

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Introduction
January 13, 2017

1.0 INTRODUCTION

1.1 PROJECT OVERVIEW

Enbridge is proposing to construct the Line 3 Replacement Project (L3RP), an oil pipeline replacement project, in the state of Minnesota. Enbridge is seeking the review and ultimate approval of the Project by the Minnesota Public Utilities Commission (Commission). The Commission has authorized Minnesota Department of Commerce, Energy Environmental Review and Analysis (DOC-EERA), in coordination with the Minnesota Department of Natural Resources (MDNR) and the Minnesota Pollution Control Agency (MPCA), to prepare an Environmental Impact Statement (EIS) for the Project.

DOC-EERA and coordinating agencies requested information relating to accidental pinhole releases and the potential effects of these releases on groundwater.

1.2 DEFINITION OF PINHOLE RELEASE

It is important to note that there is no formal industry definition for a pinhole release per relevant standards (CSA Annex E or API 1130) and the definitions of “pinhole release” as it relates to pipeline management are many and varied in the literature. Definitions are commonly based upon either subjective observation or numerical criteria based upon engineering estimates such as diameter of a theoretical breach or flow rate. In many instances in the literature the term “pinhole” is used without a specific definition. For context, a review of several industry relevant definitions of pinhole release is provided below.

Since 2001, United States Department of Transportation Pipeline and Hazardous Materials Safety Administration (PHMSA) incident reports have included “pinhole” as an option for classifying the type of leak. The term “pinhole” is not defined in the incident instruction form for hazardous liquids (PHMSA, 2014). However the corresponding PHMSA incident form for gas distribution systems defines a pinhole leak as:

“... a leak that is hard to see with the naked eye characterized as being a small hole made as by a pin.”

Alternately, the PHMSA documentation on material/weld failures includes the following definition:

“... a small, unwelded area extending through the entire thickness of the weld (PHMSA 2014).”

Several authors have defined pinhole releases in terms of numerical criteria. As part of an independent engineering assessment performed on the Keystone XL pipeline risk assessment, a

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Introduction

January 13, 2017

pinhole was defined as a “1/32-inch hole” for the purposes of modeling a pinhole leak rate (Battelle 2014).

Similarly, in the reporting of spills related to safety and environmental performance of oil pipelines, the European oil pipeline management group CONCAWE, defines a pinhole in terms of dimension as:

“... less than 2 mm x 2 mm” (CONCAWE 2011)

Alternately, authors have also attempted to quantify a pinhole leak in terms of flow rate and likelihood to be detected. As part of the risk assessment of the Keystone XL pipeline project, a numerical model was used to estimate the rate of a slow oil leak that may go undetected for extended periods of time (Exponent, 2013). Based upon the assumptions made in the modeling analysis (discussed in detail in Section 2.3 of this report), a leakage rate of 0.035 bpd could theoretically infiltrate until discovered by inspection tools or investigative excavations.

For the purposes of this document, a pinhole release is defined “as a slow and small leak of crude oil from the proposed pipeline, or its remote facilities (e.g., pump station valves) that might not be immediately detected by the leak detection systems”. The definition seeks to highlight the nature of a small release that may go undetected for a longer period of time and to provide a direct contrast with a large release or full bore rupture. An understanding of the limitations of the leak detection systems and a quantification of the rate of release anticipated to be encountered during a pinhole release is integral to this definition. The assessment of pinhole leaks will address leak detection monitoring, the nature (including rate of release), occurrence, and probability of pinhole leaks.

1.3 PURPOSE AND SCOPE

The purpose of this document is to provide an assessment of the risk of a pinhole oil release from the proposed L3RP. Risk is defined as the product of the likelihood of an adverse event occurring and the corresponding consequences that may result. In the context of a pipeline, the adverse event is the potential release of a hazardous liquid such as crude oil and the corresponding consequence is the potential for receptors to experience adverse effects as a result of exposure to the oil.

1.4 OVERVIEW OF THE ASSESSMENT

To promote increased understanding of the issues associated with accidental pinhole releases, the assessment of pinhole leaks considers, as an integrated whole, topics that describe the potential for a pinhole release to occur, the characteristics of the release and the potential consequences that may occur.

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Characteristics of Pinhole Releases
January 13, 2017

The proposed scope of work includes:

- An assessment of the potential characteristics of pinhole releases, including anticipated frequency, potential causes, size, rate of release, and maximum release volume and likely detection methods (Section 2.0.)
- The fate and transport of released hydrocarbons in the environment (e.g., factors affecting migration, movement in the unsaturated zone; movement in the saturated zone; and fate and transport of dissolved hydrocarbons in groundwater) (Section 3.0)
- Identification of potentially sensitive receptors proximal to the proposed project route and its alternatives, including: wells, surface water, calcareous fens, source water protection areas, and drinking water supply management areas (Section 4.0)
- An assessment of susceptibility of groundwater based upon the typical hydrogeologic regimes that will be traversed by the project (Section 5.0)
- The ability of groundwater to recover from the effects of a release, including an understanding of how emergency response, remediation, cleanup, natural processes and restoration can promote recovery (Section 6.0)
- A review of available case studies relevant to pinhole releases and their potential effect on the environment (Section 7.0).

Each of these topics is discussed in more detail below.

2.0 CHARACTERISTICS OF PINHOLE RELEASES

Pipelines currently under construction incorporate new tools, technologies, and strategies to protect the public and the environment. Modern pipelines are designed and constructed to rigorous standards that meet or exceed government regulations. Materials are selected and tested prior to and during manufacturing to meet quality criteria. Welds made to a pipeline section during construction are tested using X-ray or ultrasonic methods. Soil-side corrosion is prevented using a combination of external coatings that are subject to quality control/inspection before and after backfill, and cathodic protection systems that are continuously monitored. Internal corrosion is prevented by maintaining strict tariff limits on trace sediment and water; and by either flowing the pipeline rapidly enough to prevent these materials from accumulating, or by executing periodic cleaning programs to remove any accumulated matter that could cause corrosion.

Operating pipelines are equipped with sophisticated, computerized leak-detection monitoring systems and control systems that provide continuous, real-time information and are augmented with routine inspections and aerial patrols of rights-of-way. Inspection is supplemented with the periodic use of inline inspection tools capable of measuring the size, frequency, and location of small changes in pipeline walls.

Refer to the Assessment of Accidental Releases: Technical Report – Chapter 4.0 (Stantec/RPS/Dynamic Risk Assessment Systems 2016) for a detailed discussion of potential threats and a systems and protocols that are anticipated for the L3RP project.

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Characteristics of Pinhole Releases
January 13, 2017

This section describes the characteristics of potential pinhole releases (as defined above) including: potential causes, rate of release, volume, length of time until detection and anticipated frequency.

2.1 CHARACTERISTICS OF CRUDE OIL

The assessment of the risk of a pinhole oil release from L3RP is strongly influenced by the seasonal conditions, environmental setting and type of oil. A range of crude oils will be carried by the proposed pipeline. Different types of crude oil exhibit differences in chemical make-up, density and viscosity. The range of product types expected to be shipped in the L3RP may range from light crude oils such as those in the Bakken crude oil and Alberta Light Sweet Crude categories, to heavy oils such as conventional heavy crude oils and diluted bitumen products. The physical and chemical characteristics of light and heavy crude oils are quite different, although the characteristics of diluted bitumens are very similar to those of heavy conventional crude oils (Zhou et al. 2015). The physical characteristics of two example crude oils (i.e., Bakken, a light conventional crude oil, and Cold Lake Bitumen (CLB), a diluted bitumen) are discussed below. These two crude oils represent a range of product types that could be shipped in L3RP.

CLB is a diluted bitumen with a high viscosity and density, falling in the upper range of characteristic values allowed by the pipeline tariff specifications for Enbridge (typically less than 0.94 g/cm³ at 15°C). This product generally exhibits mid-range density and viscosity characteristics for the range of diluted bitumen products. Seasonal variations in environmental temperatures affect the viscosity of the diluted bitumen, which directly affects the ability to pump the fluid through the pipeline. To address this, the amount of diluent added to CLB is varied throughout the year to attain a viscosity that meets shipping requirements. The largest amount of diluent is added to the bitumen during winter to reduce the viscosity to a level suitable for shipping at low temperatures. As a consequence, the density, viscosity, and aromatic content of CLB changes throughout the year. During the winter months, CLB has a lower density and viscosity and a greater aromatic content, when compared to the summer months. As the chemical and physical characteristics of the CLB will vary seasonally, a summer blend and winter blend were considered in the assessment of pinhole leaks.

Bakken crude oil is produced in North Dakota, Montana, and the bordering Canadian provinces of Manitoba and Saskatchewan. Bakken is a light crude oil with an American Petroleum Institute (API) gravity generally between 40 and 43° a sulfur content less than 0.2% by weight, low density, low viscosity, and a high aromatic content.

The physical properties of the three crude oils are shown in Table 2-1.

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Characteristics of Pinhole Releases
January 13, 2017

Table 2-1 Physical Properties of Typical Crude Oils to be Shipped in the L3RP Pipeline

Oil Property	Bakken Crude	Cold Lake Winter Blend	Cold Lake Summer Blend
Oil type	Crude	Emulsion	Emulsion
Minimum slick thickness (µm)	0.1	10.0	10.0
Surface tension (dyne/cm)	27.3	27.1	27.1
Pour point (°C)	-55.0	-45.0	-45.0
API gravity (°)	41.80	22.69	20.73
Density (g/cm ³) at 16°C	0.81650	--	--
Density (g/cm ³) at 15°C	--	0.91770	0.92950
Viscosity (cP) at 10°C	3.88	--	--
Viscosity (cP) at 15°C	--	150.0	342.0
Viscosity (cP) at 30°C	2.49	--	--
NOTES: µm = micrometer; dyne/cm = dynes per centimeter; g/cm ³ = grams per cubic centimeter; °C = degrees Celsius; cP = centipoise			
SOURCE: Stantec/RPS/Dynamic Risk Assessment Systems 2016			

2.2 POTENTIAL THREATS TO INTEGRITY

The following briefly summarizes the potential threats to the integrity of the L3RP as it relates to a potential pinhole leak. Refer to the *Assessment of Accidental Releases: Technical Report—Chapter 4* (Stantec/RPS/Dynamic Risk Assessment Systems 2016) for a detailed threat assessment based upon the approach described in American Society of Mechanical Engineers (ASME) Code B31.8S.

During the operational life of pipelines, malfunctions have occurred due to material failures (e.g., pipeline corrosion or defects in materials), vandalism, equipment failure, third-party damage or natural events. The following processes are identified as the principal potential causes of pinhole releases. These processes may occur alone or combine to result in a pinhole leak.

- **Corrosion.** Metal loss caused by corrosion is the most common cause of leaks that can be readily detected in the pipelines that have been in service for many years. Corrosion is caused by chemical reactions (oxidation and reduction; i.e., “rusting”) that physically alter the metal and result in local areas of weakness. Underground pipelines are typically constructed of carbon steel. These materials may be subject to a variety of corrosion mechanisms in underground environments including: external corrosion, internal corrosion, and stress-corrosion cracking (SCC) (Beavers et al. 2006). The most common result of

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Characteristics of Pinhole Releases
January 13, 2017

corrosion on underground pipelines is uneven metal loss over localized areas (covering a few to several hundred square inches).

- External Corrosion. External surfaces of a pipeline may undergo corrosion influenced by environmental factors such as soil chemistry, microbes, presence of corrosive materials or films, and/or stray electrical currents.
- Internal Corrosion. Corrosion on the internal wall of a pipeline can occur when the pipe wall is exposed to corrosive materials. The nature and extent of the corrosion damage that may occur are functions of the concentration and particular combinations of these various corrosive constituents within the pipe, as well as of the operating conditions of the pipeline (e.g., temperature).
- Stress Corrosion Cracking. SCC is a cracking of a material produced by the combined action of corrosion and tensile stress. A characteristic of SCC is the development of groups of longitudinal surface cracks in the body of the pipe that link up to form long, shallow flaws. In some cases, the growth and interconnection of the stress-corrosion cracks produce flaws that are of sufficient size to cause leaks
- Manufacturing Defects. Anomalies, imperfections, flaws or defects that arise during the manufacturing of the product. Typically major manufacturing defects are screened out during integrity testing procedures.
- Construction Defects. Anomalies, imperfections, flaws or defects of construction origin, including handling, transportation, fabrication, excavation and construction.
- Equipment Failure. A failure of a pipeline component or device other than the pipe and fittings such as valves, flanges, and gaskets. This usually results in a release that is contained on company property, typically not resulting in injury to the public or adverse effects to the environment.
- Third Party Damage. Damage to the pipeline that is caused by outside parties or forces other than naturally occurring events. This can include mechanical damage caused by machinery working in the right-of-way, as well vehicle or equipment contact, vandalism, sabotage or terrorism.
- Incorrect Operation. Incorrect operations failure is defined in the context of pipeline transmission infrastructure as failures that have causal factors that are related to design, as well as operation and maintenance procedures. Includes a release or failure resulting from incorrect actions by a company or contract personnel. Examples of incorrect operations that may lead to a release include inadvertent actions (e.g., improperly setting a valve, improper performance of routine maintenance, inappropriately reacting to a condition on the pipeline).
- Geotechnical / Hydrotechnical Forces. Naturally occurring events capable of causing damage include a release or failure resulting from earth movement, earthquakes, landslides, subsidence, lightning, heavy rains/floods, washouts, flotation, mudslides, scouring, temperature, frost heave, frozen components, high winds or similar natural causes.
- Other Threats. These include incidents whose cause is unknown, or where investigation into the cause has been exhausted and the final judgment as to the cause remains unknown, or where a cause has been determined which does not fit into any of the main cause categories listed above.

While leak detection systems are capable of identifying many releases, they may not immediately detect a slow and small leak of crude oil from a pipeline (PHMSA 2016). Given that leak detection technology has limitations in detecting small leaks, protocols for the management and operation of modern pipelines have focused upon prevention of pinhole leaks within the pipeline and the system components.

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Characteristics of Pinhole Releases
January 13, 2017

Management processes include measures associated with pipeline design and construction that help to reduce the potential for, and effects of pinhole releases, such as:

- Material specifications for the pipe and components
- Methods for review and verification of the pipeline design, and engineering quality control
- Quality assurance measures to verify that construction materials used for the pipelines comply with or exceed the requirements of Code of Federal Regulations (CFR), Part 195
- Multiple levels of inspections to confirm the pipeline's integrity through the milling, transportation, and installation processes
- Design processes such as Intelligent Valve Placement
- Construction methods to reduce potential for incidents (e.g., variable minimum burial depths specific to land use types; burial depths under water crossings; variable construction techniques such as horizontal directional drilling or open cuts under roads and water crossings)
- Inspection and testing to verify the integrity of the pipelines before commissioning

Pipeline operations also employ an array of measures to avoid or reduce the risk of an accidental pinhole release and maximize the effectiveness of the emergency response (Stantec/RPS/Dynamic Risk Assessment Systems 2016). These include:

- Conducting routine aerial and ground based monitoring
- Maintaining cathodic protection to reduce corrosion
- Utilizing internal pipeline inspection technology to identify potential pipeline integrity anomalies
- Continuous monitoring through supervisory control and data acquisition (SCADA) systems
- Systems and processes for detection of pipeline leaks and malfunctions
- Use of a state of the art control center manned 24 hours a day/7 days a week to monitor and react in the event that anomalies in the operation of the pipeline are detected
- Installation and operation of remotely controlled pipeline valves
- Use of redundant monitoring and response equipment

2.3 RATE OF RELEASE

For the purposes of this assessment, a pinhole release is defined as a slow and small leak of crude oil from a pipeline or its remote facilities (e.g., pump station valves) that might not be immediately detected by the leak detection systems. An understanding of the limitations of the leak detection systems and a quantification of the rate of release anticipated to be encountered during a pinhole release is integral to this definition. In practice, a leak that continues for a long period of time would be unlikely because the rate of the leak would be expected to exceed the rate of infiltration, quickly fill the trench and appear at the surface where it would be discovered through visual surveillance.

The breach size and pipeline pressure are the primary factors that determine the leak rate (U.S. Department of State (USDOS 2014). Larger leaks are typically rapidly detected because they trigger alarms from components of the leak detection system, or are identified through visual inspections (Shaw et al. 2012). Where a leak of crude oil is below the limits of the detection

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Characteristics of Pinhole Releases
January 13, 2017

system, the released oil would likely remain within or near the pipeline trench where it can be contained and remediated after discovery.

For example, automated internal leak detection systems based on computational pipeline monitoring (CPM) are limited to the accuracy of the metering (1% accuracy of the flow rate is considered good) (Shaw et al. 2012). The proposed transmission rate for the L3RP is 760,000 barrels per day (bpd). Based upon these data only, the anticipated leak detection capabilities based on computational monitoring at the maximum rate of 760,000 bpd for the L3RP line would be approximately 222 gallons per minute (gpm) or 7,600 bpd with an anticipated response time of a few minutes (Stantec/RPS/Dynamic Risk Assessment Systems 2016). Actual pipeline leak detection systems accuracy is dependent on the pipe parameters and installed instrumentation (Shaw et al. 2012).

A release rate for L3RP approaching the CPM detection limit (e.g., would quickly fill the more permeable trench materials and reach the ground surface where it would be anticipated to be reported in several hours to days through volume reconciliation or visual observation. Additionally, to achieve a rate of release approaching 1% would require a breach in the pipeline that would be significantly larger than a pinhole. The potential effects of larger releases are discussed in detail in the Assessment of Accidental Releases: Technical Report (Stantec/RPS/Dynamic Risk Assessment Systems 2016).

However, a pinhole release may potentially continue undetected for longer periods of time resulting in a release of sufficient volume and allowing for sufficient transport time to affect groundwater. The issues surrounding rate of release and fate and transport of pinhole releases were qualitatively assessed during the independent engineering assessment of the Keystone XL Pipeline Risk Assessment (Exponent 2013). Exponent is a science and engineering consulting firm that was commissioned to provide third-party independent environmental review of a specific set of issues identified by the U.S. Department of State (DOS) in consultation with the U.S. Department of Transportation, PHMSA and the U.S. Environmental Protection Agency that relate to the Keystone XL Project. A review of the independent engineering assessment methodology was performed at the request of DOC-EERA and is presented below.

The potential scale of infiltration of oil and dissolved constituents and subsequent contamination of groundwater from a pinhole release was evaluated by Exponent using a numerical hydrocarbon spill screening model (HSSM) developed for U.S. EPA (Weaver et al. 1994). HSSM is a screening model that includes a variety of chemical and hydrologic processes, and is based upon a simplified conceptualization of an oil release. The model simulates vertical oil flow and transport from the ground surface to the water table due to gravity and capillary forces. The oil is then simulated to float and spread radially in the capillary fringe, thereby forming an oil lens (or layer). Additionally, HSSM simulates dissolution of chemical constituents of the oil into the groundwater and migration of the dissolved phase contaminant plume.

As part of the screening analysis for the Keystone XL pipeline, HSSM was used to estimate the rates of a pinhole release for a flat terrain condition. The leak calculations are intended to

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Characteristics of Pinhole Releases
January 13, 2017

provide insights into the potential transport and fate of oil spilled from the pipeline. Simulations with HSSM are an illustrative and simplified screening-level calculation and should not be relied upon for final risk determinations, emergency and/or environmental planning/response actions.

HSSM was used in the Keystone XL assessment to estimate the maximum steady-state leak rate (i.e., where infiltration is equal to leak rate out of the pipeline) per area of trench floor. Leak rates higher than the maximum steady-state infiltration rate would eventually fill the pore-space in the trench backfill at a rate equal to the difference between the infiltration rate and the leak rate. Leaks lower than the steady state infiltration rate may go undetected until discovered through means other than remote monitoring or visual inspection (e.g., scheduled maintenance or excavation inspections).

The results from HSSM simulations show that the maximum leakage rate of oil that can be vertically infiltrated through permeable sand is approximately 0.21 gallons per day (gpd) or 0.005 bpd/square ft (ft²), meaning that for every square foot of trench floor, 0.21 gallons is predicted to infiltrate through that unit area in one day if there is a pinhole leak in the pipeline. The area of the spill footprint on the bottom of the trench (i.e., infiltration site) affects the total anticipated rate of infiltration.

To provide a sense of scale for a small leak that could go undetected, Exponent conducted further analyses assuming infiltration occurs over a 3-ft diameter circle of trench floor; 3 ft was selected to coincide with the approximate maximum diameter of the pipe. However, the geometry and area of the spill footprint could be highly variable. If lateral movement of the oil through the trench backfill occurred, the area of the infiltration zone would increase, which would increase the volume of oil that could be infiltrated. These factors could result in higher leak volumes that may not come to the surface and, therefore, not be detected by inspection. Conversely, the vertical case considered for this analysis, rather than the lateral flow scenario, is also conservative in that the infiltration rate would be greater for a given area due to the assumed larger driving head.

For instance, a circular footprint of trench floor with a diameter of 3 feet has an area of approximately 7 ft², which would correspond to a total infiltration rate of:

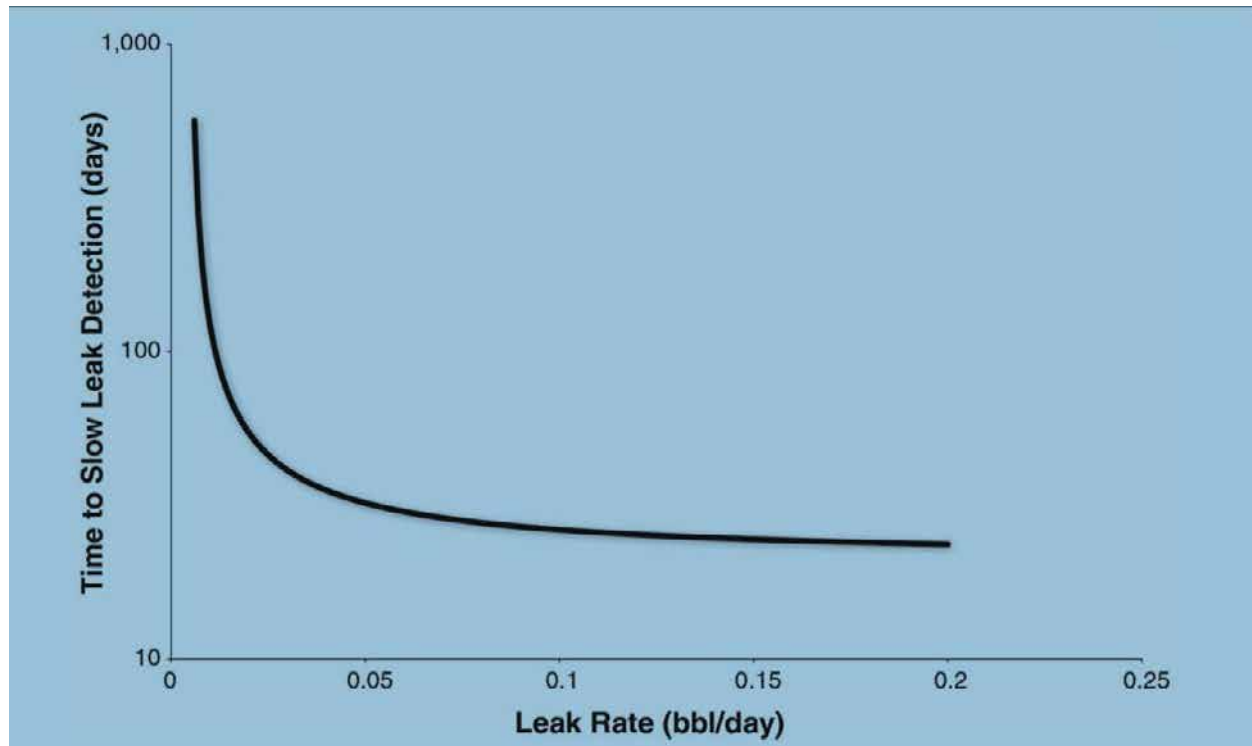
$$7 \text{ ft}^2 \times 0.21 \text{ gpd} = 1.5 \text{ gpd}$$

Thus, a leakage rate over the 3-ft diameter circle of 1.5 gpd could theoretically infiltrate indefinitely without surfacing because the infiltration rate is equal to the leak rate.

A similar process was used to estimate the time required for the oil to reach the ground surface at rates above the steady state infiltration rate. Figure 2-1 shows potential leak rates and the associated estimated time to detection.

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Characteristics of Pinhole Releases
January 13, 2017



SOURCE: Exponent 2016

Figure 2-1 Time to slow leak detection as a function of leak rate for various slow leak rates based on a 3-ft diameter circular infiltration footprint

Modeling of theoretical subsurface transport suggest that a low-volume release could go undetected as it migrates up to the surface, or as it travels along the bottom of the pipe trench. However, in practice, leaks with rates equal to or below the infiltration rate are unlikely because the flow rate for even a very small hole (1/32 in.) would be expected to be as much as two orders of magnitude higher than the infiltration rate.

As part of an independent engineering assessment performed on the Keystone XL pipeline risk assessment, a leak rate for a pinhole, defined as a 1/32-in. hole, was estimated using Process Analysis Software Tool (PHAST) (Battelle 2013). Based upon the modeling, a calculated leak rate of 28 bpd was estimated. The pinhole leak rate, 28 bpd, is almost three orders-of-magnitude greater than the maximum infiltration rate into permeable sand over the assumed area described previously under the developed HSSM scenario. This suggests that a leak from a pinhole release would quickly migrate to the surface and be discovered through visual surveillance and/or odor reports.

Visual and odor reports are provided by third parties (i.e., landowners, farmers, etc.) and from the pipeline operator's aerial and ground line patrols. For example, Enbridge typically conducts

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Characteristics of Pinhole Releases
January 13, 2017

patrols every two weeks on its entire system. Therefore, a pinhole release that goes undetected indefinitely along the pipeline is unlikely; rather it would migrate to the surface and be reported.

2.4 ESTIMATED RELEASE VOLUME

A release below leak detection thresholds, should it occur, releases a small amount of oil at a time and therefore, may not be detected immediately. Based on an analysis of estimated release rates defined in Section 2.3, leak detection systems (including patrol), and estimated response times, the following table was developed to evaluate the total volume of oil that may result from a pinhole release:

Table 2-2 Estimated Potential Release Volumes Prior to Detection

Description	Rate	Time		Total Volume of Product Before Detection	
	bpd	Days	Minutes	Barrels	Gallons
1% ¹	7,600	0.083	120	633	26,600
0.5% ¹	1,750	2	2,880	3,500	147,000
0.1% ¹	760	14	20,160	4,900	205,800
1/32 in. pinhole	28	28	40,320	784	32,928
Equivalent infiltration rate	0.035	1,825	2,628,000	64	2,683
NOTE: ¹ Percentage of pipeline throughput based upon 760,000 bpd.					

The total volume that may result from a spill is a combination of the following:

- Size of breach
- Pipeline pressure
- Fluid properties (temperature and viscosity)
- Time to detect leak
- Time to shut down pipeline and isolate leak after detection
- Pipeline diameter
- Distance between isolation valves
- Effectiveness of the isolation

Once the leak is suspected, the operator shuts down the operating pumping units and closes the nearby valves to isolate the leak. These actions eliminate the force that will maintain pressure on the pipeline that would continue the leak.

The response time between initiation of the spill event and the response is an important factor in controlling the total volume of oil released and preventing potential impacts to the environment. The following describes the various processes that control the elapsed time between the release start and detection.

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Characteristics of Pinhole Releases
January 13, 2017

First, most releases ranging in magnitude from small to medium (up to 1,000 barrels [bbl]) would occur on construction sites or at operations and maintenance facilities. At these locations, spill response typically would be quick because of the presence of local staff and contractors and often mitigation systems, such as secondary containment, are employed. Quick containment and clean-up is expected to reduce surface oil spreading and its potential infiltration into the ground.

Second, large releases are detected quickly. SCADA sensors are designed to automatically detect leaks large enough to produce noticeable changes in pipeline pressure and flow rates. The sensors have a monitoring threshold because operating variables for pipelines (e.g., give several examples such as pressure) normally fluctuate within a working range. The SCADA system, in conjunction with CPM or model-based leak detection systems are designed to detect leaks to a level of approximately 1% of the pipeline flow rate.

For releases below the automated leak detection system threshold complementary leak detection methods are also employed, along with a public awareness program, to detect the presence of leaks within the system. The CPM system is the primary method to detect leaks. In cases where a leak under detection limit of the CPM system were to occur, the use of local sensors and SCADA, extended volume balance calculations and other methods of detection such as visual surveillance, third party and employee reports are utilized to detect leaks. The speed of detection and total leakage depends on various factors, including conditions surrounding the release, surveillance frequency, and third party reporting. It is estimated that a leak near the threshold of 1% of throughput would prompt a response in the pipeline Control Center of a conservative time of 120 minutes.

SCADA systems, in conjunction with CPM or model-based leak detection systems are capable of detecting a leak relatively rapidly (i.e., within minutes) if the rate is greater than the detection threshold. Computer-based, non-real time, accumulated gain/loss volume trending also is used to assist in identifying low rate or seepage releases below the 1% by volume detection thresholds. The lower the rate the longer it would be anticipated to see the gain/loss trends. It is conservatively estimated that a leaks of 0.5% and 0.1% of throughput would prompt a response in the pipeline of 2 and 14 days, respectively.

Smaller leaks may be identified by observing pooled oil outside the pipeline or by observing environmental patterns such as stressed vegetation. The pipeline operators typically conduct aerial or ground patrols every two weeks on its entire system. For smaller releases it was conservatively estimated that the time from initial release to discovery may take up to 2 cycles of patrol or 28 days total.

Finally, releases at a rate below the threshold for infiltration would not be anticipated to be observed at the surface. In this case discovery would be anticipated to be identified through inline inspection tools or an investigatory excavation. The pipeline operators typically conduct inline inspection every two years on its entire system.

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Characteristics of Pinhole Releases
January 13, 2017

For additional context, as part of a larger study on the application and effectiveness of leak detection systems, Shaw et al. (2012) on behalf of PHMSA performed an analysis of time to shut down for hazardous liquid releases identified as originating on the right-of-way over an 18 month period between January 2010 and July 2012. Time to shut down the pipeline is taken to mean that pumping has ceased and the upstream and downstream block valves have been shut to isolate the section of pipeline containing the release. The review of the incident data showed the following for 197 incident reports:

- 47 (24%) of the incident reports had identical dates and times for the incident identification and the shutdown. This results in zero minutes to shut down the pipeline.
- For 68 (34%) of the incident reports the elapsed time to shut down could be calculated using the initial identification and the report shutdown.
- No shutdown time was reported for 66 (33%) of the incidents. Not all pipelines are shutdown as a result of a release.
- For 12 (6%) shutdown date and times provided it was not possible to compute the time taken to shut down because of the date and time values recorded.
- Ignoring zero minute shutdowns, the shortest shutdown time was 1 minute and the longest calculated shutdown time was 44 hours and 30 minutes.
- 8 of the 68 reports where a time to shut down could be calculated had a shutdown time longer than 1 hour.
- 27 of the 68 reports had a shutdown time between 15 minutes and 40 minutes.
- 32 of the 68 reports had a shutdown time between 1 minute and 14 minutes.

The results of this study validate the conservative nature of the estimated discovery times presented in Table 2-2.

2.5 FREQUENCY

Analysis of historical pipeline incident data was conducted to understand frequency of historical releases with respect to pipelines in Minnesota, the Upper Midwest Region and the United States.

The PHMSA incident and mileage reports were analyzed to show the distribution of historical spill volumes, incident causes and frequencies of crude oil pipeline incidents contained in the PHMSA database. Although the results are not a direct indicator of the nature of possible incidents that could occur in association with the proposed L3RP because the majority of the pipelines spills reviewed were of older vintage pipelines, they can provide insight into what could potentially occur with respect to spill volume, incident cause, and incident frequency.

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Characteristics of Pinhole Releases
January 13, 2017

PHMSA collects information on reportable¹ pipeline incidents. This information is available to the general public. Information collected for each incident includes the following:

- Date of each reportable incident
- Type of hazardous liquid associated with the pipeline involved in the incident
- Volume of hazardous liquid spilled in the incident
- Part of the pipeline system from which the spill occurred
- Diameter of the hazardous liquid pipeline involved in the incident
- Cause of the incident

The total mileage, type of hazardous liquid transported, and the diameter of pipelines in operation in the United States are also collected.

PHMSA incident and mileage data for the period from January 2002 through December 2015 were considered to be the most applicable to this report. Data prior to January 2002 had different reporting requirements and may not provide additional useful information. Prior to 2002, PHMSA required reports of hazardous liquid releases of greater than or equal to 2,100 gallons (50 bbl). As of 2002, PHMSA required reports of hazardous liquid releases of greater than or equal to 5 gallons (0.1 bbl). Therefore PHMSA data prior to 2002 likely understate the actual number of incidents and lead to over estimates of average spill volumes. All reported database incidents are counted, even if the information was incomplete or unspecified ("blank" or "Unknown", "Miscellaneous", and "Other").

As this assessment of pinhole leaks study focuses on the proposed pipeline and associated facilities (e.g., pump station valves) and excludes facilities that would typically have secondary containment, the historic incident data was subdivided to allow historic spill volumes and incident causes from the mainline pipe to be assessed separately from discrete elements such as pumping stations, breakout tanks, valves and other associated equipment. In addition, the PHMSA the data set, which includes incidents from hazardous liquid pipelines, can be filtered to include only crude oil pipeline incidents.

Table 2-3 is a summary of hazardous liquid pipeline incidents reported to PHMSA for the period January 2002 through December 2015 and shows the incident breakdown by pipeline system element (mainline pipe, tanks, valves, and other discrete equipment items associated with pumping stations or pipeline systems). The Project's location (Minnesota) is relatively flat, colder and more rural than the majority of U.S. pipelines, which are clustered primarily in Oklahoma, Texas, the Great Lakes area, and along the East, West, and Gulf coasts. Therefore, the data set was further evaluated to show breakdown incidents by region, represented by Minnesota, North Dakota and Wisconsin, and by Minnesota, separately.

¹ Reportable releases meets the criteria in 49 CFR §195.50. Hazardous liquid releases during maintenance activities are not to be reported if the spill was less than 5 barrels, not otherwise reportable under 49 CFR §195.50, did not result in water pollution as described by 49 CFR §195.52(a)(4), was confined to company property or pipeline right-of-way, and was cleaned up promptly. Any spill of 5 gallons or more to water during a maintenance activity is required to be reported.

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Characteristics of Pinhole Releases
January 13, 2017

Table 2-3 Summary of Crude Oil Pipeline Incidents, 2002 through 2015

Description	Number of Incidents		
	United States	Region (ND, MN, WI)	Minnesota
Crude Oil Pipeline incidents			
Crude oil mainline pipe incidents	591	44	20
Crude oil pipeline, equipment incidents (not mainline pipe)	1,227	93	41
Crude oil pipeline system, unspecified elements	641	45	19
Total crude oil pipeline incidents	2,459	182	80

For pipeline components, including the body of the pipeline itself and associated equipment, there were 2,459 reported crude oil incidents out of a total of 5,290 incidents in the entire hazardous liquid pipeline database for the time period referenced. Of the crude oil incidents in Table 2-3, 591 incidents were associated with the body of the pipeline or the welds connecting mainline pipe sections. Also, 641 incidents were reported in such a way (such as with blank data fields) that it is not clear if they were associated with the mainline pipe of a pipeline or with a discrete element.

The PHMSA data also include information on the pipelines in service in each calendar year since 2004. This information includes the pipeline length, the commodity transported, the pipeline diameter, the installation year, and the number of breakout tanks associated with the pipeline. This information was used to determine the incident rate per mile-year of pipeline.

A summary of crude oil pipeline incidents as reported to PHMSA from January 2002 through December 2015, including spill volume and incident frequency is presented in Table 2-4 and Table 2-5, and Figure 2-2 and Figure 2-3. Table 2-4 and Figure 2-2 summarizes the data for crude oil pipeline and its components. Table 2-5 and Figure 2-3 summarizes the mainline pipe. This is the section of the infrastructure most relevant to a slow and small leak of crude oil from that might not be immediately detected by the leak detection systems due to the remote location and underground construction.

Table 2-4 Historic Incident Summary, Onshore Crude Oil Pipeline, and Reported Elements

Item	United States	Region (ND, MN, WI)	Minnesota	Unit
	Value	Value	Value	
January 2002–December 2015	14	14	14	Years of data
Total Incidents	2459	182	80	Reported incidents
Pipeline Mileage	730,690	64,999	28,163	Mile-years
Incident Rate per Mile-Year	0.00337	0.00280	0.00284	Reported incident per mile-year

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Characteristics of Pinhole Releases
January 13, 2017

Table 2-4 Historic Incident Summary, Onshore Crude Oil Pipeline, and Reported Elements

Item	United States	Region (ND, MN, WI)	Minnesota	Unit
	Value	Value	Value	
Maximum Incident Volume Reported (bbl)	49,000	20,600	6,000	Barrels
Median Incident Volume Reported (bbl)	3	3	2	Barrels
Average Incident Volume Reported (bbl)	220	341	226	Barrels
0-50 barrels	81%	80%	88%	Percentage of incidents
50-1,000 barrels	16%	14%	6%	Percentage of incidents
>1,000 barrels	3%	6%	6%	Percentage of incidents

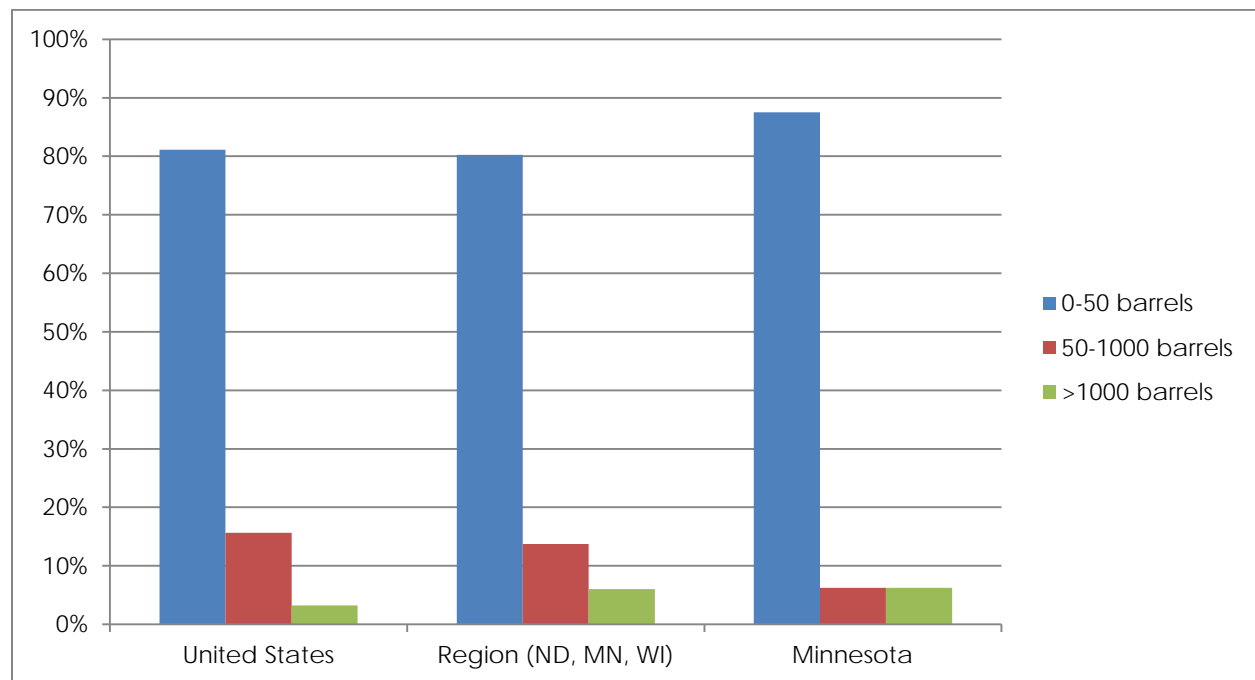


Figure 2-2 Frequency of Releases by Volume, Onshore Crude Oil Pipeline, and Reported Elements

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Characteristics of Pinhole Releases
January 13, 2017

Table 2-5 Historic Incident Summary, Onshore Crude Oil Mainline Pipe

Item	United States	Region (ND, MN, WI)	Minnesota	Unit
	Value	Value	Value	
January 2002–December 2015	14	14	14	Years of data
Total Incidents	591	44	20	Reported incidents
Pipeline Mileage	730,690	64,999	28,163	Mile-years
Incident Rate per Mile-Year	0.00081	0.00068	0.00071	Reported incident per mile-year
Maximum Incident Volume Reported	31,322	20,600	6,000	Barrels
Median Incident Volume Reported	20	45	5	Barrels
Average Incident Volume Reported	437	1,203	794	Barrels
0–50 barrels	63%	50%	65%	Percentage of incidents
50–1,000 barrels	30%	30%	15%	Percentage of incidents
>1,000 barrels	7%	20%	20%	Percentage of incidents

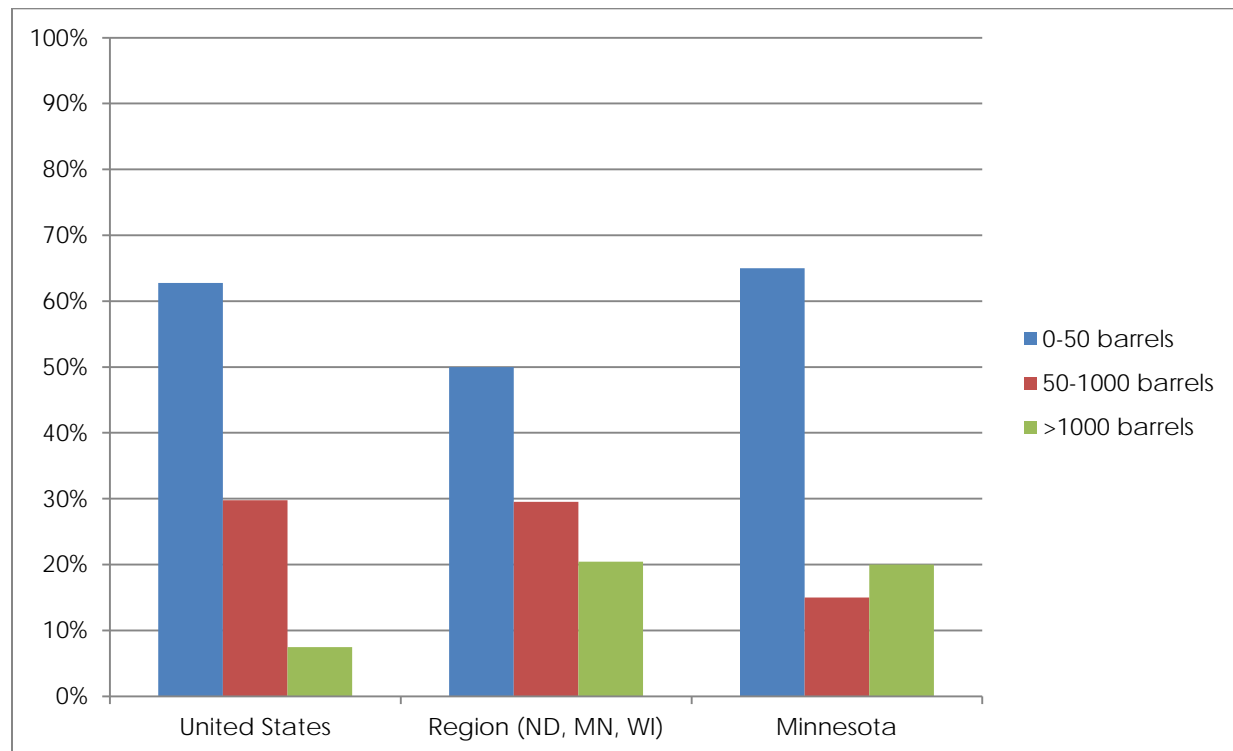


Figure 2-3 Frequency of Releases by Volume, Mainline Pipe

The summaries indicate that spill volumes from the mainline pipe tend to be larger than spills from discrete elements and that the majority of the releases are less than 1,000 barrels.

3.0 FATE AND TRANSPORT OF HYDROCARBONS IN THE ENVIRONMENT

3.1 INTRODUCTION

Crude oil consists of complex mixtures of organic chemicals that exist as a separate phase when mixed with water and are less dense than water. These two characteristics: (1) immiscibility (or inability to mix with water without substantial external mixing energy) and (2) density difference, strongly influence the fate of a crude oil in the environment. When released into the subsurface, oil has a tendency to migrate downward through materials that are partially saturated with water until they reach the water table, which impedes (but not completely prevents) their migration deeper due to both increasing water content and associated buoyancy forces arising from the oil-water density contrast. The magnitude of lateral spread of oil near the water table is determined principally by the subsurface geology, size of the release, as well as the properties of the crude oil (e.g., density, viscosity and interfacial tensions).

As is discussed in this section, many factors affect how a pinhole leak of crude oil will be transported horizontally and laterally within the subsurface materials. Other factors will influence the distribution of crude the movement of crude oil within the subsurface materials and ground water. A variety of processes will deplete the crude oil naturally, including dissolution, vaporization and local biodegradation. Plume expansion continues until a relatively stationary condition is reached, whereby the flux of dissolved components from the remaining oil is balanced by the mass removed through natural attenuation processes in the aquifer. Together, these various processes and factors tend to limit the spatial extent of crude oil contamination, Field investigations at over 600 petroleum hydrocarbon release sites indicate that the migration of dissolved constituents typically stabilize within tens to hundreds of feet from the source area for the crude oil.

3.2 FUNDAMENTAL CONCEPTS OF CRUDE OIL TRANSPORT

The mobility of the various fluids and gases present (oil, water and air) in a porous or fractured geological medium is governed largely by the relative percentage of the pore space occupied by each fluid. In the unsaturated zone, the pore spaces between soil grains are only partially filled with water. The rest of the pore space is filled with air. The water in the pore spaces coats the soil grains and is held there by capillary pressure (the same forces that cause water to soak up into a sponge or paper towel).

When crude oil is released to the ground, it needs to displace an equivalent volume of the resident fluids (air and/or water). For the oil to enter a pore space, it must overcome the

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Fate and Transport of Hydrocarbons in the Environment
January 13, 2017

capillary pressure, as well as the pressure needed to displace water (referred to as pore entry pressure).

If a sufficient volume of oil is present, it begins to enter the unsaturated pore spaces by moving downward under the force of gravity. This can be accompanied by lateral spreading due to geologic heterogeneity. However, due to the capillary pressure and presence of water and air trapped in dead end pores, the air and or water are never completely displaced. As more oil is released, it gradually forces oil into continuous linked pore spaces and migrates away from the release point in the direction of lower pressure. The permeability of the trench materials in comparison to the native soils may influence the transport of oils in the subsurface. Typically the principal direction of transport is downward in permeable sediments under the force of gravity; however, in a pinhole release within a pipeline trench where the native soils are less permeable than the trench fill material, oil may preferentially follow the path of least resistance filling the relatively higher permeability materials within the trench. For a buried pipe, this could result in filling of the pipe trench and ultimately surface expression of the oil. Lateral migration of the oil along the length of the pipeline could occur within the trench, which could extend the time until surface expression of the leaking oil occurs.

Following the termination of a release, not all of the oil drains from the formation. Similar to how water behaves in the unsaturated zone, oil migration in the subsurface leaves behind a trail of residual oil in the form of disconnected droplets. The unsaturated soil acts like a sponge that holds the crude oil in place. The percentage of pore space that contains oil held by the formation, referred to as residual saturation, is functionally immobile. Following gravity drainage, the oil within the pore space is characterized by an irregular, disconnected and heterogeneous distribution.

Residual saturation values depend upon the geological media properties, the physical properties of the crude oil, (viscosity and interfacial tensions) and the nature of the oil exposure (e.g., the residual saturation may vary with the initial saturation, and also with the type of soil in which the oil release occurred). If only a small volume of oil is released, as in a small pinhole release, the migration will cease within the partially saturated zone as mass is immobilized within soil pores due to the retention capacity of the capillary forces. For larger releases with sufficient volume to overcome the residual soil retention capacity, the oil will continue to migrate either upwards until it reaches the ground surface or downwards toward the underlying water table where the pressures are balanced by the buoyancy of the water.

The mobility of oil in the unsaturated zone depends primarily on several factors: (1) its saturation in the pore space relative to the other fluids, (2) the pressure that drives the flow of oil (i.e., the driving head); (3) the permeability of the unsaturated soils; (4) the density and viscosity of the oil and (5) the distance of travel (e.g., distance to ground surface or depth to the water table).

If the oil in the formation is below its residual saturation concentration, it is not able to move. Oil movement is resisted by capillary forces (the oil pore entry pressure or water displacement pressure). The oil needs to exceed the lower threshold of residual saturation for it to form a contiguous phase that is mobile, thereby overcoming the retention capacity of the capillary

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Fate and Transport of Hydrocarbons in the Environment
January 13, 2017

forces. As the saturation of the oil in the pore space increases, the (so-called) relative permeability of the formation with respect to the oil also increases. Oil, present in the formation, migrates along a tortuous path preferentially following the path of least resistance.

If the release is sufficiently large to exceed the residual saturation, and the pressure is high enough to drive the oil in the pore space, the oil body may migrate. More permeable soils, such as sand and gravel, will allow for relatively faster migration of crude oil than less permeable soils, such as silt and clay. Migration may occur upward through the more permeable sediments of the trench until it reaches the ground surface or, if the oil release is balanced by gravity driven infiltration, it may slowly infiltrate into the soils and, if not mitigated, may reach the water table.

Because both water and oil move slowly in the pores between soil grains, the distance between the ground surface and the water table (i.e., the depth to the water table) will also affect whether the oil reaches the water table, and the time it takes to get there. Thicker unsaturated zones (greater depths to the water table) act as a thicker "sponge" that holds more crude oil in place than thinner unsaturated zones with less pore volume storage. In situations where just a the soils are less permeable, or the water table is very deep, a release of a small amount of crude oil may remain in the unsaturated zone and never reach the water table.

Once in contact with the saturated zone, the vertical migration of the oil continues until buoyancy and increasing water content impede vertical migration. Oil begins to spread laterally at the capillary fringe unless sufficient oil elevation head exists for it to displace water and penetrate below the water table. In such a case, vertical oil penetration will continue until the pressure head is balanced by the upwards forces of buoyancy and capillary pressure, which are together referred to as either pore entry pressure or water displacement pressure. The resulting oil body will then continue to migrate laterally following the water table down hydraulic gradient and radially due to oil mounding above the water table (creating an oil head gradient) in response to the resisting forces.

At the water table, where oil can more easily push the water from the formation into the capillary fringe, oil will mound in response to resistance from buoyancy and pore entry pressures. Lateral migration will occur in response to the gravitational forces for this mounded oil enhancing the gradient laterally. The lateral migration and growth of the oil body will continue until the driving force from the release dissipates or is balanced by the formation capillary pressures and the oil pore entry pressure or water displacement pressure at the leading edges. The greater the density difference between oil and water, the stronger the buoyancy forces and less vertical penetration of the oil and greater lateral spread. At the leading edges, oil reaches residual saturation, becomes discontinuous and is immobilized by capillary forces under ambient groundwater flow conditions leading to dispersed and disconnected oil in the formation. At this point, dissolution and volatilization cause gradual depletion accelerated by local dissolved-phase plume biodegradation.

3.3 FACTORS AFFECTING CRUDE OIL DISTRIBUTION

Scientists originally conceptualized oil migration in porous media as a continuous 'pancake' layer floating on the water table. This conceptualization incorrectly assumed oil migration to the water table and lateral spread along the capillary fringe forming a continuous layer of complete saturation of the pore space by oil. The oil body was assumed to float on the water table as a separate continuous layer, and correlated directly to the thickness observed in monitoring wells (or some fraction of this observed oil thickness in wells with several theoretical and semi-empirical relations developed relating this difference). This earlier understanding failed to fully recognize the controls of capillary forces and could greatly over-predict both the amount of oil within the subsurface (particularly in fine-grained strata [Huntley and Beckett 2002]), as well as the amount of potentially recoverable oil.

A closer approximation of the oil saturation distribution is based on the capillary pressures of the various liquid phases and the development of functions that relate fluid contents of the porous media to capillary pressures (Farr et al. 1990; Lenhard and Parker 1990a, b). The oil saturation profile at the water table interface is predicted to approximate the shape of a shark fin within an unconfined aquifer under equilibrium conditions (Figure 3-1).

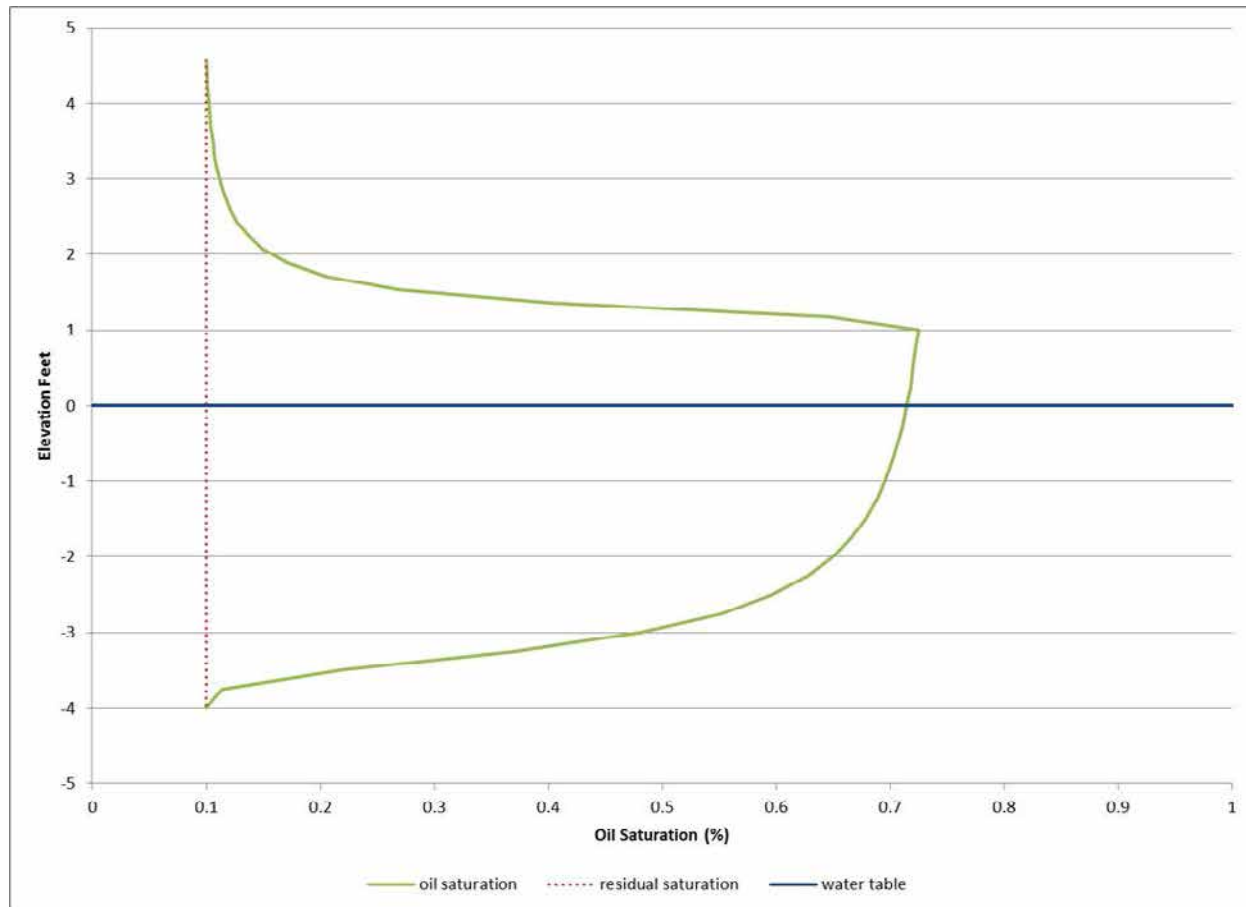
Oil type and release mode may also influence oil distribution in the subsurface. For a catastrophic release such as a pipeline rupture, oil elevation heads will initially be large and dissipate quickly. For an on-going leaking pipeline, there may be a constant elevation head that drives the migration of the oil. A longer term release with a constant pressure head will continue to overcome the resistance of capillary pressure and buoyancy, and drive the oil deeper in the formation with less lateral spread than for a similar volume of released oil from a catastrophic release.

Oil viscosity also affects timeframes for stabilization of the crude oil plume. For a limited volume release, an oil of high viscosity leads to slower migration and increased timeframes for that oil to reach hydrostatic equilibrium. Highly viscous crude oils may move very slowly through the subsurface and take years to reach equilibrium (Oostrom et al. 2006).

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Fate and Transport of Hydrocarbons in the Environment

January 13, 2017



NOTE: simulated with LDRM model

SOURCE: Charbeneau 2014

Figure 3-1 Theoretical Distribution of Oil at the Water Table in a Homogeneous Unconfined Sand Aquifer

3.4 CRUDE OIL FATE IN THE SUBSURFACE

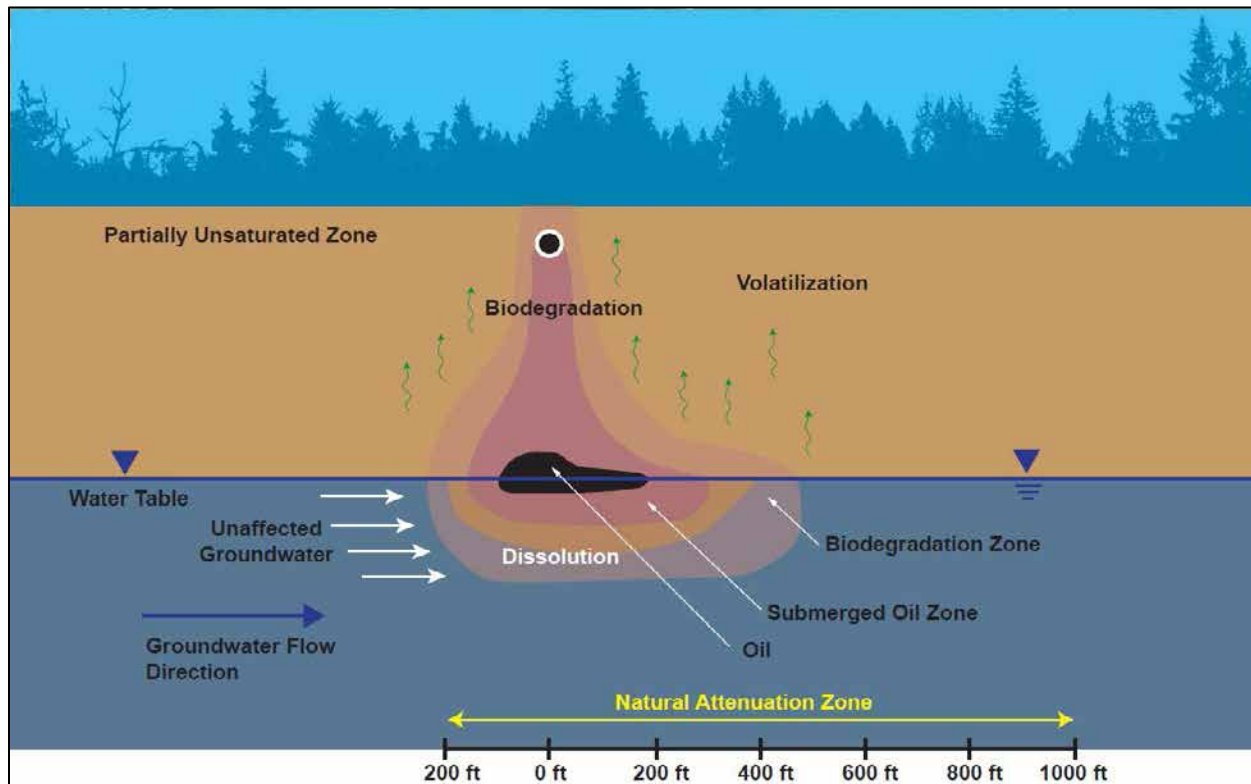
Upon release of crude oil to the subsurface environment, depletion of the oil will continue naturally by a range of processes that include dissolution, vaporization and local biodegradation in the unsaturated and saturated zone (Figure 3-2). Collectively these processes result in mass transfer away from the oil release (ITRC 2009b; Johnson et al. 2006; Lundegard and Johnson 2006).

Once released to the subsurface, the oil may dissolve into groundwater or evaporate into the soil vapor. In the former, the process of dissolution creates a dissolved-phase plume in groundwater, whereas the latter creates a vapor-phase plume above the water table. This section discusses these mass transfer processes and the fate and transport of the respective

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Fate and Transport of Hydrocarbons in the Environment
January 13, 2017

plumes that are produced. This includes the role of natural attenuation in their management and risk mitigation.



SOURCE: Modified from ASTM 2006

Figure 3-2 Subsurface Oil Fate Processes

3.4.1 Volatilization

Volatilization is the phase change from liquid to gas by which some of the smaller molecules leave the liquid phase of the crude oil and move into the atmosphere or the air in the soil pore spaces. This process is driven by the vapor pressure (volatility) of the various components of the crude oil. Crude oil contains VOCs that can vaporize during and after release in the subsurface, leading to the development of a vapor-phase in the partially saturated zone (Christophersen et al. 2005; Molins et al. 2010). Volatilization is less important for heavier oils. Key controlling parameters (vapor pressure, Henry's Law constant and diffusion coefficient) are sensitive to temperature and decrease at low temperature. This causes vapor generation and migration to be sensitive to temperature profiles in the shallow subsurface that may vary over a large range between summer and winter. Vapor generation and migration are more likely to occur on the ground surface than in the shallow subsurface where temperatures are generally cooler.

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Fate and Transport of Hydrocarbons in the Environment
January 13, 2017

In the early phases of a crude oil release, volatilization can be the primary mechanism for release of smaller molecules. Crude oil exposed to air may lose approximately 20% of its volume by evaporation in a few hours, and 30% of its volume within a day (Fingas 2011); however, in the subsurface these processes may act more slowly. Volatilization will continue throughout the soil column where crude oil has been dispersed on the surfaces of soil grains, provided the pore spaces of the soil are not filled with water or oil to the point of inhibiting air flow. Diffusive VOC transfer across the largely immobile, water-saturated capillary fringe may be slow in either direction (Davis et al. 2004; Werner and Höhener 2001). The capillary fringe may contain air-filled pore spaces, but these spaces may be physically disconnected and effectively restrict gas and vapor diffusion. Fluctuation in the water table may increase vertical mixing and can enhance volatilization by increasing the contact area between the contaminated groundwater and gas phase.

Vapor-phase contaminants are attenuated by physical-chemical mechanisms such as dilution, diffusion, atmospheric emission and partitioning into pore water, but also by sorption and biodegradation (Rivett et al. 2011). For many petroleum constituents, biodegradation may lead to substantial natural attenuation of vapor (Grathwohl et al. 2001; Lahvis et al. 2013; USEPA 2013), as exemplified by studies on petroleum hydrocarbon light non-aqueous phase liquids (LNAPLs) such as gasoline, diesel, kerosene, crude oil and others (Christophersen et al. 2005; Molins et al. 2010).

3.4.2 Dissolution

Oil trapped in the subsurface will lose mass over time due to dissolution. Soluble components are transferred from the oil to flowing groundwater infiltrating through the vadose, or unsaturated, zone or in the saturated zone and a dissolved-phase plume may develop. Dissolution rates and hence source zone longevity is influenced by:

- Oil composition
- Distribution and saturation
- Oil-water contact area
- Groundwater velocity
- Molecular diffusivity of the oil chemicals in water
- Non-equilibrium dissolution effects
- Enhanced dissolution due to biodegradation of dissolved components (Garg and Rixey 1999)

Even though crude oil has a low solubility in water, when oil comes in contact with water, some compounds from the oil will dissolve into the water. The lightest components of crude oil (benzene, ethyl benzene, toluene, and xylene (sometimes referred to collectively as BTEX)), are the most soluble components of crude oil and among the most readily degraded and volatilized. Crude oil also contains medium weighted hydrocarbons called "polycyclic aromatic hydrocarbons" or PAHs. PAHs have moderate to very low solubility in water. Crude oil also contains heavy fractions that include waxes, asphaltenes, and nonpolar compounds which do not readily dissolve in water.

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Fate and Transport of Hydrocarbons in the Environment
January 13, 2017

Dissolution of the soluble compounds in the crude oil happens relatively slowly because it takes place only where the oil is in direct contact with the slowly moving groundwater. This direct contact takes place primarily below the water table, where groundwater moves underneath the greatest accumulation of oil. Groundwater moves much more slowly than water in rivers or lakes. Even in very permeable deposits, such as sand and gravel, groundwater typically moves less than one foot per day. The plume of dissolved hydrocarbons will move even more slowly than the groundwater flow because of natural attenuation processes.

The solubility of crude oil components varies with time as the more soluble components preferentially dissolve into water, causing the remaining fractions to change. In crude oils, the light-end hydrocarbons will preferentially dissolve from the free phase oil. Medium and heavy hydrocarbons are sparingly soluble to practically insoluble and more persistent. Regardless of the type of crude oil, as the soluble components of the crude oil dissolve, the remaining residual oil is less soluble and more persistent than the source oil. Dissolution of the oil may require many thousands of pore volumes of water to be flushed through a source, with substantial variation in timescale possible due to variation in oil composition and effective solubility of components (Thornton et al. 2013).

Over a period of time, when crude oil is in contact with groundwater, dissolved crude oil constituents will enter the groundwater column, forming a contaminant plume that will move in the direction of groundwater flow. Vertical migration of contamination into groundwater is extremely limited, and is much less than horizontal migration. Where deeper aquifers are present and separated from the water table aquifer by impermeable layers, the deeper aquifers will not be affected.

Over a relatively short distance, the dissolved hydrocarbon plume will reach an equilibrium state and expand no farther as the flux of dissolved components from the remaining oil is balanced by the mass removed through attenuation processes in the aquifer (Section 3.4.4). Field investigations at over 600 petroleum hydrocarbon release sites indicate the migration of dissolved constituents typically stabilize within tens to hundreds of feet from the source area (Newell and Connor 1998; Connor et al. 2015). Over time, the contaminant plume will begin to reduce due to natural biodegradation.

3.4.3 Direct Biodegradation of Crude Oil

Biodegradation of crude oil source zones via microbial activity in the aqueous phase and vapor phase is well documented and discussed further below. In addition, direct biodegradation of the portion of the oil that does not volatilize or dissolve into groundwater has been also demonstrated to occur (e.g., Stout and Lundegard 1998). Several laboratory studies have shown that rates of mineralization of target constituents have exceeded the measured rates of aqueous-phase partitioning. These studies propose various mechanisms for bacteria to enhance biodegradation of the crude oil constituents. In general, biodegradation is not occurring within the crude oil itself, but rather at the oil-water interface through enhanced bio-activity (e.g., enzyme secretion and microbial attachment at oil-water interface). Laboratory studies confirm

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Fate and Transport of Hydrocarbons in the Environment
January 13, 2017

that biodegradation of petroleum does occur in some situations and environments; however, they also point to circumstances that would reduce or eliminate biodegradation (e.g., toxicity).

3.4.4 Natural Attenuation of Dissolved-Phase Plumes

While dissolution fundamentally controls the duration of inputs to dissolved-phase plumes, the plume size and composition is predominantly controlled by natural attenuation in the aquifer. There has been substantial interest over the past two decades in monitored natural attenuation as a management strategy for contaminated groundwater (API 1998; ASTM 1998; EA 2000; Wiedemeier et al. 1995, 1997). This has provided a comprehensive body of evidence on the theoretical basis and practical site implementation of this approach for dissolved plumes originating from petroleum sources (Rivett and Thornton 2008; Wiedemeier et al. 1999).

Natural attenuation includes all of the of physical, chemical, and biologic processes that act without human intervention to reduce the mass, toxicity, mobility, and volume of crude oil in soil and groundwater (USEPA 1999). Natural attenuation takes place in the unsaturated zone, at the water table, and in groundwater, through the processes of biodegradation, dispersion, adsorption to soil particles, and volatilization. Whether in soil or groundwater, the processes involved in natural attenuation are the same, although the relative importance of individual processes could vary by location. Of these processes, biodegradation through metabolism by naturally occurring microorganisms is generally considered to be the primary mechanism responsible for petroleum mass reduction in the subsurface soil and groundwater (MPCA 2005).

The composition of the dissolved-phase plume that develops immediately down gradient of a release source is closely linked to the chemical composition of the crude oil and its evolving dissolution (and vaporization) characteristics. Preferential dissolution of the more soluble and volatile components of the crude oil will lead to plumes that are often dominated by BTEX components (Bowers and Smith 2014; Thornton et al. 2013). However, the less soluble and typically more biodegradable aromatic hydrocarbons such as toluene, ethylbenzene and xylenes often develop dissolved-phase plumes that are restricted to the source area.

In terms of plume size and duration, the plume expansion period is short compared with the length of time most residual crude oil remains in the subsurface. Plume expansion continues until a relatively stationary condition is reached, whereby the flux of dissolved components from the remaining oil is balanced by the mass removed through attenuation processes in the aquifer.

Natural attenuation will reduce most toxic constituents of petroleum releases into non-toxic metabolic byproducts, typically carbon dioxide and water (MN PCA 2005). Numerous multi-site studies conducted since the 1990s have presented results that indicate dissolved-phase hydrocarbon plumes stabilize at relatively short distances from the source area and are unlikely to be greater than a few hundred feet in length (Newell and Connor 1998; Connor et al. 2015).

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Fate and Transport of Hydrocarbons in the Environment
January 13, 2017

3.4.4.1 Biodegradation

Many organic compounds in oils can be biodegraded by naturally-occurring subsurface microorganisms (Rivett and Thornton 2008). Microbially-mediated reactions occur, whereby organic compounds are metabolized, often to innocuous by-products, such as carbon dioxide, methane, and water. Electron acceptors used to support biodegradation include dissolved oxygen, nitrate and sulfate in pore water, and mineral oxidants such as manganese and iron-oxides present as grain coatings. Once those electron acceptors are depleted, fermentation (biochemical breakdown) of organic compounds may occur with the ultimate production of methane. Aerobic biodegradation (using oxygen as an electron acceptor) and anaerobic biodegradation (using other electron acceptors) typically occurs concurrently in groundwater plumes.

3.4.4.2 Dispersion

Dispersion is the process by which soluble hydrocarbons spread out vertically and laterally, reducing their concentration. This enhances the effects of other natural attenuation processes, such as biodegradation.

3.4.4.3 Adsorption

Adsorption slows the movement of oil in the subsurface. Adsorption is a chemical process where hydrocarbon compounds are electro-chemically attracted to the electrically charged surfaces of soil grains—particularly organic material in the soil. The extent to which adsorption slows the movement of dissolved hydrocarbons with respect to the velocity of the groundwater in which they are dissolved is called the retardation coefficient. Typical retardation coefficients for BTEX compounds are in the range of three to five, meaning they migrate three to five times slower than groundwater.

3.4.4.4 Volatilization

Volatilization is the transfer of mass from the liquid phase to the gas phase, as discussed in Section 3.4.1. This process may occur directly from the oil phase to the gas phase, but it also occurs between the dissolved phase and the vapor phase. Volatilization will continue throughout the soil column, provided the pore spaces of the soil are not filled with water or oil to the point of inhibiting air flow. Diffusive transfer across the largely immobile, water-saturated capillary fringe may be slow in either direction (Davis et al. 2004; Werner and Höhener 2001). The capillary fringe may contain air-filled pore spaces that may be physically disconnected from each other, thereby effectively restricting gas and vapor diffusion. Fluctuation in the water table may increase vertical mixing and can enhance volatilization by increasing the contact area between the contaminated groundwater and the gas phase.

4.0 NATURAL RESOURCE AND WATER SUPPLY MAPPING

At the request of DOC-EERA, the following natural resource and water supply areas have been identified within 1,000 ft of the center line (2,000 ft corridor) of the proposed L3RP Project and the route alternatives:

- Streams, wetlands, and lakes
- Calcareous fens
- Trout streams
- Wells
- Wellhead protection areas
- Drinking water supply management areas
- Surface water intakes

The location and proximity of these resources to the project were reviewed using spatial analysis tools in ArcGIS. Maps and tables identifying the natural resource and water supply features within 1,000 ft of the L3RP Project are included as Attachment A. A detailed assessment of environmental effects of oil releases on ecological and human receptors is presented in *Assessment of Accidental Releases: Technical Report—Chapter 7* (Stantec/RPS/Dynamic Risk Assessment Systems 2016).

4.1 STREAMS, WETLANDS AND LAKES

Surface water bodies, including stream wetlands and lakes, within 1,000 ft of the proposed route center line were identified in the National Wetlands Inventory (NWI; U.S. Fish and Wildlife Service) and Public Waters Inventory (PWI; MDNR 2016).

Based upon the assessment 3,913 wetlands, 88 streams, and 57 lakes (basins) were identified within 1,000 ft of the proposed right of way. Maps and tables identifying the surface water features within 1,000 ft of the L3RP Project are included as Attachment A

4.2 CALCAREOUS FENS

Three calcareous fens were identified, one each in Marshall, Pennington and Polk counties, within 1,000 ft of the proposed route center line in a data set derived from the National Heritage “Biotics” Database (MDNR 2016a). Maps and tables identifying the calcareous fens within 1,000 ft of the L3RP Project are included as Attachment A.

4.3 TROUT STREAMS

Nine state designated trout streams were identified that intersect the 2,000-ft proposed route corridor (MDNR 2016b). Maps and tables identifying the state designated trout streams within 1,000 ft of the L3RP Project are included as Attachment A.

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Natural Resource and Water Supply Mapping
January 13, 2017

4.4 WELLS

Water wells located within 1,000 ft of the L3RP Project and route alternatives (omitting monitoring wells, observation wells and abandoned wells) were identified using the MWI (MDH 2016). Based upon the analysis the following observations are made:

- 224 total wells were identified
- 201 of the 224 total wells were identified as domestic wells
- 3 of the 224 total wells were identified as exploratory well
- 8 of the 224 total wells were identified as irrigation wells
- 3 of the 224 total wells were identified as exploratory well
- 6 of the 224 total wells were identified as other or were not identified
- 2 of the 224 total wells were identified as scientific investigation wells
- 4 of the 224 total wells were identified as test wells

Maps and tables identifying the water wells within 1,000 ft of the L3RP Project are included as Attachment A.

4.5 WELLHEAD PROTECTION AREAS

Three Wellhead Protection Areas were identified that intersect the corridor within 1,000 ft of the proposed pipeline center line (MDH 2016b). Maps and tables identifying the wellhead protection areas within 1,000 ft of the L3RP Project are included as Attachment A.

4.6 DRINKING WATER SUPPLY MANAGEMENT AREAS

Three Drinking Water Supply Management Areas were identified that intersect the corridor within 1,000 ft of the proposed pipeline center line (MDH 2016b). Maps and tables identifying the wellhead protection areas within 1,000 ft of the L3RP Project are included as Attachment A.

4.7 SURFACE WATER INTAKES

One hundred and ninety-one total (27 active) surface water intakes were identified that intersect the corridor within 1,000 ft of the proposed pipeline center line (MDH 2016b). Maps and tables identifying the surface water intakes within 1,000 ft of the L3RP Project are included as Attachment A.

5.0 POTENTIAL ENVIRONMENTAL EFFECTS

5.1 GROUNDWATER SUSCEPTIBILITY TO HYDROCARBON CONTAMINATION

5.1.1 Aquifers

An aquifer is a geologic unit (or a combination of geologic units) that is capable of yielding usable quantities of water. Aquifers are typically composed of thick, laterally continuous deposits of permeable sand, gravel, or bedrock that is composed of permeable sandstone or limestone, or is highly fractured. Portions of geologic units that are not capable of yielding usable quantities of water generally are termed “aquitards” and are either too thin to accommodate wells or are composed of low-permeability materials, such as silt, clay, or crystalline bedrock. Unlike geologic units, aquifers and aquitards are not typically given formal names, but are often referred to by the geologic units that comprise them.

5.1.1.1 Glacial Aquifers

Unconsolidated permeable glacial deposits and recent alluvial deposits are the most important groundwater source along the proposed L3RP route. These deposits are typically near the ground surface, and consist primarily of glacial sand and/or gravel outwash, ice-contact deposits, or sand and gravel alluvium that was deposited along existing streams. Most glacial aquifers are classified as “surficial aquifers” because the groundwater table is located in these near surface deposits. The surficial glacial aquifers vary in thickness from a few feet to over 300 ft, and can produce water up to 3,000 gallons per minute or more, depending on the thickness and extent of the saturated deposits and the permeability of the aquifer materials.

Surficial glacial aquifers receive recharge by infiltrating precipitation and snow melt. Perched wetland deposits may also provide some minor additional recharge. Groundwater in the surficial glacial aquifers generally flows from upland areas (e.g., topographic highs) to lakes and streams. Many lakes and streams near the proposed route and its alternatives are in direct hydraulic connection with the surficial glacial aquifers and the open water of these features is typically at the same elevation as the water table. Groundwater from surficial aquifers discharges to lakes and rivers, where some water evaporates. Evapotranspiration from plants is also a mechanism of discharge.

In some locales near the proposed route and its alternatives, there may be “buried” glacial aquifers. Buried glacial aquifers are unconsolidated, permeable sand and gravel deposits that are separated from the ground surface or from overlying surficial glacial aquifers by a laterally continuous layer of lower permeability silt and/or clay that functions as an aquitard. Buried glacial aquifers are typically “confined” (i.e., the water pressure is above the aquitard base) and, in some cases, wells that are installed in buried glacial aquifers flow freely without pumping.

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Potential Environmental Effects
January 13, 2017

Flowing wells are most commonly encountered where a buried glacial aquifer is near a river because the ground surface is at a lower elevation near rivers. Buried glacial aquifers are recharged primarily by downward leakage through the aquitard. Discharge from these aquifers often takes place by upward leakage in the vicinity of rivers.

Surficial aquifers are an important source of groundwater throughout the region crossed by the proposed route and its alternatives, and can provide adequate water volumes to supply municipalities and irrigation systems. Surficial aquifers generally yield good quality water. However, there may be naturally occurring constituents, such as iron and manganese, at concentrations above secondary drinking water standards (i.e., levels that affect taste, color, and odor but not human health). In some areas, there may also be naturally high levels of constituents such as arsenic (MPCA 1999).

Glacial aquifers, and particularly surficial glacial aquifers, can be affected by surface activities, including industrial and agricultural land use, due to the relatively shallow depth of the water table and the relatively coarse texture of the material in the overlying unsaturated zone. The most common anthropogenic contaminant in glacial aquifers near the proposed routes is nitrate, which originates as fertilizer applied to agricultural fields and leaches into the groundwater system. Nitrate and other agriculturally derived contaminants are classified as “non-point source pollutants” because of their widespread use near portions of the proposed route and its alternatives. Nitrate persists in glacial aquifers for a long time because of the naturally low levels of organic material or sulfides that are able to “denitrify” nitrate.

5.1.1.2 Cretaceous Aquifers

Fine sandstone and shale of Cretaceous age are present in two areas that are traversed by the proposed route in Cass and Aitkin counties. These rocks, which are likely the stratigraphic equivalent of the Dakota Sandstone (present in southwestern Minnesota), are typically 200 to 350 ft below ground surface, and are overlain by glacial deposits. Because they are thin and of relatively low permeability, the Cretaceous aquifer near the proposed route and its alternatives yields only domestic quantities of water (i.e., 10–25 gallons per minute) and is used only in a few rural locations. The water quality of the Cretaceous aquifer is typically poor compared to glacial aquifers and has naturally elevated levels of total dissolved solids (particularly sodium, potassium and chloride) as well as undesirable levels of boron, sulfate, fluoride, molybdenum and iron in some areas (MPCA 1999).

5.1.1.3 Precambrian Aquifers

The proposed route and its alternatives are located over Precambrian aquifers consisting of undifferentiated granite, greenstone, and slate from central Minnesota to the northwest and Proterozoic meta-sediments from central to eastern Minnesota. These aquifers can yield limited supplies of water to rural domestic and livestock wells, where fractures, faults, and weatherized zones provide porosity and permeability. Wells in these aquifers are generally completed at depths ranging from 30- to 400-feet and generally yield between 1 and 25 gallons per minute.

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Potential Environmental Effects
January 13, 2017

5.1.2 Groundwater Susceptibility Evaluation Methods

Subsurface soil characteristics and the depth to the water table along the proposed L3RP route and its alternatives in Minnesota were evaluated. Statewide mapping of water-table aquifer vulnerability and depth to water table was utilized to evaluate the susceptibility of water table aquifers in the vicinity of the Project. The water table aquifer vulnerability map (MDA, 2015) assigns aquifer vulnerability ratings of high, medium, or low based on the composition of surficial materials. The vulnerability ratings are based on upon guidance from the Geologic Sensitivity Project Workgroup (DNR, 1991) and are defined as follows:

- Low: Water moving vertically will reach the aquifer within several decades to more than a century
- Medium: Water moving vertically will reach the aquifer in years to decades
- High: Water moving vertically will reach the aquifer within hours to years

Vulnerability ratings were assigned to geologic material types as follows:

- Low: Till Plain
- Medium: Supraglacial Drift Complex, Lacustrine, Peat
- High: Alluvium, Outwash, Ice Contact, Terrace, Bedrock, Sand and Gravel

The L3RP route and its alternatives were divided into one-mile segments and the vulnerability rating from the map was extracted at the midpoint of each segment. Based on professional judgment, lacustrine materials were considered low vulnerability in this analysis. Lacustrine deposits are typically composed of fine-grained sediments and such deposits have low permeability.

Depth to the water table was also taken into account in evaluating the susceptibility of water table aquifers. Depth to water table information from the Minnesota Hydrogeology Atlas (DNR, 2016) was extracted the midpoint of each one-mile project section. Project sections with a water table depth greater than 40 ft below ground surface were considered to have low susceptibility regardless of the geology. Based on professional judgment, in areas where the water table is 40 ft deep or deeper, a combination of release response and natural physical processes would make it unlikely that oil would migrate all the way down to the water table. Even for higher permeability deposits, such as sand and gravel, this is likely the case because these unsaturated deposits require large pore entry pressures to develop in order for downward migration to progress.

5.1.3 Groundwater Susceptibility Evaluation Results

From a total of 340 Project segments analyzed for the L3RP route, 137 have low susceptibility, 79 have medium susceptibility, 96 have high susceptibility, and 28 were unclassified due to lack of available data. Low -susceptibility water table aquifers are present across over 40% of the proposed L3RP route. A similar evaluation was performed for the route alternatives and are shown on Table 5-1, along with the proposed L3RP route.

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Potential Environmental Effects
January 13, 2017

Table 5-1 Summary of Groundwater Susceptibility L3RP Project Route

Route Alternative	1-Mile Linear Segment Aquifer Susceptibility Rating				
	Low	Medium	High	Unclassified	Total
L3RP Route	137	79	96	28	340
RA-03AM-L3	130	68	111	36	345
RA-06-L3	140	141	89	47	417
RA-07-L3	83	101	157	48	389
RA-08-L3	93	117	134	42	386
RSA-05-L3	11	6	7	0	24
RSA-10-L3	12	0	1	0	13
RSA-15-L3	5	0	16	0	21
RSA-21-L3	14	57	7	31	109
RSA-22-L3	27	61	17	39	144
RSA-23-L3	0	30	9	31	70
RSA-27-L3	0	13	4	13	30
RSA-28-L3	0	1	0	7	8
RSA-31-L3	0	4	2	9	15
RSA-33-L3	0	1	2	1	4
RSA-34-L3	0	0	3	3	6
RSA-35-L3	0	2	2	0	4
RSA-37-L3	36	35	8	4	83
RSA-42-L3	4	0	0	5	9
RSA-43-L3	3	0	0	5	8
RSA-44-L3	4	7	0	8	19
RSA-45-L3	4	5	0	10	19
RSA-46-L3	4	0	0	0	4
RSA-49-L3	2	7	0	3	12
RSA-51-L3	1	1	2	0	4
RSA-52-L3	0	1	1	0	2
RSA-53	83	101	160	48	392
RSA-Blandin-L3	0	6	1	1	8
RSA-White Elk Lake-L3	0	16	0	1	17
SA-04-L3	50	173	22	4	249

A complete set of figures displaying the groundwater susceptibility assessment are presented in Attachment B.

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Potential Environmental Effects
January 13, 2017

5.2 SURFACE WATER SUSCEPTIBILITY

For the purpose of this assessment, it is predicted that 28 bpd (estimated release rate from 1/32 in. hole; refer to Section 2.3) of crude oil would be released from a pinhole leak. Assuming that leak detection systems identify the leak within 100 days, it is estimated that 2,800 barrels (bbl) could be released before the leak was detected.

A release of crude oil to the environment from a pinhole leak in the proposed pipeline could occur underground, with subsequent transport into aquatic systems, should riverine and lacustrine habitats be nearby.

The proposed pipeline would carry a variety of crude oil types, ranging from very light (e.g., Bakken crude oil) to heavy (e.g., diluted bitumen such as CLB). An assessment of the fate and transport of a worst case release at seven representative river systems in Minnesota (i.e., hypothetical release directly to a water body) was conducted (Chapters 5 and 6 of the *Assessment of Accidental Releases: Technical Report* [Stantec, RPS, Dynamic Risk Assessment Systems 2016]). This report also included an assessment of expected environmental effects of these releases (Chapter 7 of the *Assessment of Accidental Releases: Technical Report* [Stantec, RPS, Dynamic Risk Assessment Systems 2016]), as well as a review of the potential and timing for the recovery of the physical, biological, and human environments following a large release of oil (Section 8.0).

The fate and downstream transport of released oil in a water body is largely determined by flow conditions (i.e., high flow coinciding with the spring freshet; average flow during summer or fall; low flow in winter typified by freezing conditions and probable ice cover on water) and oil type. In general, lighter crude oils such as Bakken crude oil is predicted to evaporate more and to travel equal or farther distances downstream than heavier crude oils such as CLB. Bakken crude oil is also predicted to spread more thinly on the water surface and to adhere less to river banks than Cold Lake Blend. Evaporative losses of both oil types would be greater in summer due to hotter ambient temperatures. Under low flow conditions, the downstream extents of released oils would be similar, but shorter than under spring and summer conditions. Ice cover on rivers and lakes during winter would strongly limit or prevent evaporation to the atmosphere of both oil types.

Overall, the effects of a release of light crude oil compared to heavy crude oil on human and ecological receptors are expected to be similar in overall magnitude, while varying in specific details. For sediment, shoreline and riparian areas, light oil is expected to have less of an effect than heavier oil. However, for other receptors (river and lakes, quality, aquatic plants, benthic invertebrates, fish, amphibians and reptiles, birds and semi-aquatic mammals, and air quality, human receptors and public use of natural resources), lighter oil is expected to have similar or potentially more serious effects, when compared to heavy oil. The overall impact of an oil spill, including the effectiveness of an oil spill response, depends mainly on the environment and conditions (weather, waves, etc.) where the spill takes place and the time lost before remedial operations (Lee et al. 2015).

5.3 WETLANDS, FENS AND PEATLANDS SUSCEPTIBILITY

The fate and downstream transport of released oil would be largely determined by flow conditions of water bodies (i.e., high flow coinciding with the spring freshet; average flow during summer or fall; low flow in winter typified by freezing conditions and probable ice cover on water) and oil type. Oil that reaches soil would be physically remediated and vegetative cover would be restored as part of the clean-up process. Soil would be physically remediated to established standards (Stantec et al. 2016).

Flooded riparian areas and wetland habitats (e.g., fens and peatlands) could also be exposed to released oil, and if not properly remediated, crude oil residues could kill plants in these areas. This could affect the biological integrity and productivity of the habitat, and potentially lead to erosion and further damage to the habitat. In the early summer, oiling of emerging wild rice plants could lead to growth inhibition or death. Later in the summer, oiling at water level of the stems of emerged plants is unlikely to affect the plants. A release of crude oil in winter would have little direct effect on aquatic plants, as they would be in a dormant state (Stantec et al. 2016).

Wetlands, fens and peatlands are also home to amphibians (e.g., frogs, salamander), reptiles (e.g., turtles, snakes), birds (e.g., ducks, geese, shorebirds, raptors), and semi-aquatic mammals (e.g., muskrat, beaver, mink and otter). Within the oil-exposed habitats that support amphibians (adults, juveniles, and eggs), oiling effects including mortality would be observed (Stantec et al. 2016). Turtles appear to be relatively tolerant of external crude oil exposure, and although these animals are likely to become oiled, mortality of turtles as a result of this exposure is less likely. Reptiles like lizards and snakes are primarily terrestrial species and are less intimately associated with aquatic environments. Amphibians and reptiles undergo a winter dormancy period when temperatures drop below approximately 41 to 45°F. At this time, amphibians and turtles typically bury themselves in river bottom substrates or other similar habitats. Therefore, during the winter (and likely up until April or May when winter ice is gone), these organisms would have very little exposure to released oil moving on the water surface or within the water column (Stantec et al. 2016).

If exposed to external oiling, the ability of birds and mammals to maintain body temperature may be compromised, leading to death as a result of hypothermia (Stantec et al. 2016). Birds and mammals that survive external oiling may experience toxicological stresses as a result of ingesting crude oil residues during preening/grooming or ingesting food, and birds can also transfer potentially lethal quantities of crude oil residue from their feathers to the external surface of eggs. Waterfowl and other semi-aquatic birds and mammals present in the affected rivers and lakes would be most affected. Animals upstream, farther downstream, or occupying other nearby habitats, would likely be less affected as it is assumed that emergency response measures to prevent or reduce further possible downstream transport of oil would be in place within 24 hours of the release. Timely capture and rehabilitation of oiled birds and mammals may help to mitigate the environmental effects of a crude oil release (Stantec et al. 2016).

6.0 RECOVERY OF GROUNDWATER FROM THE EFFECTS OF A RELEASE

Because oil spill detection and response times are much faster than the times required for an oil spill to develop hydrocarbon plumes and for those plumes to travel toward receptors, spill countermeasure plans and associated cleanup actions should be effective at protecting groundwater resources. Containment, recovery, and clean-up actions would be undertaken to reduce the effects on human health and the environment. Measures would be specific to the affected receiving environment and include consideration of local sensitivities such as human health, public safety, priority ecosystem values, weather, and other site-specific considerations. Without treatment or physical removal, crude oil could be a long-term source of groundwater contamination. For this reason, release recovery efforts aim to reduce potential for groundwater contamination by removing pooled oil and affected surface materials as quickly as possible, and as deeply as needed to remove oil so that aquifers are not affected.

6.1 REMEDIATION TECHNOLOGIES

After initial recovery efforts are complete and immediate risks to human health addressed, longer term remedial technologies can be implemented. Corrective remedial actions must be reviewed and approved by the United States Environmental Protection Agency (USEPA) or MPCA prior to execution of the selected technology. Remedial technologies would be chosen based upon the volume of the release, environmental setting, regulatory clean-up objectives and potentially affected receptors.

6.1.1 Ex-Situ Technology

6.1.1.1 Soil Excavation

Soil excavation consists of removal and disposal of soil that contains oil from a release by using earth moving equipment. Soil is transported by a licensed waste hauler to an approved disposal or treatment facility. During excavation activities, soils are either screened in the field with portable instruments or submitted to a laboratory for analytical testing. Field screening or laboratory testing may indicate when cleanup standards have been achieved. Soils substantially below the groundwater table are not typically excavated due to dewatering and stability requirements. After excavation is complete, clean material is used to fill the excavation and return the area to pre-excavation conditions.

Soil excavation would be effective for the cleanup of the majority of pinhole leaks. Excavation is typically confined to the pipe trench backfill and immediately adjacent materials. Excavation would also be effective in sensitive areas with shallow groundwater or where groundwater may discharge to seeps or surface water. Excavation can be more difficult during cold weather if the ground is frozen. Excavation is typically limited to soils above bedrock.

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Recovery of Groundwater from the Effects of a Release
January 13, 2017

6.1.1.2 Skimmer Systems

Skimmer systems consist of recovery wells equipped with skimmer pumps designed to remove oil that floats on the groundwater table. Skimmer pumps have intakes that float at the oil-groundwater interface. The intakes are designed to only allow oil to enter the pump. The recovered oil is then pumped to a holding tank. Skimmer pumps can be installed in numerous wells to remove oil over small or large areas. The pumps are controlled from a central location. Periodic maintenance of the pumps and intakes is required.

Skimmer systems are effective in sensitive areas with shallow groundwater and areas with deeper groundwater. These systems can be installed when the ground is frozen and in bedrock. These systems would not typically be installed for pinhole releases contained within the pipe trench backfill materials, but could be installed if a release were to extend beyond the limits of the trench to the groundwater table.

6.1.1.3 Pump and Treat Systems

Pump and treat systems consist of recovery wells installed within affected areas that are equipped with pumps for removing oil and groundwater if oil has dissolved into groundwater. Multiple wells can be connected to a central control building. Oil and water are separated prior to disposal. The recovered oil is typically sent to a holding tank. Groundwater is processed through one or more treatment systems to remove constituents of concern that dissolved into the groundwater. Common treatment technologies include air stripper systems (in which air is pumped through the water to volatilize dissolved oil) and granular activated carbon (GAC) tanks. Groundwater is pumped through the GAC tanks and dissolved oil is adsorbed onto the carbon surface. The used carbon is taken to an approved disposal facility. After the groundwater is treated, it may then be re-injected into the subsurface or discharged into the local municipalities' sanitary sewer system.

Pump and treat systems are effective for long-term containment of groundwater contamination in sensitive areas with shallow groundwater and areas with deeper groundwater. They typically require operation over several years because mass removal via pump and treat systems is relatively slow. These systems can be installed when the ground is frozen and in bedrock.

6.1.1.4 Multi-Phase Extraction Systems

Multi-phase extraction systems consist of wells that are installed within the affected area if constituents of concern from the oil have dissolved into groundwater. These are called multi-phase systems because they simultaneously extract soil vapor, oil and groundwater. Multiple wells can be connected to a central control building. A vacuum is applied to the wells to extract soil vapor, oil and groundwater from the area affected by a release. Oil and water are separated prior to disposal. The recovered oil is typically sent to a holding tank. Groundwater is processed through one or more treatment systems as discussed in the section on pump and treat systems. The soil vapor may be treated to remove the volatilized oil.

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Recovery of Groundwater from the Effects of a Release
January 13, 2017

Multi-phase extraction systems are effective in sensitive areas with shallow groundwater and areas with deeper groundwater. These systems can be installed when the ground is frozen and in bedrock. These systems would not typically be installed for pinhole releases contained within the pipe trench backfill materials, but could be installed if a release were to extend beyond the limits of the trench.

6.1.1.5 Air Sparge/Soil Vapor Extraction Systems

Air sparge (AS)/soil vapor extraction (SVE) systems consist of wells that are installed within the affected area if oil has dissolved into groundwater. Multiple wells can be connected to a central control building. These systems consist of a combination of wells installed below the groundwater table. The AS wells are used to pump air into groundwater in the area affected by a release. The SVE wells, which are installed above the groundwater table, are used to extract soil vapor. The AS wells are used to volatilize dissolved constituents within the groundwater into the soil vapor above the groundwater table. Simultaneously, soil vapor is extracted through the SVE wells. The soil vapor may be treated to remove the volatilized constituents.

AS/SVE systems are effective in sensitive areas with shallow groundwater and areas with deeper groundwater. These systems can be installed when the ground is frozen and in bedrock. These systems would not typically be installed for pinhole releases contained within the pipe trench backfill materials, but could be installed if a release were to extend beyond the limits of the trench.

6.1.2 In-Situ Technology

6.1.2.1 Chemical Treatment

Chemical treatment commonly consists of using compounds that release oxygen into groundwater. The oxygen enhances the breakdown of oil dissolved in groundwater into harmless end products. The oxygen releasing compounds can be added to groundwater through wells or temporary injection points. Periodic testing of groundwater is performed to assess the effectiveness of the treatment.

Chemical treatment is effective in sensitive areas with shallow groundwater and areas with deeper groundwater. This approach can be taken when the ground is frozen and in bedrock. This approach would not typically be selected for pinhole releases contained within the pipe trench backfill materials, but could be used if a release were to extend beyond the limits of the trench.

6.1.2.2 Biodegradation

Naturally occurring microbes feed upon oil and have been shown to not only limit how far the effects of a release can extend, but also reduce the amount of oil dissolved in groundwater. Once the majority of the released oil has been recovered, biodegradation is a common

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Case Studies
January 13, 2017

approach for managing residual effects of a release. These processes can be allowed to progress naturally, an approach called natural attenuation, or the natural processes can be enhanced by adding oxygen releasing compounds or other nutrients. If nutrient enhancement is used, then the nutrients can be added to groundwater through wells or temporary injection points. Periodic testing of groundwater is performed to assess the effectiveness of the natural degradation.

This approach is acceptable in sensitive areas with shallow groundwater and areas with deeper groundwater. It may not be an option if wells are used for water supply, in areas where groundwater may discharge to seeps, or surface water is located within a few hundred feet of the oil release.

6.1.3 Physical Barriers and Hydraulic Containment

Subsurface physical barriers or hydraulic containment may be installed to protect sensitive receptors or influence the flow direction of oil dissolved in groundwater. The barriers can consist of:

- Sheet piling or slurry walls to form physical barrier
- Extraction wells to form hydraulic containment
- Permeable reactive barriers that can be used to direct groundwater flow to an area where materials have been installed below the groundwater table that will treat the groundwater as it passes through them

These approaches may require active operation, treatment of groundwater and periodic groundwater monitoring.

These approaches are most effective in areas with shallow groundwater. Excavation to install slurry walls or reactive barriers and driving sheet piling can be more difficult during cold weather if the ground is frozen, and are generally limited to soil above bedrock. These approaches would not typically be selected for pinhole releases contained within the pipe trench backfill materials, but could be used if a release were to extend beyond the limits of the trench and had the potential to affect a sensitive area.

7.0 CASE STUDIES

Cases studies were identified to provide a historical context for pinhole releases. A review of available case studies relevant to pinhole releases and their potential effect on the environment was performed, with a focus on case studies most relevant to conditions in Minnesota.

Two relevant case studies for L3RP are discussed, a release of crude oil from a pipeline system near Bemidji, Minnesota and a release of crude oil near Cass Lake, Minnesota. While these releases are not classified as a pinhole releases, the studies provide a great deal of insight into the potential effects of a release into a northern Minnesota environment. In particular, the well-

Case Studies
January 13, 2017

Additionally, since 2001, PHMSA incident reports have included “pinhole” as an option for classifying the type of leak. It is noted that PHMSA definition of a pinhole leak is subjective (refer to Section 1.1) and may include leaks that are generally considered to be larger than a pinhole as defined in this report. The PHMSA database categorized eight releases in Minnesota as “pinhole releases” of petroleum related products during the period from 2001 to 2015. Information requests were submitted to the MPCA for each of the eight pinhole releases. Summaries describing the quantity released, impacts to the environment, and remediation efforts, where available, are provided in Section 7.3. A case study location map is provided as Figure 7-1.



7.1 ENBRIDGE ENERGY, LIMITED PARTNERSHIPS' LINE 3, BEMIDJI, MINNESOTA

The Bemidji release is the sentinel study that vastly increased the scientific understanding of natural attenuation processes. In 1979, Enbridge's Line 3 released approximately 10,700 barrels of crude oil near Bemidji, Minnesota. Initial clean-up efforts removed approximately 8,200 barrels (75% of the original volume) and an unquantified volume was lost to the atmosphere to volatilization. There was a substantial volume (up to approximately 2,500 barrels) of unrecovered crude oil that remained in the soils and subsoils after clean-up. The release occurred in an area of very sandy soils with shallow groundwater. The water table ranges from near land surface to approximately 36 feet below the land surface. Since the release occurred within a state forest with few environmental receptors (e.g., drinking water intakes, populated areas) in close proximity to the release site, the State of Minnesota, the U.S. Geological Service, and Enbridge collectively agreed to monitor effects of crude oil and its dissolved constituents on groundwater. As part of this research initiative, these agencies and Enbridge agreed that further cleanup and remediation of the site (i.e., treatment of contaminated soils and subsoils) would not be undertaken at that time. Seventeen years after the release, natural attenuation had limited the movement of the hydrocarbon plume to 650 feet in length, compared to groundwater movement of 1,640 ft (Delin et al. 1998).

7.2 SOUTH CASS LAKE PUMPING STATION, MINNESOTA

A subgrade leaking flange at the Cass Lake pumping station in north-central Minnesota was discovered in 2002. An estimated 1,143 barrels of crude oil were present at the groundwater table (approximately 26 to 28 ft below ground surface), and the dissolved phase plume (greater than 10 ppb benzene) extended 500 ft downgradient (Drennan et al. 2010). Because the oil resided under a gravel-covered yard at Cass Lake, enhanced surface recharge was suspected as a factor accelerating degradation (Drennan et al. 2010). To further accelerate groundwater recovery, a bioventing groundwater remediation system was installed in 2014. Monitoring data following just three months of operation suggest biodegradation was being enhanced with increased oxygen, decreased carbon dioxide, and increased temperature in the unsaturated zone (AECOM 2015).

7.3 PHMSA REPORTED PINHOLE RELEASES

A search of the PHMSA release database identified eight releases in Minnesota classified as "pinhole" releases of petroleum products that occurred during the period from 2001 to 2015. A description of the available case studies is provided below.

7.3.1 Enbridge Line 3, Milepost 952, Cass Lake, Minnesota

On March 20, 2012 Enbridge pipeline maintenance (PLM) personnel discovered historical contamination near a PLIDCO repair fitting during a routine maintenance dig along Enbridge's

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Case Studies
January 13, 2017

Line 3 crude oil transmission pipeline at milepost 952 near Cass Lake, Minnesota. Upon evaluation of the PLIDCO repair fitting and site conditions and a review of historical documentation, it was determined that residual contamination was from the historical leak identified in 1973. Approximately 5900 cubic yards of contaminated soil caused by the historical leak was removed from the site and disposed of at an off-site facility (AECOM 2012). Groundwater monitoring wells indicated the presence of dissolved benzene ranging from non-detect to 89 micrograms per liter ($\mu\text{g/L}$). The water table was located approximately 5 to 22 feet below ground surface. Despite the relatively old age of the release, dissolved benzene in groundwater was limited to approximately 250 ft in length (AECOM 2012).

7.3.2 Enbridge Line 3, Milepost 893, Trail, Minnesota

Crude oil on the surface was observed and reported by a railroad engineer on April 14, 2003 approximately 16.5 miles upstream of the Clearbrook Terminal. Enbridge immediately shut down five lines in the vicinity of the discovered release and mobilized a response crew to the incident area. The source of the release was identified as a failed girth weld on the Line 3 pipeline. An estimated 125 barrels of crude oil were estimated to have been released (Natural Resources Engineering 2003). Crude oil on the surface was contained and removed via vac truck and subsurface soils containing residual oil were excavated. The water table was located approximately 1.5 ft below ground surface. Approximately 2,500 cubic yards of soil containing residual crude oil were excavated and treated off site. Subsequent investigation indicated the site did not pose additional risk to human health or the environment (Natural Resource Engineers 2003). The MPCA issued a case closure letter on July 17, 2003 (MPCA Spill Number 58832).

7.3.3 Enbridge Line 2, Milepost 1007, Grand Rapids, Minnesota

A subgrade pinhole leak was encountered during maintenance excavation of a 26-in. pipeline near the City of Grand Rapids, Minnesota in February, 2004. An estimated 714 barrels of crude oil were estimated at the groundwater table located approximately 36 to 45 ft below ground surface (Natural Resources Engineering 2005), and the dissolved phase plume (greater than 10 ppb benzene) extended approximately 200 ft down gradient of the free phase crude oil body and was approximately 500 ft in length total (AECOM, 2013). Analysis of natural attenuation parameters indicated that conditions were acceptable to promote natural attenuation of petroleum related constituents in groundwater (AECOM 2013). To further accelerate groundwater recovery, an oil recovery system was installed. Groundwater monitoring data following the discovery of the release indicated that the dissolved phase plume was limited in extent and relatively stable (AECOM 2013). The active remediation soil and groundwater remediation and natural attenuation processes resulted in significant reduction in dissolved phase constituents, most notably benzene by 2012. The MPCA issued a case closure letter on July 16, 2013 (MPCA Spill Number 17922).

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Case Studies
January 13, 2017

7.3.4 Enbridge Line 3, Milepost 927.5, Wilton, Minnesota

Crude oil on the ground was observed and reported by an individual at milepost 927.5 near the City of Wilton, Minnesota on October 20, 2006 (MPCA Spill Number 68260). Enbridge immediately mobilized a response crew to the incident area. The source of the release was identified as a failed weld. An estimated five barrels of crude oil were estimated to have been released (Barr Engineering 2008). The pipeline was excavated and repaired on October 21, 2006. Approximately 727 cubic yards of soil contain residual crude oil were excavated and treated off site. Subsequent investigation indicated the water table was located at a depth of approximately 10 to 15 ft below ground surface and a dissolved phase plume (greater than 10 ppb benzene) approximately 140 to 200 ft in length was identified (Barr 2008). Analysis of natural attenuation parameters indicated that natural attenuation was expected to decrease dissolved benzene concentrations in shallow groundwater (Barr 2008). The MPCA issued a case closure letter on November 12, 2008.

7.3.5 Enbridge Line 3, Milepost 912, Clearbrook, Minnesota

An Enbridge employee identified oil in a ditch on November 13, 2007. Upon excavation of the site, it was determined that two pinhole leaks had occurred on the long seam of Line 3 at milepost 912. The leak was isolated and a tight fitting sleeve was put on as a temporary repair until plans could be made to cut the section out for further investigation. An estimated two barrels of crude oil was released. The MPCA issued a case closure letter on December 10, 2008 (MPCA Spill Number 71592).

7.3.6 Magellan Pipeline Company, L.P., Rosemount, Minnesota

An in-line inspection of a 10.75-in. diameter gasoline pipeline identified a location requiring repair on January 11, 2014. The pipeline had already been shutdown to facilitate completion of the inspection. Upon excavation for repair, the pipeline was found to have a "low rate" release. The release was located at milepost 0.29 of the pipeline (referred to as #3-10" Pine Bend to Rosemount Line) in Rosemount, Minnesota. According to the PHMSA incident report the cause of the rerelease was external corrosion and the pipeline was installed in 1957. The pipeline was repaired and approximately 50 cubic yards of soil was "rehabilitated" (MPCA Spill Number 89107).

7.3.7 Koch Pipeline Company, Lino Lakes, Minnesota

A release occurred during hydrostatic testing of a crude oil pipeline on September 25, 2014 near Lino Lakes in Anoka County, Minnesota (MPCA Spill Number 91343). Loss of pressure during hydrostatic testing indicated a release which was confirmed via excavation along the pipeline. Specifically, the release occurred near milepost 218 of the Loop 7 segment of the pipeline referred to as Minnesota Pipe Line 2. The release location was within a jurisdictional wetland that was dry at the time of the release. The cause of the test failure was identified as a manufacturing defect. The release included an estimated 2,000 gallons of hydrostatic test water

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Conclusions

January 13, 2017

and 88 to 165 gallons of crude oil. A total of 915 tons of impacted soil was excavated for off-site disposal (Barr 2015a). The excavation encountered perched groundwater at approximately 5–6 ft below grade (Barr 2015a). The perched groundwater was reportedly separated from the uppermost aquifer by a clay layer that is present from 15 to 40 ft below grade. Residual petroleum impacts were not identified and an evaluation of potential soil, groundwater and vapor receptors identified minimal risks (Barr 2015a). The MPCA granted Site closure on February 26, 2016.

7.3.8 Koch Pipeline Company, Shevlin, Minnesota

Crude oil on the ground was observed by Koch Pipeline Company L.P. (KP) staff at the Itasca Pump Station on December 18, 2014 located near the town of Shevlin in Clearwater County, Minnesota (MPCA Spill Number 91983; PHMSA Report Number 20150021). The pipeline control center was notified and the pipeline was shut down. The source of the release was determined to be a pinhole leak in a suction line at the station. It was estimated that approximately 20 barrels of crude oil was released. Approximately 320 cubic yards of impacted soil was excavated for off-site disposal (Barr 2015b). Subsequent investigations delineated the extent of impacts. It was estimated that the deepest contamination at the site reached a confining layer at approximately 22 ft below grade. Groundwater was not encountered at the Site and based on County Well Index records the groundwater elevation at the site was estimated to be more than 80 feet below grade (Barr 2015b). Given the low potential for impacts to reach the water table it was concluded that remaining soil impacts above the MPCA Soil Leaching Values (SLVs) were not of concern (Barr 2015b). The MPCA granted Site closure on September 3, 2015.

8.0 CONCLUSIONS

Pipeline releases in general are uncommon and pinhole releases historically have occurred infrequently. The calculated incident rate per mile-year for the on-shore mainline crude oil pipeline is 0.00081, 0.00068, 0.00071 in the United States, upper Midwest region, and Minnesota, respectively for the period from January 2002 to December 2015. Additionally, of the 80 total releases reported in Minnesota during this period, 11 have been classified as pinhole releases in the PHMSA database of reportable pipeline incidents.

The potential for pinhole leaks to occur in newer pipelines and the potential impact of releases has been reduced through the use of new tools, technologies, and strategies to protect the public and the environment. Modern pipelines are designed and constructed to rigorous standards that meet or exceed government regulations. Materials are selected and tested prior to and during manufacture to meet quality criteria and all welds made to a pipeline section during construction are tested using X-ray or ultrasonic methods. Soil-side corrosion is prevented using a combination of external coatings that are subject to quality control/inspection before and after backfill, and cathodic protection systems that are continuously monitored. Internal corrosion is prevented by maintaining strict tariff limits on trace sediment and water; and by either flowing the pipeline rapidly enough to prevent these materials from accumulating, or by

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

Conclusions

January 13, 2017

executing periodic cleaning programs to remove any accumulated matter that could cause corrosion. Operating pipelines are equipped with sophisticated, computerized leak-detection monitoring systems monitoring and control systems that provide continuous, real-time information and are augmented with routine inspections and aerial patrols of rights-of-way. Inspection is supplemented with the periodic use of inline inspection tools capable of measuring the size, frequency, and location of small changes in pipeline walls.

Pinhole leaks in pipelines rarely go undetected for long periods of time. Most pinhole releases (greater than 28 bbls per day) of crude oil would fill the more permeable trench materials in a relatively short time and reach the ground surface, where they would be reported in several hours to, at most days, through CPM, volume reconciliation and/or visual observation. While unlikely to occur, a very small leak rate (e.g., less than 0.035 bpd or 1.5 gpd) could potentially continue undetected for longer periods of time resulting in a release of sufficient volume and allowing for sufficient transport time to affect groundwater. However, conclusions from other reports indicate that a release as small as 1/32-in. would result in a release of 28 bpd (nearly three orders of magnitude higher than 0.035 bpd) (Battelle, 2014). Therefore it is unlikely that a pinhole release as low as 0.035 bpd would occur. This is further evidenced by the relative scarcity of pinhole releases in the PHMSA database of reportable pipeline incidents and the case studies presented that indicate releases pinhole releases were discovered relatively quickly through observation of crude oil at the surface.

Surficial aquifers would be most susceptible to effects of a crude oil release in areas where the water table is within 40 ft of the ground surface and unsaturated zone soils are permeable enough to allow oil to migrate down to the water table. However, even in a scenario where crude oil from a release migrates to the water table and soluble hydrocarbons dissolve into the groundwater, the distance that a plume of dissolved hydrocarbons will move from the site of the release will be reduced by natural processes. Field investigations at over 600 petroleum hydrocarbon release sites indicate the migration of dissolved constituents typically stabilize within tens to hundreds of feet from the source area.

After emergency response and remediation activities remove contaminated soil, natural attenuation would reduce the maximum movement of a plume of dissolved hydrocarbons to a distance on the order of a few hundred feet.

Assessment of water table aquifers along the L3RP project route and its alternatives shows that very-low- or low-susceptibility water table aquifers are present across approximately 62% of the L3RP route. Where high-susceptibility areas are located along the proposed route, potential impacts to water supplies are limited because water quality in the water table aquifer tends to be degraded by fertilizers, herbicides, and pesticides from agricultural applications and is not typically used for water supply.

In the event of a crude oil release, a wide variety of techniques are available to contain, capture, and remove released oil. Initial remediation activities can include excavating affected soil and pumping out oil that is accumulated at the water table. If groundwater was affected by

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

References

January 13, 2017

a crude oil release, monitoring would be conducted to document the movement of dissolved hydrocarbons in the groundwater and the activity of natural attenuation processes. If monitoring indicated that a plume of dissolved hydrocarbons had the potential to reach a nearby downgradient water supply or sensitive environment, then additional remediation techniques are available to mitigate impacts to groundwater and slow or stop the movement of the plume.

Given the generally low-susceptibility of surficial aquifers along the Project route and its alternatives and the ability of release response, remediation, and natural attenuation to limit the movement of dissolved hydrocarbons in groundwater, the Project is expected to result in no effects or localized effects on groundwater if a small release of crude oil were to occur.

9.0 REFERENCES

- AECOM. 2012. Documentation Report, Enbridge MP 951.6748 Historic Leaksite – Cass Lake, Minnesota.
- AECOM. 2013. LNAPL Remediation, Natural Attenuation, and Case Closure Request Report - MP 1007.33 Leak Site, Grand Rapids, Minnesota.
- AECOM. 2015. 2014 Annual Monitoring and Operations and Maintenance Report South Cass Lake Pumping Station.
- API. 2004. API interactive LNAPL guide. Version 2.04. Soil and Groundwater Technical Task Force.
- ASTM (American Society for Testing and Materials). 1998. ASTM Guide for Remediation by Natural Attenuation at Petroleum Release Sites. ASTM E1943.
- ASTM. 2016. ASTM Standard Guide for Development of Conceptual Site Models and Remediation Strategies for Light Nonaqueous-Phase Liquids Released to the Subsurface, ASTM E2531.
- Barr (Barr Engineering Co.). 2008. Remedial Investigation Report – Enbridge Milepost 927.5 Release, Wilton, Minnesota.
- Barr. 2015a. Koch Pipeline Company, L.P., Lino Lakes Loop 7 Crude Oil Release, Initial Response Summary and Request to Close Spill #91343.
- Barr. 2015b. Minnesota Pollution Control Agency (MPCA) Investigation Report Form Guidance Document 4-06. MPCA Site ID: Spill#91983.
- Battelle Memorial Institute. 2013. Keystone XL Pipeline: Independent Engineering Assessment – Final Report Energy Systems Battelle Memorial Institute.

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

References

January 13, 2017

- Beavers, J.A., and N.G. Thompson. 2006. External corrosion of oil and natural gas pipelines. ASM Handbook, Volume 13C, Corrosion: Environments and Industries. Bowers and Smith, 2014.
- Charbeneau, R.J. 2014. LNAPL Distribution and Recovery Model (LDRM2). Prepared for American Petroleum Institute, Regulatory and Scientific Affairs Department.
- Charbeneau, R.J., J.W. Weaver, and B.K. Lien. 1994. The Hydrocarbon Spill Screening Model (HSSM). U.S. Environmental Protection Agency, Washington, D.C., EPA/600/R-94/039b (NTIS 95-210084), 1994.
- Christophersen, M., M.M. Broholm, H. Mosbæk, H.K. Karapanagioti, V.N. Burganos, and P. Kjeldsen. 2005. Transport of Hydrocarbons from an Emplaced Fuel Source Experiment in the Vadose Zone at Airbase Vaerlosee, Denmark. *Journal of Contaminant Hydrology*, 81, 1-33.
- Connor, J.A., R. Kamath, K.L. Walker and T.E. McHugh. 2015. Review of Quantitative Surveys of the Length and Stability of MTBE, TBA, and Benzene Plumes in Groundwater at UST Sites. *Groundwater*, 53: 195–206.
- Davis, G.B., M.G. Trefry, and B.M. Patterson. 2004. Petroleum and Solvent Vapours: Quantifying Their Behaviour, Assessment and Exposure. CSIRO Land and Water Report.
- Delin, G.N., H.I. Essaid, I.M. Cozzarelli, M.H. Lahvis and B.A. Bekins. 1998. Ground Water Contamination by Crude Oils Near Bemidji, Minnesota. United States Geological Survey.
- DNR (Minnesota Department of Natural Resources), Division of Waters. 1991. Criteria and Guidelines for Assessing Geologic Sensitivity of Ground Water Resources in Minnesota. Prepared for the Legislative Commission on Minnesota Resources, 122 p., June 1991.
- DNR (Minnesota Department of Natural Resources). County Geologic Atlas Program. 2016. Water-Table Elevation and Depth to Water Table. Minnesota Hydrogeology Atlas series HG-03. GIS coverage, accessed from <https://gisdata.mn.gov/dataset/geos-hydrogeology-atlas-hg03>. Published 6/2/2016.
- Drennan, D.M., B.A. Bekins, E. Warren, I.M. Cozzarelli, M.J. Baedeker, W.N. Herkelrath, G.N. Delin, R.J. Rosenbauer and P.L. Campbell. 2010. Fate and Transport of Petroleum Hydrocarbons in the Subsurface Near Cass Lake, Minnesota: U.S. Geological Survey Scientific Investigations Report 2010-5085. 33 pp.
- EA (Environment Agency). 2000. Guidance on the Assessment and Monitoring of Natural Attenuation of Contaminants In Groundwater. Environment Agency R&D Publication 95.
- Exponent. 2013. Third-Party Consultant Environmental Review of the TransCanada Keystone XL Pipeline Risk Assessment.

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

References

January 13, 2017

- Farr, A.M., R.J. Houghtalen, and D.B. McWhorter. 1990. Volume Estimation of Light Non-Aqueous Phase Liquids in Porous Media. *Groundwater* 28(1), 48-56.
- Fingas, M. 2011. "Evaporation Modeling", Chapter 9, in *Oil Spill Science and Technology*, M. Fingas, Editor, Gulf Publishing, NY, NY, pp. 201-242.
- Garg, S., and W.G. Rixey. 1999. The Dissolution of Benzene, Toluene, M-Xylene and Naphthalene from a Residually Trapped Non-Aqueous Phase Liquid Under Mass Transfer Limited Conditions. *Journal of Contaminant Hydrology*, 36, 311-329.
- Grathwohl, P., I.D. Klenk, U. Maier, and S.B.F. Reckhorn. 2002. Natural Attenuation of Volatile Hydrocarbons in the Unsaturated Zone and Shallow Groundwater Plumes: Scenario-Specific Modeling and Laboratory Experiments. In *GQ2001: Natural and Enhanced Restoration of Groundwater Pollution*, Sheffield, U.K., 16-21 June 2001. (eds, Thornton, S.F & Oswald, S.O.), IAHS Publ. No. 275, 141-146.
- ITRC (Interstate Technology and Regulatory Council). 2009. Evaluating LNAPL Remedial Technologies for Achieving Project Goals. (No. LNAPL-2). Interstate Technology & Regulatory Council, LNAPLs Team. Washington, D.C.
- Johnson, P.C., P. Lundegard, and Z. Liu. 2006. Source Zone Natural Attenuation at Petroleum Hydrocarbon Spill Sites: I. Site-Specific Assessment Approach. *Groundwater Monit. R.*, 26(4), 82-92.
- Lahvis, M.A., I. Hers, R.V. Davis, J. Wright, and G.E. DeVaul. 2013. Vapor Intrusion Screening at releases of oxygenated gasoline in the vadose zone. *API Bulletin* 21.
- Lee, K. (chair), M. Boufadel, B. Chen, J. Foght, P. Hodson, S. Swanson and A. Venosa. 2015. Expert Panel Report on the Behaviour and Environmental Impacts of Crude Oil Released into Aqueous Environments. (No. ISBN: 978-1-928140-02-3). Royal Society of Canada. Ottawa, ON.
- Lenhard, R.J. and J.C. Parker. 1990a. Discussion of Estimation of Free Hydrocarbon Volume from Fluid Levels in Monitoring Wells. *Groundwater*, v. 18 no. 5, pp 800-801.
- Lenhard, R.J. and J.C. Parker. 1990a. Estimation of Free Hydrocarbon Volume from Fluid Levels in Monitoring Wells. *Groundwater*, v. 18 no. 1, pp 56-57.
- Lundegard, P.D., and P.C. Johnson. 2006. Source zone natural attenuation at petroleum hydrocarbon spill sites: II. Application to a former oil field. *Groundwater Monitoring and Remediation*, 26(4), 93-106.
- MDA (Minnesota Department of Agriculture). 2015. Minnesota Water Table Aquifer Vulnerability. GIS coverage, accessed from <https://gisdata.mn.gov/dataset/water-aquifer-vulnerability>. Published 5/28/2015.

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

References

January 13, 2017

- Molins, S., K.U. Mayer, R.T. Amos, and B.A. Bekins. 2010. Vadose Zone Attenuation of Organic Compounds at a Crude Oil Spill Site – Interactions Between Biogeochemical Reactions and Multicomponent Gas Transport. *Journal of Contaminant Hydrology*, 112, 15-29.
- MPCA (Minnesota Pollution Control Agency). 1999. Baseline Groundwater Quality of Minnesota's Principal Aquifers, Northwest Region.
- MPCA. 2005. Assessment of Natural Biodegradation at Petroleum Release Sites Guidance Document 4-03.
- Natural Resources Engineering. 2003. Site Investigation Report, April 14, 2003 Crude Oil Release at Milepost 893.
- Natural Resources Engineering. 2005. Interim Remedial Investigation Report; Grand Rapids, Minnesota.
- Newell, C.J. and J.A. Connor. 1998. Characteristics of Dissolved Petroleum Hydrocarbon Plumes: Results from Four Studies. American Petroleum Institute Soil / Groundwater Technical Task Force. December 1998.
- Oostrom, M., C. Hofstee, and T.W. Wietsma. 2006. Behavior of a Viscous LNAPL Under Variable Water Table Conditions. *Soil Sediment Contamination*, 15(6):543-564.
- PHMSA (Pipeline and Hazardous Materials Safety Administration). 2016. Fact Sheet: Leak Detection Systems.
<https://primis.phmsa.dot.gov/comm/FactSheets/FSLeakDetectionsystems.htm>. accessed August 16, 2016.
- Rivett, M.O., and S.F. Thornton. 2008. Monitored Natural Attenuation of Organic Contaminants In Groundwater: Principles and Application. *Water Management*, 161(6), 381-392.
- Rivett, M.O., G.P. Wealthall, R.A. Dearden, and T.A. McAlary. 2011. Review of Unsaturated-Zone Transport and Attenuation of Volatile Organic Compound (VOC) Plumes Leached from Shallow Source Zones. *Journal Of Contaminant Hydrology.*, 123, 130-156.
- Shaw, D., M. Phillips, R. Baker, E. Munoz, H. Rehman, C. Gibson, and C. Mayernik. 2012. Final Report Leak Detection Study – DTPH56-11-D-000001 U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration Final Report No. 12-173.
- Stantec Consulting Services Inc. RPS ASA and Dynamic Risk Assessment Systems Inc. 2016. Assessment of Accidental Releases: Technical Report.
- Thornton, S.F., K. Tobin, and J.W.N. Smith. 2013. Comparison of Constant and Transient-Source Zones. on Simulated Contaminant Plume Evolution in Groundwater: Implications for Hydrogeological Risk Assessment. *Groundwater Monitoring and Remediation*.

LINE 3 REPLACEMENT PROJECT: ASSESSMENT OF POTENTIAL PINHOLE RELEASE

References

January 13, 2017

- USDOS (U.S. Department of State). 2014. Final Supplemental Environmental Impact Statement Chapter 4, Keystone XL Project. Bureau of Oceans and International Environmental and Scientific Affairs
- USEPA (United States Environmental Protection Agency). 1999. Monitored Natural Attenuation of Petroleum Hydrocarbons. U.S. EPA Remedial Technology Fact Sheet. EPA/600/F-98/021. Washington, D.C.
- USEPA. 2013. Evaluation of Empirical Data to Support Soil Vapor Intrusion Screening Criteria for Petroleum Hydrocarbon Compounds, EPA-510-R-13-001.
- Werner, D., and P. Höhener. 2001. The Influence of Water Table Fluctuations on the Volatilisation of Contaminants from Groundwater. In: Natural and Enhanced Restoration of Groundwater Pollution. IAHS Publ. 275, 213-218.
- Wiedemeier, T.H., H.S. Rifai, C.J. Newell, and J.T. Wilson. 1999. Natural Attenuation of Fuels and Chlorinated Solvents in the Subsurface. John Wiley & Sons, Inc., New York. ISBN 0 471 19749 1.
- Wiedemeier, T.H., J.T. Wilson, D.H. Kampbell, R.N. Miller, and J.E. Hansen. 1995. Technical Protocol for Implementing Intrinsic Remediation with Long Term Monitoring for Natural Attenuation Of Fuel Contamination Dissolved In Groundwater. U.S. Air Force Center for Environmental Excellence.
- Zhou, J., H. Dettman and M. Bundred. 2015. A Comparative Analysis of Environmental Behaviour of Diluted Bitumen and Conventional Crudes., Proceedings of the Thirty-eighth AMOP Technical Seminar on Environmental Contamination and Response. (pp. 495-516). Vancouver, British Columbia, Canada. Environment Canada, Ottawa, ON.