PIPELINE OCCURRENCE REPORT
P96H0012

NATURAL GAS PIPELINE RUPTURE

TRANSCANADA PIPELINES LIMITED
LINE 100-2, 864-MILLIMETRE (34-INCH) MAINLINE
KILOMETRE POST MAINLINE VALVE 39-2
+ 6.07 KILOMETRES
ST. NORBERT, MANITOBA
15 APRIL 1996

Transportation Safety Board
of Canada

Bureau de la scurit des transports

du Canada

The Transportation Safety Board of Canada (TSB) investigated this occurrence for the purpose of advancing transportation safety. It is not the function of the Board to assign fault or determine civil or criminal liability.

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Synopsis

At 1815 eastern standard time (EST), on 15 April 1996, a rupture, followed by an explosion and fire at 1829 EST, occurred on the TransCanada PipeLines Limited 864-millimetre (34-inch) natural gas pipeline, at Kilometre Post Mainline Valve 39-2 + 6.07 kilometres, 10 kilometres southwest of Winnipeg, near the town of St. Norbert, Manitoba.

The Board determined that the rupture of Line 100-2 was caused by a ductile overload fracture, the result of high external stresses on the surface of the pipeline; stresses which were, in turn, the result of movement of the slope in which the pipe was buried. The rupture was assisted by the existence of an environmentally assisted crack at the toe of the circumferential weld that connected two joints of pipe together. There is the possibility that the initial crack could have been present since the original construction of that section of the pipeline.

Ce rapport est également disponible en français.

1.0 Factual Information

1.1 The Accident

At approximately 1815, TransCanada PipeLines Limited (TCPL) 864-millimetre (mm) outside diameter (nominal pipe size (NPS) 34 inches) main natural gas pipeline, designated as Line 100-2, suddenly experienced a release of natural gas at the crossing of the La Salle River,
10 kilometres (km) southwest of Winnipeg, near St. Norbert, Manitoba. Local residents in the vicinity of the crossing noted a loud noise and shaking walls. Several eye witnesses saw flying debris and a geyser of mud and water shooting up from the La Salle River, at a point where TCPL crosses the river. The exact time of these observations has not been determined.

At 1817, the Winnipeg Emergency Centre (911) was advised of the situation at the La Salle River by a local resident. The 911 call was re-routed to the Winnipeg Fire Department, resulting in the initiation of a Level 2 Hazard Response at 1818. Nine firefighting units from the greater Winnipeg area and its surrounding communities were dispatched to the scene. An additional five units responded during the course of the emergency. The 911 call also prompted the dispatch of five District Police Detachments, one Royal Canadian Mounted Police (RCMP) officer and an ambulance from the Winnipeg Victoria Hospital.

At 1819, several spectators, who had arrived off the Pembina highway and from the surrounding area to observe the geyser of mud and water at the crossing, were warded off by a local resident. The spectators were warned by the local resident of the impending dangers of a potential leak from a high pressure natural gas pipeline and to maintain their distance.

At 1827, having earlier called local police, a local resident provided first notification of the ensuing situation to the TCPL Winnipeg Regional Control Centre, reporting mud and ice spewing out of the La Salle River. At this time, the local residents could hear the responding Winnipeg Fire Department en route to the occurrence site.

At 1829, a local resident called the TCPL 24-hour emergency phone number. The call was re-routed to the Winnipeg Regional Control Centre, providing first notification to TCPL concerning a pipeline break in the La Salle River. While the resident was on the phone with the Winnipeg Regional Operations Controller (ROC), the escaping natural gas ignited, cutting power and phone services to the area surrounding the occurrence site. The resident immediately evacuated the house, because of the intense heat flux ensuing from the fireball. Three local eyewitnesses reported that the ignition of the natural gas appeared to start from a

[1] All times are eastern standard time (Coordinared Universal Time (UTC) minus five hours) unless otherwise indicated.

point near the top of the geyser of mud and water. At this time, a local Winnipeg television station was televising the events at the La Salle River during its regular newscast. Firefighters from the Winnipeg Fire Department observed the large fireball while en route to the scene.

At 1830, TCPL's Regional Supervisor of Right of Way, Safety and Environment responded to the events transpiring at the La Salle River crossing, having been advised by TCPL's Senior Right of Way Agent of the contents of the local news reports.

At 1832, the ROC was advised of the events occurring at the La Salle River by TCPL's Senior Right of Way Agent.

At 1835, TCPL's Calgary Gas Controller (Calgary Controller) was advised of the occurrence by the ROC. However, at 1838, the Calgary Controller advised the ROC that the Calgary Gas Control Centre (Calgary Centre) was unable to detect the occurrence because of a telemetry outage originating at TCPL's Île des Chênes compressor station No. 41, east of Winnipeg. While the ROC had direct telemetry communication with station No. 41, and was receiving the Supervisory Control and Data Acquisition (SCADA) data at this time, the Calgary Centre was not receiving SCADA data. At 2230, telemetry communication was restored between station No. 41 and the Calgary Centre.

At 1837, having observed pressure dropping on all six mainline pipelines into the station, the ROC isolated Plant "A" from the mainline operating system at station No. 41, which resulted in pressure surges in Plant "E" at the station.

At 1841, the ROC initiated the TCPL emergency auto-dialler to advise its Winnipeg Regional Management Team and the appropriate station and pipeline supervisors of an emergency situation on the pipeline system. The automated call-out system will initiate a maximum of 23 phone calls and continue to cycle through a list of phone numbers until the intended recipients acknowledge the calls.

At 1842, the ROC was advised that the Winnipeg Regional Facilities Manager was en route to the occurrence site and would perform the duties of the TCPL On-Scene Commander (OSC).

At 1843, the ROC requested permission from the Calgary Controller to isolate the pipeline system.

At 1845, 27 minutes after the first notification to 911 of an occurrence, the Calgary Controller instructed the ROC to isolate Lines 100-1 and 100-2 between station No. 34, at Portage la Prairie, Manitoba and station No. 41, at Île des Chênes, Manitoba. The ROC first isolated the station No. 41 suction side of Lines 100-1 and 100-2 and then isolated the station No. 34 discharge side of Lines 100-1 and 100-2. The Île des Chênes compressor station No.41, which was occupied by TCPL personnel, is about 30 km by highway from the occurrence site.

At 1846, a low pressure shut-off (LPS) device automatically activated on Line 100-2 at mainline valve (MLV)

39-2, located 6 km upstream of the occurrence site. When the pressure in the pipeline reaches the pre-set LPS pressure of 3,450 kilopascals (kPa) (500 pounds per square inch gauge (psig)), the MLV will shut automatically, as it did in this case. MLV 41-2, the first MLV downstream of the occurrence site (12 km), was closed at the time of the occurrence; it normally operates in a closed position when Station 41 is pumping into Line 2, as it was at the time of the occurrence.

At 1848, the ROC received confirmation from the SCADA system that the isolation of Lines 100-1 and 100-2, at compressor stations 34 and 41, was complete.

At 1849, the ROC observed that the suction pressure on Line 100-2 at station No. 41 was dropping rapidly. It continued to drop from this time.

At 1850, having identified themselves to the police and fire officials, first responders for TCPL helped to secure the occurrence site, provided assistance with the evacuation of a house, and advised police and fire officials on safety and emergency response issues associated with the rupture.

At 1856, the ROC received a report from an unidentified caller of a large fireball south of Winnipeg on Highway 75, at the La Salle River.

At 1900, the major fire at the La Salle River crossing self-extinguished and a small, 600 mm residual flame continued to burn for some time. At this time, the Fire Department relaxed site security without consulting TCPL personnel, which enabled the media and onlookers to approach the river bank and a burning house. Site security was regained by TCPL, with the assistance of the police, around 1915.

At 1913, the OSC reported to the ROC that there was a small fire and a natural gas leak at the occurrence site. It was also reported to the ROC that a house was on fire to the east of the river crossing and that the Winnipeg Fire Department had indicated to TCPL personnel that the house did not appear to be occupied at the time.

At 1917, the Winnipeg Regional SCADA specialist directed that the SCADA communication problems between the Calgary Controller and station No. 41 needed to be corrected immediately.

At 1924, the Calgary Controller requested to the ROC that SCADA communications with station No. 41 be restored.

At 1942, the senior patrol pilot for TCPL was instructed to fly over the occurrence site with the company helicopter.

At 1945, the station No. 41 utility person was en route to MLV 39 to ensure closure of the valve.

At 1946, the station No. 41 technicians advised the ROC that the St. Norbert sales meter station had been isolated from Line 100-1.

At 1952, the ROC confirmed to the Calgary Controller that MLV 39-2 was closed.

At 2004, the Calgary Controller granted authority to proceed at MLV 39 with the opening of the upstream 2:3 tie-over valve located between Lines 100-2 and 100-3. The upstream valve was confirmed open at 2015.

At 2007, senior TCPL managers were advised of the activities at 1952 and 2004, and that Line 100-1 would remain isolated until security of the pipeline was confirmed.

At 2016, isolation valve No.6 was confirmed closed at the St. Norbert sales meter station.

At 2023, the OSC confirmed that MLV 39-2 closed on low pressure, but that MLV 39-1 did not close and that internal pressure was holding steady.

At 2034, the ROC was advised by TCPL field personnel that the pipeline rupture was located in the La Salle River, which was about 100 metres wide due to spring flood, instead of a normal width of 30 metres. The ROC was also advised that Lines 100-1 and 100-3 appeared to be unaffected by the rupture.

At 2035, the Calgary Controller confirmed that Line 100-2 ruptured in the La Salle River, south of Winnipeg, at approximately MLV 39+6.07 km.

At 2036, TCPL first notified the TSB of the occurrence at the La Salle River on Line 100-2 and then, at 2043, notified the National Energy Board (NEB).

At 2045, compressor units No. 4 and No. 5 of Plant “A” at station No. 41 were restarted in order to recommence pumping natural gas in Line 100-1, east of Winnipeg, to eastern Canada.

At 2051, the Calgary Controller requested that the section of Line 100-1, from compressor station No. 34 to Winnipeg sales meter station No. 39, be returned to normal pipeline service.

At 2128, three hours after the first indication of a fire and explosion, the small, 600 mm residual flame at the occurrence site self-extinguished.

At 2130, having completed the task of fighting and containing the fire at the occurrence site, the Winnipeg Fire Department began preparations to leave the occurrence site.

Between 2132 and 2220, the ROC completed a series of procedures that re-established natural gas flows, around the occurrence site, on Line 100-2 at the La Salle River, through adjacent pipelines.

At 2208, having brought all fires under control, the Winnipeg Fire Department terminated its role as site commander and handed control of the site over to the Winnipeg Police Department. TCPL's OSC was advised of this fact, together with representatives from Manitoba Hydro and Centra Gas Inc.

At 2312, the ROC directed that measurement personnel remain at MLV 39 for the remainder of the night in order to monitor regulated pressures on Line 100-1 and to maintain gas supplies to the Transcona Sales Meter Station at that location.

At 2349, five and one half hours after the rupture of Line 100-2, the ROC advised the Thunder Bay and Regina Regional Control Centres that pipeline operations were back in service, except for the section of Line 100-2 that contained the La Salle River crossing.

Due to the very high water levels at the La Salle River crossing, on April 18, Line 100-2 was isolated from the main line, and welded end-caps were installed until water levels receded to normal levels.

On June 25, TCPL's contractor was mobilized to begin the repairs of Line 100-2. On June 27, as a precautionary measure, TCPL removed Line 100-1 from service at the La Salle River crossing.

Between July 23 and August 3 the old pipeline crossing of Line 100-2 was removed, a new crossing was installed and then hydrostatically tested in-place. On August 15, Line 100-2 was returned to normal pipeline operations.

Between July 31 and August 13 the old pipeline crossing of Line 100-1 was removed, a new crossing was installed and then hydrostatically tested in-place. On August 14 Line 100-1 was returned to normal pipeline operations.

From August 15 to 23 Line 100-2 was electronically internally inspected for any pipe surface defects between MLV 34 and station No. 41. On August 25 Line 100-2 was returned to full mainline service.

On August 25 Line 100-3 was removed from normal service due to the presence of a bend in the pipeline on the east side of the crossing. Before the pipeline was returned to normal service, stress relieving activities were executed on the pipeline from the edge of the La Salle River crossing and up the slope of the crossing. On August 29, Line 100-3 was returned to normal pipeline service.

On September 20 clean-up and reclamation activities at the occurrence site were completed.

1.2 Injuries

There were no injuries to TCPL employees or to nearby residents.

1.3 Damage to Pipeline Equipment and Private Property—Product Lost

Damage to Line 100-2 consisted of 6.325 m (20.75 feet) of ruptured pipe which had split open longitudinally. There was one bolt-on pipeline weight within the limits of the rupture which was destroyed and according to TCPL records was located on, near or adjacent to a circumferential weld at the upstream limit of the break. While Line 100-1 was not damaged by the rupture of Line 100-2, it passed through the same area of pre-existing slope instability as Line 100-2 and was replaced for reasons of pipe security.

The ruptures of Line 100-2 produced two pipe fragments, which were found within a 40 m (130 foot) radius of the crater. The first section, with a longitudinal seam 1.175 m (3.86 feet) long, was blown out of the pipeline system and came to rest in a wooded area on the river bank. The second section, with a longitudinal seam 5.150 m (16.89 feet) long, was located by divers at the bottom of the river directly above the Line 100-4 La Salle River crossing. The ruptures created an irregular shaped crater on the river bottom which measured approximately 13.5 m wide by 17 m long and roughly 5 m deep, with a crater volume of approximately 550 cubic metres (m^3).

The explosion and fire resulted in the loss of one house, which was 178.1 m (584 feet) south of the rupture site. Hydro-electric power lines, poles, transformers and associated equipment in the general area of the rupture were damaged and had to be replaced. Trees and other vegetation on both sides of the river located within the burn impact area were damaged or destroyed by the explosion and fire and had to be removed.

An estimated 97,800 m^3 (3,470,000 cubic feet) of natural gas was lost, a result of the initial, 12-minute release, and the subsequent fire.

Sections of damaged and undamaged pipeline were removed upstream and downstream of the occurrence site. There were 166.44 m (546.1 feet) of pipe used in the repair of Line 100-2. Since Line 100-1 passed through the same general area as Line 100-2, these sections of pipeline were replaced for reasons of pipeline security; there was 185.87 m (609.8 feet) of pipe used in the repair of Line 100-1.

1.4 Weather and River Conditions

On 15 April 1996, at 1900, the weather conditions at the Winnipeg Airport, approximately 10 km northeast of the rupture site, were clear skies with scattered cloud cover; a 5,000 m ceiling; visibility of 24 km; an outside temperature of 2 degrees Celsius (°C); winds out of the north-northwest at 12 km/h; barometric pressure of 101.15 kPa; dew point of -3°C; and humidity at 30 per cent.
The La Salle River is a regulated watercourse with a drainage area of 1,900 square kilometres (km^2), which drains into the Red River approximately 3 km downstream of TCPL’s right of way. At the time of the occurrence, the river was running above normal water level. While the mean annual stream-flow in the La Salle River is 2.42 cubic metres/second (m^3/s), April exhibits the highest mean monthly stream-flow at 15.9 m^3/s. The mean monthly stream-flow from June through October is less than 1 m^3/s.

1.5 Particulars of the Pipeline

At the occurrence site, TCPL has six parallel lines of pipe (see Appendix A), as follows:

Designation	Nominal Outside Diameter
Line 100-1	864 mm (NPS 34)
Line 100-2 (ruptured)	864 mm (NPS 34)
Line 100-3	914 mm (NPS 36)
Line 100-4	1067 mm (NPS 42)
Line 100-5	1219 mm (NPS 48)
Line 100-6	1219 mm (NPS 48)

The six pipelines are buried at depths of between 1.5 and 4.0 m, in soil, within the Black Soil zone of Manitoba (with predominantly Chernozemic and Gleysolic soils). These soils are of the St. Norbert clay variety of the Red River association and exhibit slow to moderately slow permeability.

The nominal wall thickness of the ruptured section of the Line 100-2 river crossing pipe is 12.7 mm (0.5 inches). The section of pipe was manufactured in 1962 by A.O. Smith with a straight "square seam" or "flash butt" welded longitudinal seam weld and a specified minimum yield strength (SMYS) of 359 megapascals (MPa) (American Petroleum Institute pipe grade 5LX). The section of Line 100-2 was constructed in 1962 and was externally coated at that time with a wet-applied mastic and an outer wrap, comprised of three layers (an outer resin hot-rolled film, a saturated and treated fabric reinforcing layment, and a second inner resin insulative film) wrapped over the wet-applied mastic to form a laminar cold-applied electrically insulative and mechanically reinforced coating system. As a means of providing buoyancy control, the original design called for the installation of nine bolt-on, 34-inch concrete river weights, each weighing 2,800 kilograms (6,200 pounds). Separating the bolt-on weights was wood lagging, which had been wired in place at the time of the original construction. A review of welding records from the original construction of the crossing show that 60 per cent of the circumferential welds had been radiographed. From this review it was not discernible which welds in the river crossing were radiographically inspected, and which were not.

Outside of the La Salle River crossing, the pipe of Line 100-2, produced in 1962 by Welland Tube, has a nominal wall thickness of 9.53 mm (0.375 inches) and a SMYS of 359 MPa (X-52).

The section of Line 100-2 that ruptured had been hydrostatically tested in 1962 to a test pressure between 8,095 and 8,301 kPa (1,174 and 1,204 psig). The National Energy Board issued a Leave to Open to TCPL on 29 November 1962 at a maximum allowable operating pressure (MAOP) of 5,695 kPa (826 psig) which corresponds to 57 per cent of the SMYS. During the period 1968 and 1969, the MAOP for this section was raised to 6,068 kPa (880 psig) which corresponds to 61 per cent of the SMYS. Although this section of Line 100-2 was re-rated, the section was not re-tested, since the original hydrostatic test exceeded the new criteria in 1968 for determining the NEB approved MAOP.

There is a history of prior repairs and construction in the section of Lines 100-2, from MLV 34 to MLV 41. These repairs and construction have consisted mainly of drain installations, of some road replacements work, of fixing leaking valve-body bleed valve fittings and of repairing shorted road crossing casings. The nearest repair work site was at MLV 39+6.916 km to repair a shorted road crossing casing.

The failure of Line 100-2 did not cause any damage to the other lines at this crossing. However, as Line 100-1 passed through the same area of slope instability and movement as did Line 100-2, it was replaced. Since a section of the Line 100-3 river crossing adjacent to Line 100-2 rupture was found to have shifted, Line 100-3 was daylighted and stress-relieved by allowing the pipeline to return to a neutral position. There was no evidence of surface damage on Line 100-3 after the stress-relieving activities.

Prior to the occurrence, the most recent TCPL weekly aerial patrol over this portion of the pipeline system had been conducted on Wednesday, 10 April 1996, with no concerns noted. At the time of the aerial patrol, the river crossing was frozen solid, which was normal for that time of the year.

As part of its ongoing operational activities, TCPL personnel perform natural gas leak surveys of its pipeline system by walking the right of way with hand-held gas detectors. As prescribed by the company's Code of Operating Practice (COOP), entitled *Line Walking Leak Detection Survey*, a line survey on pipelines west of Winnipeg should be performed once every four years. A review of the company's records, from the survey in 1993, demonstrated that there had been no abnormal conditions or third-party interference observed at the La Salle River crossing.

As prescribed by one of the company's COOPs, entitled *Underwater Survey*, TCPL have conducted underwater inspections of the La Salle River crossing. While the COOP does not prescribe a frequency for conducting an underwater survey, four underwater surveys had been conducted on the La Salle River crossing as follows: in 1967, 1976, 1983 and 1988. The reason for these four surveys was the unexpectedly high water table conditions prevalent at the time. A review of the records from these surveys confirmed that there was no identifiable problem with the crossing. During the 1983 survey, probing of Line 100-2 indicated a minimum soil cover over the pipeline of 1.3 m.

As part of its ongoing operations, TCPL has established a pipeline integrity program, to enhance pipeline safety and security by identifying structurally weak sections in the system and initiating the necessary remedial programs. TCPL has available a wide range of internal inspection devices to identify problems such as structural weakness, external loads affecting roundness, and pipe shifted from the installed neutral axis by external forces. Prior to this occurrence, TCPL had not performed any internal inspections of the sections of Lines 100-1, 100-2 and 100-3, the first two of which were eventually replaced due to the occurrence at the La Salle River crossing.

1.6 Pipeline Operations

The Calgary Controller located in the TCPL Control Centre, in Calgary, relies on telemetric data (from compressor and meter stations) from the SCADA network to optimize movement of contracted quantities of western Canadian natural gas. The TCPL pipeline system is subdivided in regional control centres, each under the direct command of a ROC, with direct remote control over a series of compressor stations. At the time of this occurrence, the ROC was located in Winnipeg. While the ROC was able to obtain telemetric data from station No. 41 throughout this occurrence, that data was not available to the Calgary Controller, due to a telemetry outage.

During the two-week period preceding the pipeline rupture, a consultant employed by TCPL had been working on the SCADA system, conducting tests and point checks for the new station No. 41, Plant “A”, automation system. As part of this work, a new version of the automation system was undergoing programming changes. During this period, and upon the consultant’s arrival each day at station No. 41, the existing version of the production system would be turned off and the new version of the production system would be activated.

On the day of the occurrence, the telemetry signal coincidentally stopped working between station No. 41 and the Calgary Centre when the existing version of the production system was re-activated at the end of the day. A review of the telemetry outage has determined that a telemetry problem existed in the virtual connection between the VAX and the terminal server port through which telemetry communications are served. All functions had been normal for the previous two-week period. As the consultant deactivated and reactivated the existing Plant “A” automation system for purposes of working on the new automation system, no previous abnormalities in operations had occurred. However, before leaving the station on the day of the occurrence, the consultant had failed to verify the operation of the telemetry communication signal with the Calgary Centre.

At 2230, after performing a number of soft resets on the telemetry ports at station No.41, the telemetry link between station No. 41 and the Calgary Centre was restored, four hours after the first indication of a telemetry outage.

1.7 Isolation of Mainline Facilities

In accordance with the company's Emergency Procedure Manual (EPM), section 04-07, entitled *Winnipeg Region - Regional Control Centre*, and upon verification of a pipeline break or an emergency situation affecting the security of the pipeline system, TCPL's procedures call for the immediate isolation by the ROC of all pipelines between compressor stations, either side of the occurrence site. During this occurrence, and in a deviation from company isolation procedures, not all sections of the pipelines between stations No. 34 and 41 were isolated.

TCPL's decision to deviate from section 04-07 of the EPM was made after consultation between the Calgary Controller, the ROC and the Assistant Manager at the Calgary Centre. Since the St. Norbert sales meter station is connected to Lines 100-1 and 100-2, and since either of the two pipelines might have been involved in the rupture, it was thought prudent to isolate both lines. It was decided to isolate only Lines 100-1 and 100-2 between stations No. 34 and 41 for the following reasons:

1. While an explosion had been reported at St. Norbert, there was no immediate indication of a fire;

2. The rate of pressure change at station No. 41 indicated that a fairly small diameter pipeline was involved in the rupture, contributing to the initial suspicion that the pipeline that had ruptured was the one from TCPL facilities which fed the St. Norbert sales meter station;

3. The rate of change in the flow and the pressure of natural gas at station No. 34 was very small;

4. The location of the pipeline rupture was unusual. The operating pressure is relatively low in that section of the system, typically near 5000 kPa (725 psig);

5. The completion of Line 100-6 (between stations No. 34 and 41) allowed for a line-by-line isolation.

For these reasons, at 1845 the Calgary Controller instructed the ROC to isolate only Lines 100-1 and 100-2, between stations No. 34 and 41.

1.8 Cathodic Protection on Line 100-2

Cathodic protection (CP) on Line 100-2 between MLV 39+0.00 km and MLV 39+7.99 km is provided by means of remote impressed current ground bed systems. The distribution system for CP in the general area is connected to the pipeline at MLV 39+8.55 km and at MLV 39+3.81 km. There are no magnesium anode installations in the immediate area of the pipeline system. The section of Line 100-2 between MLV 39+0.00 km and MLV 39+7.99 km was constructed in 1962, and the first CP ground bed installation was completed in 1965. A review of the records for the CP ground beds yields the following information:

Ground Bed Installation	MLV 39+8.55 km	MLV 39+3.81 km
First installed	1965	1974
Replaced	1973, 1990, 1993	1991
Period out-of-service (1980–1993)	11 months	11 months
Reasons out-of-service	- construction activities - electrical problems - damage requiring repair - system shut down for depolarization surveys	- ground bed depletion - construction-related activities - system shut down for depolarization surveys

In accordance with the company's COOPs, *Annual Pipe-to-Soil Surveys*, and *Close Pipe-to-Soil Survey* (usually once every two years), TCPL field staff perform pipe-to-soil surveys to determine the effectiveness of the CP system, and to ensure that the existing minimum industrial norm of 850 millivolts (mV) "off" cathodic potential and of 900 mV "on" cathodic potential are met. Close pipe-to-soil surveys for the La Salle River crossing were performed on Line 100-2 in 1980, 1984, 1986, 1988 and 1992. They showed that the CP potentials at the rupture site exceeded the minimum industrial norm. During 1983, concurrent with an underwater survey of the La Salle River crossing, a pipe-to-soil survey test found that the CP potential on Line 100-2 exceeded the minimum industrial standard.

1.9 Spacing of Mainline Pipes at the La Salle River Crossing

TCPL's records indicate that, at the site of the rupture, the limits of TCPL's right of way measure 67.244 m (220.62 feet), and that the six pipelines run parallel to each other (see Appendix A). Within the TCPL right of way, the spacing between the north edge and Line 100-1 is 7.6 m (24.93 feet). The spacing between Lines 100-1, 100-2, 100-3, 100-4 is 9.1 m (29.85 feet), between

Lines 100-4 and 100-5, 10.0 m (32.81 feet), and between Lines 100-5 and 100-6, 12.0 m (39.37 feet). The spacing between Line 100-6 and the south edge of the right of way is 9.8 m (32.15 feet). Adjacent to the north edge of TCPL's right of way runs a buried telephone cable.

1.10 Geotechnical Survey Program

Since this area of St. Norbert has a history of high water levels and unstable soil conditions, a detailed geotechnical examination at the La Salle River crossing was undertaken by TCPL's consultant. The geotechnical examination included:

. A site reconnaissance of the crossing;

2. A review of historical aerial photographs, going back before the 1959 installation of Line 100-1;

3. An analysis of the subsurface, through a probing and drilling program;

4. The installation and monitoring of temporary slope instrumentation;

5. The assessment of slope stability conditions;

6. A detailed forensic inspection of the soil substrates (during the installation and removal of the replacement pipeline crossings);

7. The installation of permanent slope instrumentation (after completion of the crossings); and

8. A detailed stress analysis of the pipeline using various potential loading mechanisms associated with geological conditions present at the slope.

The results of the geotechnical examination indicate that, on the east bank of the La Salle River crossing, Lines 100-1 and 100-2 pass through an area of pre-existing slope instability. A pre-1959 construction profile of the crossing illustrates classic slope instability features, such as a bulging slope toe, an up-slope slump and indications of a concave slope surface. Previous ground movement was evident as surface features on the slope area near the occurrence site, and included arc-shaped tension cracks and vertical displacement of the ground surface up-slope of the rupture site.

Geotechnical examination determined that the occurrence site is underlain by highly plastic, compressible, swelling, low-sensitivity clay sediments, deposited by glacial Lake Aggasiz, which covered this area in ancient times. The water level of the river at the pipeline crossing rapidly rises and falls each spring, which results (temporarily) in rapid draw-down conditions at the crossing. These are exacerbated by coincident seasonal increases in piezometric pressures in a deep aquifer beneath the occurrence site. In the Winnipeg area there have been similar situations which have resulted in well-documented slope movement. Slope monitoring instruments, installed during the late spring of 1996 and after the rapid fall of the water level at the crossing, detected subtle evidence of slope movement. A comparison of the 1996 monitoring results with those predicted from the 1959 pre-construction profile for the crossing shows a correspondence between the two, indicative of slope movement.

Previous construction activities have highlighted the instability of the east bank of the La Salle River crossing. During the installation of Line 100-4, a significant slump occurred, when the Line 100-4 trench wall failed, exposing Line 100-3. During the installation of Line 100-5 in 1991, excavated soil was stockpiled temporarily on the slope over Line 100-2. Ground movement was observed beneath this stockpile, in the vicinity of Line 100-2. There was no record of any follow-up excavations, checks or pipe surface inspections of adjacent lines by TCPL field staff. Such inspections might have identified potential safety concerns regarding ground movements at the crossing.

Prior to the commencement of construction activities to repair the Line 100-2 crossing, each pipeline was located and ground stakes were installed over the lines. The alignment of survey stakes over Line 100-3 illustrated possible displacement during the post-construction period. At the edge of the river, Line 100-3 is displaced in a south-southwest direction upriver towards Line 100-4. Line 100-3 was excavated on both sides of the river crossing. After exposure of Line 100-3 on the east side of the crossing, the pipe rebounded about 0.3 m in a northern direction. Based on the geometry of the bend in the pipe and the direction of rebound of the pipe, it appears that the pipe had experienced lateral movement to the south and some previous subsidence on the east bank of the river crossing. There was no significant rebound of the pipe observed on the west bank of the crossing.

The geotechnical examination determined that, since the installation of Line 100-2, episodic slope movement has occurred on the east bank of the crossing along a pre-existing surface of instability. These episodes of slope movement resulted in incremental, monotonic loading of Line 100-2 pipe, which could have been predicted to result in bending stresses in the pipe at the rupture site. There was no evidence found of slope instability on the west bank of the La Salle River crossing.

To evaluate the relative importance of stresses that may have contributed to the pipeline rupture, the following potential loading mechanisms associated with geological conditions were considered:

- Buoyancy-induced, cyclic loading in response to seasonal fluctuations in river levels;
- Soil expansion and contraction, inducing seasonal cyclic loading on the pipe;
- Longitudinal loading applied to the pipe through the soil–pipe interaction associated with friction due to soil movement parallel to the pipe axis; and
- Transverse loading caused by a shear surface passing across the pipeline.

The stress analysis determined that the weighted pipeline was negatively buoyant even during high water conditions, and was therefore not considered to be a significant external loading mechanism. The stress analysis also determined that the stress created in the pipe by the expansion of the silty clay soil around the pipe appears to be insignificant. The longitudinal stress analysis, carried out to determine the pipeline's response to longitudinal loading caused by soil movement parallel to the direction of the pipe, suggested that the pipeline is not susceptible to buckling failure from the potential loading by the soil. Loading of a transverse nature on the pipe, carried out to determine if shear displacement of the soil across the pipe, associated with slope instability, could yield the pipe, determined that slope movement between 150 mm and 350 mm could potentially yield the pipe. The geotechnical assessment of the east slope of the La Salle River, in particular the identification of an arc-shaped feature in the vicinity of Lines 100-1 and 100-2, past construction practices, and the results of monitoring for slope movement, indicated that between 150 mm and 350 mm of past slope movement was possible in the vicinity of the occurrence site. However, the geotechnical assessment could not determine how much the slope had moved, or when slope movement might have occurred.

1.11 Photogrammetric Survey and Site Documentation of Burn Area

The environment immediately surrounding the occurrence site was burnt, damaged or destroyed during the explosion of Line 100-2 and the subsequent fire. Aerial and terrestrial photogrammetry documented the burn area. Infrared aerial colour photography, and ground and aerial colour photography were used to determine the extent and severity of damage. A ground survey walk recorded actual site evidence. A photogrammetric record was made of the fire-damaged house.

This work showed that there was a defined burn area around the rupture site on both sides of the La Salle River crossing. The largest area of burn was downwind of the rupture; the fire-damaged house was in this area. Within the limits of the trees, which are present on both sides of the crossing, there were three definable burn zones. These zones are as follows: trees burnt on the face towards the rupture; trees burnt on the face towards the house; and trees burnt entirely around. Trees burnt entirely around were located closest to the fire-damaged house. The radius of the combined burn and heat-affected area around the pipeline system measured about 160 m (525 feet) (see Appendix B). The infrared photography confirmed the extent of the fire damage by illustrating the burn area and the level of vegetation stress at the site.

The inspection and review of the photogrammetric record of the house illustrated that the fire damage had begun on the exterior surface of the roof and then spread to the interior roof structure. The lower parts of some of the roof trusses did remain. While the upper rooms were all missing their ceilings, the supporting walls and floors, and the lower rooms were still in place. All parts of the house suffered extensive water damage, presumably from the efforts of the firefighting crews, as well as from the rain and snow that fell later. There was no evidence that the house was damaged by the initial pipeline explosion. The windows and doors of the house were found to be intact whereas, if the source of ignition of the natural gas had been within the house, the windows and doors would have been blown out. There was no evidence of external sources of ignition, such as a pilot light or electrical contact, either in or around the house.

1.12 Metallurgical Testing

The chemical composition and mechanical properties of the pipe sections from Line 100-2, remote from the area directly affected, were consistent with the pipe specifications at the time of purchase.

The metallurgical analysis of the fracture area determined that Line 100-2 ruptured as a result of a circumferential crack which developed in the toe of a girth weld from the outside surface. The cracking mechanism can best be described as a long-term, multi-stage, environmentally assisted process, technically referred to as "environmental assisted cracking." The fracture exhibited similarities with accepted stress corrosion cracking characteristics, but closer analysis revealed significant differences.

After the initial rupture and explosion, two fragments of pipe were projected from Line 100-2. The force of the explosion deformed the metal, turning it inside out. The first fragment included a 1.175 m (3.86 foot) section of the longitudinal seam. Preliminary examination of the first fracture surface indicated that this fragment also included the fracture origin. The fracture path followed the toe of a circumferential weld joint for some distance before changing orientation.

The second, much larger fragment was located by divers on the river bottom immediately over the buried Line 100-4 crossing. This piece represented 5.150 m (16.89 feet) of the pipeline. The configuration and orientation of the second fracture was consistent with a helical fracture path, which intersected the longitudinal seam three times. Taken together, the lengths of the two fragments agreed with the gap between the terminal rupture points of Line 100-2, suggesting that all of the pipe fragments had been found. The large fragment did not contain the mating portion of the fracture origin. Removal of the upstream and downstream ends of the undisturbed sections of Line 100-2 produced the mating portion of the fracture origin on the upstream end of the pipeline.

After the four Line 100-2 pipe fragments were washed with water, to remove mud and clay, the original external protective coating was examined. The coating was disbonded, and easily flaked off. The deformation of the metal likely contributed to this disbondment. Remnants of external coating were subsequently removed by blasting with crushed walnut shells. A visual examination of the pipe surface revealed isolated patches of corrosion pits. The exterior coating was removed to prepare the surface for magnetic particle examination in search of any cracking colonies (such as stress corrosion cracking colonies). While the magnetic particle examination did not reveal any stress corrosion cracking colonies, indications of isolated longitudinal cracking were found. Pipe samples with the representative longitudinal indications were removed, sectioned and polished. All indications were found to be surface slivers from the original manufacturing stage of the pipe.

Careful examination of the fracture surface disclosed that the final fracture had been preceded by a pre-crack that was centred at about the two o'clock position and ran parallel with the circumferential weld. The pre-crack had reached a length of 450 mm and had penetrated
5.8 mm of the 12.7 mm pipe wall. The crack formed along the downstream side of the weld toe, running around the pipe. When the crack reached critical size and became unstable, the fracture path deviated and started running downstream, in a spiral fashion. This deviation to a spiral orientation is thought to be promoted by dynamic reaction forces, consistent with a progressive growing leak prior to the final rupture.

The original crack formed a single-plane crack front, except for a short distance of 70 mm where the crack skipped to a plane 3 mm downstream. In addition, there was a secondary crack following the original crack front. The upstream pipe, adjacent to the girth weld, showed evidence of corrosion pitting. In the overstress extension of the pre-crack, the fracture path followed the weld profile for a few short stretches.

Detailed examination of the fracture surface in the vicinity of the two o'clock position revealed three main stages of crack advancement. Starting from the outside surface of the pipe, the first stage was the corroded/oxidized stage which consisted of several distinct bands indicating periods of different cracking activities. The maximum depth of the corroded/oxidized stage was 5.8 mm, which probably took several years to reach. In this stage of crack growth, the crack resembles cracks formed under conditions of low pH stress corrosion cracking.

Two additional main stages of crack extension followed, and are clearly characterized by an absence of corrosion scale. The second stage crack propagation advanced the crack front to a pipe wall thickness depth of 8.5 mm. The last two stages were separated by a slight corrosion stain and the second stage crack exhibited a finer texture than the final stage, which penetrated the pipe wall. Scanning electron microscope examination of the last two stages of crack growth revealed a mixed fracture topography consisting of cleavage and dimples for the second stage, while the third stage was dominated by dimples. The relative absence of corrosion products on the last two stages indicate that these stages of crack growth were recent, and that the third stage closely followed the second stage.
Since the corrosion scale on the first stage crack had obliterated the fractographic features, one of the secondary cracks was sectioned and opened, in order to identify the cracking mechanism. Metallographic examination of the secondary crack tip revealed a transgranular crack propagation mechanism. The microstructure at the secondary crack tip was that of banded ferrite/pearlite, although the principal crack started at the heat-affected zone. Scanning electron microscope (and visual) examination of the opened secondary crack revealed both

distinct stages of crack advancement and the presence of corrosion/oxidation all the way to the crack tip. The minimal thickness of the corrosion layer immediately adjacent to the crack tip was such that it was still possible to recognize cleavage/quasi-cleavage features at this location.

A similar situation was encountered when the toe crack, where the principal crack skipped momentarily to a different plane, was examined. A branching crack tip, presumed to be transgranular in nature, together with a corroded crack surface, was observed. There were up to nine distinct crack propagation stages illustrated on the toe crack surface.

As an aid to determining the type of cracking mechanism present, the residues found on the fractures and crack surfaces were analysed using the energy dispersive x-ray technique. This analysis found a presence of residues of magnesium, aluminum, silicon, potassium, and calcium, in addition to the elements normally found in carbon steel. The non-steel elements were probably present as a mixture of oxides. Corrosion product deposits within a closed crack were also analysed and similar combination of elements was found. However, light-element, energy-dispersive scanning showed a presence of carbon and oxygen peaks, which seems to indicate the possible presence of mixed oxides and carbonates.

Since the crack originated at the toe of the circumferential weld, a transverse section through the weld was prepared, to examine its integrity. The examination revealed a multi-pass weld, with a slight amount of mismatch, occasional interpass porosity and slag entrapment. One section exhibited a small crack in the root weld-pass, while the cap weld-pass showed some evidence of a mild undercut. Overall, the circumferential weld had some discontinuities, but none of these discontinuities was considered serious enough to compromise the fitness-for-purpose of the joint.

Hardness traverses were conducted to establish if the weld had been embrittled. The hardness values near the outside surface of the pipe were somewhat higher than at the inside surface of the pipe. A larger increase in hardness values in the heat-affected zone near the outside diameter were noted. However, this hardness variation was considered normal. The examination found no evidence of hard spots, or zones which would have made the weld joint susceptible to preferential cracking. A spectrographic analysis of both pipe plates showed compliance with the chemical composition limits set forth by the applicable specification in force at the time of pipe fabrication. The microstructure of the parent metal consisted of banded pearlite/ferrite which is typical for hot-worked carbon steels. Inclusions (also referred to as stringers) in the pipe steel were present in normal concentrations. The mechanical properties of both adjacent joints of pipe satisfied the specified values. Fracture toughness of the weld joint was evaluated by a consultant. Detailed calculations and tests showed that the 450 mm long and 5.8 mm deep flaw was still subcritical for the normal operating pressure fluctuations. The fact that the crack developed at the toe of the girth weld instead of at the long seam weld was related to the source of the stress responsible for cracking. Even taking into account the stress concentration due to joint misalignment and undercutting, it was concluded that a large external force was required to extend the crack through the pipe wall. The detailed analysis found that the operating pressure generated only about 13 per cent of the total stress associated with the fracture and that the main loading force leading to failure came from pipe bending caused by external forces, most notably, ground movement.

1.13 Site Investigation of Environmental Conditions Associated with the

Failure

While the environment at the occurrence site was obliterated during the rupture and explosion/fire of Line 100-2, a detailed site investigation of the undisturbed sections of pipe adjacent to the occurrence site illustrated the severity of the environmental conditions present. An investigation by a consultant employed by TCPL included the following analyses:

1. A chemical analysis of the river weight concrete;

2. The conditions of the pipe and soil were recorded (during the excavation of the 100-1, 100-2 and 100-3 crossings), and samples of soil analysed;

3. An analysis of the soil water samples taken from under the disbonded external coatings of Lines 100-2 and 100-3;

4. An assessment of CP conditions on the Line 100-2 pipe, prior to the occurrence;

. A non-destructive field examination of girth welds on Lines 100-2 and 100-3;

. A detailed chemical analysis and fractographic examination of the failed pipe section; and

. A fracture mechanics assessment was conducted on the failed weld.

The original construction drawings showed a concrete river weight over the girth weld that subsequently failed. During the failure of Line 100-2, the concrete weight had been fractured into many pieces and scattered over the site. Excavation of Line 100-2 revealed that most of the river weights for the crossing were not located at the expected positions (as shown in the company's drawings). The concrete weights were unevenly spaced. It is possible that the rupture and explosion caused the concrete river weights to shift, but no evidence was found at the site to support this theory. Since the external asphalt coating adjacent to the fractured weld had been stripped off during the rupture, it was impossible to trace the exact position of the destroyed concrete weight. Once Line 100-2 was excavated, the fracture weld was determined to have been located either just outside, or just inside, the coverage of the concrete weight. To demonstrate the effect of the concrete weight on water alkalinity, a portion of the failed concrete weight was placed in distilled water. Within four days of immersing the concrete, the pH of the water increased to around 11.

Excavation revealed a deflection of Line 100-2 towards the south. Since the construction records and drawings indicated that Line 100-2 had been laid straight in the trench, the noted deflection in Line 100-2 resulted from the ground movement of unstable soil in the slope. Both upstream and downstream of the rupture, the backfilled ditch contained a lot of organic loamy soil. This would result in high levels of carbon dioxide, and eventually an increased level of bicarbonate ions, around the pipeline.

The first remaining concrete weight upstream of the rupture was examined. Lifting the upper half of the weight revealed that the asphalt coating covering the seam weld was very thin under the weight, and that bare pipe was exposed in some spots. The moisture remaining on the pipe surface was found to have a pH of 11. At the second weld, further upstream from the rupture site, the concrete weight at this location was 0.3 m from the circumferential weld, and the entrapped moisture on the pipe surface had a pH of 8.8. In general, the sections of pipe within the range of one joint downstream and three joints upstream of the rupture had similar surface conditions, without significant general or pitting corrosion. However, pitting corrosion was visible on pipe further uphill. Removal of the external coating of Line 100-2 (which was usually loosely bonded to the pipe surface), revealed a creamy corrosion product consisting mostly of iron carbonate ($FeCO_3$) with traces of hematite (Fe_2O_3). In summary, the pipe joints that ran across the riverbed showed very little corrosion, whereas the pipe joints further uphill exhibited pitting corrosion at certain locations. The differences in corrosion were likely a result of different levels of CP being delivered to the pipe surface.

The CP coverage of the La Salle River crossing was assessed. A plot of the average monthly current output from the two ground beds installed at MLVs 39+3.81 km and 39+8.55 km determined that the output current from the downstream ground bed had increased by more than 100 per cent since 1989. Between 1990 and 1996, there had been three outages in the upstream ground bed and one outage in the downstream ground bed. For asphalt-coated pipe, the amount of CP arriving at a particular area of the pipe depends to large extent on the local conditions of the external coating. To address the issue of shielding effects of a bolt-on concrete weight, field measurements were carried out at the time of excavation. A series of readings, taken for different positions inside the concrete/pipe gap, confirmed that there was CP current entering the gap between the coated pipe and the concrete weight. The level of CP diminished towards the centre of the weight.

An assessment was also made of the moisture found under sites of disbonded coating on pipe excavated at the crossing. In general, locations not covered by concrete had pH levels between 7 and 9, while covered locations had pH levels between 10 and 11. The effects of concrete on the chemistry of the water between the pipe and the concrete weight revealed that corrosion products contained high levels of chloride ions (Cl^-), sodium ions (Na^+) and magnesium (Mg). There were also high levels of bicarbonate ions. The bicarbonate and pH levels were more typical of a high-pH, stress corrosion cracking (SCC) solution than of a near-neutral-pH SCC solution. However, concentrations of carbonate ions were not as high as those of a high-pH SCC solution. Similar field work was carried out on Line 100-3, samples from which showed levels of carbonic acid and bicarbonate ions much lower than for samples from Line 100-2.

Other than the failed weld, field examination of the girth welds and pipe bodies of Lines 100-1, 100-2 and 100-3 at the La Salle River crossing found no additional cracks. There were no crack colonies close to the failed weld or any other girth weld. The fact that the crack developed at the toe of the girth weld instead of the long seam weld was certainly related to the source of the stress responsible. The operating pressure of the pipeline generated only 13 per cent of the total stress associated with the failed weld. Therefore, the main loading force came from pipe bending, the result of some external force, most notably, ground movement.

A fracture mechanics assessment was performed. The critical stress at which a crack of the size in question becomes unstable was determined to be 93 per cent of the actual yield stress of the pipe. Generation of axial stresses of critical value were found to require pipe bending. This assessment showed that such bending of the pipe can be generated by ground movement and that only small displacements of the pipe were required. This

work determined that the
Line 100-2 pipe displacement, observed during excavation, was sufficient to generate external stresses large enough to yield the pipe. This assessment also showed that the undercut at the toe of the weld (found during the metallurgical analysis), resulted in a significant stress concentration there.

1.14 Emergency Preparedness

In accordance with subsection 48(1) and section 49 of the NEB's regulations entitled *Onshore Pipeline Regulations (OPR)* (SOR/DORS/89-303), federally regulated pipeline companies are required to establish emergency response plans for the pipeline system. In accordance with
sub-subsections 10.2.2 and 10.3.3, both entitled *Pipeline Emergencies,* of the Canadian Standards Association (CSA) standard, entitled *CAN/CSA Z662-96 - Oil and Gas Pipeline Systems (CSA Z662),* pipeline companies are required to establish emergency response procedures for the safe shutdown of a pipeline system in the event of a failure or other pipeline emergency, to establish safety procedures for personnel at emergency sites, and to maintain records to assist in the development of emergency procedures. Pursuant to subsection 49(2) of the *OPR*, a pipeline company shall update, on a regular basis, those aspects of the emergency response manual related to plans for cooperation with appropriate public agencies during an emergency, as well as update those aspects of the manual related to emergency evacuation procedures. To ensure,

during the development and updating stages of an emergency response plan, the CSA has produced and issued a standard, entitled *CAN/CSA - Z731-95 Emergency Planning for Industry (CSA 731),* although neither the *OPR* nor the *CSA Z662* reference it as a requirement for the pipeline industry in Canada.

As part of its Public Awareness Program, TCPL installed signs at all crossings, and other locations, warning the public of the potential dangers of the natural gas moving through the pipeline system. Important emergency-related information is indicated on the TCPL signs. People living near the TCPL system regularly receive information from TCPL on the potential dangers of the pipeline, and are visited regularly by TCPL right of way agents as part of this program. TCPL is a participant in the City of Winnipeg Disaster Plan. Relevant information on the TCPL system has been put into the Disaster Plan database, and is readily available to first responders (police and fire department personnel) during an emergency.

During this occurrence, at 1817, the Winnipeg Emergency Centre (911) was advised by a local resident of the situation at the crossing. Having been advised, at 1818 a Level 2 Hazardous response was initiated by the Winnipeg Fire Department, which resulted in the deployment of 13 firefighting units, an ambulance, and many police officers from the City of Winnipeg and the RCMP over the course of the occurrence. TCPL was not notified of the initiation of the Level 2 Hazardous alarm. At 1827, TCPL was made aware of the events at the crossing by a local resident and initiated the TCPL emergency response plan. At 1829 the natural gas ignited and the resulting fireball was observed by the firefighters en route to the occurrence site. During the 14 minutes preceding ignition, some local residents and members of the public, unaware of the potential hazards associated with a pipeline rupture, were seen gathering near the occurrence site. Prior to ignition, and in spite of the potential danger of the ensuing situation, one local resident returned home to retrieve personal effects and, at 1829, placed an emergency call to TCPL advising of the pipeline rupture. After ignition of the natural gas, the Winnipeg fire chief drove the spouse of the local resident to a safe vantage point and, after seeing that their house was unaffected by the fire, the resident proceeded to find the family member who had placed the 1829 telephone call to TCPL. At 1900, the fire department relaxed site security, permitting the media and the general public to approach the site. TCPL was not advised of these actions and only regained control of the site at 1915.

2.0 Analysis

2.1 Introduction

The metallurgical examination identified an environmental assisted cracking (EAC) mechanism as the source of the pipeline weakness that led to the stress overload at a pre-existing defect in the exterior surface area, adjacent to the circumferential weld between two joints of pipe. Because of the rupture, explosion and fire, a house and the forested area on both sides of the river crossing were destroyed. Power and telephone services in the area were also destroyed by fire. The rupture and loss of internal operating pressure in the pipeline was acted upon, triggering a series of emergency responses by the Winnipeg Fire Department, the Winnipeg Police Department, the RCMP, TCPL operations and field staff and several other public authorities.

The analysis will focus on TCPL's emergency response; the emergency shut-down of TCPL's pipeline facilities; the environmental conditions that produced an EAC; and the policies and procedures employed by TCPL when identifying, and verifying unstable pipeline crossings.

2.2 Consideration of the Facts

2.2.1 Emergency Response by Pipeline Personnel and Other Agencies

When a pipeline company designs a new pipeline system, both the *OPR* and the *CSA Z662* standard dictate norms with which the pipeline industry must comply. These norms are meant to ensure that a system is properly designed, satisfying current safety, operational and emergency planning requirements. The *OPR* and the *CSA Z662* standard dictate the need for an emergency response plan (the Plan) and specify the minimum requirements of the Plan. In addition, the *OPR* requires regular updating of those sections of the Plan that concern cooperation with public agencies. However, there is no assurance, either during the development stage or when the Plan is updated, that the plan will be complete, since neither the *OPR* nor the *CSA Z662* require that federally regulated pipeline companies use the CSA standard, entitled "*CAN/CSA - Z731-95 Emergency Planning for Industry (CSA 731)"*. The *CSA 731* was developed as a guide in the production of a Plan that integrates the concerns of all interested parties.

In accordance with the existing requirements of the *OPR* and the *CSA Z662*, TCPL is a participant in the City of Winnipeg Disaster Plan, with relevant information on the pipeline system put into the database of the Disaster Plan. Information in the database is readily available to first responders (police and fire department personnel) during an emergency. During this occurrence, and while a Level 2 Hazardous Response had been declared and was underway by the Winnipeg Fire Department, TCPL was not made aware of the events transpiring at the La Salle River crossing and could not initiate the company's emergency response. At 1827, 10 minutes after the declaration of a Level 2 Hazardous Response, TCPL was made aware of the events transpiring at the crossing by a local resident and immediately initiated an emergency response, deploying personnel from the Île des Chênes compressor station and other locations on the system.

A key component of every Plan is early notification from passers-by or eyewitnesses. To this end, pipeline companies install signs at road, river, and railway crossings, and at fences, indicating that a buried, high-pressure pipeline is located nearby. The sign provides important information such as the name of the pipeline company, the product being transported, and a 24-hour-a-day emergency telephone number. In case of an emergency, a passer-by is encouraged to immediately call the pipeline company. TCPL has installed signs such as these at the La Salle River crossing.

With the emergency response in motion, the ROC started the emergency auto-dialler system. The stated purpose of this system is to alert TCPL's regional management teams and the appropriate station and pipeline supervisors that an emergency situation is underway. Once initiated, the system is automatic, allowing the ROC to attend to other priorities. The TCPL Plan does not stipulate the immediate initiation of the system by the ROC as an emergency action.

The auto-dialler system cycles through a list of 23 phone numbers until the recipient acknowledges the call. Since the cycle can take as long as 40 minutes, the notification system could be improved by prioritizing the list of phone numbers and by ensuring that the pre-recorded message is as site specific as possible.

2.2.2 Emergency Shut-down of Pipeline Facilities

The TCPL Emergency Response Plan (ERP) clearly outlines the policies and procedures that company personnel are to follow during an emergency. To ensure that TCPL personnel are familiar with the ERP, company personnel perform surveys and tests of the performance capabilities of the pipeline system's Emergency Shut Down and SCADA systems. TCPL continuously upgrades those systems to ensure that the pipeline meets an adequate level of response during both normal and emergency situations. There did not appear to be any problem, during this occurrence, in the ROC obtaining SCADA information with which to make minute-by-minute decisions regarding pipeline operations, but the SCADA information from compressor station No. 41 was not forthcoming to the Calgary Controller.

During the period leading up to the occurrence, the SCADA system was being modified by the new "A" plant automation at station No. 41. At the time of his departure from the station, the consultant performing these tasks did not ascertain that there was a telemetry problem between station No. 41 and the Calgary Controller. At 1835, 20 minutes after the rupture, the Calgary Controller was advised of the occurrence by the ROC. At 1838, the Calgary Controller advised the ROC that there was a telemetry outage between the Calgary Centre and station No. 41. At 2230, more than four hours after the Calgary Controller received initial notification, telemetry communications were re-established between the Calgary Centre and station No. 41. During this time, and while the ROC was in constant telemetry communication with station No. 41 and could make well-informed decisions, the Calgary Controller could not access relevant SCADA information from station No.41 upon which to make informed decisions about the operating system. The Calgary Controller had to communicate all instructions verbally to the ROC, who in turn would execute the instructions. During a telemetry outage, the SCADA system did not have a feature that would allow the re-establishment of telecommunications between itself and any compressor station on the system.

Section 04-07 of the EPM dictates that, upon verification of a pipeline break, both the ROC and the Calgary

Controller will observe all pipeline pressures in the reported valve section. Only then will the ROC isolate all pipelines between the compressor stations, either side of the occurrence site. At 1829, an occurrence was confirmed to the ROC when a local resident described the events at the crossing, just as the escaping natural gas exploded. At 1845, the Calgary Controller instructed the ROC to shut down only two lines between stations No. 34 and 41, and not all six lines, as prescribed by the policies and procedures of TCPL's EPM. The policies and procedures of TCPL's EPM were clear with respect to isolation procedures; at the time of the occurrence, TCPL's EPM did not provide latitude to either the Calgary Controller or the ROC to deviate from the prescribed policies and procedures of the company. However, in circumstances (such as this) where sufficient information is available, departures from established procedures should be considered acceptable.

2.2.3 Conditions at Crossing Conducive to Environmental Assisted Cracking

The metallurgical examination determined that an EAC mechanism was present at the time of the failure. EAC is a generic term for the cracking and fracture of metals under the combined actions of stress and a corrosive environment—usually a wet environment, such as that of the La Salle River crossing. An EAC mechanism in an aqueous medium may be classified as either of two sub-types. The first, where the loading stress is alternating, is called "corrosion fatigue" (CF). The second, where the cracking occurs under static stress in a corrosive medium, is called "stress corrosion cracking" (SCC). Hydrogen assisted cracking (HAC) is also an EAC mechanism. Recent research has shown that some types of cracking (near-neutral-pH SCC) currently classified as SCC require a component of dynamic loading to achieve significant growth rates. Research has also found that SCC may result from a variety of micro-mechanisms, the most commonly accepted being anodic dissolution and HAC. If the crack propagates by an anodic process (either the dissolution of metal atoms or repeated formation and rupture of an anodic film at the crack tip), the cracking is undoubtedly a type of SCC, an example of which is the cracking of pipeline steel in high-pH SCC solution. On the other hand, if the crack propagation is mainly a result of a mechanical micro-fracture process assisted by hydrogen at the crack tip, then the term hydrogen embrittlement (HE) is more precise.

The exact mechanism(s) for the interaction between hydrogen and metal is the subject of vigorous debate. The main models are de-cohesion and enhanced crack-tip plasticity. When the hydrogen is produced as a result of a natural corrosion reaction, rather than by cathodic charging, the cracking is sometimes classed as SCC. However, cracking of steels under adequate CP is more precisely described as a HAC since, under sufficient electro-chemical polarization, anodic processes (dissolution and/or passivation) are suppressed. At the St. Norbert river crossing, TCPL had installed a CP system that provided adequate CP to the pipe.

2.2.4 Monitoring of Pipeline Crossings on the TCPL System

The slope that contained the ruptured Line 100-2 pipe was found to be unstable and moving downward during periods of seasonally high river levels. This slow, downward movement of ground about the pipeline resulted in abnormally high axial stresses on the Line 100-2 pipe, which contributed directly to the advancement of the transverse crack in the toe of the circumferential weld. Abnormally high axial stresses were also applied to

[2] TCPL detailed report, *St. Norbert Line Break,* Appendix Q

Lines 100-1 and 100-3 but did not result in failures. A TCPL consultant found evidence that the slope had been unstable at the time that TCPL installed Line 100-1 in 1959. The same consultant noted that slope movement had been evident during the construction of other lines on the TCPL system in the vicinity of the occurrence.

The *OPR* requires that monitoring and surveillance programs of the pipeline system form an integral part of the company's operating and maintenance manuals. As a result of the TSB's investigation (P90H1006) into a similar occurrence on another pipeline system, on 26 November 1993 the NEB sent out a reminder, to all pipeline companies under its jurisdiction, of the obligation under the *OPR* requiring the monitoring and surveillance for the protection of the pipeline and the environment. The NEB also directed companies to include in their monitoring and surveillance programs any sensitive slopes, on or near the right of way, that may affect pipeline integrity. The NEB recognizes that in certain cases there may be value in including instrumentation for slope movement detection as a component of the companies' monitoring and surveillance program for identified suspect areas; however, the NEB has decided that this decision would be left to the discretion of the company and must be weighed against cost, operational considerations and the value of the information to be gained. The NEB's letter to the pipeline companies did not include any suggestion or direction to companies to include installation of slope movement detection and monitoring equipment. While TCPL performs regular aerial surveillance of its pipeline system in order to satisfy the requirements of the *OPR*, and while the pilots for TCPL had been instructed on the detection of soil instability, soil subsidence and signs of soil siltation, the pilot carrying out the aerial surveillance had not been trained to identify unusual geotechnical events (such as occurred at the St. Norbert pipeline crossing) that would be indicative of slope movement. In any event, while aerial surveillance would have identified a catastrophic slope failure, it would not have detected this type of slope movement.

Prior to this occurrence, TCPL did not have a policy to internally inspect all slope on its system for the purposes of identifying changes in pipe contour, nor did it have a policy to install slope movement detection and monitoring equipment to determine if a particular slope was stable or unstable.

On a number of occasions, as prescribed by the company's COOP entitled *Underwater Survey,* (which forms an integral part of the company's on-going pipeline integrity program), TCPL performed underwater surveys of the La Salle River bed to ensure that it was stable. The company's COOP does not prescribe the location of these surveys, nor how often they are to be performed. While not a contributing factor to this occurrence, the investigation identified that neither the *OPR*, nor the *CSA Z662* prescribe (as an integral part of a monitoring and surveillance program) that a pipeline company perform this type of survey.

3.0 Conclusions

3.1 Findings

1. The Line 100-2 rupture initiated at a major pre-existing defect, located in the toe of the circumferential weld. It is possible that the initial crack was there from the time of the original construction in 1962.

2. The pipeline ruptured as a result of a stress overload indicative of a cracking mechanism referred to as environmental assisted cracking. A detailed fracture analysis of the failed pipe determined that the main loading force leading to failure came from pipe bending caused by external forces.

3. A geotechnical examination of the crossing found an area of pre-existing slope instability, through which the failed pipeline was constructed. The area surrounding TCPL's La Salle River crossing has had a history of slope failures and previous construction activity on the east bank of the La Salle River had revealed the instability of the river crossing. There was no record prior to the failure that there had been any follow-up excavations, checks or pipe surface inspections of any of the six pipelines to address the issue of ground movement at the crossing.

4. Surveys of the effectiveness of the CP system showed that the CP potentials at the rupture site exceeded minimum industrial norms.

5. Underwater surveys had been carried out by TCPL at the La Salle River crossing, in line with the company's prescribed procedures.

6. The SCADA telemetry communication signal between station No. 41 and the Calgary Centre coincidentally stopped working on the day of the occurrence, due to a failure by TCPL's contract technician working on the system at the station to verify the operational mode of the signal.

7. The SCADA telemetry communication signal between station No. 41 and the Calgary Centre could not be reset by the Calgary Controller, as there was no dial-up feature on the SCADA system for the Calgary Centre.

8. While TCPL's Emergency Procedure Manual (EPM) is specific in directing the Regional Operations Controller (ROC) to immediately isolate all pipelines between compressor stations either side of a confirmed occurrence on the system, not all sections of the pipeline system between stations No. 34 and No. 41 were shut down. However, in this case, sufficient information was available to the decision makers so that the departure from established procedures should be considered acceptable.

9. While the National Energy Board had communicated with all federally regulated pipeline companies, on 26 November 1993, indicating that the NEB's regulatory requirements for monitoring and surveillance programs included the monitoring of slopes susceptible to failure or

movement, TCPL had not installed any equipment at the La Salle River crossing to monitor slope movement.

10. Although TCPL is a member of the Winnipeg Disaster Response Plan, when the Winnipeg Emergency Centre first received news of the occurrence, the company was not immediately notified. TCPL only became aware of the events transpiring at the crossing fourteen minutes later, when advised by a member of the general public and by a TCPL employee who happened to observe a live report on a local television station.

3.2 Cause

The rupture of Line 100-2 was caused by a ductile overload fracture, the result of high external stresses on the surface of the pipeline; stresses which were, in turn, the result of movement of the slope in which the pipe was buried. The rupture was assisted by the existence of an environmentally assisted crack at the toe of the circumferential weld that connected two joints of pipe together. There is the possibility that the initial crack could have been present since the original construction of that section of the pipeline.

4.0 Safety Action

4.1 Action Taken

The section of Line 100-1 at the river crossing was replaced, since it passed through the same area of slope instability. Also, since a section of Line 100-3 was found to have shifted, this section of pipeline was exposed and stress-relieved by allowing the section of pipeline to return to a neutral position.

As a result of this occurrence, TCPL has modified the scope and depth of its operating practices and procedures, as follows:

i) the SCADA telemetry connection has been modified to enable the Calgary Centre to re-establish communications with a compressor station in the event of a loss of primary telemetry signal;
ii) the company's Emergency Procedure Manual has been rewritten to permit deviation from the established "total shut-down" procedures;
iii) company procedures have been amended to allow for faster notification of its management teams;
iv) a long-term program has been established to ensure the success of the site stabilization and monitoring instituted for the La Salle River crossing; and
v) a system-wide geotechnical program is underway to examine the pipeline right of way for any evidence of slope movement, and will assemble a database of soil types, pipe coatings and geotechnical and geographical features for all river crossings on the system.

In addition, TCPL held a community meeting (together with a follow-up meeting) to inform residents near the La Salle River crossing of all TCPL activities resulting from this occurrence. As part of an enhanced community relations initiative, on 19 March 1997, TCPL met with the Reeves and Councilors of the Rural Municipalities of Macdonald and Richot as well as the City of Winnipeg.

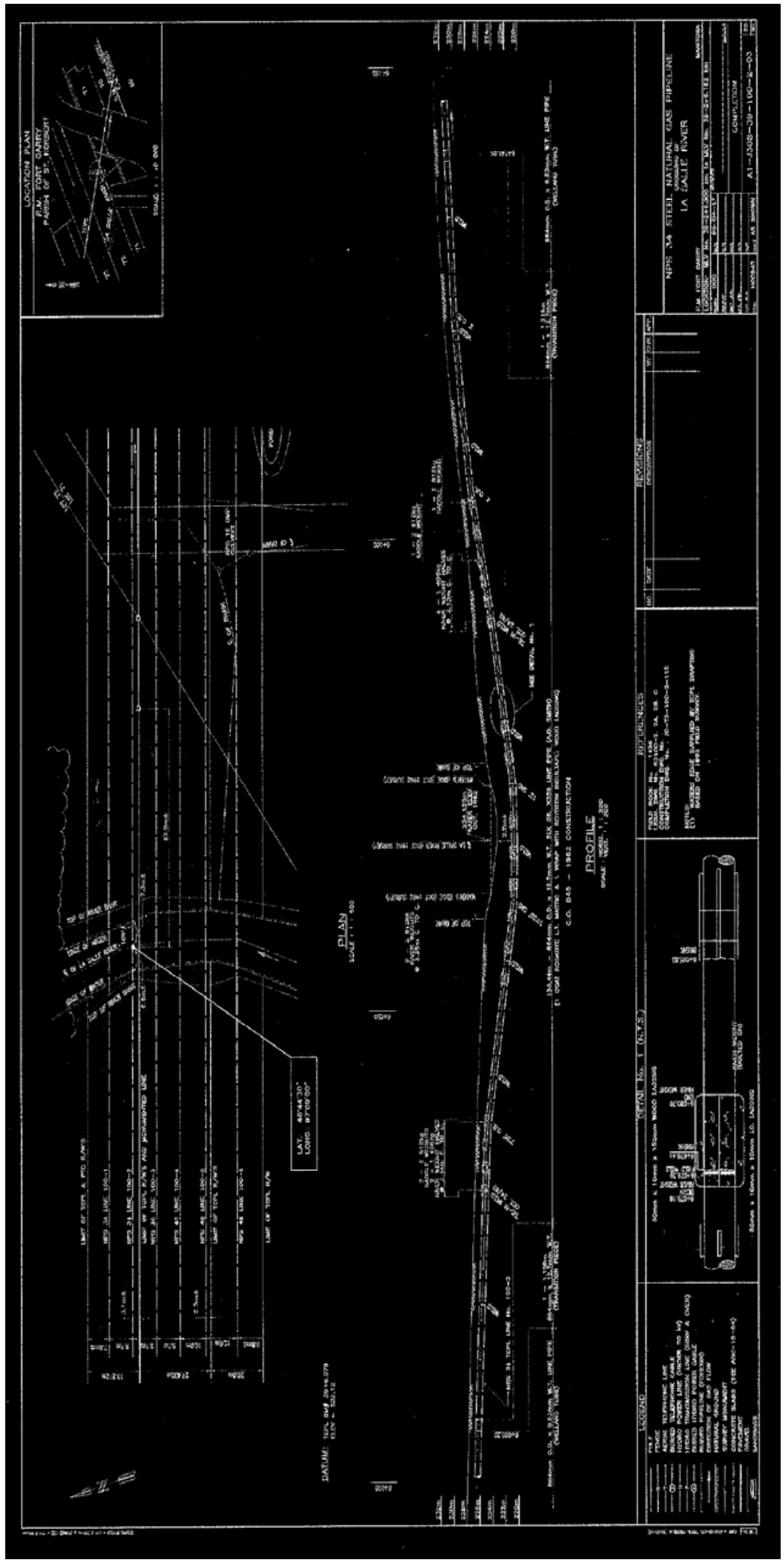
The TCPL Emergency Procedure Manual, which contains the Emergency Response Plan, has been modified such that TCPL's Regional Operations Controllers across the TCPL system will immediately initiate the Regional Call-Out procedure upon suspicion of a pipeline emergency. Should the event be identified as a false alarm, the Regional Operations Controllers have been instructed to log the event as a simulated line break which will then be used for discussion purposes at the next available Operations meeting. As part of a company-wide initiative, TCPL Regional Offices have held emergency response planning sessions with each Fire Department along the complete TCPL system. The emergency response planning sessions included a discussion regarding communications, coordination and the need for continuous site security at occurrence sites.

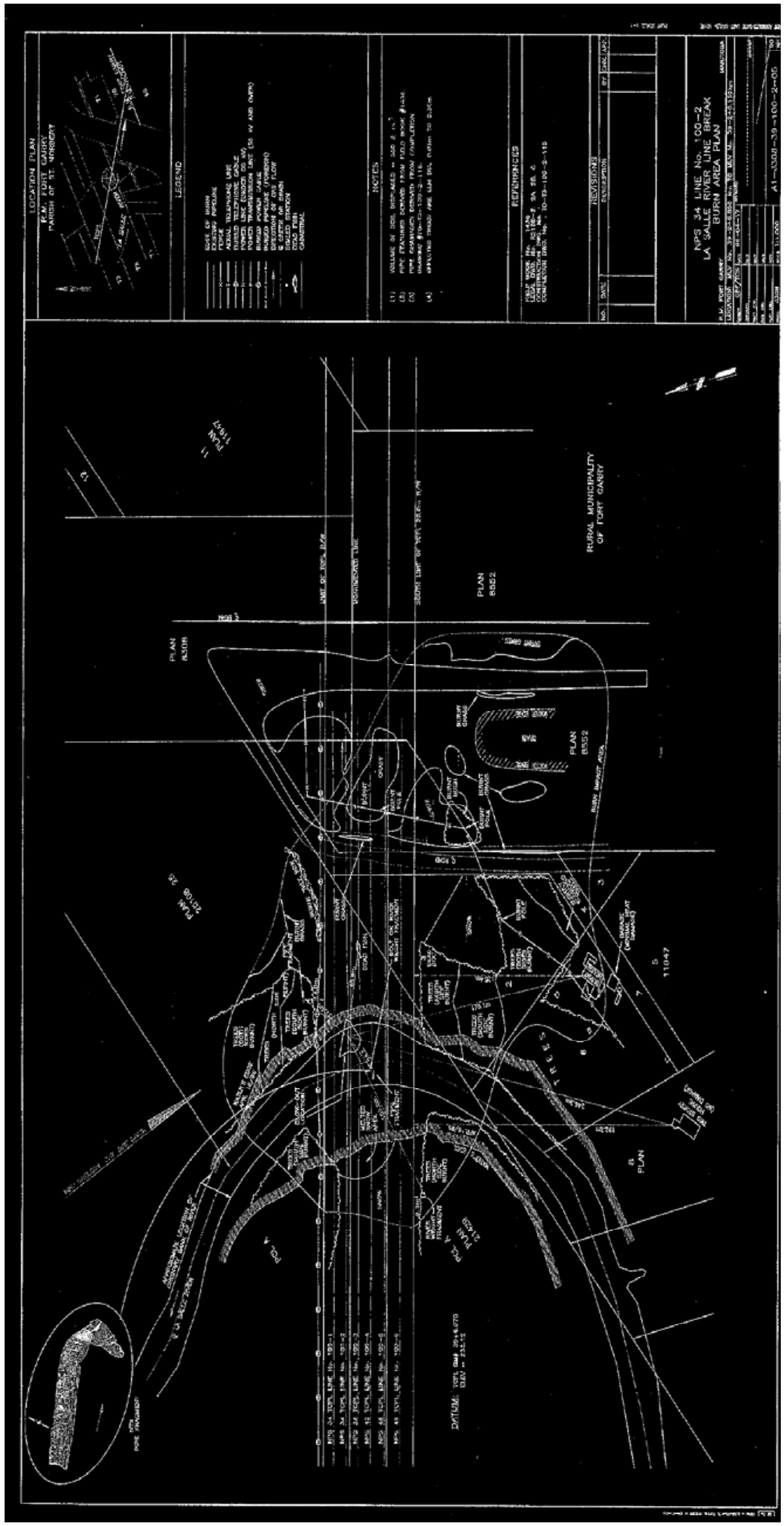
Prior to September 1995, First Response Agencies (fire departments, police and emergency control centres) were contacted on a four-year frequency. In accordance with the last revision to the TCPL Code of Operating Practices, COOP POP-01-04, titled "Public Awareness Programs", First Response Agencies are now contacted annually.

This report concludes the Transportation Safety Board's investigation into this occurrence. Consequently, the Board, consisting of Chairperson Benoît Bouchard, and members Maurice Harquail, Charles Simpson and W.A.

Tadros, authorized the release of this report on 27 January 1999.

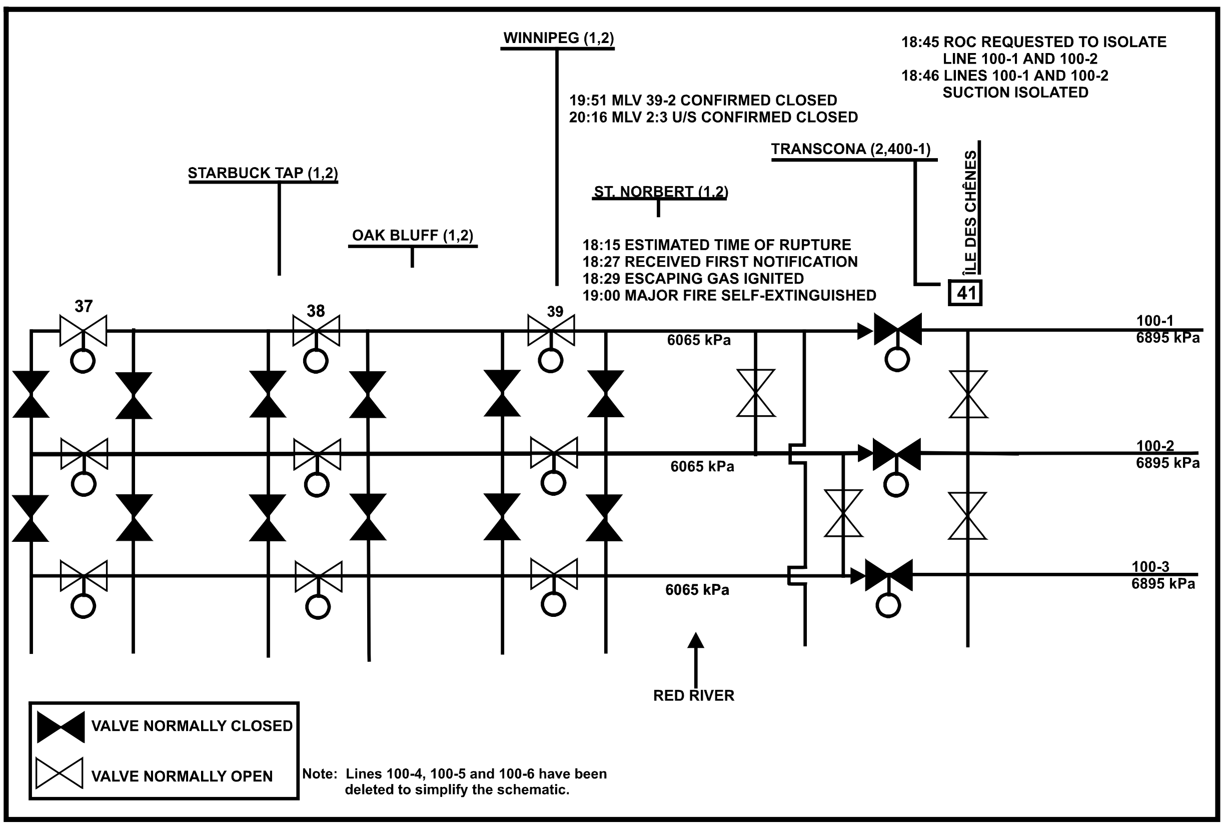
Appendix A - Plan and Profile of the River Crossing (from TCPL)


LOCATION PLAN
PLAN
PROFILE
NPS 34 STEEL NATURAL GAS PIPELINE
LA SALLE RIVER



Appendix B - Burn Area Plan (from TCPL)

Appendix C - Valve Schematic



Appendix D - Glossary

COOP	Code of Operating Practice
CP	cathodic protection
CSA	Canadian Standards Association
EAC	environmental assisted cracking
EPM	Emergency Procedure Manual
EST	eastern standard time
HAC	hydrogen assisted cracking
km	kilometre(s)
km^2	square kilometres
kPa	kilopascal(s)
m	metres(s)
m^3	cubic metres
m^3/s	cubic metres per second
MAOP	maximum allowable operating pressure
MLV	mainline valve
mm	millimetre(s)
MPa	megapascal(s)
mV	millivolt(s)
NEB	National Energy Board
NPS	nominal pipe size
OSC	On-Scene Commander
OPR	*Onshore Pipeline Regulations*
psig	pound(s) per square inch gauge
RCMP	Royal Canadian Mounted Police
ROC	Regional Operations Controller
SCADA	Supervisory Control and Data Acquisition
SCC	stress corrosion cracking
SMYS	specified minimum yield strength
TCPL	TransCanada PipeLines Limited
TSB	Transportation Safety Board of Canada
UTC	Coordinated Universal Time