greater WELLINGTON
THE REGIONAL COUNCIL

Report 03.146
Date 18 March 2003
File B/09/02/02

Committee Utility Services
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Possible Kaitoke Water Main Diversion - State Highway 2 to State Highway 58

1. Purpose

To background the seismic risks associated with the Kaitoke wholesale water main between State Highway 2 (SH2) and State Highway 58 (SH58), and gain approval to relocate this section of the water main along a less vulnerable route.

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* identified the Kaitoke main between SH2 and **SH58** as vulnerable to landslides triggered by earthquakes. Subsequently the ***Wellington Regional Council Bulk Water Supply – Seismic Security Assessment, July*** *1993* confirmed this vulnerability.

An alternative route following SH58 has been investigated and $1.8 million programmed in the draft capital works programme in 04/05 to construct a new water main along this route. The existing water main alignment and proposed diversion are shown in Figure 1.

This paper makes a direct comparison of seismic risks to the existing water main segment and the proposed diversion based on a study carried out by Beca Carter Hollings & Ferner Ltd. The study's Executive Summary is appended as Attachment 1 as background information.

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 seismic 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 metre horizontal and 1 metre vertical fault movement. The event has an average recurrence interval of 600 years, and the elapsed time since the last rupture is approximately 340 to **490** years. The probability of a Wellington Fault event occurring in the next 50 years is approximately 10%.

The existing water main segment is at a distance of approximately 100 metres to 600 metres from the Wellington Fault. Given this very close proximity, strong near-fault ground shaking is expected.

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

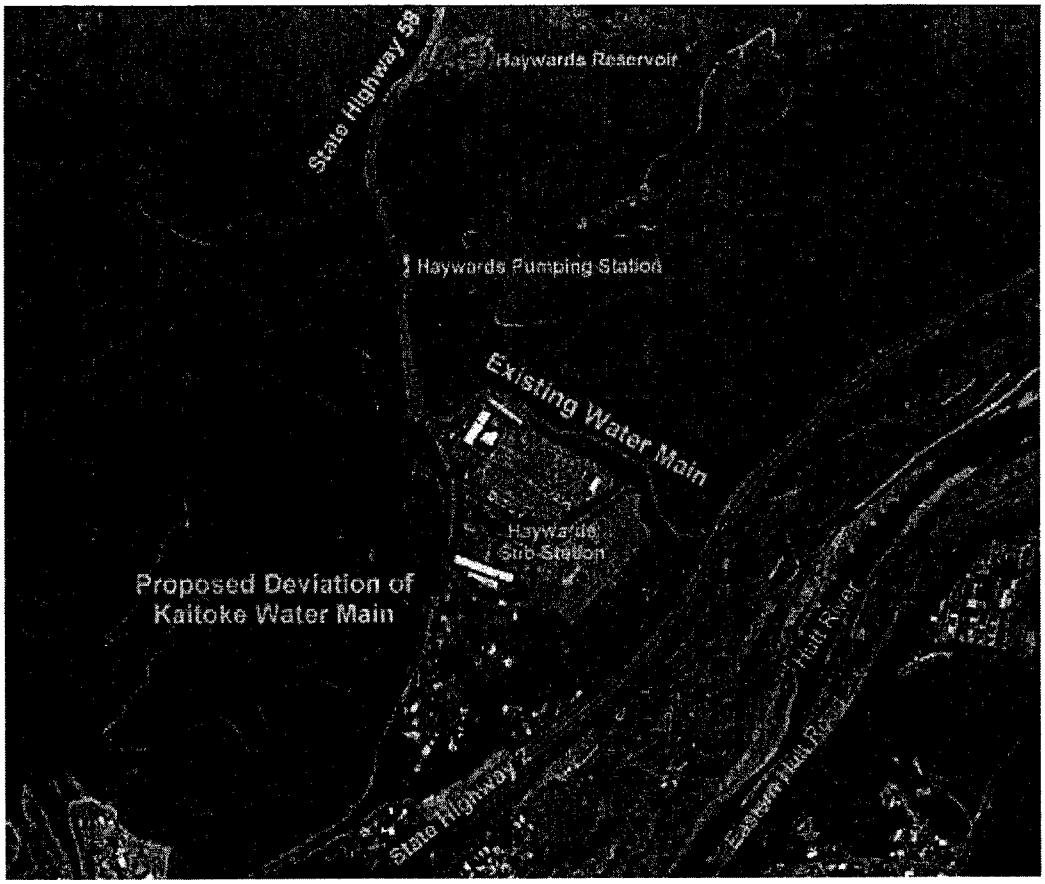

Figure 1 : Existing and proposed diversion of the Kaitoke Main.

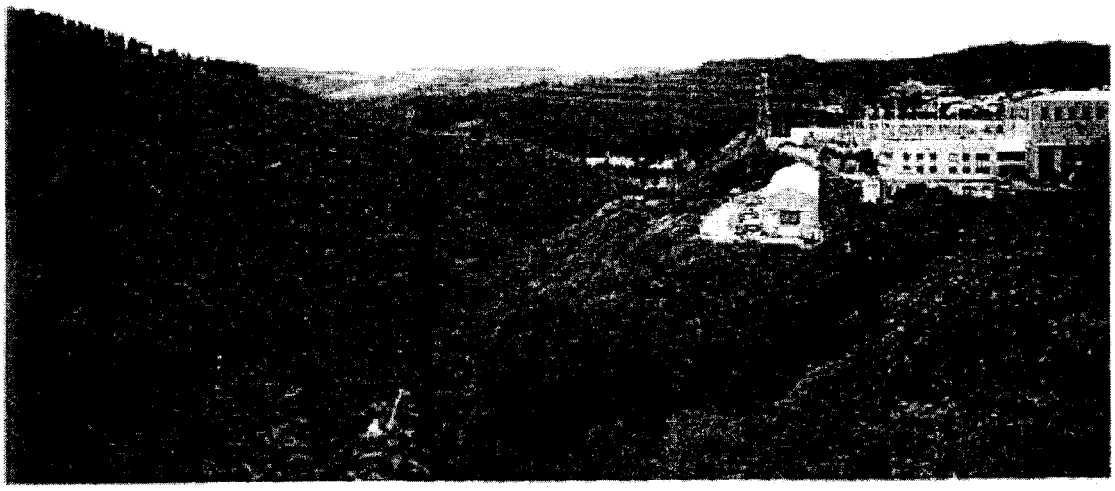

Figure 2 : Steep terrain along Old Haywards Hill Road portion of Water Main (on hillside below Haywards substation).

4. Existing Water Main

4.1 Description

The 700 metre long water main segment under consideration runs from the point where the Haywards Stream crosses SH2 up a steep slope to Old Haywards Hill Road. The main then follows Old Haywards Hill Road to the junction with SH58. Carrying approximately 35 percent of the Region's water, the 36'' diameter welded joint steel main was constructed between 1951 and 1953. 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.

The Old Haywards Hill Road runs across steep weathered greywacke rock terrain. Gullys have been formed by preferential erosion in the rock, and some gullys have been partially filled in with eroded material (colluvium). Colluvium has also been deposited on slopes at some locations. Weathering of the greywacke rock has also occurred.

The colluvium is more susceptible to instability than the parent rock. Where the colluvium predominates, a number of slips have occurred below the road indicating these areas are marginally stable. **A** rise in water level after prolonged rainfall may be sufficient to cause instability at these locations, with or without seismic loads.

The Old Haywards Hill Road has been formed by cutting into the side of the steep hill. It is probable that the outer section of the road is constructed from fill material placed on the slope. Crib retaining walls have been used to retain the ground above the road in some areas, indicating the presence of potentially unstable material.

Telecom use Old Haywards Hill Road for a fibre optic cable as part of their network.

4.2 Seismic Risk to Existing Water Main

Records and observations from previous earthquakes around the world show that the performance of underground pipelines during an earthquake is strongly correlated to whether the pipe is subjected to permanent ground deformations and, to a lesser extent, ground shaking. Permanent ground deformation may be due to a wide variety of causes. Examples are deep-seated landslides, seismic settlement, lateral spreading due to liquefaction, fault movement and differential pipe movement.

The major hazard to the existing watermain is landslides resulting fkom seismic shaking acceleration, which will result in damage to, or complete loss of, the water main, and severely limit access to effect repairs.

Little information exists for statistical comparison of actual reported damage for similar water mains in similar ground conditions. Instead an assessment of the extent of slope failure, its effect on the water main and the probability of damage has been carried out in order to estimate the likely damage to the water main.

Damage estimates reflect the nature of the terrain and the likely slope failure effects following an earthquake event. The estimated extent of damage for two earthquake intensity ranges is shown in Table 1. The damage assessment is based on a lower to upper bound assessment for expected earthquakes.

*Earthquake Intensity**	*Effects*	*Mean Return Period (in Wellington)*	*Water Main Damage Estimate*
MMVII – VIII	Likely to have major and severe slope failure effects. Effects include debris and trees falling onto the access track, deep seated hillside failures and localised landslides.	32 to 100 years	95 metres (14%)
MMIX – X	e.g. a Wellington Fault event. Likely to cause major and severe slope failure effects, including deep seated hillside failures and landslides.	Over 370 years	360 metres (51%)

* Expressed in terms of the modified Mercalli scale

Table 1 : Assessment of Water Main Damage

Water main breaks ocurring during earthquakes will result in water discharging at the pipe break points down the adjacent hillside to the Haywards Stream. The stream crosses SH2 and the Wairarapa Railway Line and then meanders through the Manor Park Golf Course before discharging to the Hutt River. Damage from water flows could range from minor golf course damage (stream bank erosion and flooding) to flooding and erosion of SH2 and the Wairarapa Railway Line.

If major slope failures occur during an earthquake, it is likely that landslide debris could deposit in the stream course. An unstable damming of water in the stream may result. Any subsequent dam failure could result in a large surge of water and debris which could block and/or erode SH2 and/or the Wairarapa Railway Line.

The Haywards Substation, owned by Transpower, is at the top of slopes adjacent to the water main. A water main burst may affect the slopes surrounding the substation. In particular, the Upper Hutt line termination tower is at the top of a slope adjacent to the water main. The vulnerability of this tower to being undermined by a water main burst, has been assessed. The tower is indicated to be founded on large diameter cylinder, probably on bedrock, although this is not known for certain. A water main break itself is unlikely to undermine the termination tower foundations before water from the burst is turned off. Further investigation of the ground conditions is required to assess this risk with certainty.

The Telecom fibre optic cable along Old Haywards Hill Road would also be vulnerable to seismic events.

5. Proposed Water Main Diversion

5.1 Description

A 1500 metre water main diversion, as shown in Figure 1 between SH2 and SH58 has been investigated. $1.8 million is allocated in the draft capital works programme in 2004/05 to construct the diversion. The proposed water main route continues south of Old Haywards Hill Road along SH2 and McDougall Grove, west along a short section of walkway then up a steep slope at the head of a gully and north along the uphill side of SH58 to join with the existing main at the top of the Old Haywards Hill Road.

The final route selection will be dependent on detailed investigation, roading, upgrade proposals, other services, property requirements and geotechnical investigations. The route selection from McDougall Grove to SH58 requires further investigation to minimise the water main length and reduce risks due to earthquake and slope failure hazards.

5.2 Seismic Risk to Diversion

Observed pipeline performance under earthquake loads from around the world indicates that damage is strongly correlated to whether the pipe is subjected to permanent ground deformations and to a lesser extent, to ground shaking. Permanent ground deformation may be due to a wide variety of causes (e.g. deep-seated landsliding, seismic settlement, lateral spreading, fault movement and differential pipeline movement).

The risk from permanent ground deformation such as landslides along the alternative route is assessed as not significant, and the damage to the water main has been assessed considering it as a general 'buried pipeline'. It is expected that damage to the proposed water main would be as shown in table 2. It should be noted that the diversion does not completely eliminate the risk of failure of the main and emergency materials and appropriate emergency planning are to be put in place.

Earthquake Intensity	*Effects*
MMVII – VIII	1 break
MMIX – X	Up to 8 breaks

Table 2 : Assessment of Likely Damage to Diverted Water Main

Estimates of general buried pipeline breaks are based on very limited knowledge and experience from the repair of water mains in other parts of the world. The time to repair breaks is dependent on whether the break location is known and/or water is available to locate or test repairs.

Pipe breaks occurring during earthquakes will result in water discharging at the break points. Road pavements and subgrades will be compromised at pipe break points. Flooding of roads and houses adjacent to SH58 may occur.

To assist with repairs, additional isolating valves will be considered as part of the diversion design. Once the diversion is complete, the superseded section of the existing water main would be decommissioned to reduce the risk of water damage from water main breaks.

6. Comparison of the Existing Water Main and Diversion

While both the existing water main and proposed diversion are likely to be damaged in the event of a Wellington Fault event, the diversion is likely to suffer considerably less damage. A quantitative probabilistic assessment has been 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 segment with the diversion.

This approach includes 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 shown in column **2** of table **ESl** in Attachment 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 ES 1 in Attachment 1.

The present value cost of damage/repair costs (excluding professional and contingency fees) and construction costs for the existing main and proposed diversion are $3.6M and $1.8M respectively. That is, when discounted back to this point in time, the total cost of damage and repair of the existing main is approximately double the cost of constructing a new main. The benefit/cost ratio is 2.

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 likely to be widespread regional damage. The need for the **SH2** to **SH58** segment to be operational will depend on upstream and downstream damage to the water main and other facilities.

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 difficult, as there will be very high and competing demands on available resources following an earthquake. Any pre-earthquake capital improvements and planning that significantly reduces the time to recover will be very advantageous. The time for repair of the two options is based on unrestricted availability of resources for the repair works, including stockpiled pipe and fittings. Non-availability of stockpiled pipe and fittings will increase the repair time by up to 12 weeks.

Estimates of times to complete repairs are 90 to 120 days for the existing main and 8 to 15 days for the proposed diversion for an MMIX – **X** intensity event (e.g. a Wellington Fault event). For a moderate event MMVII – VI11 the times

to complete repairs are 25 to 45 days and 1 to 3 days for the existing and proposed mains respectively. Where major slope failures have occurred, a working day of 24 hours has been assumed. Some concurrent repair is assumed for diversion repairs.

There is a significant difference in the time to recover for the two options of approximately 80 to 100 days for a Wellington Fault event.

The cost and the time required for repairs are significantly in favour of the proposed diversion because of the lower **risk** from landslides and much easier access to the main. The vulnerability of the existing main to smaller, more frequent earthquakes suggests that it will be damaged more frequently than the proposed diversion.

In summary the comparison is shown in table **3.**

	Comparison	*Existing Main*	*Diversion*
1.	Construction cost		\$1.8M
2.	Pipe Damage		
	Earthquake Intensity		
	MMVII – VIII	95m	1 break
	MMIX – X *	360m	**up** to 8 breaks
3.	Present Value of Damage and Construction Cost	\$3.6M	\$1.8M**
4.	Time to complete repairs		
	MMVII – VIII	*25* to 45 days	1 *to* **3** days
	MMIX – X *	90 to 120 days	8 to 15 days

* e.g. a Wellington Fault Event
** The present value **of** the damage cost to the diversion is less **than** \$5,000.

Table **3** *: Comparison* ***of*** *the Damage/Construction Costs and Recovery Time for Existing Main and Proposed Diversion.*

Consideration was given to the use of a smaller capacity (25%) temporary above ground unrestrained pipe (such as PE) for the 700 metre segment repair. However, this relies on the availability of stockpiled pipe and fittings or immediate manufacture. Apart from potential construction difficulties, the additional temporary repair costs would further increase the present value of damage and construction costs for the existing water main. In the case of a Wellington Fault Event, a temporary above ground pipe repair time may be in the order of **20** to 50 days or 40 to 70 days should priority pipe manufacture be unavailable with additional repair costs in the order of \$0.35 million to \$0.9 million.

The 700 metre segment of water main from the top of the Old Haywards Road to the Haywards reservoir is also vulnerable to damage from seismic events. A detailed **risk** analysis of this section will be carried out in the future. However, plans to realign SH58 have a significant influence on the vulnerability of the pipe, and it may be best to co-ordinate the water main upgrading with the

highway upgrade.

7. Discussion

The Beca Carter Hollings and Ferner Ltd study focused on an engineering assessment of the direct effect of seismic events on the existing main and the proposed diversion. 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.

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.

The health, social, financial and environmental implications of areas in the Wellington Region being without water for more than 48 hours are significant. Providing temporary water supplies sufficient for only drinking and cooking to Wellington City residents and the hospitals for any length of time will be 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 will be significant.

The majority of the damage to the water supply network will not be evident until water is returned to the water mains. Repair of 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 upstream failures of the water supply system.

Strengthening of the existing water main between SH2 and SH58 could be carried out by relocating some sections of the water main onto bedrock, stabilising the rock with rock anchors and strengthening other higher risk sections in potentially unstable colluvium slopes and gullies. However, this work would be very costly and the risk reduction achieved limited and uncertain compared to the diversion. The proposed diversion seeks to reduce the risk by providing a route less susceptible to landslides and with better access for repair.

An upgrade of SH58 at Haywards Hill is proposed by Transit New Zealand and there would be advantages in installing the new water main in conjunction with this upgrade. Transit is committed to the upgrade once all the necessary requirements, such as resource consents, land, funding and designation are achieved. However, there is uncertainty as to the timing of the upgrade. The Transit Draft State Highway Programme for 2003/04 is proposing to delay the project with construction beyond their 10 year programme period (20 12/2013).

On the basis of present knowledge of the proposed highway upgrade, the diversion could be laid within the existing road without the need to make any major adjustments to accommodate the new highway alignment.

a. Summary

The SH2 to SH58 segment of the Kaitoke main is a very vulnerable element in the wholesale water system during seismic events. A $1.8 million diversion is proposed in the 2004/05 draft capital works programme to reduce this vulnerability. The cost and the time required for repairs are significantly reduced by the diversion.

The assessed vulnerability of the existing pipeline route to small frequent earthquakes results in expected losses significantly in excess of those for the proposed diversion. Based on the investigations and assessment of relative risks the proposed diversion is a viable option and is justified in economic terms.

The diversion of the pipeline between SH2 and SH58 should be constructed as soon as practicable. It should be noted that the diversion does not completely eliminate the risk of damage to the water main and emergency materials and appropriate emergency planning measures are to be put in place.

9. Recommendations

That the Committee:

(1) ***Note*** *the risks associated with the segment of the Kaitoke water main between SH2 and SH58.*

(2) ***Note*** *that $40,000 is included in the draft capital work programme for 2003/2004 for investigation and design of the diversion.*

(3) ***Note*** *that $1.8 million is included in the draft capital works programme for the construction of the diversion in 2004/2005.*

(4) ***Note*** *that the diversion does not completely eliminate the risk of damage to the water main, and emergency materials and appropriate emergency planning are to be put in place.*

Report prepared by:	Report approved by:	Report approved by:
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Attachments

1 Executive Summary, ***Kaitoke Main*** *SH2 to SH58* ***Seismic Risk,*** Beca. Carter Hollings and Femer Ltd

Kaitoke Main SH2 to SH58 Seismic Risk Assessment Executive Summary

Beca Carter Hollings and Ferner Ltd

Executive Summary

Beca Carter Hollings & Ferner Ltd (Beca) has been commissioned by the Wellington Regional Council (WRC) to review the seismic risk to the section of the Kaitoke water main between State Highway 2 and SH 58 (Old Haywards Hill Road), and a proposed alternative route. These routes are shown in Appendix B.

The Lifelines in Earthquakes, Wellington Case Study, 1991, identified a number of potentially vulnerable parts of the wholesale water supply pipeline, including the Hutt River crossing at Silverstream, the adjacent Wellington fault crossing and the segment along the Old Haywards Hill Road (OHHR).

Beca (July 2001) provided an assessment and a comparison of risks for the Hutt River and Wellington fault crossing segments of the pipeline and the proposed diversion.

This desktop study required Beca to review and extend the findings of previous reports on the OHHR segment by OPUS International Consultants Ltd. The evaluation of the seismic risk has been completed by assessing likely repair costs and times for both the existing main along the *OHHR* and the alternative route. The risk from earthquake for the *two* routes can now be compared.

We have assessed the risk in terms of present value replacement cost and the relative times to repair both options to restore water supply. The results of our assessment are summarised in Tables ES1 and ES2.

Table S1

Present Value of Cost (rounded) Comparison

Option	Total Annualised Damage/Repair Cost	Construction Cost	Present Value Cost (rounded)
Existing Pipeline	$180,000	-	$3.6 million
Alternative Route	$230	$1,800,000	$1.8 million

Table E 2

Estimated Time to Complete Repair Comparison

	Estimated time to complete repair for MM intensity (days)		
	V - VI	VII – VIII	IX – X (e.g. a Wellington Fault Event)
Existing Pipeline	0 to 25	25 to 45	90 to 120
Alternative Route	0	1 to 3	8 to 15

The above estimates of annualised repair cost are based on an assumption that the repairs carried out after an earthquake would result in the pipeline being of the same standard as it was before the damage (i.e., subsequent losses, in earthquakes of the same size, would result in the same level of damage).

The cost and the time required for repairs are significantly in favour of the alternative route. This is because of the much smaller risk from the landslides and the much easier access to the route. The assessed vulnerability of the existing pipeline route to small frequent earthquakes results in expected losses significantly in excess of the alternative route. The time for repairs assessment is based on some repairs being carried out concurrently for the alternative route.

We conclude that the proposed alternative route is a viable mitigation option. However, as this option does not completely eliminate the risk of failure of the main, we recommend that the WRC prepares now for the likely repairs required following a significant earthquake by:

- Preparing an emergency repair plan for repairing this segment of the wholesale water supply network
- Determining appropriate quantities and stockpiling repair materials in an easily accessible adjacent location.
- Entering into agreements with appropriately skilled contractors with appropriate equipment to undertake the repairs immediately following an earthquake.
- Entering into mutual aid agreements with other local authorities with a similarly skilled workforce for sharing skilled manpower and equipment in the event of an earthquake.
- Preparing a methodology to review and update the emergency plans on a regular basis.

We further recommend that the WRC consider undertaking the same types of preparations for emergency repairs to restore water supply service for the rest of the bulk water supply network. This is, of course, also applicable to the segment along the Old Haywards Hill Road, if WRC opts not to proceed with the construction of the alternative route.

Beca previously assessed (Beca, 2001) that the present value of annual repair costs for the Te Mama to Karori water supply main is approximately $440,000. A simple quantitative analysis used the same probabilistic total risk approach expressed in present value terms (assuming a 5% rate of return). It is likely that this number would increase if the results of the assessment for the existing segment of the pipeline along the OHHR were included.