuits are via underground cables. Since 1968 all new subdivisions have been supplied by underground cables.

Other 400V circuits are via a mixture of overhead lines and underground cables with approximately 80% overhead in the older suburbs. MED Capital Power has a long term programme for completely undergrounding the main overhead reticulation. The house services will remain overhead.

The Hutt Valley Energy Board operates a 33kV sub-transmission system supplied from Trans Power stations and serving seventeen zone substations. The 33kV system uses twin parallel 33kV overhead line or underground cable circuits between the Trans Power stations and the HVEB zone substations. Typically 60% of these circuits are underground. There is no 33kV interconnection between zone substations but interconnection can be provided by using available 11kV circuits.

Each zone substation has up to eight 11kV feeder circuit breakers distributing supply as a radial feed to the local area. The 11kV distribution circuits are either underground cable (40%) or pole mounted overhead line 11kV circuits. These connect to further 11kV local distribution substations or to miniature road berm substations or pole mounted transformers to supply at 400 volts or 230 volts. Supply can therefore be at 11kV for large industrial users, at 400V for smaller industrial and commercial users and at 230 volts to domestic customers.

The HVEB local network comprises 11kV and 400 volt distribution circuits, of which 40% and 59% respectively are underground. There are approximately 1800 pole mounted 11kV/400V transformers and 950 ground mounted transformers.

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.

Two Network Management Centres are staffed 24 hours per day to monitor the state of the network and can implement traffic control measures within minutes of problems being detected.

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.

Figure 8 shows the layout and position of principal elements of the telecommunications network

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 operates seven broadcast radio stations in the region, five AM and two FM. These rely on the transmitter at Mt Kau Kau and on Telecom circuits between studios and Radio New Zealand House in Bowen Street. One of the AM stations, 2ZB, is designated as the primary local region broadcast information station for Civil Defence.

Six private radio stations, two AM and four FM, also broadcast within the region. The AM stations rely on Telecom circuits while the FM stations broadcast through transmitters on Mt Kau Kau with programme feed by UHF radio link. 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.

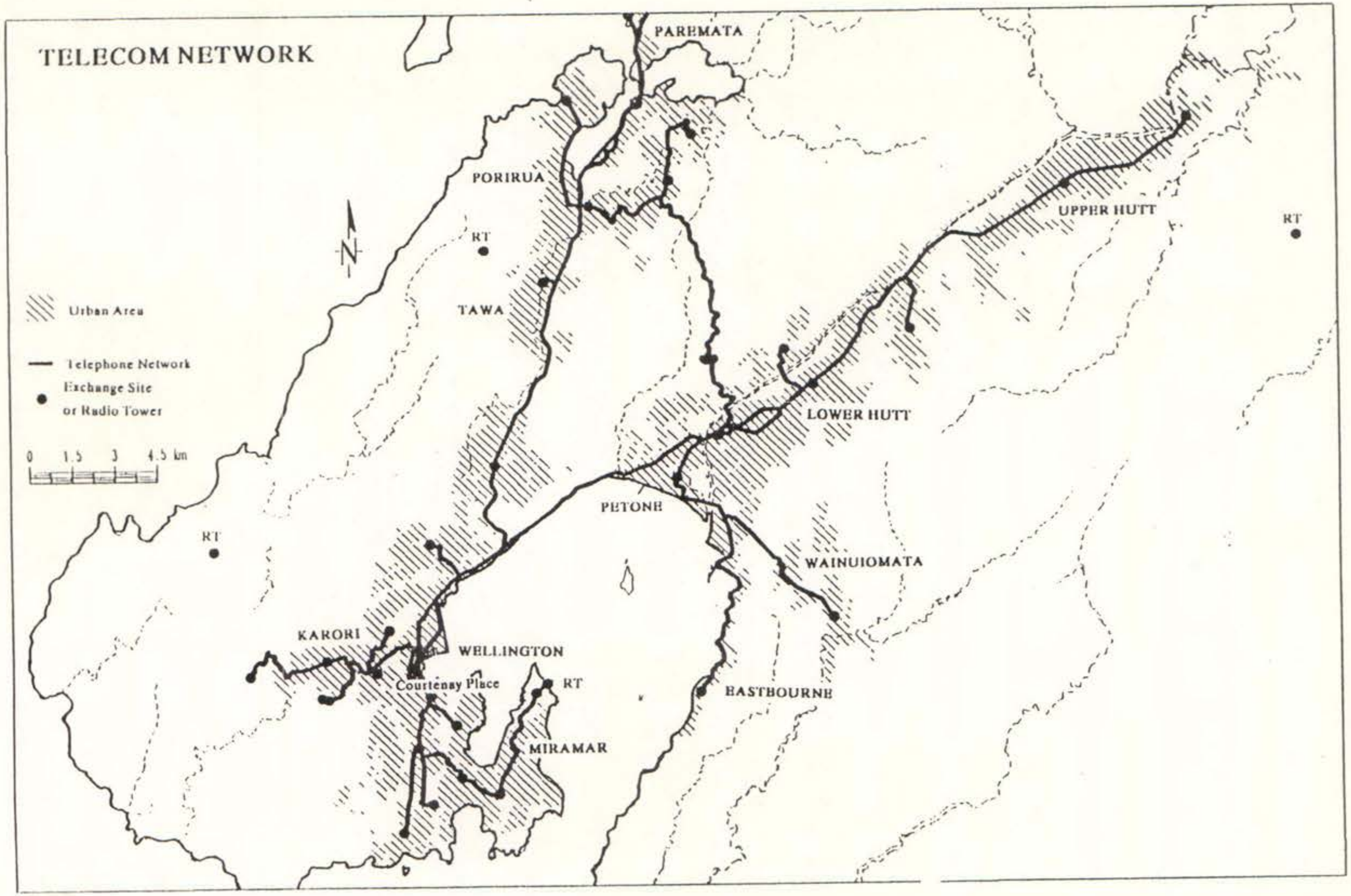

FIGURE 8: Location of Telecommunications Lifelines

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 are located about the region which obtain their programme feed from the main signal transmitted from Mt Kau Kau. 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.

From Ngauranga the motorway enters the city by extensive overhead structures leading to a subgrade freeway with off ramp feeds into the city, and finally enters the central city after passing through the Terrace tunnel.

State Highway 58 between Porirua and the Hutt Valley links State Highways 1 and 2 in the north of the region.

The district road system for the City of Wellington reflects its topography with very limited outlets to the north and with many suburbs entered by steep winding roads or through tunnels. The Central Business District has a strong network on a basic grid pattern with a major eastside route around the harbour. To the west the CBD is bounded by the city motorway below grade with links to the western suburbs over flyover structures. The city motorway runs along the Wellington Fault.

To the south-east the flat central area is bounded by Mt Victoria hills and the major route to the eastern suburbs and the airport is through the Victoria tunnel.

The primary distributor for Lower Hutt is State Highway 2 running up the western side of the city with feeds to the western hillside suburbs. Distribution into the central valley is constrained by the Hutt River and the railway line, with two major distributors involving river crossings at Melling and Avalon. Only the Avalon bridge is of recent construction.

The major southern distributor follows the Petone foreshore, an uplifted marine sand formation, and crosses the Hutt River estuary to provide routes to Eastbourne suburbs and Wainuiomata.

Upper Hutt has two main north/south routes in addition to the bypass River Road. These are well cross connected but come to a single northern outlet. Further north the Akatarawa Road provides a minor narrow winding route across to State Highway 1 at Waikanae.

The district network serving the City of Porirua includes two crossings of the North Island main trunk railway line and the adjoining Porirua stream with hilly roads serving the large residential areas to the east of the city. These two crossings provide an east-west constraint in an otherwise well interconnected network.

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 ten kilometre Johnsonville line is now exclusively a passenger line. A short spur from the Wairarapa line serves the Lower Hutt western suburbs with a terminus at Melling. The southern terminus to all lines is Wellington Station with its supporting railyard. The latter covers some 45 hectares and provides a wide range of supporting infrastructure.

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 ground 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. With a natural harbour capable of accommodating ships up to 10.2 metres draught (plus any tidal allowance), the port is a major national shipping node point. It 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 immediately adjacent several berths for conventional cargos at Aotea Quay

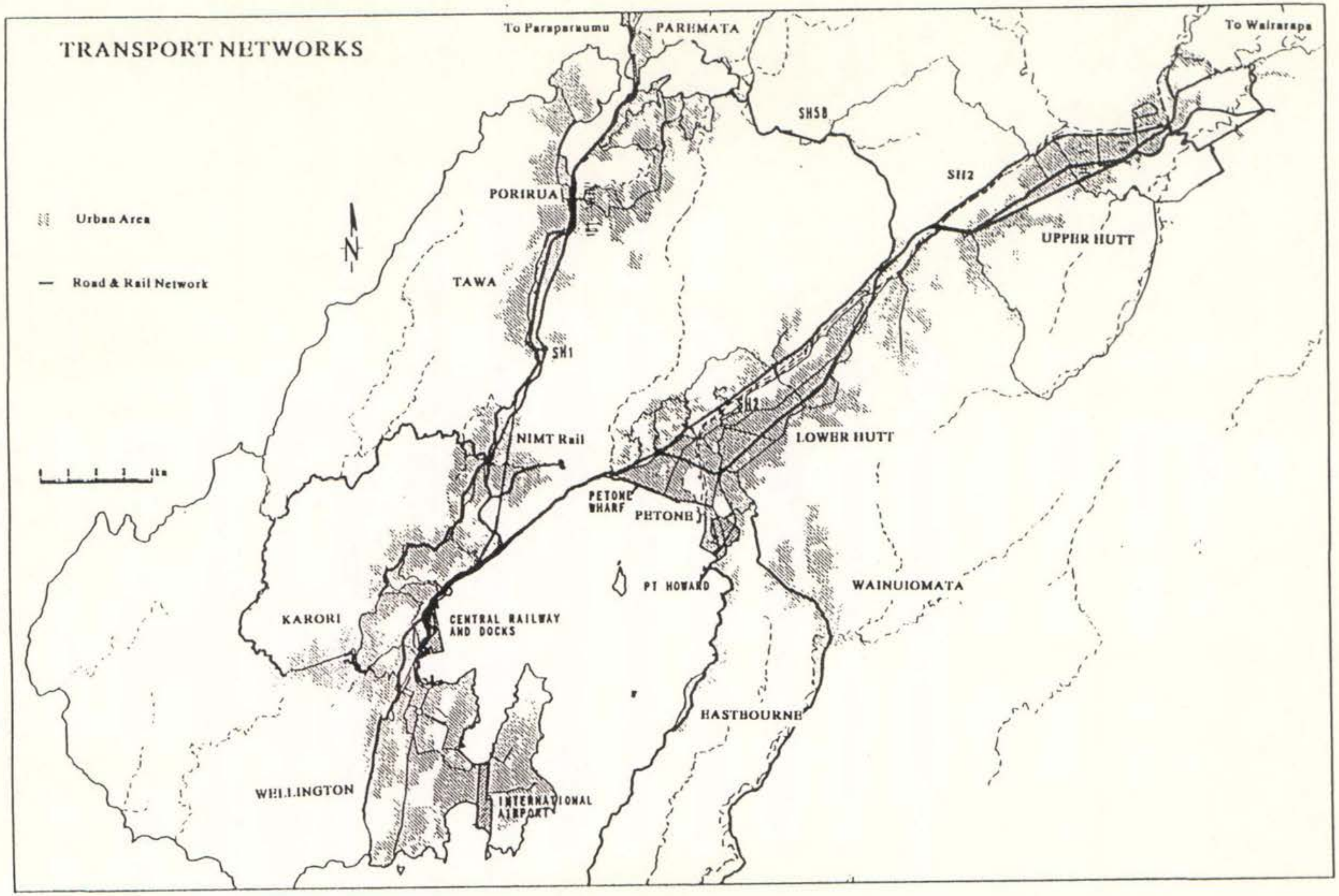

FIGURE 9: Location of Transport Lifelines

and Glasgow Wharf, many with access available to wharf cranes and to wharf sheds within the port security area. Much of this port infrastructure is on reclamation.

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.

The inner city wharves outside of the commercial port area can accommodate passenger vessels up to 9.2 metres draught at berths close to the city centre. Inner city berths accommodate the fishing fleet, harbour ferry and tour craft. In addition there are several jetties and marinas available for safe berthing of smaller recreational craft within the harbour.

Air Transportation

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.

Figure 9 shows the location of major transport lifelines.

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 the following services examined:

- electrical
- heating, ventilating and air conditioning (HVAC)
- plumbing
- fire protection
- vertical transportation
- security
- communications
- processes.

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 refers essentially 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 and 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.

SECTION B
VULNERABILITY AND INTERDEPENDENCE OF LIFELINES

1. INTRODUCTION

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.

2. VULNERABILITY HIGHLIGHTS

Water Supply

- Te Marua Lakes are 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 which 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.

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.
- The section of the interceptor from Queens Drive to the outfall, particularly the old unreinforced concrete main, is laid in ground of high liquefaction risk.
- Mechanical and electrical plant is vulnerable to shaking and internal flooding.
- Pipe joints and connections are highly vulnerable.
- Ground settlement in flat areas will necessitate regrading of pipes.

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.

Gas

- The main supply line to Wellington City crosses the Wellington Fault in two locations.
- 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.

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.
- Nairn Street substation is threatened by the possible failure of an adjacent retaining wall.
- The Wellington Fault earthquake would cause extensive disruption to major equipment and buildings.
- 11kV 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 HVEB system would be affected in the Wellington Fault Event.

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 and the Makara Microwave Station.

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, with the railyards in Thorndon extensively affected.
- 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 containing the Wellington Fault.

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.

3. 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 S1 shows assessed times to recover for each lifeline, made independently.

TABLE S1: Recovery of Service - A Preliminary Assessment of Time to Recover Following a Major Event (Wellington Fault)

Utility	Recovery of Basic Service or Control	Provision of 50% Service	Provision of Normal Service	Comment
Water	Up to 2 days	2 weeks	12 months	Access & equipment Pipe structures Treatment plant
Drainage:				
Sewerage	Up to 2 weeks to control	12 weeks minimum	24 months minimum	As for water 6 months minimum 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:				Radio communic.
* Regional	Up to 3 days	2 weeks	9-12 months	Access & equip. Transmission. towers
* District	Up to 3 days for control 1 week for service	4 weeks	12 months	Substations Cable structures
Telecom				
* VHF Mobile Radio	Up to 4 hours	2-3 days	2-6 months	Access & equip. Standby fuel
* Local Telephone	Up to 2 days	2 weeks	12 months	Building Line structures
Tolls	Up to 5 days	4 weeks	12 months	Transmission. towers
* Cellular Network	Up to 5 days	4 weeks	2 months	Switching units Transmission. towers
Broadcasting	Up to 6 hours	2-3 days	2-6 months	Access & 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 Yards	2-3 months	2-3 months	12 months	Track alignment Buildings Signalling
North from Upper Hutt	1 day			Slips
North by	Up to 12 months	12 months	18 months	Depends on extent of slips at Paekakariki hills.
Port	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 & earth-moving plant Asphalt plant Controls & navigation aids.
Definitions	Ability to provide a basic manageable service for priority use.	Provision of a general service to most areas. Some queuing or overload Temporary fixes in place.		

Table S2 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.

TABLE S2: Interdependence of Lifelines - First Week After Earthquake

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	Equipment	Total Equivalent Importance
Water Supply		0	1	0	0	0	0	0	0	0	0	0	0	0	3	3	1	8
Gas Supply	0		0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2
Sanitary Drainage	0	0		0	0	0	0	0	0	0	0	0	0	0	0	3	0	3
Storm Drainage	0	0	2		0	0	0	0	0	0	0	0	0	0	0	0	0	2
Mains Electricity	2	0	2	1		0	3	3	0	3	0	0	0	0	0	0	1	15
Standby Electricity	3	0	2	1	0		3	3	0	0	0	3	3	0	0	3	2	23
VHF Radio	3	3	3	0	3			3	2	2	0	2	3	0	3	0	2	29
Telephone Systems	1	1	1	0	1	0	0		0	0	0	0	3	0	2	1	1	11
Roading	2	2	2	2	3	2	2	2		0	3	3	3	2	2	1	1	32
Railways	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0
Sea Transport	0	0	0	0	0	0	0	0	0	0		0	0	2	0	0	0	2
Air Transport	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	1	1
Broadcasting	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0
Fuel Supply	3	0	0	0	0	3	2	2	3	2	0	1	1		2	2	0	21
Fire Fighting	0	0	0	0	0	0	0	0	0	0	0	2	0	0		1	0	3
Building Services	0	0	0	0	0	0	0	2	0	0	0	1	1	0	0		0	4
Equipment	3	3	3	2	3	3	1	3	3	3	3	3	3	2	2	3		43
Total Equivalent Dependency	17	9	16	6	10	8	11	18	8	10	6	15	17	6	14	18	10	
Interdependence Quotient	136	18	48	12	150	184	319	198	256	0	12	15	0	126	42	72	430	

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

Interdependence Quotient
= Dependency total x Importance total

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 may be applied to lifelines in other cities.

SECTION C
RECOMMENDED MITIGATION MEASURES AND GENERAL CONCLUSIONS

1. INTRODUCTION

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.

2. MITIGATION MEASURES

Some of the specific mitigation measures recommended were:

Water Supply

- Review the need for standby power plant at pumping stations as a matter of urgency.
- Install tie bolt couplings on the water main where it crosses the Wellington Fault.
- Install isolation valves in the water supply system to avoid unnecessary loss.
- Review alternative sources of water.
- Decommission Karori's reservoir.
- Adopt an overall plan to keep major supply lines away from the Wellington Fault wherever possible.

Sewage Disposal

- Review the need to provide standby power plant at pumping stations.
- Implement a comprehensive review of the system to establish an appropriate mix of mitigation and response measures which will reduce the risk.
- Secure key items of plant.
- Review all pumping stations and treatment plants for potential liquefaction settlement. Examine options available to reduce these risks.

Stormwater Disposal

- Formulate and implement a long term plan of replacement of brick stormwater culverts in Wellington City.
- Review the likely performance of the Horokiwi, Ngauranga and Ngaio Streams, especially their capacity to wash out road and rail links.

Gas Supply

- Pinpoint likely trouble spots in gas lines. Plan for isolation of damaged sections and plan for speedy response.
- Progressively replace the cast iron/lead jointed pipes in and around the CBD.

Electricity Supply

- Review earthquake design standards and implement a programme of strengthening or replacement.
- Review the adequacy of emergency communication facilities between Trans Power Control Centre (Haywards) and those of the Supply Authorities.
- Review and secure all 33kV/11kV transformers.
- Brace zone transformers and older models of switchgear.
- Check the retaining wall at the back of the Central Park Substation. Strengthen/modify as necessary.
- Make a more detailed assessment of Seaview Substation with respect to damage due to liquefaction.
- Review alternatives for the Haywards to Trentham 33kV overhead lines. Consider underground cables designed for seismic movement.
- Review of required spare parts and cables to ensure reinstatement of electrical supply is not unnecessarily delayed.

Telecommunication & Broadcasting

- Pay closer attention to seismic issues for extensions and new equipment.
- Increase awareness and effectiveness of mitigation measures through staff training, and adoption of risk management procedures.
- Review key telephone exchanges for seismic integrity.
- Review Broadcasting House and its role as a common distribution link.
- Review equipment, studios, buildings and transmission towers. Identify and remedy any specific weak links.
- Improve standby power provisions, especially at Mt Kau Kau.
- Implement plans to set up outside broadcasts from mobile studios.

Transportation

- Investigate the usability of the Port of Wellington and the Wellington Airport following an earthquake.
- Review capability to clear key roads subject to landslip settlement or fault displacement.
- Carry out detailed reviews of performance of important bridges, notably Silverstream, Paremata, and the Thorndon motorway viaduct.
- Review air conditioning systems where these are critical to switchgear operations.
- Increase redundancy as roading system is developed.
- Make a closer and more detailed analysis of the Thorndon region, including the motorway overbridges, railyards, main road and ferry terminal.
- Increase redundancy in the Cook Strait ferry service, particularly the ability to use alternative berths.

Building Services

Building owners should examine their dependence and implement preparatory and/or mitigation measures accordingly.

- Incorporate shut off valves in buildings for gas.
- Encourage businesses, building owners and managers to review the earthquake

integrity of their buildings, operations, equipment and stock. Extend the review to cover aspects of business interruption.

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

3. 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 come 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 to these aspects 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 which could 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 on the various affected lifelines.

Identification of mitigation measures was only partially achieved. However, as a result of project involvement, many service companies intend to pursue this further.

Movement on the Wellington fault was, of course, important but many other significant hazards were identified which were 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.

Interdependence analysis proved worthwhile, both in terms of the results obtained and because a potentially valuable methodology was developed.

Principal recommendations resulting from the project include:

3.1. 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.
- The key issues identified in this project are generally common to other centres.

3.2. 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.

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

3.4. It is vital that an on-going forum for sharing experience, knowledge and concerns is established on a New Zealand wide basis. This would require 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.

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.

Final Comment

At the first session of the Workshop in September 1990, the objective of the project was restated as "Making the best possible use of available information and technology so that in, say, 20 years we can look back at money well spent on reducing earthquake risk to lifelines".

This project and the Workshop have provided a great start to that process, thanks to the support of many people and organisations. It is to be hoped that it will continue.

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