NATIONAL ENERGY BOARD

IN THE MATTER OF the *National Energy Board Act*, R.S.C. 1985, c. N-7, as amended, (the "*Act*") and the Regulations made thereunder;

IN THE MATTER OF the *Canadian Environmental Assessment Act*, S.C. 1992, c.37, as amended, and the Regulations made thereunder;

AND IN THE MATTER OF an Application by TransCanada Keystone Pipeline GP Ltd., as the general partner acting on behalf of the TransCanada Keystone Pipeline Limited Partnership, for a certificate of public convenience and necessity authorizing the construction and operation of oil transmission facilities pursuant to Part III of the *Act*, approval of a change in service for an existing pipeline under section 43 of the *Onshore Pipeline Regulations, 1999,* and approval of the tolls and tariff for the facilities pursuant to Part IV of the *Act*.

AFFIDAVIT OF MARK STEPHENS

I, MARK STEPHENS, of the City of Edmonton, in the Province of Alberta, MAKE OATH AND SAY THAT:

1. I am the Manager, Integrity Management, Pipelines and Structures for C-FER Technologies (1999) Inc. ("**C-FER**") and as such I have knowledge of the matters and facts deposed herein.

2. C-FER was retained by TransCanada Keystone Pipeline GP Ltd. ("**Keystone**"), the applicant in this proceeding before the National Energy Board, to carry out a quantitative analysis of the release volumes associated with a possible failure of the Canadian portion of the pipeline proposed in the Keystone Pipeline Application.

3. A report entitled "Outflow Modelling of the Canadian Portion of the Keystone Pipeline", dated February 2007 ("**Outflow Modelling Report**"), was prepared by me or under my direction and control and is true and accurate to the best of my knowledge and belief.

4. The Outflow Modelling Report, attached as Exhibit "A" to this affidavit, is Appendix 8-12 to the Keystone Pipeline Application and was filed with the National Energy Board on March 5, 2007 as Exhibit B-9c to Hearing Order OH-1-2007.

5. I make this affidavit in support of the Keystone Pipeline Application and for no improper purpose.

Sworn before me at Edmonton, Alberta on May 31 , 2007	))))	
A Commissioner for Oaths for the Province of Alberta	))	Mark Stephens

LESLEY C. WILSON
EXPIRES SEPTEMBER 28, 2009

This is Exhibit "A" referred to
in the Affidavit of Mark Stephens
Sworn before me this 31 day of May, 2007.

A Commissioner for Oaths in and for
the Province of Alberta
LESLEY C. WILSON
EXPIRES SEPTEMBER 28, 2009

APPENDIX 8-12

OUTFLOW MODELLING OF THE CANADIAN PORTION OF THE KEYSTONE PIPELINE

C-FER Technologies

200 Karl Clark Road
Edmonton, Alberta
Canada T6N 1H2
Tel 780.450.3300
Fax 780.450.3700
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Final Report

Outflow Modelling of the Canadian Portion of the Keystone Pipeline

Prepared for
TransCanada Keystone Pipeline GP Ltd.

February 2007
M003100

Final Report

Outflow Modelling of the Canadian Portion of the Keystone Pipeline

Prepared for
TransCanada Keystone Pipeline GP Ltd.

Prepared by
Marissa McKay, EIT

Reviewed by
Mark Stephens, MSc, PEng

PROFESSIONAL ENGINEER ALBERTA
M. J. STEPHENS
26 Feb 2007

PERMIT TO PRACTICE
C - FER Technologies
Signature
Date Feb 26 / 2007
PERMIT NUMBER: P 04487
The Association of Professional Engineers, Geologists and Geophysicists of Alberta

February 2007
M003100

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1. INTRODUCTION

1.1 Objective and Scope

At the request of TransCanada Keystone Pipeline GP Ltd. (Keystone), C-FER Technologies (1999) Inc. (C-FER) carried out a quantitative analysis of the release volumes associated with possible failure of the Canadian portion of the proposed Keystone pipeline running from Hardisty, Alberta to markets in Illinois, USA. The Canadian portion of the Keystone pipeline, extending from Hardisty, Alberta to a point near Haskett, Manitoba at the Canada/USA border, will include 271 km of newly constructed pipeline in Alberta, the conversion of 864 km of existing natural gas pipeline in Saskatchewan and Manitoba, and 100 km of newly constructed pipeline in Manitoba. The objective was to calculate the expected release volumes associated with three different failure scenarios characterized by hole sizes representative of a small leak, a large leak and a rupture.

1.2 Report Organization

The analysis approach used in calculating outflow volumes is described in Section 2. The different product and throughput scenarios analyzed, as well as the modelling assumptions made, are described in Section 3. The analysis results obtained for each of the scenarios, based on the elevation profile data as provided, are described in Section 4. Analysis results, with adjustments to the spill volume estimates for the converted portion to account for the impact of low-resolution elevation profile data on drainable length estimates, are described in Section 5. A summary of results is provided in Section 6.

2. ANALYSIS APPROACH

The calculation of the total outflow volume associated with failure at a given location was based on estimates of the product release rate before and after leak detection, the time required to detect and respond to the release event, and the drainable volume associated with the failure location.

For large leak and rupture failures, where the release rate is typically a significant fraction of the normal pipeline flow rate, it was assumed that actions will be taken to shut in the pipeline as soon as a leak is detected. For these cases, the release rate estimate was based on an assumed hole size and an effective driving pressure equal to a fraction of the normal operating pressure at the point of failure. (The effective driving pressure was determined with due consideration of the pressure drop following failure and the effective hydrostatic pressure head acting at the point of failure.) The release volume prior to shut in was calculated by multiplying the effective initial release rate by the time required to detect and isolate the portion of the line containing the failure location by closing the surrounding block valves. The total release volume was estimated as the sum of the volume released prior to shut in and the drainable volume associated with the failure location. The drainable volume was estimated from the elevation profile of the line segment between the block valves surrounding the failure location, assuming that liquid at elevations below the point of failure and liquid contained in 'hanging valleys' above the point of failure will not escape.

For small leaks, where the release rate is typically a very small fraction of the flow rate, it was assumed that actions will be taken to locate and stop the leak as soon as it is detected. In addition, it was assumed that normal operating conditions will be maintained during this time. For this case, the release rate estimate was based on an assumed hole size and a driving pressure equal to the normal operating pressure. The total release volume was calculated by multiplying the release rate by the time required to detect and then stop the leak.

3. SCENARIO DESCRIPTIONS

3.1 General Assumptions

The diameters and wall thicknesses used in this analysis are summarized in Table 3.1.

Table 3.1 Pipeline Properties

Segment	Diameter (mm)	Wall Thickness (mm)
Alberta	762	9.8
Converted	864	9.53
Manitoba (0 - 10 km)	864	11.1
Manitoba (10 - 100 km)	762	9.8

Three different hole sizes were considered in calculating releases volumes resulting from possible line failure. A small leak was defined as one that results from a hole having a mean diameter of 1.5 mm. As the release rate will be a very small percentage of the flow rate, this leak will not be detected by the leak detection system (LDS). As such, it was assumed that this leak would be detected by line patrol or a third party, and the time required for detection was taken to be one-half of the line patrol frequency. Assuming a bi-weekly patrol frequency for this line, the time to detection was taken to be 7 days. Following detection, it was further assumed that normal operating conditions would be maintained and that the time to stop the leak would be 18 hours. This 18-hour assumption takes into account the time required to find the leak, mobilize for in-service repair and effectively control the leak.

A large leak was taken to be one that results from a hole with a mean diameter of 50 mm. The LDS will detect this leak, as it will be a significant fraction of the normal operating flow rate, and following detection, it was assumed that action will be taken to shut in the pipeline. Based on the LDS data provided by Keystone, detection was assumed to occur when the accumulated volume loss reached 217 m^3 as determined over a rolling 90-minute time window. Following detection, shut in was assumed to occur by valve closure, with an effective closing time of 63 minutes for remotely-controlled valves (60 minutes for pipeline shutdown and 3 minutes for remote valve closure) and 24 hours for manually-controlled valves. (Closure time estimates were supplied by Keystone.)

A rupture was taken to be a hole in the pipeline with a diameter equal to the line diameter. In this case, as the release rate from the rupture will be similar to the operating flow rate, it was assumed that the LDS will detect the leak. Again, based on LDS data provided by Keystone, detection was assumed to occur when an accumulated volume of 134 m^3 was lost within a rolling 5-minute time window. Following detection of a rupture, the line was assumed to be shut in, with an effective valve closure time of 20 minutes for remotely-controlled valves and 250 minutes for manually-controlled valves. (Closure time estimates were again supplied by Keystone.)

The leak detection and valve closure assumptions for all failure modes are summarized in Tables 3.2 and 3.3.

Table 3.2 Leak Detection Assumptions

Leak Size	Hole Size	Detectable Volume	Time to Detect	Time to Leak Control
Small leak	1.5 mm	N/A	7 days	18 hours
Large leak	50 mm	217 m^3	N/A	N/A
Rupture	Line diameter	134 m^3	N/A	N/A

Table 3.3 Valve Closure Assumptions

Leak Size	Effective Valve Closure Time		
	Remote Valve	Manual Valve	Check Valve
Small leak	N/A	N/A	N/A
Large leak	63 min	24 hr	N/A
Rupture	20 min	250 min	N/A

3.2 Case-specific Assumptions

In performing the analysis, two cases were analyzed reflecting two products (a synthetic crude and a heavy blend) at the design capacities of 76,800 m^3/day flow rates. The product, flow rate and product properties for the two cases are summarized in Table 3.4.

Table 3.4 Summary of Product and Flow Characteristics for Scenario Analysis

Case	Product	Flow Rate (m^3/day)	Flow Rate (kg/s)	Density (kg/m^3)[1]	Kinematic Viscosity (cSt)
1	Synthetic crude	76,800	729.5	865	12
2	Heavy blend	76,800	789	940	350
Note 1: Properties at 7.5°C.					

4. ANALYSIS RESULTS

The spill volumes for each failure mode were calculated assuming line failure at locations spaced 30 m apart along the entire length of the pipeline. From these location-specific estimates, minimum, maximum and average spill volumes were calculated for each hole size. The case-specific spill volume estimates are summarized in the following sections.

4.1 Case 1: Synthetic Crude 76,800 m^3/day

The results obtained for Case 1 are summarized in Table 4.1 and in Figures 4.1 through 4.3.

Table 4.1 Average, Minimum and Maximum Spill Volumes for Case 1

Leak Size	Average Spill Volume (m^3) [minimum / maximum]			
	Alberta Segment	**Converted Segment**	**Manitoba Segment**	**Canadian Section**
Small Leak	42.9 [14.6 / 74.1]	40.2 [21.3 / 65.3]	45.7 [24.4 / 69.8]	41.2 [14.6 / 74.1]
Large Leak	1,255 [308 / 3,144]	4,268 [362 / 13,700]	1,540 [373 / 10,784]	3,387 [308 / 13,700]
Rupture	1,899 [1,094 / 3,876]	4,942 [1,091 / 14,300]	2,197 [1,147 / 11,499]	4,053 [1,091 / 14,300]

Analysis Results

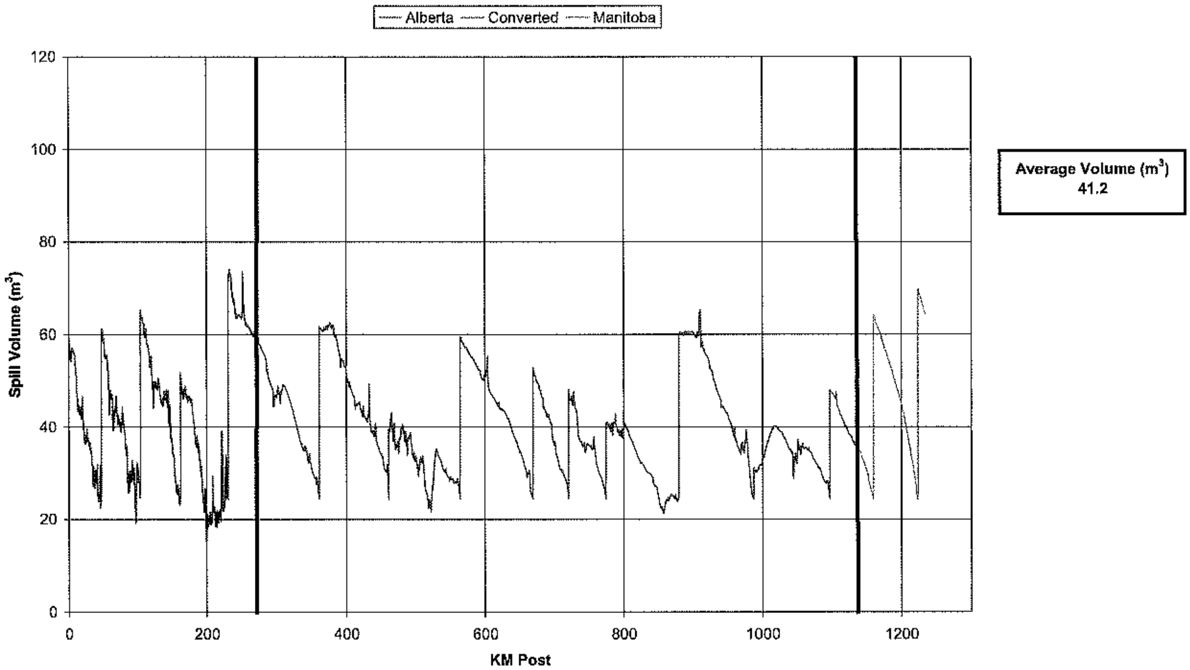

Figure 4.1 Small Leak Spill Volume Profiles for Case 1

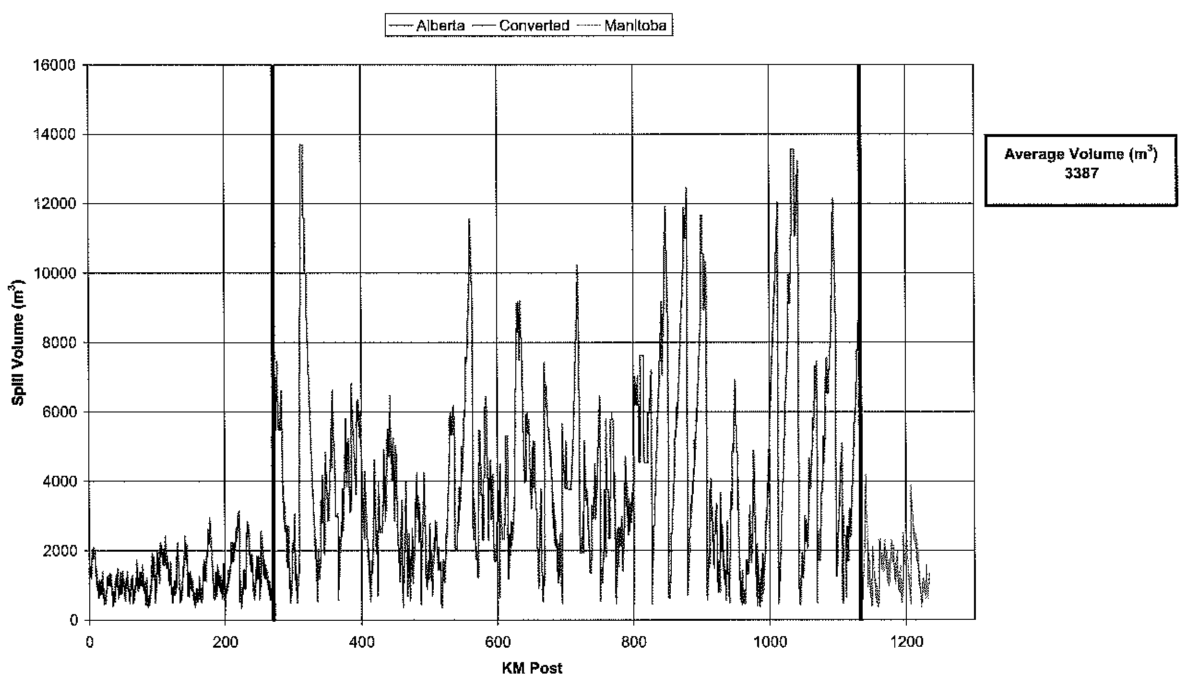

Figure 4.2 Large Leak Spill Volume Profiles for Case 1

Analysis Results

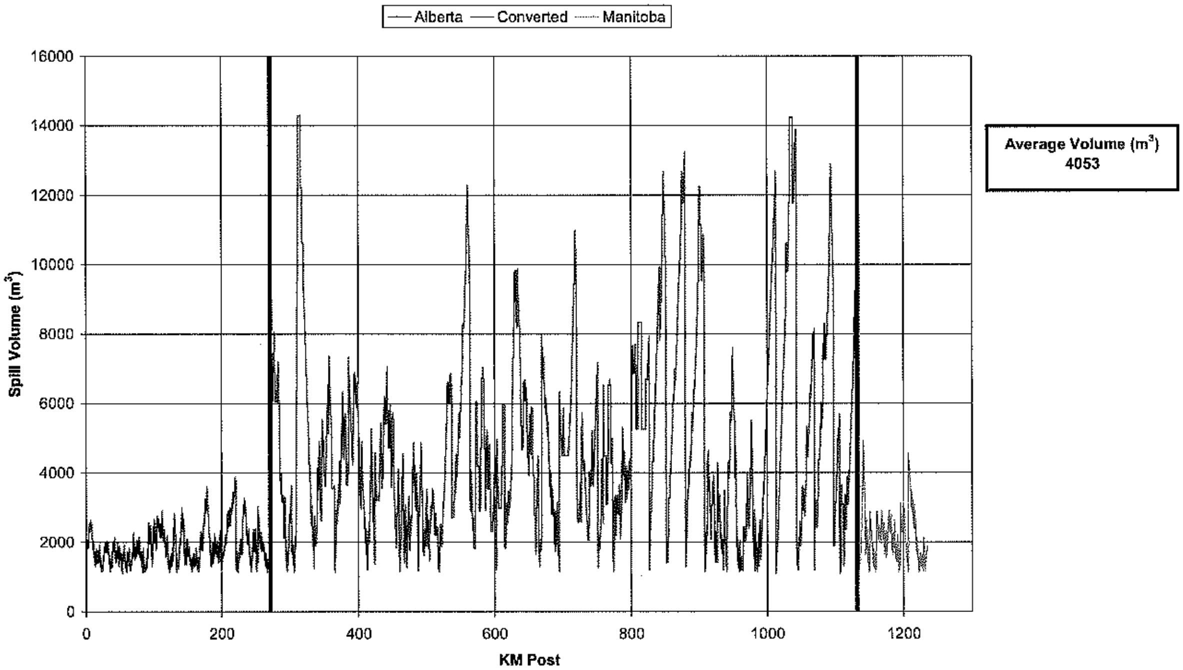

Figure 4.3 Rupture Spill Volume Profiles for Case 1

4.2 Case 2: Heavy Blend 76,800 m^3/day

The results for Case 2 are summarized in Table 4.2 in Figures 4.4 through 4.6.

Table 4.2 Average, Minimum and Maximum Spill Volumes for Case 2

Leak Size	Average Spill Volume (m^3) [minimum / maximum]			
	Alberta Segment	Converted Segment	Manitoba Segment	Canadian Section
Small Leak	60.1 [22.4 / 99.0]	54.6 [23.4 / 83.9]	57.8 [23.4 / 89.5]	56.1 [22.4 / 99.0]
Large Leak	1,351 [388 / 3,180]	4,349 [363 / 13,781]	1,607 [375 / 10,848]	3,470 [363 / 13,781]
Rupture	1,905 [1,112 / 3,885]	4,944 [1,101 / 14,330]	2,191 [1,141 / 11,493]	4,055 [1,101 / 14,330]

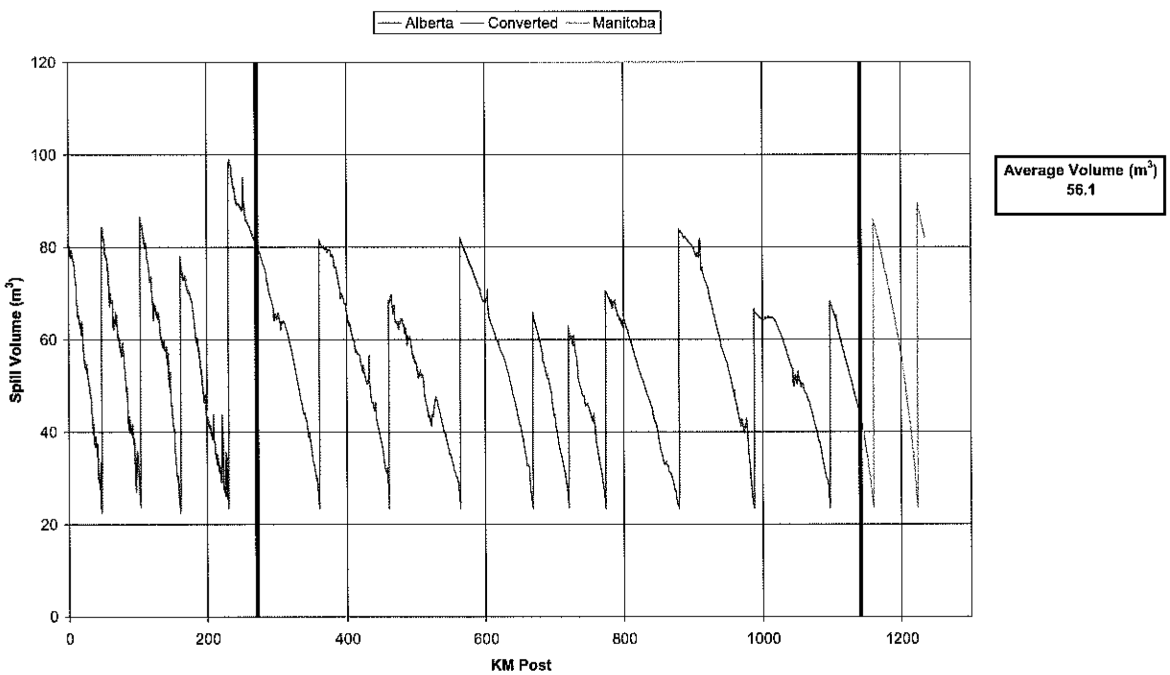

Figure 4.4 Small Leak Spill Volume Profiles for Case 2

Analysis Results

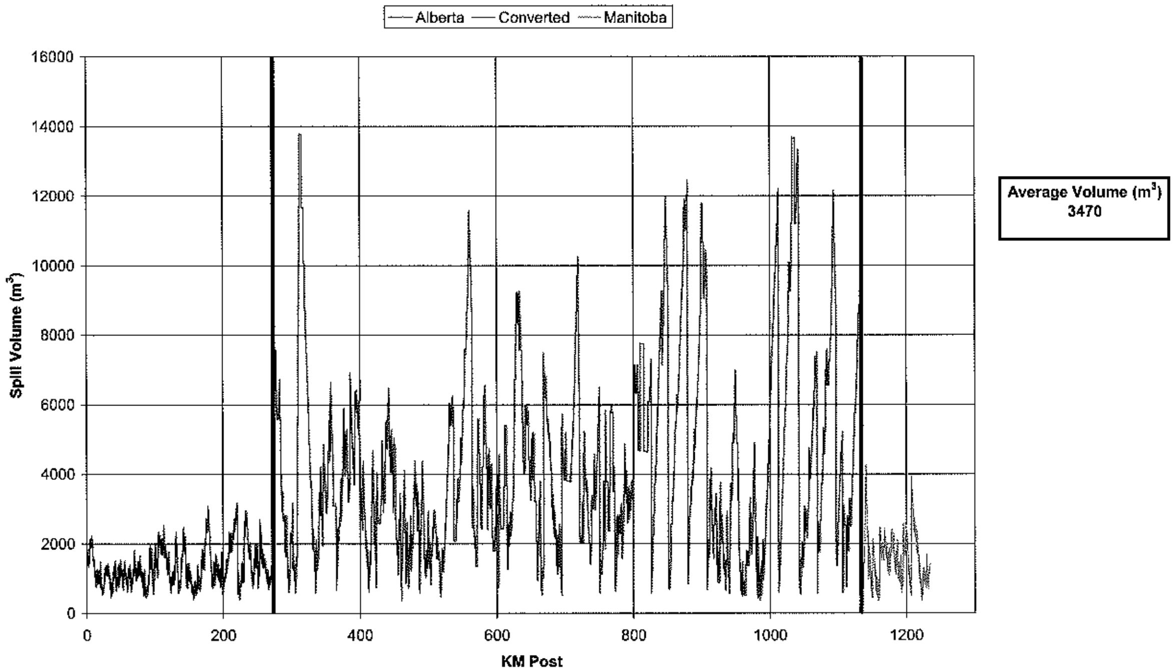

Figure 4.5 Large Leak Spill Volume Profiles for Case 2

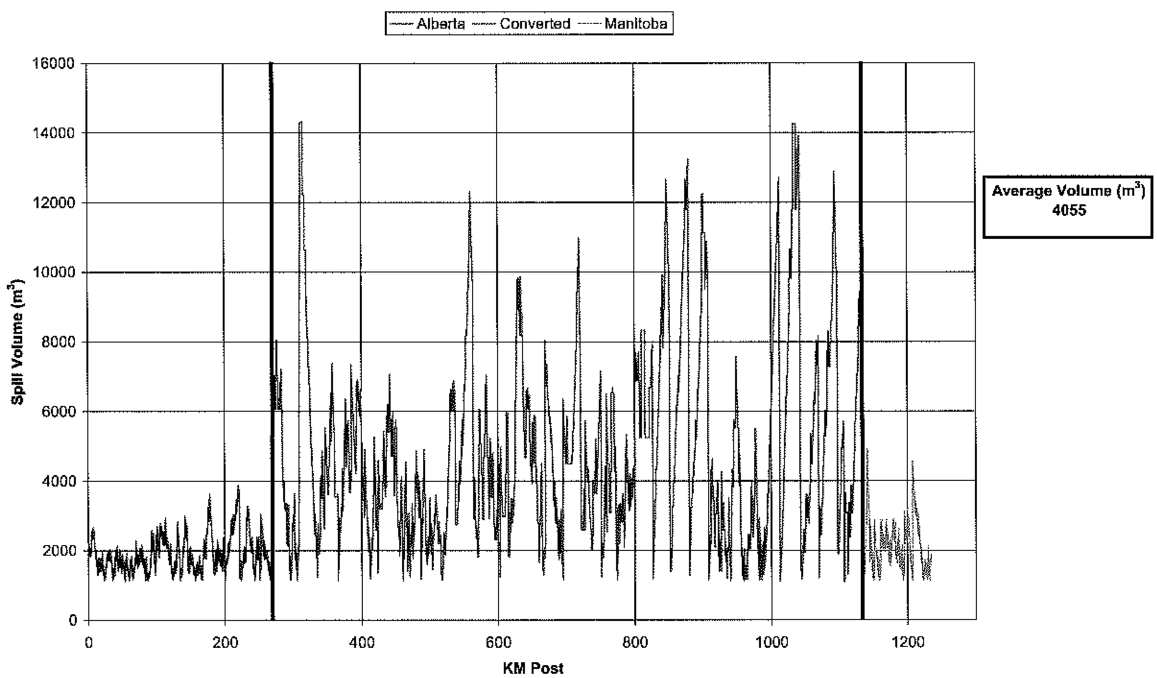

Figure 4.6 Rupture Spill Volume Profiles for Case 2

4.3 Discussion of Results

For each of the product and throughput scenarios considered in this study, the tabulated results and spill volume profiles indicate that there are clear differences between the expected spill volume estimates obtained for the newly constructed Alberta and Manitoba segments and the converted segment. On average, the small leak spill volumes are estimated to be lower for the converted segment, while the large leak and rupture volumes are estimated to be higher for the converted segment.

With regard to small leaks, since the assumed hole size is very small compared to the line diameter, the hole has little effect on the flow rate and the driving pressure for the release is effectively equal to the line pressure. Therefore, for a given time to leak stoppage, where the operating pressure is higher, the release rate and resulting spill volume should be higher. For the proposed Canadian portion of the Keystone pipeline, the average operating pressure for the Alberta and Manitoba segments is higher than that in the converted section, so higher average small leak volumes would be expected, which is consistent with the analysis results obtained.

For large leaks and ruptures, where the large hole size and corresponding high release rate cause the effective driving pressure to drop to product vapour pressure (effectively zero), the operating pressure is not a significant factor in determining spill volume. The spill volume is instead primarily controlled by the effective drain volume, which in turn is controlled by the line diameter, valve spacing and elevation profile. The converted segment of the pipeline has a larger diameter and slightly longer average valve spacing than the new Alberta and Manitoba segments. This implies that the effective drain volume for the converted segment should on average be higher than that for the new segments. Based solely on the larger line diameter and longer average valve spacing, the average spill volume for the converted segment should be about 1.4 times as high as that of the Alberta and Manitoba segments. However, the results obtained from the outflow modelling indicate that the average spill volume for the converted segment is approximately 2 to 3 times as high as that obtained for the Alberta and Manitoba segments. The discrepancy was attributed to elevation data quality as discussed in the following paragraphs.

A review of the nature and quality of the input data provided for this outflow modelling study, as well as a sensitivity analysis based on the findings of this review, suggests that the disproportionately higher large leak and rupture release volume estimates obtained for the converted portion are largely attributable to the lower quality (or resolution) of the elevation data used to develop the elevation profile for the converted portion of the line.

Low resolution terrain elevation data, specifically data sets where the spacing between elevation data points is large, yields a ground elevation profile and a corresponding pipe elevation profile that effectively misses the local peaks and valleys that fall between the elevation data points. These local peaks and valleys serve to trap oil in the event of line failure. If the local peaks and valleys are not reflected in the profile used to calculate the effective drain volume, then spill volume estimates for release scenarios that assume drain down (i.e. large leaks and ruptures) will overestimate the actual outflow volumes.

Analysis Results

To estimate the degree to which a lower resolution elevation profile inflates the release volume estimate, the Alberta and Manitoba segments (both defined by higher resolution terrain elevation data) were re-analyzed using artificially smoothed elevation profiles. The profile smoothing was achieved by dividing the Alberta and Manitoba profiles into 500-m length blocks and setting the elevation of the line over the length of each block to the block average. The block averaging length of 500 m was chosen to match the elevation step length typically observed in the profile of the converted segment. The differences in the resolution of the elevation profiles for the converted and new construction, and the effect of profile smoothing, are highlighted in Figure 4.7. The figure shows the original elevation profile for the end of the converted portion and the start of the new Manitoba portion, as well as the smoothed profile obtained for the Manitoba portion using a 500-m block averaging length.

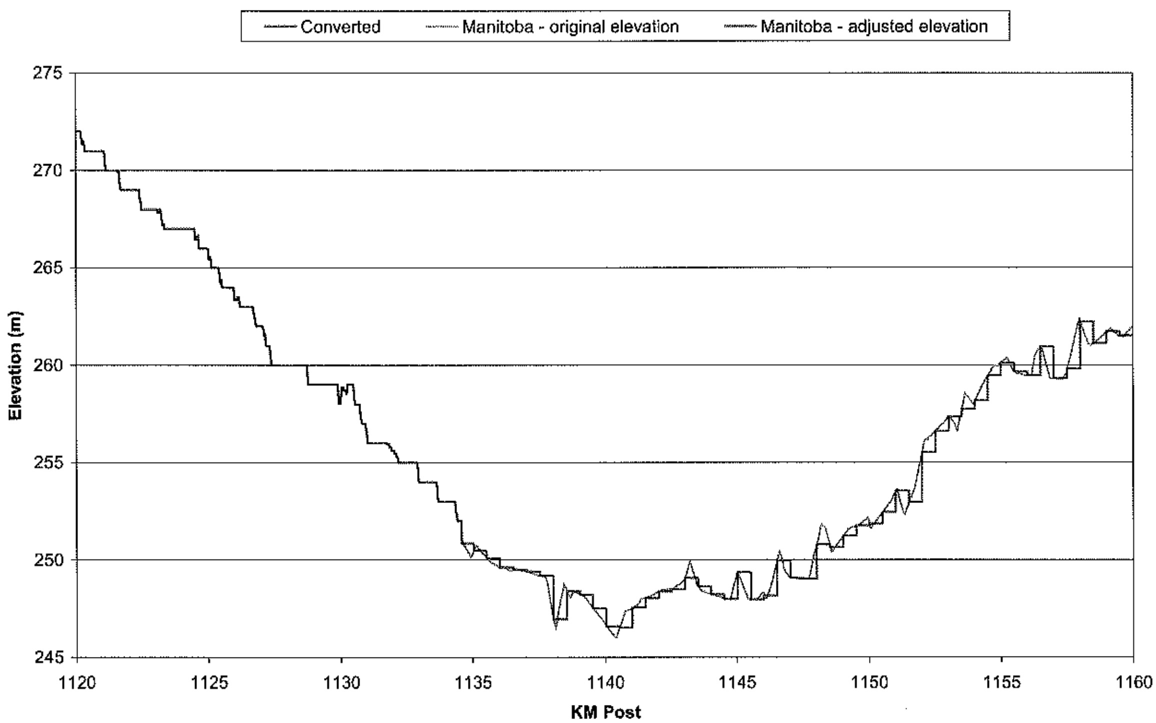

Figure 4.7 Original and Adjusted Elevation Profiles for a Representative Portion of the Line

For the Alberta segment, the spill volume estimates were found to increase by a factor of 1.66 for large leaks and 1.41 for ruptures after profile smoothing. For the Manitoba segment, the volumes increased by a factor of 1.70 for large leaks and 1.45 for ruptures after smoothing. The arithmetic mean of the large leak and rupture volume increases for Alberta and Manitoba are 1.68 and 1.43, respectively.

Analysis Results

The proportional increase in the average spill volumes obtained for the Alberta and Manitoba segments, after profile smoothing, is assumed to be indicative of the degree to which the spill volume is overestimated when calculations are based on elevation data having a resolution comparable to that available for the converted segment. Based on this assumption, it is reasonable to assume that spill volume estimates for the converted portion can be at least partially corrected to account for elevation profile resolution issues by multiplying the calculated large leak spill volume estimates by 0.60 (1/1.68) and rupture volume estimates by 0.70 (1/1.43). Adjusted analysis results based on this spill volume prorating approach are presented in Section 5.

It is noted that these spill volume adjustment factors are approximations developed from the available elevation data and a relatively simplistic approach to accounting for the effects of elevation profile smoothing. The factors so obtained are intended to be interpreted as illustrative values. That said, it is reasonable to assume that volume estimates for the converted portion, if prorated by the above factors, will tend to overestimate the actual release volumes, making the results so obtained conservative. This assumption is supported by the fact that if the spill volumes for the converted portion are multiplied by the above factors, the averages for the converted portion will still exceed the averages for the new Alberta and Manitoba portions by more than a factor of 1.4, that being the factor attributable to line diameter and average valve spacing differences.

5. ANALYSIS RESULTS ADJUSTED TO ADDRESS ELEVATION PROFILE ISSUES

Based on the spill volume prorating approach discussed in Section 4.5, the outflow volume estimates obtained for the converted portion were adjusted to account for elevation profile resolution issues. As discussed, the adjustments to the converted portion outflow volumes were made by multiplying the large leak spill volumes by 0.6 and the rupture spill volumes by 0.7. The adjusted case-specific spill volume estimates are summarized in the following sections.

5.1 Case 1: Synthetic Crude 76,800 m^3/day – Adjusted Results

The adjusted results for Case 1 are summarized in Table 5.1 and in Figures 5.1 through 5.2.

Table 5.1 Average, Minimum and Maximum Spill Volumes for Case 1 (after volume adjustment on converted segment)

Leak Size	Average Spill Volume (m^3) [minimum / maximum]			
	Alberta Segment	Converted Segment	Manitoba Segment	Canadian Section
Small Leak	42.9 [14.6 / 74.1]	40.2 [21.3 / 65.3]	45.7 [24.4 / 69.8]	41.2 [14.6 / 74.1]
Large Leak	1,255 [308 / 3,144]	2,538* [215* / 8,146*]	1,540 [373 / 10,784]	2,176* [215* / 8,146*]
Rupture	1,899 [1,094 / 3,876]	3,459* [764* / 10,010*]	2,197 [1,147 / 11,499]	3,015* [764* / 10,010*]

* Note: Volume estimates were adjusted to address the effect of low resolution elevation profile data on drain length estimates for the converted portion.

Analysis Results Adjusted to Address Elevation Profile Issues

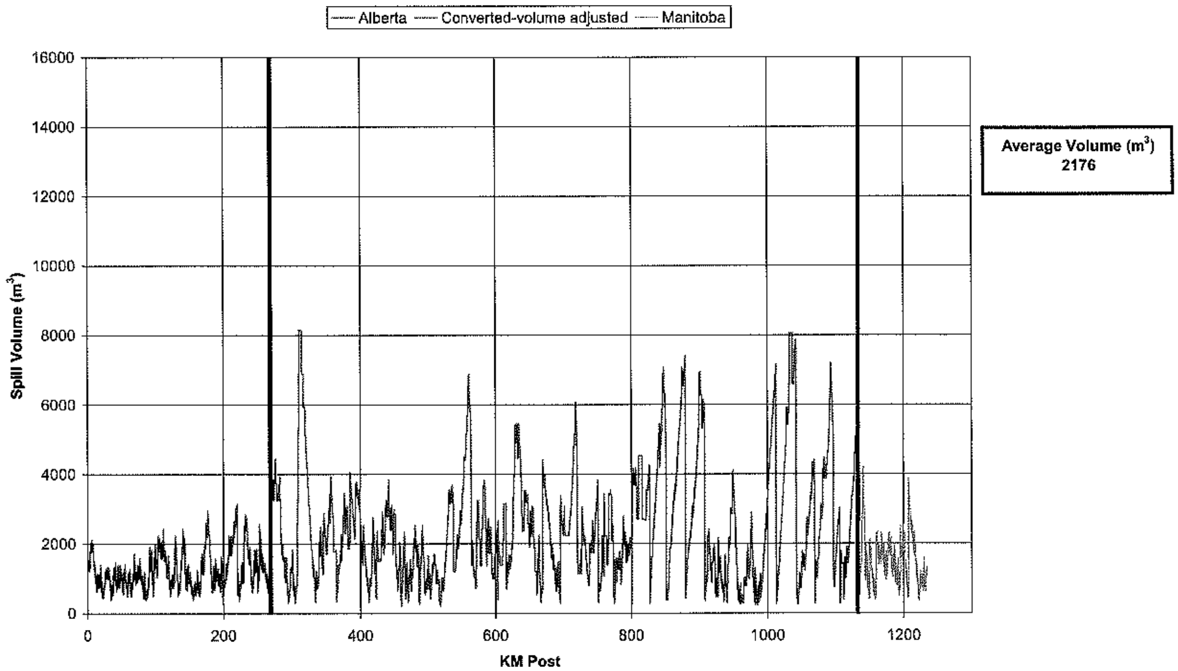

Figure 5.1 Large Leak Spill Volume Profiles for Case 1 (after volume adjustment on converted segment)

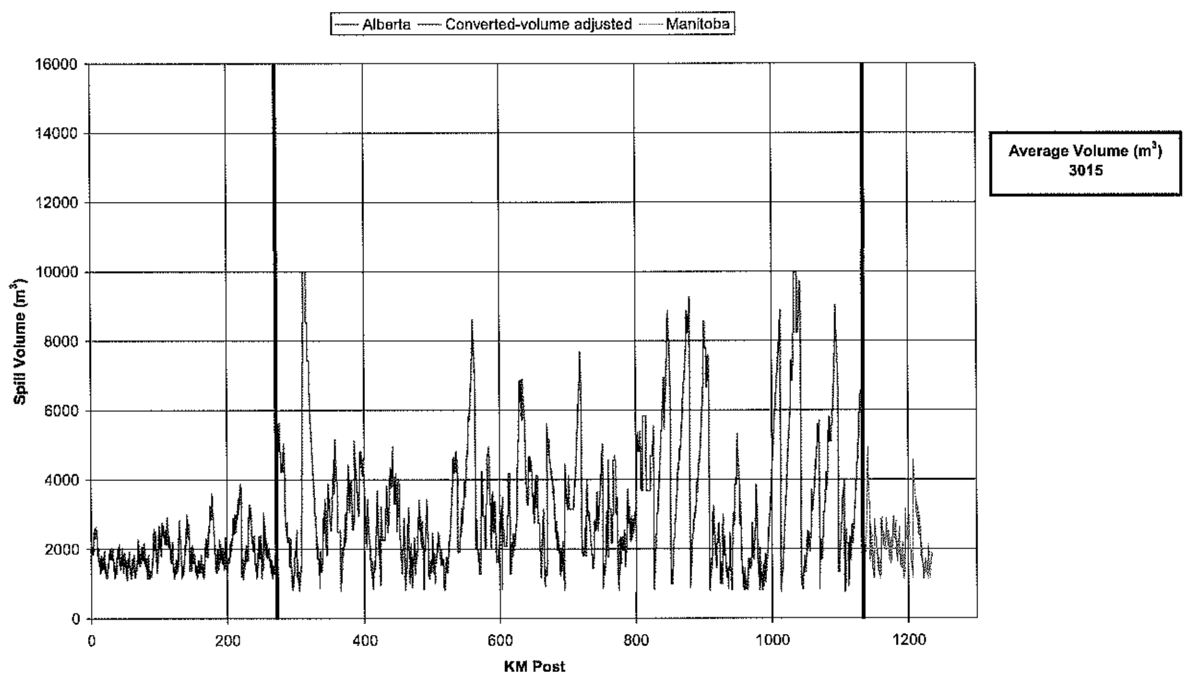

Figure 5.2 Rupture Spill Volume Profiles for Case 1 (after volume adjustment on converted segment)

5.2 Case 2: Heavy Blend 76,800 m³/day – Adjusted Results

The adjusted results for Case 2 are summarized in Table 5.2 and in Figures 5.3 through 5.4.

Table 5.2 Average, Minimum and Maximum Spill Volumes for Case 2 (after volume adjustment on converted segment)

Leak Size	Average Spill Volume (m^3) [minimum / maximum]			
	Alberta Segment	**Converted Segment**	**Manitoba Segment**	**Canadian Section**
Small Leak	60.1 [22.4 / 99.0]	54.6 [23.4 / 83.9]	57.8 [23.4 / 89.5]	56.1 [22.4 / 99.0]
Large Leak	1,351 [388 / 3,180]	2,586* [216* / 8,194*]	1,607 [375 / 10,848]	2,236* [216* / 8,194*]
Rupture	1,905 [1,112 / 3,885]	3,460* [770* / 10,031*]	2,191 [1,141 / 11,493]	3,017* [770* / 10,031*]

* Note: Volume estimates were adjusted to address the effect of low resolution elevation profile data on drain length estimates for the converted portion.

Analysis Results Adjusted to Address Elevation Profile Issues

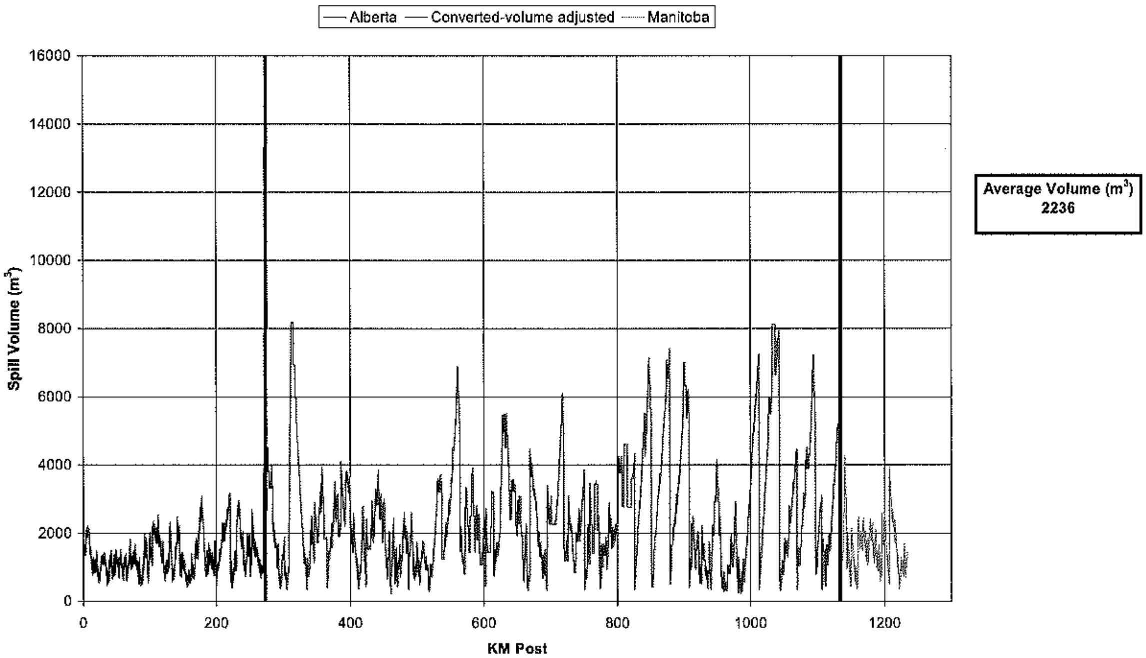

Figure 5.3 Large Leak Spill Volume Profiles for Case 2 (after volume adjustment on converted segment)

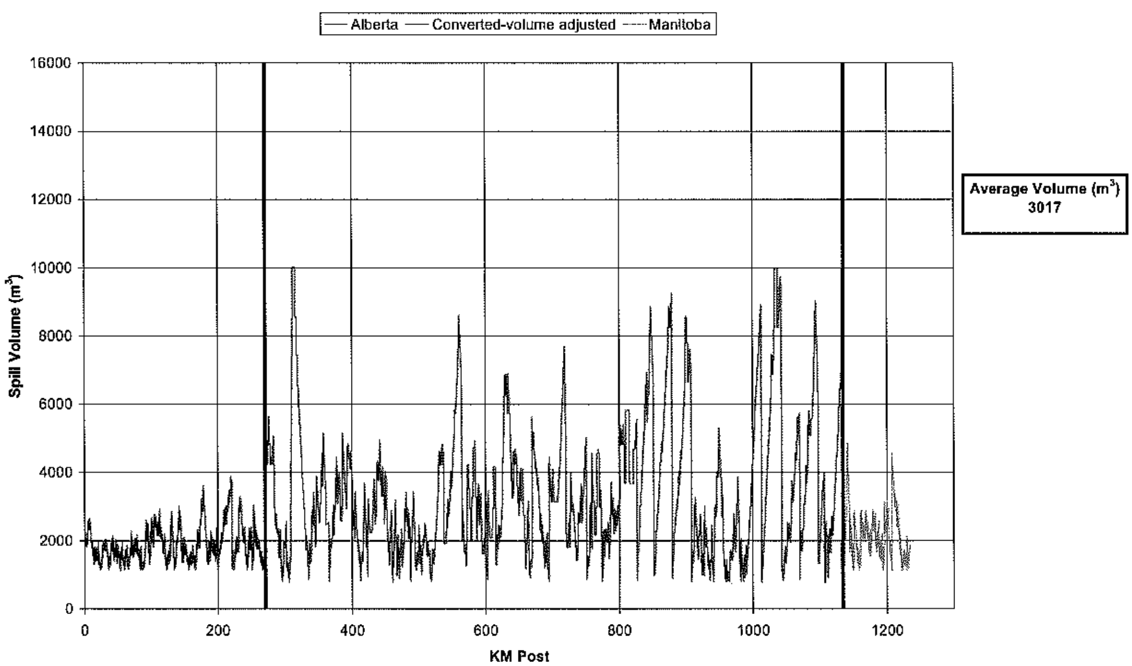

Figure 5.4 Rupture Spill Volume Profiles for Case 2 (after volume adjustment on converted segment)

6. SUMMARY

The average spill volumes for the two product/throughput cases, as calculated in the initial analysis, with the elevation profiles as given, are summarized in Table 6.1.

Table 6.1 Summary of Average Pre-adjusted Spill Volumes

Case	Average Pre-adjusted Spill Volume (m^3)		
	Small Leak	**Large Leak**	**Rupture**
Synthetic Crude 76,800 m^3/day	41.2	3,387	4,053
Heavy Blend 76,800 m^3/day	56.1	3,470	4,055

The average spill volumes for each case, after adjusting the large leak and rupture spill volume estimated for the converted portion to account for elevation profile resolution issues, are shown in Table 6.2. The results obtained following the volume adjustments are considered more realistic; however, as previously noted, the volume adjustment factors employed are approximations developed from the available elevation data and a relatively simplistic approach to account for the effects of profile smoothing. It is anticipated that additional analytical effort may yield a further reduction in the spill volume estimated for the converted portion and a corresponding reduction in the averages for the Canadian section as a whole.

Table 6.2 Summary of Average Spill Volumes
(after volume adjustment on converted segment)

Case	Average Adjusted Spill Volume (m^3)		
	Small Leak	**Large Leak***	**Rupture***
Synthetic Crude 76,800 m^3/day	41.2	2,176	3,015
Heavy Blend 76,800 m^3/day	56.1	2,236	3,017
* Note: Volume estimates were adjusted to address the effect of low resolution elevation profile data on drain length estimates for the converted portion.			

Elevation profile resolution issues aside, the tabulated results indicate that for a given hole size, the outflow volume estimates are somewhat influenced by both product type and flow rate. It is noted that the product sensitivity is more a function of the differing operating pressures (and pressure profiles) required to move the respective products at the desired flow rates, rather than the physical characteristics of the products.

For small leaks, where the hole size is very small compared to the line diameter and the release rate is therefore a very small fraction of the flow rate, the pressure driving the release is effectively the normal operating pressure at the failure location. Where the assumed time to leak detection and stoppage is constant, it follows that the spill volumes resulting from small leaks should be higher for cases where the operating pressures are higher. The small leak spill volume estimates obtained in this analysis are consistent with this assumption since the higher average spill volume estimates are associated with cases for which the average operating pressures are higher.

For ruptures, where the large hole size and high initial release rate cause the effective pressure driving release to fall to the product vapour pressure (essentially zero), the operating pressure is not a significant factor in determining the total spill volume. In the event of a rupture, the spill volume is primarily controlled by the effective drain length associated with a given failure location, which is dependent on the local pipeline elevation profile and the spacing of the surrounding valves and independent of the product type and flow rate. However, since the total outflow volume for a rupture is equal to the drainable volume (as controlled by the effective drain length) plus the product lost prior to valve closure, the volume estimate will also be influenced by the product flow rate since it will affect the volume lost prior to valve closure. The rupture volume estimates obtained in this analysis are essentially the same for both cases as the flow rates are almost identical.

For large leaks, as for ruptures, the spill volume is primarily controlled by the effective drain length. However, because the hole size associated with a large leak is smaller than that assumed for a rupture, the release rate prior to valve closure, and therefore the volume lost prior to valve closure, is smaller. As a result, large leak spill volumes estimates are smaller than rupture volumes.