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Report to the Utility Services Committee
from Keith Woolley, Asset Engineer

Possible Kaitoke Water Main Diversion at Silverstream Bridge

1. Purpose

To background the seismic risks and possible mitigation measures associated with the Kaitoke wholesale water main at the Silverstream Bridge.

2. Introduction

The Wellington Region generally and the wholesale water supply network is exposed to seismic hazard from a number of different fault sources. The *Lifelines in Earthquakes, Wellington Case Study*, 1991 and subsequent *Wellington Regional Council Bulk Water Supply – Seismic Security Assessment*, July 1993, identified the Hutt River crossing at Silverstream and the adjacent Wellington Fault crossing as a vulnerable element.

Subsequently a 1.5 km new water main diversion option was proposed and designed to reduce potential damage to the water main at the existing river and fault crossings. The capital works programme for years 2003 to 2005 has provisionally $2.5 million allocated for the diversion construction. This paper makes a direct comparison of seismic risks to the existing water main segment and the diversion option, based on a study carried out by engineering consultants Beca Carter Hollings and Ferner Ltd. The study's Executive Summary is appended as Attachment 1 as background information.

Near the completion of the study, Upper Hutt City Council advised of its intention to strengthen the bridge in the near future. Details of the proposed bridge strengthening are included in this paper.

Construction costs in table 1 of the Executive Summary of the Consultant's report have since been revised.

The diversion construction cost has been revised and reduced to allow for an agreed Transit New Zealand contribution and for pipeline already laid. Costs for the existing pipeline segment now include a bridge strengthening contribution and costs for replacing and raising the main on the bridge. Both options now include the cost of stockpiling material for emergency repairs.

3. Seismic Hazard

Seismic hazards to the wholesale water supply include movement of the Wellington Fault, movement of the West Wairarapa Fault, movement of other faults in the Region producing strong ground shaking, and earthquakes at more remote locations. The Lifelines Group adopted the Wellington Fault event as the more severe seismic scenario for consideration of impact on lifelines such as the wholesale water supply.

Typically a Wellington Fault event would have a Richter magnitude of 7.5 and approximately 5 m horizontal and 1 m vertical fault movement. The event has an average recurrence interval of 600 years and an elapsed time since the last rupture of approximately 340 to 490 years.

The Wellington Fault is near the Silverstream Bridge but the exact location is not conclusively defined. Available information points to the fault being located close to the western side of the Hutt River, passing through the Manor Park Golf Course and then running close to the western abutment of the Silverstream Bridge.

Seismic damage estimates are based on limited damage reports of past earthquakes and damage estimates made by various researchers. Considerable interpretation and engineering judgement is required in order to apply the limited information available to the study.

4. Existing Water Main

4.1 Description

The water main segment under consideration runs from the intersection of the Eastern Hutt Road and Ferguson Drive across the Hutt River on the Silverstream Bridge, as shown on figure 1. It follows State Highway 2 south to a point just north of Haywards Stream. The 1955 constructed 36" diameter welded joint steel main carries approximately 35 percent of the Region's water. The asset life of the main is assessed at 90 years and recent inspections indicate the main is in good condition with a remaining life of approximately 45 years.

State Highway 2 was widened in 1997 along the western side of the Hutt River immediately south of the Silverstream Bridge. The cover to the water main was increased up to approximately 3 m as a consequence of the roading realignment. Given the additional cover to the water main, repairs will be expensive and very disruptive to traffic.

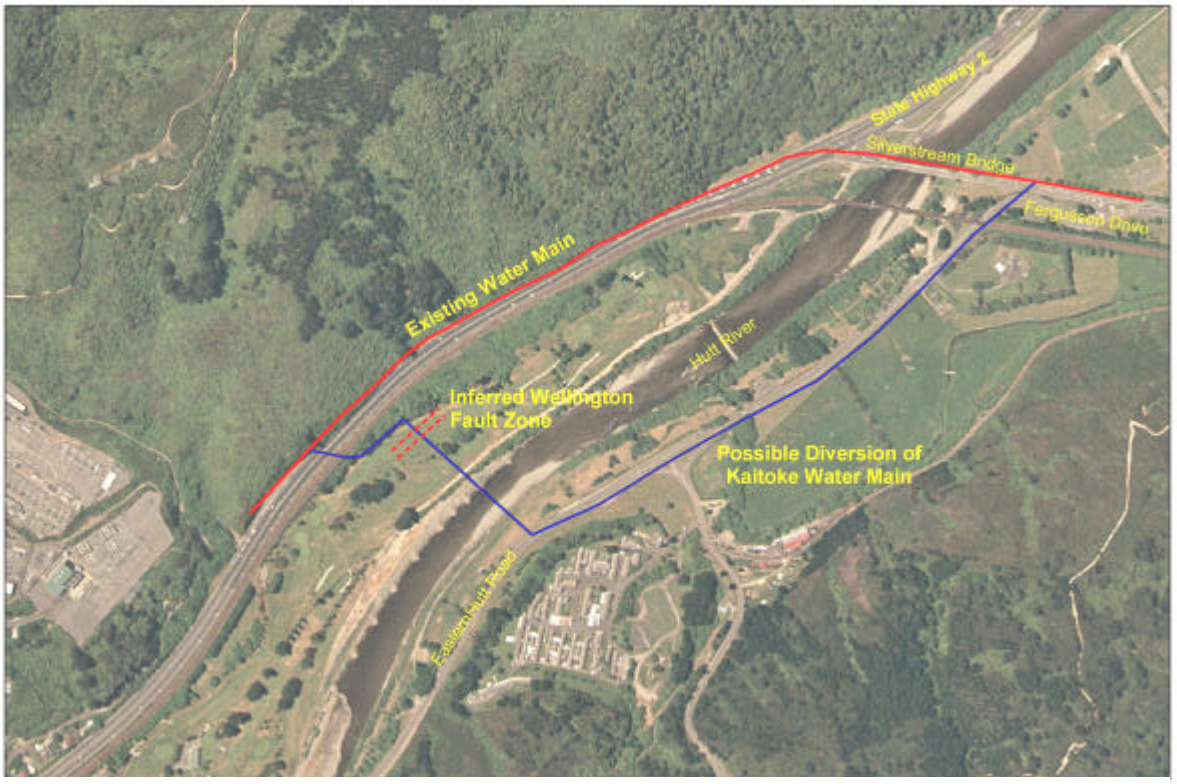

Figure 1 : Existing and possible diversion of the Kaitoke Main

Figure 2 : Silverstream Bridge – water main located on upstream side of the Bridge

The water main is attached to the upstream side of the 160 m long Silverstream road bridge and is 600 mm below the bridge soffit at mid-span. The main on the bridge is expected to have an asset life of 60 years and has a remaining life of approximately 15 years.

4.2 Silverstream Bridge

The Silverstream Bridge, as shown on figure 2, is located on Fergusson Drive at the southwestern end of Upper Hutt. It was built in 1937/8 and has a remaining serviceable life considered to be 36 years. The bridge is in good condition for its age. Carrying 14,500 vehicles per day, the bridge is strategically important to Upper Hutt's roading network and serves as a primary arterial and main access route into Upper Hutt.

The return period of the seismic event that will cause structural damage sufficient to render the existing bridge and the water main unusable is 60 to 90 years. A seismic event with a 60 year return period has a high (50 percent) probability of occurring within the remaining life of the bridge. Currently access to the bridge in flood events greater than 1 in 15 years would not be possible because of inundation of Fergusson Drive.

Upper Hutt City Council proposes in its Strategic Plan to upgrade the bridge in 2004/5 at a cost of $1.15 million. The proposal is to seismically strengthen the bridge and construct a flood bund along Fergusson Drive allowing access to the bridge in up to 1 in 40 year flood events. Funding would be subject to public consultation, obtaining agreement with Hutt City Council (joint owner) and approval of a Transfund New Zealand subsidy.

Strengthening would be to the recommended design return period for a bridge of such importance, that is 1,000 years. It is expected that the strengthened bridge would resist the acceleration forces generated by a Wellington Fault event but would not survive if the fault moves at the site and the fault passes under the bridge. It is likely that it would be neither practical nor economic to design a structure that would resist a Wellington Fault movement.

The current risk to the water main from flood events is relatively small, even though the water main hangs below the soffit at the bridge mid-span, slightly reducing the waterway capacity under the bridge. When the bridge is strengthened, Upper Hutt City Council has requested that the existing main be lifted as high as possible to maximise the waterway capacity under the bridge.

Upper Hutt City Council has asked for a $60,000 contribution towards the bridge strengthening based on the relative additional weight of the water main. The cost of replacing and raising the water main on the bridge is estimated to be approximately $0.4 million.

4.3 Seismic Risk to the Existing Water Main

The buried main, being constructed of moderately ductile steel in good stable ground, has reasonable seismic resistance. However, the bridge and water main are

vulnerable to damage from not only a Wellington Fault event but also smaller more frequent events. Once the bridge is strengthened, it is expected the main on the bridge will only be vulnerable if there is a fault movement at the site and the fault passes under the bridge.

The predicted impact of a Wellington Fault event on the existing water main segment is:

- Five breaks per kilometre on average will require repair, though this is about to be reviewed.
- There should be no significant permanent ground deformation such as landsliding, lateral spreading or liquefaction.
- The water main on the bridge will buckle and fall into the river, although damage to the bridge itself may range from light damage through to partial or full collapse. The water main crossing the bridge will require replacement.
- The water main crossing the fault (if on the western side of the river) will be significantly damaged and require replacement of approximately 200 m.
- Major changes to the Hutt River, including rapid bed accretions and channel realignment, may occur immediately after the event.

To reduce the impact of a Wellington Fault event, materials should be stockpiled and appropriate planning in place for:

- A temporary pipe crossing of the Hutt River at or near the Silverstream Bridge.
- Water main break repairs.
- Water main repairs across the fault.

The capital cost of spare materials, raising the water main on the bridge, and bridge strengthening contribution is estimated to be $0.7 million.

5. Possible Water Main Diversion

5.1 Description

A possible water main diversion, as shown in figure 1, was designed in 1993 and $2.5 million is currently allocated in the 2003/5 capital works programme for its construction. The diversion would start at the intersection of the Eastern Hutt Road and Fergusson Drive, extend south beside the Eastern Hutt Road, cross under the railway underpass and Hulls Creek and then cross the Hutt River with a buried river crossing.

The diversion crosses the Manor Park Golf Course and would connect with the part of the diversion already laid across State Highway 2 and under the railway at the south end of the new State Highway 2 widening.

Transit New Zealand met the cost of the already constructed short length of diversion as a trade-off for making the crossing point further south to suit the highway requirements.

Based on the inferred location of the Wellington Fault, the water main diversion would cross the fault in the Manor Park Golf Course utilising a specifically designed fault crossing. The river crossing site was chosen to enable the water main to be concreted into bedrock under the river.

Transit New Zealand agreed in August 1996 to pay the Wellington Regional Council $0.3 million towards the cost of the deviation in lieu of a 50 percent contribution towards the cost of relocating the section of main affected by the State Highway 2 widening.

5.2 Seismic Risk to Diversion

An assessment of the likely impacts of a Wellington Fault event on the diversion showed:

- Five breaks per kilometre on average will require repair (one of those breaks may occur within the river crossing under the Hutt River).
- There should be no significant permanent ground deformation such as landsliding, lateral spreading or liquefaction.
- The water main at the fault crossing on the western side of the Hutt River will be significantly damaged and require replacement for approximately 75 m.
- Major changes to the Hutt River, including rapid bed accretions and channel realignment, may occur immediately after the event.

To reduce the impact of a Wellington Fault event, materials should be stockpiled and appropriate planning in place for:

- A temporary pipe crossing of the Hutt River.
- Water main break repairs.
- Water main repairs across the fault.

The cost of stockpiled spare materials is estimated to be $0.2 million. The capital cost of spare materials and the diversion is estimated to be $2.3 million. Note that this figure supersedes the cost given in table 1 of Attachment 1, *Kaitoke Water Main Diversion Assessment – Executive Summary*.

6. Comparison of the Existing Water Main and Diversion

Both the existing water main and possible diversion are likely to be significantly damaged in the event of a characteristic Wellington Fault event, although the diversion is likely to suffer less damage. A quantitative probabilistic assessment was completed using a total risk approach to compare present value replacement costs, including damage and repair costs (5 percent rate of return assumed) of the existing water main (without bridge strengthening) segment with the diversion.

The present value of damage and the repair cost is relatively small at less than $40,000 for each option (refer to table 1 in Attachment 1).

To quantitatively analyse the risk of damage, a probabilistic approach (total risk approach) has been taken to include consideration of all possible earthquakes. An average annual damage rate is calculated and then combined with the replacement/repair cost to provide an annualised replacement cost as provided in column 2 of table 1. Assuming construction is carried out now, the present value of the construction cost and the total annualised replacement cost is calculated to provide the present value of replacement cost in column 4 of table 1.

It is difficult to justify the construction of the diversion on economic grounds based on seismic risk. This is often found to be the case when the effects of high impact but low probability events are being assessed. The study does not include indirect costs such as social, economic or public health impacts, which are likely to be considerable. Indirect costs resulting from damage to a part of the system are difficult to assess when there is widespread regional damage. The need for the Silverstream segment to be operational will depend on upstream and downstream damage to the water main and other facilities.

Subsurface conditions on the western hills along State Highway 2 are complex and difficult to determine accurately, and are subject to considerable interpretation. Surficial soils and steeper slopes may fail onto State Highway 2 under a seismic load, impeding access for main break repairs. No allowance has been made for impeded access.

The time to restore water after a seismic event is critical. The total time to recover is influenced by the extent of damage, resources available and the priority assigned to the work. Estimates of recovery times are problematical, as there will be very high and competing demands on available resources following an earthquake. Any pre-earthquake capital improvements and planning that significantly reduce the time to recover will be very advantageous.

Estimates of time to repair are 5 to 7 days for the existing water main segment and 3 to 5 days for the diversion, or 5 to 7 days if the Hutt river crossing requires repair. These estimates are based on engineering judgement and assume that water, plant, staff, contractors, materials and machinery are available, and concurrent repairs are made.

However, it is the marginal difference in the time to recover for the two options that is the key to the comparison.

There is only a small difference between the recovery for the existing and diversion option.

In summary, the comparison is:

	Comparison	Existing Main (Strengthened Bridge) $ million	Diversion
1.	Contribution to bridge strengthening Stockpile spare material Raise main on bridge Diversion construction	0.06 0.25 0.40 -	- 0.2 - 2.1
	Total	0.7	2.3
2.	Approximate length of damaged pipe at fault, after fault movement event.	200 m	75 m
3.	Breaks per kilometre after a fault movement event.	5	5
4.	Time to repair following a fault movement.	5-7 days	3-5 days*

* Assumes no breaks at the river crossing. This increases to 5-7 days if the river crossing requires repair.

While the majority of the senior managers in the Utility Services Division believe the cost of the diversion does not justify the benefits of a reduced repair time, a minority believes the cost is justified.

7. Discussion

The Beca Carter Hollings and Ferner Ltd study focused on an engineering assessment of the direct effect of a Wellington Fault movement on the alternative water main routes. The time for repair of the two options is based on unrestricted availability of resources for the repair works. The costs do not include the costs to the community of not having a sufficient water supply.

Damage predictions for the water supply system are less severe for seismic events involving movement of other faults in the Region. The diversion is unlikely to be damaged as a result of these smaller earthquakes but the existing water main is likely to rupture at the Silverstream Bridge abutments. Rapid loss of water from the rupture will damage the road approaches to the bridge. These differences are reflected in the probabilistic risk analysis. Significant damage to the bridge and the water main on the bridge is unlikely to occur if the bridge and the pipeline are strengthened as proposed by the bridge owners, unless the fault moves at the site and the fault passes under the bridge.

A major seismic event will cause extensive damage to buildings, roading and utilities. Resources (equipment, materials and appropriately trained personnel) to carry out repair work will be limited. Roading and service authorities will be competing for resources for the repair of damaged facilities. A large number of repair crews from other areas of New Zealand will be required to carry out the repair works. Concurrent repair of the damage on the existing water main is unlikely to be possible in the Wellington Fault event. The time to repair the existing main could be greater than the 5 to 7 days assumed. This only becomes critical if the water service from Te Marua to the Silverstream Bridge is repaired before the pipeline at the bridge is repaired.

The health, social, financial and environmental implications of areas in the Wellington Region being without water for more than 48 hours is significant. Providing temporary water supplies sufficient for only drinking and cooking to Wellington City residents and the hospitals for any length of time will require a major operation. Temporary water supplies would not provide sufficient water for washing, toilets, firefighting and reconstruction of buildings and infrastructure. Industry and commercial offices will be unable to function without a water supply. Every day without water has a significant effect.

The majority of the damage to the water supply network will not be evident until water is returned to the water mains. Repair work to local reticulation will be dependent on the resumption of wholesale water supply. The length of time it takes to restore water supplies to an area will be compounded by the upstream failures of the water supply system.

Other sections of main that are vulnerable to earthquake damage are also being investigated. In particular the section of the Kaitoke main immediately south of that under report has a high risk of damage.

The section of the Kaitoke main between State Highways 2 and 58 follows the side of a steep narrow gully beneath the Haywards TransPower substation. There is a high risk of failure of this steep slope in an earthquake. Reinstating the main would be difficult and time consuming.

A report is presently in preparation describing and quantifying this risk, and examining the benefits and cost of relocating this section of main.

8. Customer Consultation

There is a paradox in assessing the effects of major seismic events on lifelines. Fortunately major earthquakes in countries with a similar level of infrastructure to that in New Zealand are relatively rare. This rarity though means there is limited information available on which to base an engineering assessment of the performance of water utilities during a major earthquake.

The four city customers have been consulted about this particular issue following a detailed presentation. Perhaps not surprisingly, the customers do not have a unanimous view. Three customers feel that the diversion option cannot be justified at $2.3 million estimated cost based on the damage scenarios and estimated repair times. One of the customers felt that, although the cost is high, the social and economic indirect benefits are sufficient to justify the work proceeding. There is also a divergence of opinion whether an above river crossing for a pipeline (on a bridge) is better than a crossing below the bed of a river.

This relates to the ease in repairing an above ground pipe compared to repairing a pipe buried beneath a river should the need arise.

9. Summary

The Hutt River crossing at Silverstream and the adjacent Wellington Fault crossing is a vulnerable element in the wholesale water system during seismic events, particularly a Wellington Fault event. A $2.5 million diversion is proposed in the 2003/5 capital works programme to reduce this vulnerability. Construction of a diversion cannot be easily justified on the basis of seismic risk. Both the existing water main and diversion are likely to be significantly damaged in the event of a characteristic Wellington Fault event, although the diversion is likely to suffer less damage.

Based on investigations and the assessment of relative risk expressed both in terms of present value replacement cost and the relative time to repair and restore water, the diversion cannot be easily justified. There is no significant difference in times to recover between the existing and diversion options.

To reduce the impact of a Wellington Fault event, materials should be stockpiled and appropriate planning in place for:

- A temporary pipe crossing at Silverstream Bridge.
- Water main break repairs.
- Water main repairs across the fault.

The proposed strengthening of the bridge to resist seismic shaking offers a significant reduction in risk at moderate cost and also provides other community benefits. However, the strengthened bridge is unlikely to be able to sustain damage resulting from a Wellington Fault event if the fault moves at the site and the fault passes under the bridge. Support should be provided to Upper Hutt City Council's proposal to seismically strengthen the Silverstream Bridge, and Upper Hutt and Hutt City Councils should be encouraged to give this work urgency.

10. Recommendations

That the Committee:

(1) Note the risks associated with the Kaitoke water main at Silverstream Bridge.

(2) Support Upper Hutt City Council's proposal to seismically strengthen the Silverstream Bridge to a level suitable for a lifeline, and advocates that this work be given a high priority.

(3) Note $0.25 million is included in the 2003/4 capital works programme for the stockpiling of spare materials.

(4) *Note that a sum of $0.46 million has been allocated in the capital*

works programme for a contribution to the seismic strengthening of the Silverstream Bridge and raising of the water main on the bridge when the bridge owners decide to proceed with the seismic strengthening work.

(5) *Note that the Silverstream diversion project will be deleted from the 10 year capital works programme.*

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Attachment

1 Executive Summary, *Kaitoke Water Main Diversion Assessment*, Beca Carter Hollings and Ferner Ltd

Kaitoke Water Main Diversion Assessment
Executive Summary

Beca Carter Hollings and Ferner Ltd

Note:

Construction costs in table 1 do not include the stockpile of materials, bridge strengthening contribution and raising pipe on the bridge. The diversion construction cost has been significantly revised and reduced to allow for an agreed Transit New Zealand contribution and pipeline already laid.