ATTACHMENT A

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Part 1

Enbridge Incorporated
Hazardous Liquid Pipeline Rupture and Release
Marshall, Michigan
July 25, 2010

Accident Report

NTSB/PAR-12/01
PB2012-916501

National
Transportation
Safety Board

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Pipeline Accident Report

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National
Transportation
Safety Board

490 L'Enfant Plaza, S.W.
Washington, D.C. 20594

National Transportation Safety Board. 2012. ***Enbridge Incorporated Hazardous Liquid Pipeline Rupture and Release*****,** ***Marshall, Michigan*****,** ***July 25, 2010*****. Pipeline Accident Report NTSB/PAR-12/01. Washington, D.C.**

Abstract: On Sunday, July 25, 2010, at 5:58 p.m., eastern daylight time, a segment of a 30-inch-diameter pipeline (Line 6B), owned and operated by Enbridge Incorporated (Enbridge) ruptured in a wetland in Marshall, Michigan. The rupture occurred during the last stages of a planned shutdown and was not discovered or addressed for over 17 hours. During the time lapse, Enbridge twice pumped additional oil (81 percent of the total release) into Line 6B during two startups; the total release was estimated to be 843,444 gallons of crude oil. The oil saturated the surrounding wetlands and flowed into the Talmadge Creek and the Kalamazoo River. Local residents self-evacuated from their houses, and the environment was negatively affected. Cleanup efforts continue as of the adoption date of this report, with continuing costs exceeding $767 million. About 320 people reported symptoms consistent with crude oil exposure. No fatalities were reported.

As a result of its investigation of this accident, the National Transportation Safety Board (NTSB) makes recommendations to the U.S. Secretary of Transportation, the Pipeline and Hazardous Materials Safety Administration (PHMSA), Enbridge, the American Petroleum Institute, the Pipeline Research Council International, the International Association of Fire Chiefs, and the National Emergency Number Association. The NTSB also reiterates a previous recommendation to PHMSA.

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Acronyms and Abbreviations

API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
CAO	corrective action order
CEPA	Canadian Energy Pipeline Association
CFR	*Code of Federal Regulations*
CMT	commodity movement and tracking
Coast Guard	U.S. Coast Guard
CPM	computational pipeline monitoring
CRM	crew resource management
DOT	U.S. Department of Transportation
DSAW	double submerged arc welded
Enbridge	Enbridge Incorporated
EPA	U.S. Environmental Protection Agency
FAA	Federal Aviation Administration
FOSC	Federal on-scene coordinator
HCA	high consequence area
Line 6B	30-inch-diameter accident pipeline
LPM	Line Pressure Management
MBS	Material Balance System
MFL	magnetic flux leakage
MOP	maximum operating pressure
MP	mile point
NEB	National Energy Board

NOPV	Notice of Probable Violation
NRC	National Response Center
NTSB	National Transportation Safety Board
PAP	public awareness program
PAPERS	Public Awareness Program Effectiveness Research Survey
PG&E	Pacific Gas and Electric Company
PHMSA	Pipeline and Hazardous Materials Safety Administration
PII	PII Pipeline Solutions
PIPES	Pipeline Inspection, Protection, Enforcement and Safety
PLM	pipeline maintenance
PREP	Preparedness for Response Exercise Program
PS	pump station
psi	pounds per square inch
psig	pounds per square inch, gauge
RP	recommended practice
SCADA	supervisory control and data acquisition
SCC	stress corrosion cracking
SMS	safety management system
SMYS	specified minimum yield strength
TSB	Transportation Safety Board of Canada
USCD	UltraScan Crack Detection
USGS	U.S. Geological Survey
USWM	UltraScan Wall Measurement
Volpe	Volpe National Transportation Systems Center

Executive Summary

On Sunday, July 25, 2010, at 5:58 p.m., eastern daylight time, a segment of a 30-inch-diameter pipeline (Line 6B), owned and operated by Enbridge Incorporated (Enbridge) ruptured in a wetland in Marshall, Michigan. The rupture occurred during the last stages of a planned shutdown and was not discovered or addressed for over 17 hours. During the time lapse, Enbridge twice pumped additional oil (81 percent of the total release) into Line 6B during two startups; the total release was estimated to be 843,444 gallons of crude oil. The oil saturated the surrounding wetlands and flowed into the Talmadge Creek and the Kalamazoo River. Local residents self-evacuated from their houses, and the environment was negatively affected. Cleanup efforts continue as of the adoption date of this report, with continuing costs exceeding $767 million. About 320 people reported symptoms consistent with crude oil exposure. No fatalities were reported.

The National Transportation Safety Board (NTSB) determines that the probable cause of the pipeline rupture was corrosion fatigue cracks that grew and coalesced from crack and corrosion defects under disbonded polyethylene tape coating, producing a substantial crude oil release that went undetected by the control center for over 17 hours. The rupture and prolonged release were made possible by pervasive organizational failures at Enbridge Incorporated (Enbridge) that included the following:

- Deficient integrity management procedures, which allowed well-documented crack defects in corroded areas to propagate until the pipeline failed.
- Inadequate training of control center personnel, which allowed the rupture to remain undetected for 17 hours and through two startups of the pipeline.
- Insufficient public awareness and education, which allowed the release to continue for nearly 14 hours after the first notification of an odor to local emergency response agencies.

Contributing to the accident was the Pipeline and Hazardous Materials Safety Administration's (PHMSA) weak regulation for assessing and repairing crack indications, as well as PHMSA's ineffective oversight of pipeline integrity management programs, control center procedures, and public awareness.

Contributing to the severity of the environmental consequences were (1) Enbridge's failure to identify and ensure the availability of well-trained emergency responders with sufficient response resources, (2) PHMSA's lack of regulatory guidance for pipeline facility response planning, and (3) PHMSA's limited oversight of pipeline emergency preparedness that led to the approval of a deficient facility response plan.

Safety issues identified during this accident investigation include the following:

- **The inadequacy of Enbridge's integrity management program to accurately assess and remediate crack defects.** Enbridge's crack management program relied on a single in-line inspection technology to identify and estimate crack sizes. Enbridge used the resulting inspection reports to perform engineering assessments without accounting for uncertainties associated with the data, tool, or interactions between cracks and corrosion. A 2005 Enbridge engineering assessment and the company's criteria for excavation and repair showed that six crack-like defects ranging in length from 9.3 to 51.6 inches were left in the pipeline, unrepaired, until the July 2010 rupture.

- **The failure of Enbridge's control center staff to recognize abnormal conditions related to ruptures.** Enbridge's leak detection and supervisory control and data acquisition systems generated alarms consistent with a ruptured pipeline on July 25 and July 26, 2010; however, the control center staff failed to recognize that the pipeline had ruptured until notified by an outside caller more than 17 hours later. During the July 25 shutdown, the control center staff attributed the alarms to the shutdown and interpreted them as indications of an incompletely filled pipeline (known as column separation). On July 26, the control center staff pumped additional oil into the rupture pipeline for about 1.5 hours during two startups. The control center staff received many more leak detection alarms and noted large differences between the amount of oil being pumped into the pipeline and the amount being delivered, but the staff continued to attribute these conditions to column separation. An Enbridge supervisor had granted the control center staff permission to start up the pipeline for a third time just before they were notified about the release.
- **The inadequacy of Enbridge's facility response plan to ensure adequate training of the first responders and sufficient emergency response resources allocated to respond to a worst-case release.** The first responders to the oil spill were four Enbridge employees from a local pipeline maintenance shop in Marshall, Michigan. Their efforts were focused downstream along the Talmadge Creek rather than near the immediate area of the rupture. The first responders neglected to use the culverts along the Talmadge Creek as underflow dams to minimize the spread of oil, and they deployed booms unsuitable for the fast-flowing waters. Further, the oil spill response contractors, identified in Enbridge's facility response plan, were unable to immediately deploy to the rupture site and were over 10 hours away.
- **Inadequate regulatory requirements and oversight of crack defects in pipelines.** Title 49 *Code of Federal Regulations* (CFR) 195.452(h) fails to provide clear requirements for performing an engineering assessment and remediation of crack-like defects on a pipeline. In the absence of prescriptive regulatory requirements, Enbridge applied its own methodology and margins of safety. Enbridge chose to use a lower margin of safety for cracks than for corrosion when assessing crack defects. PHMSA expects pipeline operators to excavate all crack features; however, PHMSA did not issue any findings about the methods used by Enbridge in previous inspections.
- **Inadequate regulatory requirements for facility response plans under 49 CFR 194.115, which do not mandate the amount of resources or recovery capacity required for a worst-case discharge.** In the absence of such requirements, Enbridge interpreted the level of oil response resources required under PHMSA's

three-tier response time frame, resulting in a lack of adequate oil spill recovery equipment and resources in the early hours of the first response. By contrast, the U.S. Coast Guard (Coast Guard) and the U.S. Environmental Protection Agency (EPA) regulations specify effective daily response capability for each of the three tiers for oil spill response planning.

- **PHMSA's inadequate review and approval of Enbridge's facility response plan that failed to verify that the plan content was accurate and timely for an estimated worst-case discharge of 1,111,152 gallons.** PHMSA's facility response program oversaw 450 facility response plans with 1.5 full-time employees, which is a lower staffing commitment than comparable response plan review programs carried out by the EPA and the Coast Guard. PHMSA and other Federal agencies receive funding from the Oil Spill Liability Trust Fund to cover operational, personnel, enforcement, and other related program costs.

As a result of this investigation, the NTSB makes safety recommendations to the U.S. Secretary of Transportation, PHMSA, Enbridge, the American Petroleum Institute, the Pipeline Research Council International, the International Association of Fire Chiefs, and the National Emergency Number Association. The NTSB also reiterates a previous recommendation to PHMSA.

1 Factual Information

1.1 Introduction

On Sunday, July 25, 2010, at 5:58 p.m., eastern daylight time,[1] a segment of a 30-inch-diameter pipeline (Line 6B), owned and operated by Enbridge Incorporated (Enbridge) ruptured in a wetland in Marshall, Michigan, about 0.6 mile downstream of the Marshall Pump Station (PS), releasing about 843,444 gallons of crude oil.[2] The accident pipeline was part of Enbridge's liquid pipeline system that originates in Edmonton, Alberta, Canada, and terminates in Sarnia, Ontario, Canada. The 1,900-mile U.S. portion, known as the Lakehead System, consists of pipelines of various diameters and ages operated from a control center in Edmonton. Line 6B is a 293-mile section of the Lakehead System, which crosses the state of Michigan joining Griffith, Indiana, to Sarnia. (See figure 1.)

Line 6B was installed in 1969 and constructed from 30-inch-diameter carbon steel pipe wrapped with a single layer of polyethylene tape. The ruptured pipe segment was manufactured to an American Petroleum Institute (API) Standard 5LX[3] grade X52[4] specification with a 0.25-inch wall thickness and a double submerged arc welded (DSAW) longitudinal seam; it was cathodically protected. Immediately prior to the accident, the highest recorded downstream pressure at the Marshall PS was 486 pounds per square inch, gauge (psig).[5] During 2010, Line 6B transported about 11.9 million gallons of crude oil per day.

The rupture occurred in the final stages of a planned Line 6B shutdown that was scheduled to have the pipeline out of operation for 10 hours. The shutdown, started at 5:55 p.m., was performed in just a few minutes by shutting off pumps from the Griffith PS to the Marshall PS while increasing pressure at a pressure control valve that was downstream of the Marshall PS at the Stockbridge Terminal. (The shutdown, during which oil would not be pumped through the pipeline, had been planned to accommodate the oil delivery schedule at the Griffith Terminal.) About 1 minute after increasing the pressure at the Stockbridge Terminal, the pipeline ruptured downstream of the Marshall PS. Multiple alarms were immediately generated at the Enbridge control center following the rupture, but Enbridge staff believed the alarms

[1] All times in this report are eastern daylight time unless otherwise specified.

[2] Line 6B transports multiple grades of heavy bituminous crude oil from the oil sand regions of Western Canada that require dilution with lighter petroleum products to enable the crude to flow easier. For simplicity, this report will refer to the product in Line 6B as crude oil.

[3] The API develops industry-based consensus standards that support oil and gas production and distribution. API 5LX is a specification for line pipe.

[4] Grade X52 signifies that the pipe has a specified minimum yield strength (SMYS) of 52,000 pounds per square inch (psi). Yield strength is a measure of the pipe's material strength and indicates the stress level at which the material will exhibit permanent deformation. Although yield strength is expressed in psi, this value is not equivalent to a pipe's internal pressure.

[5] Psig is a unit of measure for pressure expressed relative to pressure exerted by the surrounding atmosphere. Psi will be used in this report as a unit of measure for stress and is a measure of force acting over a given area.

resulted from a combination of column separation[6] and erratic pressures generated during shutdown rather than a rupture.

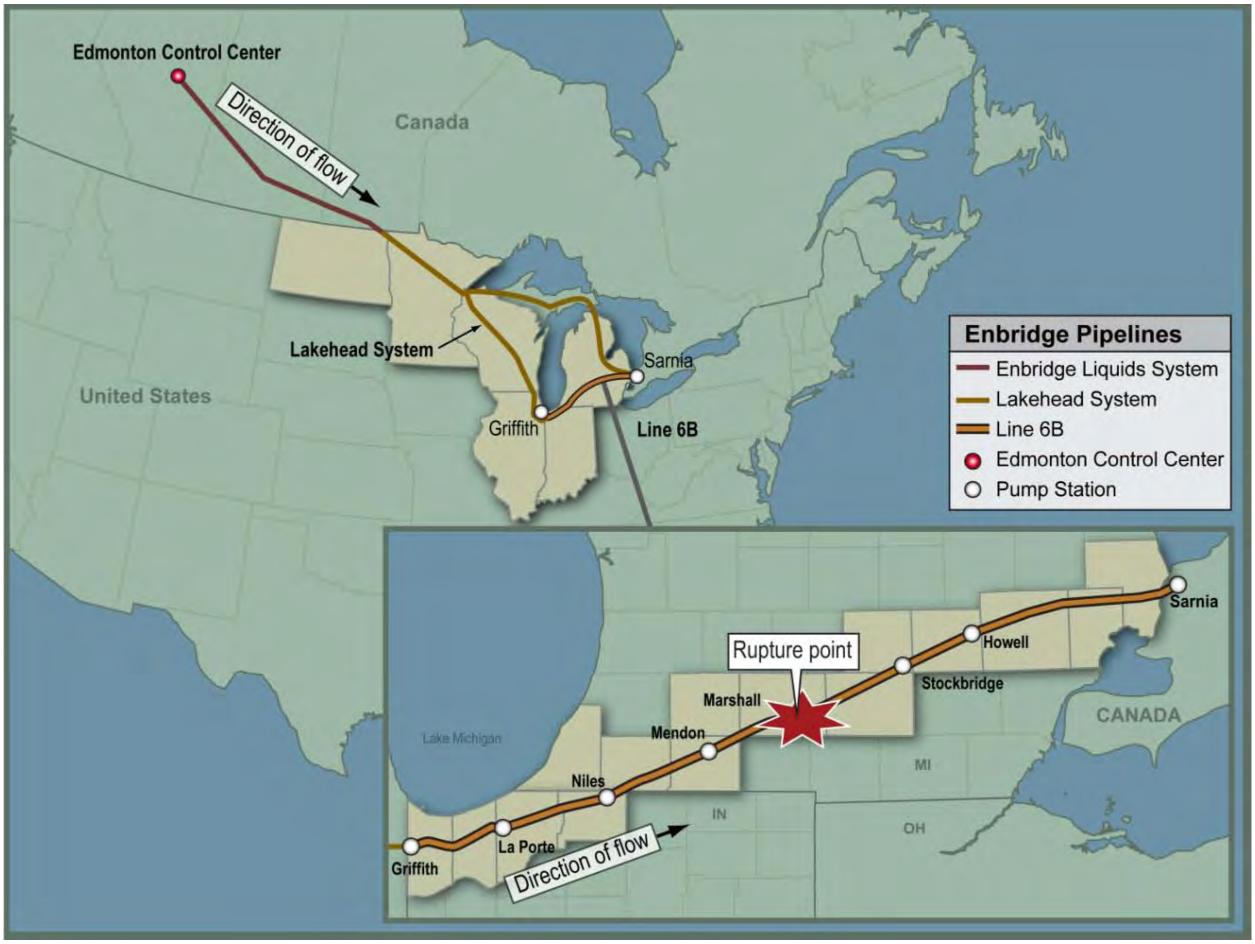

Figure 1. Enbridge's Liquids System and the 1,900-mile Lakehead System (the U.S. portion). Inset shows Line 6B, the 293-mile extension from Griffith to Sarnia installed in 1969.

To resume operations following the planned 10-hour shutdown, Enbridge staff started Line 6B once at 4:04 a.m. on July 26 and pumped oil for about 1 hour before shutting down the line. At 7:20 a.m., Enbridge staff started Line 6B again and pumped oil for about 30 minutes before shutting down the line. During the two startups and 1.5 hours of operation, Enbridge staff pumped about 683,436 gallons of oil[7] (81 percent of the total release) into the ruptured pipeline without seeing an increase in the pressure. Leak-detection alarms were generated, but Enbridge staff continued to believe the alarms were the result of column separation, even though the Marshall area was relatively flat, without significant elevation changes. Enbridge staff also

[6] *Column separation* is a condition indicating a mixture of liquid and vapor—a vapor bubble—exists in the pipeline. Column separation usually occurs at changes in elevation or where liquid does not completely fill the pipeline. The immediate area around the Marshall PS was relatively flat; however, a 100-foot elevation increase existed about 13 miles downstream. For more information about column separation, see section 1.11.5.4, "Column Separation," of this report.

[7] An NTSB study estimated this amount.

considered operational changes implemented before the startups, including a Niles PS shutdown and valve closure (due to an in-line crack inspection) and the possibility that large volumes of oil had settled into lower elevations and delivery locations, to be complicating factors.

The Calhoun County 911 dispatch center received the first call about odors associated with the oil release about 9:25 p.m. on July 25 (3.5 hours after the rupture) and dispatched firefighters from Marshall City; however, firefighters were unable to pinpoint a source of the odors. A gas utility worker, responding to the area because of numerous calls about gas odors, notified the Enbridge control center about oil on the ground at 11:17 a.m. on July 26 (more than 17 hours after the rupture). In less than 5 minutes, Enbridge staff began closing remote valves upstream and downstream of the rupture, sealing off the site within a 2.95-mile section.

The fracture in the ruptured segment measured 6 feet 8.25 inches long and up to 5.32 inches wide. (See figure 2.) External corrosion was present along the longitudinal weld seam and in areas where the adhesive bond between the pipe and its protective polyethylene tape coating had deteriorated (disbonded). The coating was wrinkled and had separated from the pipe surface as shown in the red circle in figure 2.

Figure 2. The ruptured segment of Line 6B in the trench following the July 25, 2010, rupture. The fracture face measured about 6 feet 8.25 inches long and was 5.32 inches wide at the widest opening. The fracture ran just below the seam weld that was oriented just below the 3 o'clock position. A red circle shows a location where the coating was wrinkled and had separated from the pipe surface.

The crude oil release soaked the rupture site and the surrounding wetlands, eventually spreading to the Talmadge Creek and the Kalamazoo River. Enbridge's early response efforts were focused downstream of the rupture. Recent heavy rainfall had increased the flow of the Talmadge Creek and the Kalamazoo River, which spread the oil faster, hindering the response efforts. (See figure 3.)

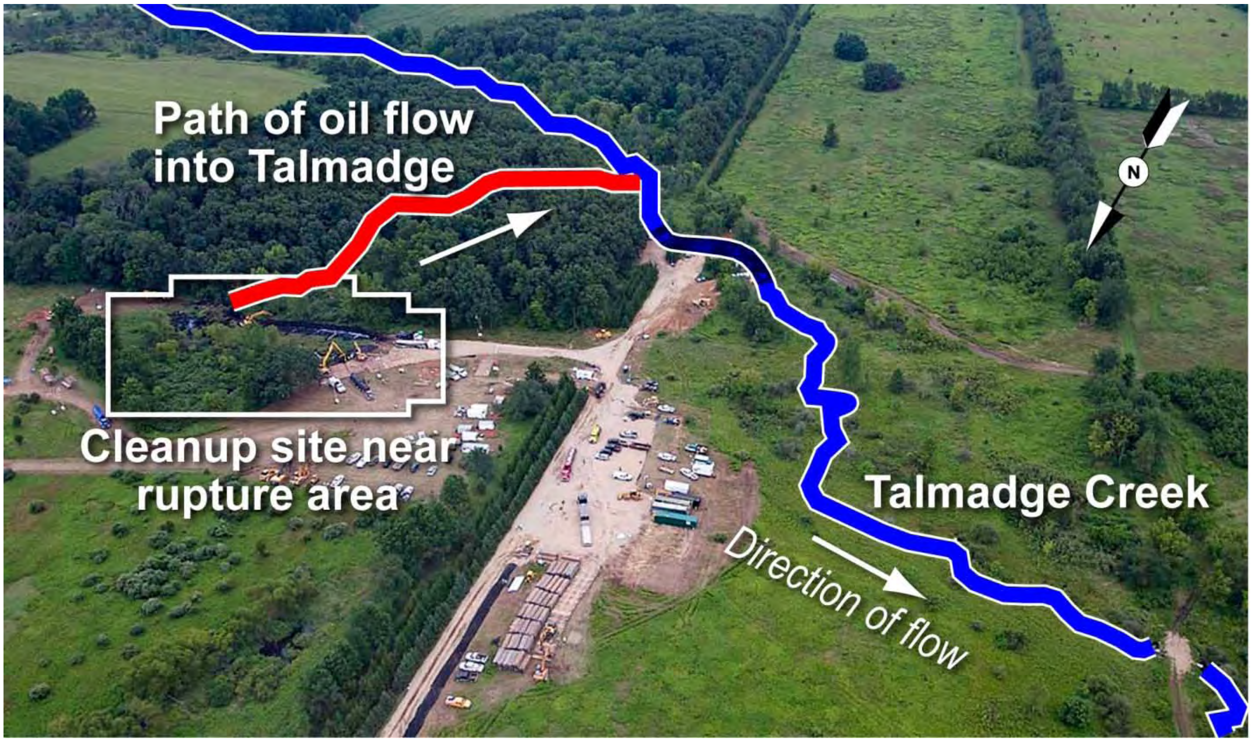

Figure 3. Aerial view of the accident location showing the rupture site to the left and the Talmadge Creek flowing west toward the Kalamazoo River.

The wetland conditions in addition to the crude oil release made it difficult for vacuum trucks and excavators to get near the rupture location. Large wooden matting had to be placed around the rupture location to bring heavy equipment close to the release. (See figure 4.) The conditions at the accident site also delayed efforts to extract the pipe and to contain the oil near the rupture source.

Figure 4. Cleanup efforts in an oil-soaked wetland near the rupture site. Saturated soil complicated the cleanup and excavation efforts. An excavator with a vacuum attachment is shown situated on wooden matting near the rupture site.

Figure 5 shows a timeline highlighting the accident events that spanned over 17 hours from the time of the rupture until the Enbridge control center was made aware of it. Figure 6 shows the key Enbridge staff involved.

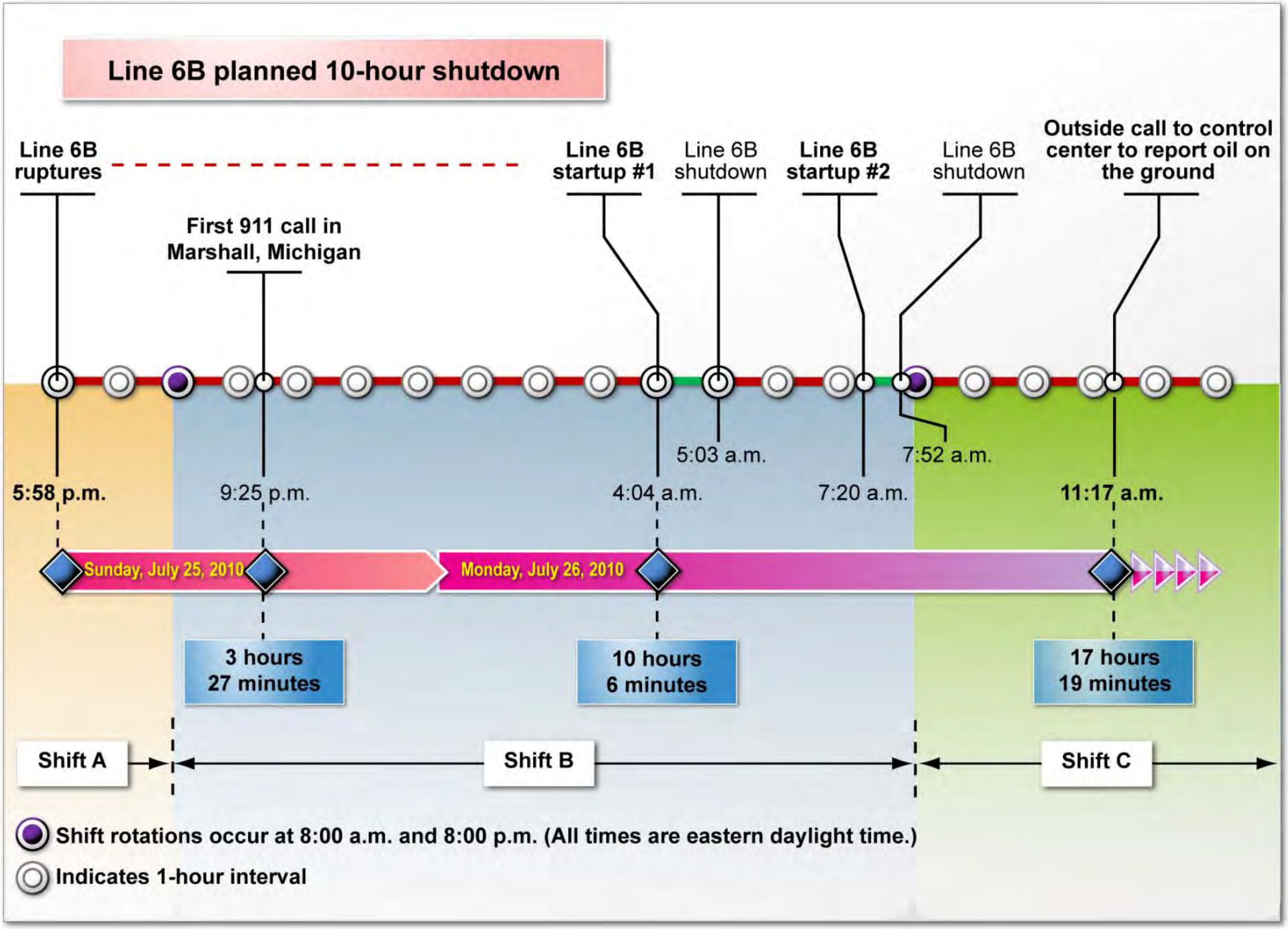

Figure 5. Key events timeline of the Line 6B rupture in Marshall, Michigan, showing the events from the time of rupture on July 25, 2010, to the time of discovery on July 26, 2010.

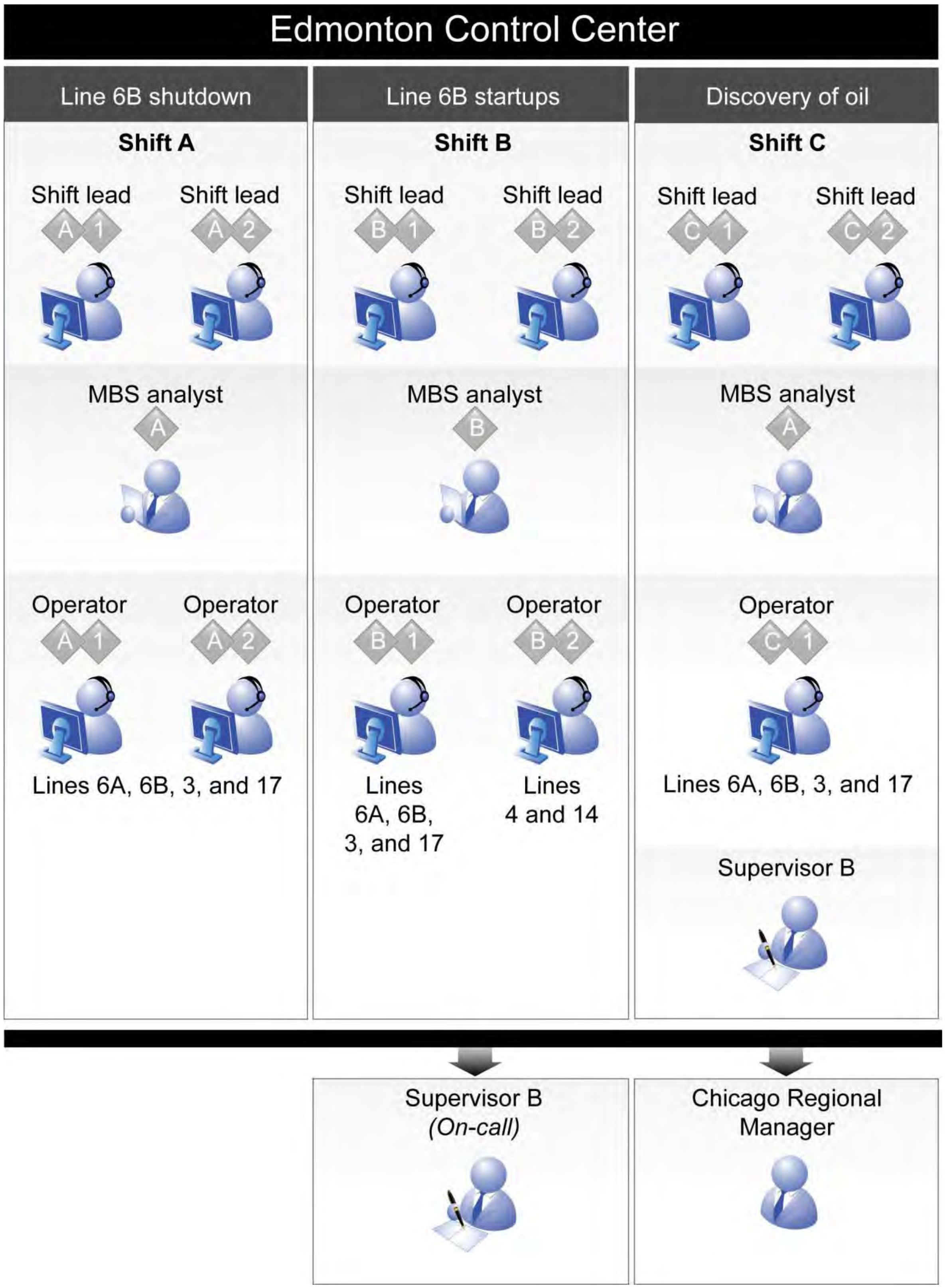

Figure 6. Key Enbridge staff involved in the 17-hour accident sequence. MBS refers to Material Balance System.

1.2 Accident Narrative

1.2.1 Preaccident Events

The planned shutdown of Line 6B was scheduled to begin following the last crude oil delivery to the Stockbridge Terminal, located downstream of the Marshall PS (see figure 7). A shutdown was to be performed by pipeline operator A1, sequentially, in the direction of flow, by turning off the pumps at the following PSs: Griffith, La Porte, Niles, Mendon, and Marshall. The shutdown was started at 5:55 p.m. by stopping two pumps at the Griffith PS and a pump at the La Porte PS. At 5:57 p.m., operator A1 increased the upstream pressure at a pressure control valve[8] at the Stockbridge Terminal before stopping a pump at the Niles PS and a pump at the Mendon PS about 1 minute later.

1.2.2 The Rupture—Shift A

The rupture occurred on July 25, 2010, at 5:58 p.m. in the final minute of a planned Line 6B shutdown, about 45 seconds after operator A1[9,10] increased upstream pressure (toward the Marshall PS) at a pressure control valve located at the Stockbridge Terminal and had stopped pumps at the Niles and the Mendon PSs. When the pipeline segment ruptured, the Marshall PS shut down automatically and three alarms almost simultaneously appeared on operator A1's supervisory control and data acquisition (SCADA) system display: an invalid-pressure[11] alarm (a severe alarm),[12] a low-suction-pressure alarm (a warning alarm),[13] and a station local shutdown alarm[14] (a warning alarm). The first two alarms cleared within 5 seconds but then reappeared because of the pressure changes resulting from the rupture. Within the same few seconds, operator A1 stopped the Marshall PS as part of the planned shutdown; he later told investigators that he had not recognized that a rupture had occurred. After the pipeline shut down, valves were closed at the Niles PS (see figure 7) to accommodate a Line 6B in-line inspection tool[15] that had been launched the previous day.

[8] Operator A1 increased the holding pressure from 50 to 200 psig at the Stockbridge Terminal pressure control valve (see appendix C for more information).

[9] Operator A1 had 29 years of pipeline operator experience but was requalifying after a 6-month-long disability leave from the control center. During his requalification, a mentor was overseeing his work. The mentor (operator A2) had an equivalent amount of experience.

[10] Control center operators were responsible for the operation of multiple pipelines and sometimes pipelines and terminals. The Line 6B operator (operator A1) was also responsible for Lines 3, 17, and 6A.

[11] This alarm was generated by the Line Pressure Management (LPM) system, which is designed to protect the pipeline from being overpressured.

[12] Enbridge defined a "severe alarm" as requiring the control center operator to notify the shift lead, advise the on-site/on-call staff, and create an entry in the facility maintenance database system.

[13] Enbridge defined a "warning alarm" as discretionary operator response dependent on operating conditions. Multiple alarms can result in an increased severity.

[14] These latter two alarms were generated by the Marshall PS.

[15] A cleaning tool and an in-line crack inspection tool were launched on July 24 at the Griffith Terminal, separated by about 5 miles. They remained upstream of the Niles PS even after the oil release was identified. The tools remained in the pipeline until the failed section was replaced and Line 6B returned to service in September 2010.

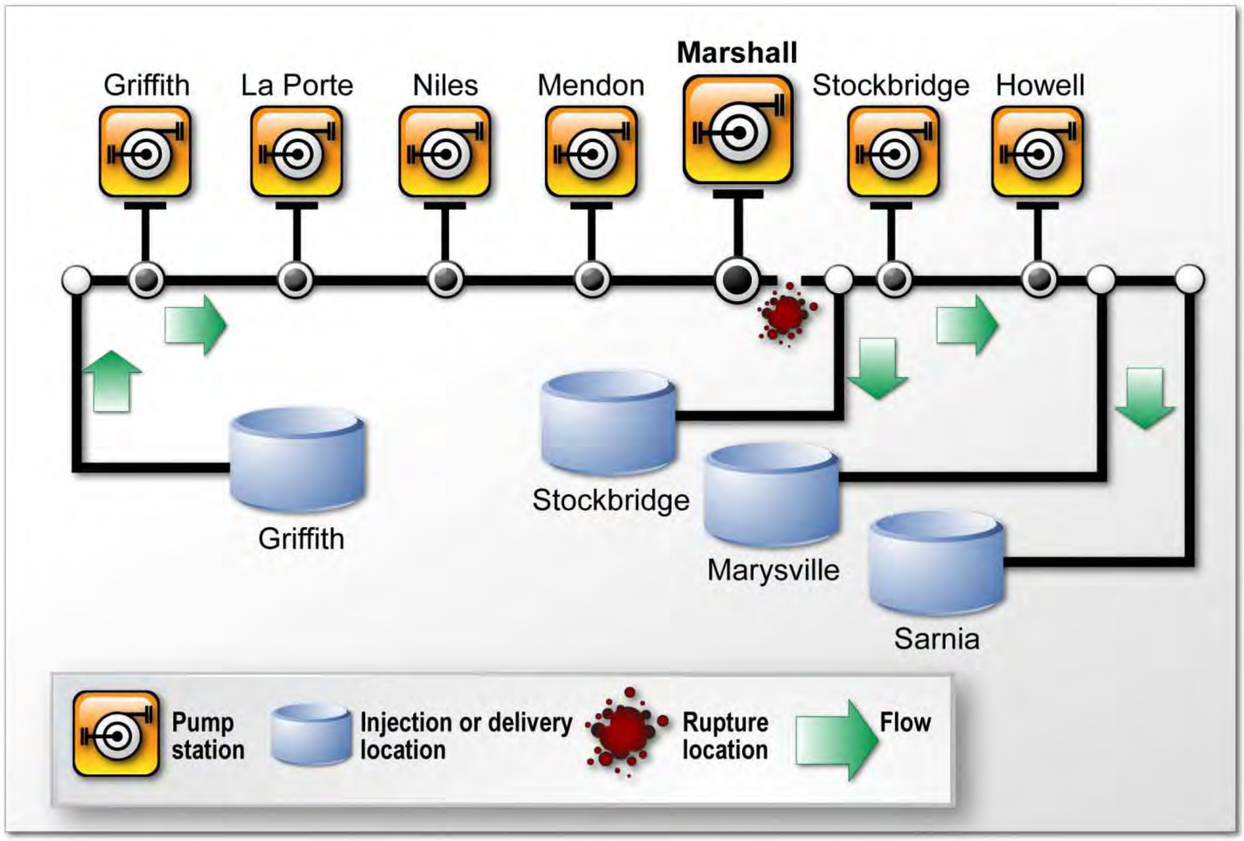

Figure 7. Simplified schematic of Line 6B, showing pump stations and delivery locations.

By 6:03 p.m., operator A1 had received several more alarms related to the Line 6B rupture, including a 5-minute Material Balance System (MBS) alarm[16] (a severe leak alarm), another low-suction-pressure alarm, and six additional invalid-pressure alarms. (All of the alarms were indications of the rupture.) The 5-minute MBS alarm indicated that a large oil volume imbalance had been detected in the pipeline. Operator A1 informed shift lead A1 about the MBS alarm, and shift lead A1 contacted MBS analyst A about the MBS alarm.

At 6:05 p.m., MBS analyst A called operator A1 to explain that he had concluded column separation near the Marshall PS had generated the MBS alarm.

Within minutes, the MBS alarm cleared on its own. (MBS alarms clear after a shutdown because the oil flow stops.) About this time, MBS analyst A told shift lead A2 about the alarm, his conclusion about its suspected cause, and its status. There was no further discussion about the MBS alarm during the shift.

[16] A single MBS alarm may be associated with multiple instances of column separation. MBS alarms display as 5-minute, 20-minute, or 2-hour alarms, indicating relative leak size. The 5-minute alarm represents the largest leak rate, and the 2-hour alarm represents the smallest leak rate.

Operators A1 and A2[17] independently told National Transportation Safety Board (NTSB) investigators that when the MBS alarm had cleared, they were no longer concerned about the low pressure at the Marshall PS because they believed the alarms were related to column separation and the shutdown. Line 6B remained shut down[18] for 10 hours, as scheduled. The Marshall PS pressures remained at zero.

1.2.3 First Line 6B Startup—Shift B

The Sunday second shift control center staff took over operations between 8:00 p.m. and 8:30 p.m.[19] During shift rotations, a verbal exchange of operational information, known as a shift exchange, took place among the control center operators, MBS analysts, and the shift leads. At the time of the accident, Enbridge had a procedure that required specific information to be exchanged during shift changes, but no formal documentation or written record of the exchanged information was required.

Shift lead B1 told investigators that, during the shift exchange, he was not informed about the previous shutdown or the pending startup of Line 6B, the MBS alarm, or the in-line inspection tool in Line 6B. Operator B1[20] said that he was not informed about the alarms that occurred during the shutdown but that he had been told about the scheduled Line 6B startup, the in-line inspection, and the Niles PS valve closure for the in-line inspection. He stated that he expected the Line 6B startup would be difficult because of the Niles PS being shut down to accommodate the in-line inspection tool. This meant that the Niles PS pumps could not be operated and the pressures would be lower coming into the Mendon PS (upstream of the Marshall PS). He did not question the low pressures at the Marshall PS.

At 8:56 p.m., Michigan Gas Utilities dispatched a senior service technician to respond to a residential report of natural gas odor. At 9:25 p.m. on July 25, a local resident called the Calhoun County 911 dispatch center and stated the following:

> I was just at the airport in Marshall and drove south on Old 27 [17 Mile Road] and drove back north again and there's a very, very, very strong odor, either natural gas or maybe crude oil or something, and because the wind's coming out of the north, you can smell it all the way up to the tanks, right across from where the airport's at, and then you can't smell it anymore.

By 9:32 p.m., the Marshall City Fire Department had been dispatched in response to the 9:25 p.m. call to 911. The 911 dispatcher told the responders there was a report of a bad smell of natural gas near the airport.

[17] Operator A2 told investigators that she was working on special projects alongside operator A1 when the accident occurred. She said she was aware of the MBS alarm but not directly involved with handling it.

[18] When Line 6B was shut down, valves upstream and downstream of the rupture were closed, isolating a 75-mile span of the line and the rupture site.

[19] The control center work shifts were 12 hours.

[20] Operator B1 had about 3.5 years experience in the Edmonton control center as a pipeline operator. See table 3 for further information about control center staff experience.

Marshall City Fire Department personnel responded to the area near the airport and requested the Marshall Township Fire Department to respond as well. To find the source of the odor, fire department personnel investigated several pipeline facilities and industrial buildings around Division Drive and 17 Mile Road, using a combustible gas indicator[21] to try to locate the origin of the odor. No combustibles were detected. The Michigan Gas Utilities senior service technician crossed paths with some of the fire department personnel also trying to locate the source; he found no evidence of a gas leak. The fire department personnel departed the scene at 10:54 p.m. to return to the station. At 11:33 p.m., an employee at a business called 911 to report a natural gas odor. The 911 dispatcher explained that the fire department had already responded to calls in the area, and no more personnel were dispatched.[22] (See figure 8.)

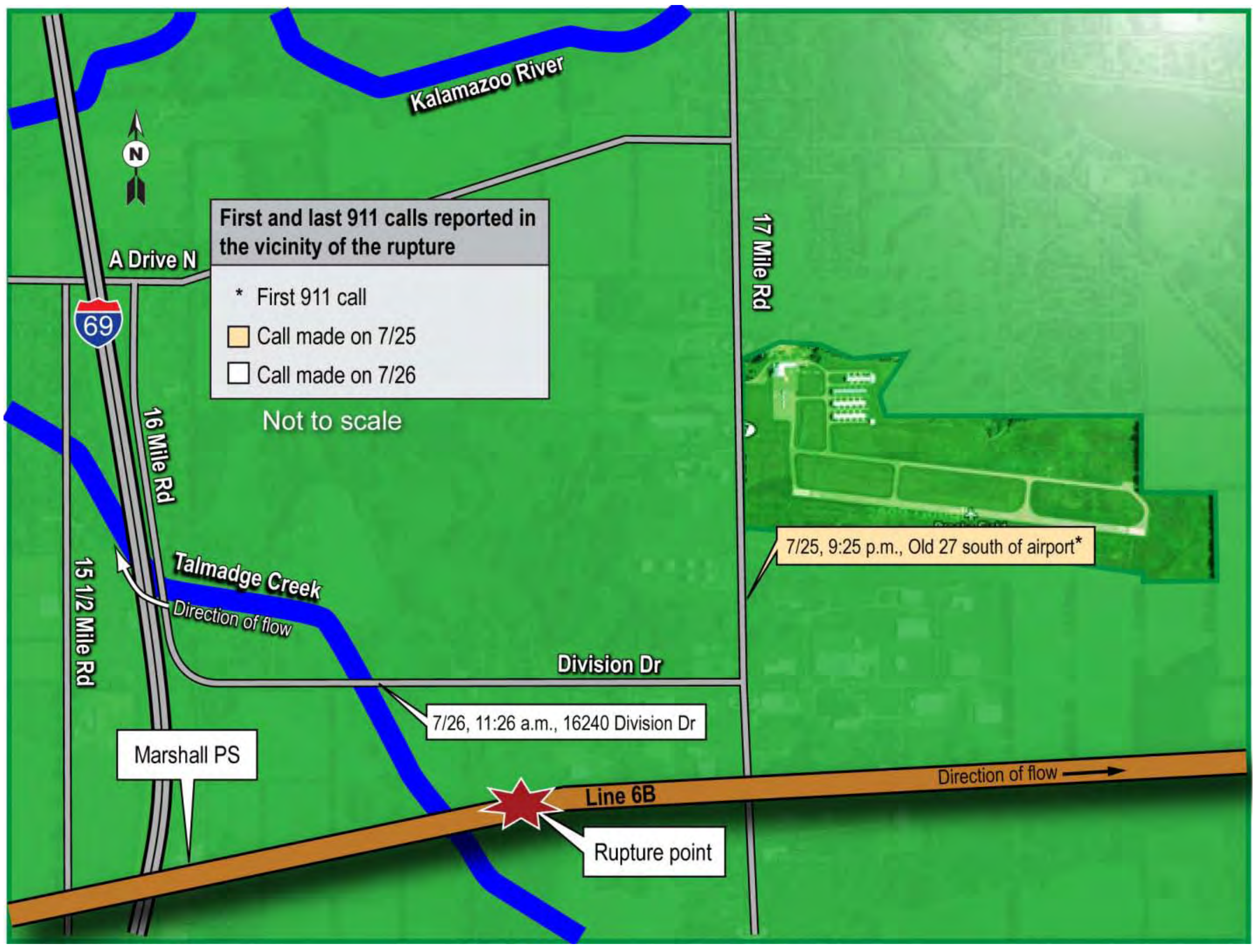

Figure 8. Emergency response and 911 calls from nearby residents. First and last calls are noted.

[21] Because a combustible gas indicator measures percentage of the lower explosive limit, it likely would not detect the oil unless it was very close to the source.

[22] Over the next 14 hours, the local 911 received seven more calls reporting strong natural gas or petroleum odors in the same vicinity. The 911 dispatcher repeatedly informed the callers that the fire department had been dispatched to investigate the reported odors.

On Monday, July 26, at 4:00 a.m., while preparing to start Line 6B for deliveries into the Marysville and Sarnia Terminals, operator B1 reduced pressure settings at two PSs (Marshall and Mendon) upstream of a valve that had lost communication.[23] Line 6B was going to be started without the Niles PS, which remained out of service for the in-line inspection tool.

About 4:04 a.m., operator B1 started Line 6B from the Griffith PS to the Mendon PS, and by 4:12 a.m., the first 5-minute MBS alarm appeared on his SCADA display. Operator B1 called MBS analyst B about the alarm. MBS analyst B told operator B1 that the alarm was due to column separation. After talking with operator B1, the MBS analyst realized that the MBS software had not been set up correctly[24] because the Niles PS valves were closed. According to MBS analyst B, the valve closure at the Niles PS might have resulted in additional column separation indications that morning.[25]

By 4:24 a.m., operator B1 had received a 20-minute MBS alarm and another 5-minute MBS alarm. He notified shift lead B2 that Line 6B had been operating for 10 minutes but pressure remained less than 1 psig downstream of the Marshall PS. Enbridge's control center procedures required operators to shut down the pipeline when column separation could not be restored within 10 minutes.[26] Shift lead B2 and MBS analyst B told operator B1 to continue pumping oil to restore the column. Operator B1 started a larger pump upstream of the Marshall PS to increase the pipeline pressure.

During this time, operator B2[27] referred shift lead B1 to a draft column separation procedure that she had used earlier in the year. According to the draft procedure, when known column separation existed, an operator would calculate the time needed to fill the pipeline before starting the line. Once started, if column separation were present 10 minutes beyond the calculated time, the pipeline would be shut down. In effect, the draft procedure allowed the pipeline to operate in excess of the 10-minute limit under certain conditions. As operator B1 continued to pump additional oil into the pipeline, shift lead B1 attempted to estimate the time needed to restore the pressure downstream of the Marshall PS.[28] To do this, shift lead B1 tried to determine (1) the volume of oil that had settled throughout Line 6B during the shutdown and (2) the volume of oil that had drained into the Marysville Terminal during startup. Shift lead B1 estimated it would take about 20 minutes to bring the column back together.

[23] These were settings that protected the pipeline from overpressure in the event that the valve that had lost communication was closed.

[24] When the station valves at the Niles PS were closed to accommodate an in-line inspection tool, following the shutdown, the SCADA pressure transmitters used by the MBS were no longer using the real-time pipeline pressures, which resulted in errors in the MBS. To correct the MBS software, the MBS analyst had to override the pressures on both sides of the Niles PS. The MBS analyst stated that the lack of live pressures at the Niles PS may have affected the MBS alarms that morning.

[25] According to Enbridge, the software showed more instances of column separation before the software was adjusted.

[26] This duration was commonly referred to as the "10-minute rule" by the control center staff and represented the amount of time a pipeline was allowed to operate in instances of column separation or abnormal operations before being shut down.

[27] This was the shift mate of operator B1, who was operating Lines 4 and 14. Operator B2 had just over 2 years of experience as a pipeline operator. See table 3 for further information about control center staff experience.

[28] By dividing the amount of oil drained out into delivery locations during shutdown by gallons per hour, the shift lead can estimate how long the system must be run to restore pressure.

Operator B1 continued to start pumps on Line 6B and received multiple MBS alarms from 4:24 a.m. until 4:57 a.m. During this time, the Marshall PS discharge pressure never exceeded 3 psig. During this time when the Sarnia Terminal operator called operator B1 and remarked on the slow startup, operator B1 stated that "I'm just wondering either they really drained [Line 6B] out, which I think they did, because I don't have any pressure farther down the line…Or else I'm—or else I'm leaking. One of the two." Operator B1 called shift lead B1 about 5:00 a.m. to report that he had exceeded the estimated time to resolve the column separation issue. Operator B1 stated that the flow into the pipeline, upstream of the Marshall PS, was about 396,000 gallons per hour. After confirming with the Sarnia Terminal operator that only 71,062 gallons had been received since the startup, shift lead B1 instructed operator B1 to shut down Line 6B. About 5:03 a.m., Line 6B was shut down.

1.2.4 Second Line 6B Startup—Shift B

At 6:35 a.m., shift lead B2 called the on-call control center supervisor, and he then asked MBS analyst B to participate in the call. Shift lead B2 explained that they had been unable to resolve the column separation at the Marshall PS and that they had exceeded the estimated time needed to fill the pipeline. Shift lead B2 and the control center supervisor questioned MBS analyst B about the difference in pumped versus received volume. MBS analyst B explained that because of what he believed to be the severe column separation, the oil was filling the line rather than flowing through it to the delivery location.

The control center on-call supervisor stated that there were two choices: identify the alarms as a leak or identify the alarms as column separation and try to restart the pipeline again. Shift lead B2 asked MBS analyst B whether the MBS alarm was valid or invalid. MBS analyst B told shift lead B2 that the alarm was "false" because the MBS software was unreliable when column separation was present. The control center supervisor told shift lead B2, "To me it sounds like you need to try again and monitor it. Like [MBS analyst B] said, do it over again."

About 7:09 a.m., operator B1 notified the Sarnia Terminal[29] operator that they were going to start Line 6B for a second time. The Sarnia Terminal operator expressed disbelief at the idea of a second startup. He told investigators that he had voiced his concerns about a Line 6B leak to shift leads B1 and B2 and MBS analyst B that morning. He stated that MBS analyst B had dismissed his concerns and, because he was dealing with other issues that morning, he had not pursued the matter.

Line 6B was started a second time about 7:20 a.m. By 7:36 a.m., as the Marshall PS discharge pressure started to increase, the first 5-minute MBS alarm appeared, followed by a 20-minute MBS alarm. Many additional 5-minute and 20-minute MBS alarms subsequently appeared through 7:42 a.m. During this time, operator B1 unsuccessfully attempted to start additional Line 6B pumps at the La Porte PS; the Marshall PS downstream pressure never increased above 4 psig. After shutting down Line 6B at 7:52 a.m., just before ending his shift, operator B1 made the following comment to the Sarnia Terminal operator.

[29] Because Line 6B was delivering oil into the Sarnia Terminal, the Sarnia Terminal operator was involved in the startup, opening valves and moving oil into the terminal tanks. The Sarnia Terminal operator stated that he was able to watch the Line 6B operation on his SCADA display.

> I've never seen this…and to me like it looks like a leak…like I've never ever heard of that where you can't get enough—I can pump as hard as I want and I—I'd never over pressure the line. I don't know. Something about this feels wrong.

1.2.5 Discovery—Shift C

The shift C rotation occurred between 8:00 a.m. and 8:30 a.m. on Monday morning, July 26. The shift staff included the control center supervisor, who had been contacted during shift B while on call, and MBS analyst A, who had been on duty when the rupture occurred. During the shift exchange, shift leads C1 and C2 were informed about the presumed Line 6B column separation. Shift leads C1 and C2 called the control center supervisor to discuss the column separation issue.

Operator C1 told investigators that he had questioned the volume loss information during the shift exchange. By 8:46 a.m., operator C1 explained to shift leads C1 and C2 that in the past he had started Line 6B using every other PS and without operating the Niles PS. Operator C1 told investigators that he had reviewed SCADA data from the previous shifts that morning, saw the large pressure drop at the Marshall PS during the shift A shutdown, and immediately notified shift lead C1.

At 10:16 a.m., acting on the findings from operator C1 and discussions with shift lead C1, shift lead C2 called and asked the Chicago regional manager whether to send someone to walk along the pipeline, upstream and downstream of the Marshall PS. The Chicago regional manager replied, "I wouldn't think so. If it's right at Marshall—you know, it seems like there's something else going wrong either with the computer or with the instrumentation. …you lost column and things go haywire, right?" He went on to say, "…I'm not convinced. We haven't had any phone calls. I mean it's perfect weather out here—if it's a rupture someone's going to notice that, you know and smell it." The Chicago regional manager told shift lead C1 that he was okay with the control center starting Line 6B again.

At 11:17 a.m., the control center was notified about the rupture via its emergency line. The caller said, "I work for Consumers Energy[30] and I'm in Marshall. There's oil getting into the creek and I believe it's from your pipeline. I mean there's a lot. We're getting like 20 gas leak calls and everything." Remote valves were closed at 11:18 a.m., sealing off the rupture site within a 2.95-mile section. By 11:20 a.m., the shift lead had called the Chicago regional manager to tell him about the notification. By 11:37 a.m., another Consumers Energy employee notified 911 about the crude oil leak in a creek near Division Drive. The Fredonia Township Fire Department was dispatched by the 911 center shortly after the call. At 11:41 a.m., the Edmonton control center received confirmation from an Enbridge crossing coordinator located at the Marshall pipeline maintenance (PLM) shop confirming the oil on the ground.

[30] Consumers Energy is an electric and gas utility provider with services in Calhoun County and Marshall, Michigan.

1.2.6 Enbridge Initial Response

At 11:45 a.m. on July 26, the initial Enbridge personnel at the accident location included the Marshall PLM shop crossing coordinator, an electrician, and two senior pipeline employees. After confirming the presence of oil near the ruptured pipeline, the crossing coordinator followed Talmadge Creek downstream to determine the extent of the oil discharge. He found that the oil had not migrated past A Drive North, about 1.5 miles downstream of the rupture, but he observed a large amount of oil at a creek crossing on 15 1/2 Mile Road, about 1 mile downstream of the rupture.

The four-person crew returned to the Marshall PLM shop and retrieved a vacuum truck, a work truck, a semi-truck, and an oil boom trailer. About 12:10 p.m., they returned to A Drive North and installed a double 20-foot length of sorbent boom across Talmadge Creek, where they observed only a little oil flowing. They also installed 20-foot lengths of sorbent boom across Talmadge Creek upstream of A Drive North and at a culvert on the south side of A Drive North. The Enbridge crossing coordinator told NTSB investigators that the Marshall PLM crew was not aware of the severity of the oil spill when it used these initial oil containment measures. The Enbridge first responders did not have an estimate of released volumes when they began their efforts to contain the oil. (See figure 9 for a map of the area around the rupture site where response efforts began.)

Figure 9. Area between rupture site and the Kalamazoo River where first responders concentrated efforts to contain the released oil.

About 12:30 p.m., the Marshall PLM crew moved upstream to the 15 1/2-Mile Road crossing of Talmadge Creek. The crew installed a 40-foot containment boom and sections of sorbent boom on the upstream side of the culvert and spent the remainder of the day, until 11:00 p.m., using the Marshall PLM vacuum truck and skimmer to recover oil.

The Enbridge Bay City PLM supervisor (the interim incident commander until the Chicago regional manager arrived on site) told NTSB investigators that upon his arrival about 12:46 p.m., he observed an oily mixture discharging at a high rate through a 48-inch-diameter steel culvert pipe under Division Drive and continuing downstream in Talmadge Creek. He said the bulk of the released oil was contained upstream (south) of Division Drive. The supervisor stated that he considered having the culvert pipe plugged with earth; however, the water flow was too strong to enable him to do that.

About 1:30 p.m., the Marshall PLM supervisor arrived on scene and conferred with the Bay City PLM supervisor. They decided that the Marshall PLM supervisor would focus on stopping the leak source while the Bay City PLM supervisor would focus on installing oil boom at downstream locations ahead of the advancing oil. The National Response Center (NRC) was notified of the release about this same time on July 26. The NRC notified 16 Federal and state agencies about the spill.

About 2:45 p.m., the Bay City PLM supervisor worked with the Battle Creek Fire Department hazardous materials chief to locate an area for deploying boom for recovering the oil. About 15 minutes later, an Enbridge vacuum truck from the Bay City PLM shop began skimming oil from the water surface near Division Drive.

Between 4:30 and 6:30 p.m., four oil storage tanks were delivered to the Marshall PLM shop to temporarily store the oil that was being collected by the vacuum trucks. The Bay City PLM supervisor estimated that a total of 14 Enbridge personnel and between 6 and 10 personnel from Terra Contracting and Baker Corporation (contractors contacted by the incident commander for oil recovery and storage equipment) were working on scene to contain the oil during this time. The first U.S. Environmental Protection Agency (EPA) on-scene coordinator arrived in Marshall to assess the extent of the spill into Talmadge Creek about 4:32 p.m. The Marshall PLM shop was used as the incident command center.

Working with a six-person crew, the Marshall PLM supervisor constructed an earthen underflow dam, which consists of a mound of soil holding back oil-contaminated water with pipes submerged on the dam side and rising toward the discharge end. The angle of the pipe allows the deeper water in the dam to flow downstream, preventing the contaminated surface waters from flowing into Talmadge Creek. (See figure 10.)

Figure 10. Underflow dam on Talmadge Creek on July 30, 2010.

However, the crew found the width of the marsh too great and the ground too soft to construct an earthen dam near the source; instead the crew constructed a gravel-and-earth underflow dam at the confluence of the contaminated marsh and Talmadge Creek, which was accessible by heavy equipment. Enbridge crews used sections of 12-inch-diameter surplus polyvinyl chloride pipe they had found at the Marshall PLM shop to construct the underflow dam. Enbridge crews had learned of this oil containment strategy from participating in drills and exercises; this dam was the first they created during an actual emergency response. The heavy-equipment operators encountered significant difficulty because of the muddy conditions and the high-water flows. The construction of the first underflow dam began early in the afternoon on July 26, but it was not functional until 9:00 p.m. that evening. Crews had to tow the vacuum trucks through the mud to the underflow dam site and to the oily marsh locations until the first gravel roadway was constructed. The Marshall PLM supervisor told NTSB investigators that a considerable volume of oil was present in Talmadge Creek between the first underflow dam that Enbridge constructed and Division Drive. On July 26, Enbridge also deployed at least 12 vacuum trucks to begin recovering oil from the source area underflow dam, the Talmadge Creek stream crossings on Division Drive and 15 1/2 Mile Road, and from the Kalamazoo River at Calhoun County Historic Bridge Park (referred to as Heritage Park).[31]

[31] The two initial EPA on-scene coordinators noted that only five vacuum trucks were operating on July 26, while seven additional vacuum trucks that were ordered did not arrive on site until July 27.

Additional contractors would not arrive until the following day to continue a larger scale oil response effort.

1.3 Injuries and Evacuations

1.3.1 Injuries

No immediate injury reports were made as a result of the Marshall release. The Michigan Department of Community Health conducted a followup study and issued its results in a November 2010 report titled *Acute Effects of the Enbridge Oil Spill*. The study was based on four community surveys along the affected waterways, 147 health care provider reports on 145 patients, and 41 calls placed to the poison center. The study identified 320 people and an additional 11 worksite employees who reported experiencing adverse health effects. Headache, nausea, and respiratory effects were the most common symptoms reported by exposed individuals. The report concluded that these symptoms were consistent with the published literature regarding potential health effects associated with crude oil exposure, which include irritation to the eyes, nose, and throat, as well as dizziness and drowsiness. Contact with the skin and eyes may also cause irritation or burns.

1.3.2 Evacuations

On July 26, the residents of six houses self-evacuated because of odors associated with the oil spill. On July 29, an EPA contractor produced a map outlining the recommended evacuation area, which extended from the spill area north and northwest to the Kalamazoo River, beyond the 15 Mile Road bridge crossing, and included 61 houses.[32] The Calhoun County Public Health Department issued a voluntary evacuation notice to about 50 houses. The health department developed residential evacuation recommendations based on the concentration of benzene in the air. Benzene is a toxic constituent of crude oil that can cause drowsiness, dizziness, and unconsciousness. Long-term exposure to benzene causes effects on bone marrow and can cause anemia and leukemia. On August 12, the recommended evacuation of houses near the oil spill site was lifted after the benzene concentrations in the air were below the levels requiring evacuation.

1.4 Damages

1.4.1 Pipeline

The *Enbridge Inc. 2010 Annual Report* listed revenue losses for the Line 6B accident at $13.2 million. Enbridge has stated that the cost to replace the 50-foot section of Line 6B was $2.7 million.

[32] See "Emergency and Environmental Response Attachment 39—Recommended Evacuation Zone Map," in the NTSB public docket for this accident.

1.4.2 Environment

Enbridge's estimated costs for emergency response equipment, resources, personnel, and professional and regulatory support in connection with the cleanup of oil discharged from Line 6B were about $767 million as of October 31, 2011.[33] This figure also encompasses the estimated cost of the Federal government's role in the cleanup, including employing contractors, which was an estimated $42 million.

1.5 Environmental Conditions

1.5.1 Meteorological

The National Weather Service data recorded from Brooks Field Airport, Marshall, Michigan, at 5:55 p.m. near the time of the rupture showed the wind was from 10° at 4 knots, with good visibility and clear skies, the temperature was 79° F, and the dew point was 59° F. A light to moderate rain had occurred on the morning of July 24. On July 25, skies were clearing during the afternoon and evening hours, the high temperature was 79° F, and the low temperature was 69° F.

Weather reports from the W.K. Kellogg Airport, Battle Creek, Michigan, about 13 miles west of Marshall, reported rainfall amounts of about 2.4 inches on July 22 and July 23, 0.6 inch on July 24, and 1.37 inches on July 25.

1.5.2 Kalamazoo River Conditions

On July 26 at 12:45 p.m., the U.S. Geological Survey (USGS) reported the Kalamazoo River level in Marshall, Michigan, was 7.19 feet. Within 24 hours, the river level fell below 6 feet. The established flood state for this location is 8 feet. The USGS gauging station on the Kalamazoo River in Marshall, Michigan, reported the average current velocity at 1.44 mph.

1.6 Pipeline Information

1.6.1 Pipeline History

Enbridge documentation showed that the ruptured pipe segment was part of a purchase of 30-inch pipe from Siderius Inc. of New York on November 14, 1968, which was manufactured by Italsider s.p.a.[34] An inspection report dated March 18, 1969, noted that the chemical analysis and mechanical tests met the requirements of API and Enbridge specifications. Upon fabrication, the pipe was shipped bare from the Italsider s.p.a. facility located in Taranto, Italy, to the Port of Windsor, Ontario, and was delivered by truck to staging sites within Michigan. According to Enbridge, a field-applied spiral wrap of polyethylene tape coating was put on the pipe by machine at the time of Line 6B's construction.

[33] This was the most recent figure available at the time of this report.

[34] S.p.a. refers to Societa Per Azioni, a joint stock company with shareholders.

The ruptured segment was tested hydrostatically on November 21, 1969. No leaks or ruptures were documented. The certification letter, from the hydrostatic testing contractor, dated February 3, 1970, indicated that the ruptured segment had been tested to a minimum pressure of 783 psig and a maximum pressure of 820 psig for a 24-hour period. Enbridge used 796 psig as the hydrostatic test pressure of the ruptured segment in the integrity management assessments. The SMYS[35] of the ruptured segment was about 867 psig.

1.6.2 Pipeline Operating Pressure

The pipeline segment that ruptured had a maximum operating pressure (MOP) of 624 psig. However, the Marshall PS downstream pressure was limited to 523 psig at the time of the accident based on defects identified during a 2007 in-line inspection for corrosion (these features did not contribute to the rupture) of Line 6B. Historical pressure trends show that the Marshall PS was operating at 624 psig until 2004 when Enbridge imposed a 525 psig pressure restriction. No pressures in excess of 532 psig were noted from 2005 up until the time of rupture. Based on the SCADA pressures readings at the time of the rupture, the highest recorded discharge pressure at the Marshall PS, immediately preceding the rupture, was 486 psig. (See appendix C).

1.6.3 Site Description

The ruptured segment was buried about 5 feet below the ground surface and located 0.60 mile downstream from the Marshall PS. The rupture and release occurred in a wetland area near mile point (MP) 608.22 in Marshall, Michigan. The wetlands were located in an undeveloped, mostly rural area about 0.4 mile west of 17 Mile Road and about 0.2 mile south of Division Drive. Industrial complexes were located north and west along 17 Mile Road, less than 1 mile from the rupture site. The ruptured segment of Line 6B was operating in a high consequence area (HCA) identified as an "other populated area," which is defined at Title 49 *Code of Federal Regulations* (CFR) 195.450(3) as a place "that contains a concentrated population, such as an incorporated or unincorporated city, town, village, or other designated residential or commercial area."

1.6.4 Other Enbridge Pipeline Incidents

In 49 CFR 195.50, the Pipeline and Hazardous Materials Safety Administration (PHMSA) requires that pipeline operators submit an accident report for hazardous liquid releases, not related to a maintenance activity, that are 5 gallons or more and resulting in $50,000 property damage, explosion, or fire. PHMSA publishes the summaries from these reports on its website.[36] The PHMSA incident and accident statistics for liquid transmission onshore crude oil releases sorted by volume from 1986 through 2011 show that Enbridge releases represent the second and fifth largest crude oil spills and that the company is included in

[35] The *SMYS* is the internal pressure that produces a calculated hoop stress equivalent to the minimum yield strength of the material assuming a nominal wall thickness and outside diameter.

[36] Information obtained from PHMSA's website <http://phmsa.dot.gov/pipeline/library/data-stats> (accessed June 5, 2012).