BAKKEN CRUDE OIL SPILLS – RESPONSE OPTIONS AND ENVIRONMENTAL IMPACTS

Prepared for:

MassDEP
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Department of Environmental Protection

Prepared by:

CB&I Environmental and Infrastructure, Inc.
150 Royall Street
Canton, MA 02021

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PRIMARY AUTHORS

John H. Mitchell, CHMM
CBI Project Manager
CB&I Environmental & Infrastructure, Inc.
150 Royall Street
Canton, MA 02021
Office Tel: (617) 589-1265
John.Mitchell@CBI.com

Nicholas J. Child, MA MPA
MassDEP Project Manager
Chief Emergency Planning Officer
Commissioner's Office
Massachusetts Department of Environmental Protection
1 Winter Street, 2nd Floor
Boston, MA 02108
Office Tel: (617) 574-6847
Nick.Child@state.ma.us

Additional support was provided by:

Joanne Perwak, CB&I (Health and Risk),
Vikas Tandon, CB&I (Fate and Transport)
Andrea Steele, CB&I (Response)
Heather Fariello, CB&I (Technical Support).
David Slowick MassDEP ER WERO
Kingsley Ndi MassDEP ER NERO
Dan Crafton MassDEP ER SERO
Albe Simenas MassDEP ER Boston
Mike Hutcheson MassDEP ORS Boston
Robert Shaughnessy MassDEP Fiscal Boston
Elsbeth Hearn EPA Region 1
James Carew EPA Region 1
Norman Seymour MassDFS
David Loh MassDFS
Jeff Timperi MEMA
Dennis Farrar NY DEC
Mike Castro Mass. Association of HazMat Technicians

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Executive Summary

Since 2011, North America has experienced a dramatic increase in the overall volume of domestic crude oil transported via rail. The increase in crude oil production is primarily due to the growth of crude oil production in Canada, North Dakota, Montana and Texas.

The increase in crude oil production has not coincided with infrastructure improvements that support transportation of crude oil. Therefore, oil production companies are relying upon an existing rail network to transport crude to refinery locations in the U.S. Gulf States, eastern United States and Canada. Although the overall number of accidents resulting in releases of crude is decreasing, catastrophic accidents and large-scale releases remain a cause for concern.

Due to the variability in characteristics of crude oil and the significant increase in the volume of crude oil transported via rail, it is imperative that first responders receive information and training to properly respond to catastrophic releases.

For this document, we are focusing on Bakken Crude because of its involvement in a significant number of crude oil derailments and subsequent explosions/fires. Bakken is the name given to oil producing rock formation in North Dakota, Montana and adjoining Canadian provinces.

Petroleum (crude oil) is a complex mixture that’s composition varies widely. Generally, crude oil is divided into three categories (light, medium or heavy). Each category is distinguished by its overall composition. Light crude is highly volatile and highly soluble in water while heavy crude is a highly viscous, semi-solid, black substance with few volatile constituents and is insoluble in water. Crude oil is also comprised of many materials existing in proportions depending upon the source and can vary across multiple wells within the same oil field. Crude oil with high sulfur content is referred to as “sour”, while oil with low sulfur content is referred to as “sweet”.

Bakken Crude is generally considered a light-weight sweet petroleum crude and therefore may contain flammable gases in solution that raise the vapor pressure, and lower the flash point and initial boiling point of the material. As ambient temperature increases, gases held in solution can release to the vapor space of tank cars. Gases in the vapor space may create a flammable and inhalation hazard in the event of a spill or catastrophic release.

Flammability is the greatest hazard associated with crude oil in a rail incident. Because of its flammable nature, the crude may ignite resulting in explosions, fireballs, and pool fires. Explosion may occur following a major tank rupture, spilling fuel which vaporizes, contacts an ignition source, and explodes and also rapidly burns in a fireball.

Crude oil fires generally produce dense clouds of soot, liquid, aerosols, and gases. However, Crude oil has been found to have a relatively low acute toxicity. The acute toxicity of VOCs in crude oil is lower than that of hydrogen sulfide, although Bakken crude is typically low in hydrogen sulfide compared to other crude oil. In addition to the organic chemicals released, oil fires produce dense clouds of soot, including particulates, metals, sulfur compounds, and nitrogen compounds.

However, chronic exposures to crude oil are unlikely to occur as a result of a spill, due to the rapid biodegradation and evaporation of Bakken crude oil and the personnel monitoring associated with a typical spill incident.

Due to the potential for toxic and flammable hazards associated with a Bakken crude oil, fire personnel should wear protective clothing consisting of self-contained breathing apparatus and full turn-out gear during initial Size-Up activities, evacuation and firefighting activities.

Spill assessment and investigation process should mimic that utilized for a petroleum fuel oil release. This would include screening of ambient air within and outside the release area for the components of interest; visual determination of impacts including stressed vegetation, evidence of impacted aquatic biota, and visual detection of petroleum sheens; statistical determination of appropriate sampling locations and numbers; collection and screening of environmental samples; and the collection and confirmatory analysis of samples.

Consideration of past Bakken crude oil incidents provides some insight into fate and transport in a spill situation, as well as response activities that have been effective. Consideration of these incidents, the actions implemented in response and possible additional response actions leads to the following recommendations:

In the presence of a fire involving flammable liquid tanks or car/trailer loads, here are some initial considerations:

- Confirm that adequate foam supplies and equipment available for vapor suppression.
- Withdraw from the area and let fire burn if proper equipment is not available
- Utilize water spray, fog, or gentle application of vapor suppressing foam. Do no use straight streams. Fight fire from maximum distance or use unmanned monitor nozzles.
- Cool containers with flooding quantities of water until well after fire is out to prevent re-ignition and explosion of heated containers. Avoid applying water into rail/tanker domes, as this may cause boil-over explosions, but rather cascade water over the length of the rail car.

In the event of a spill or leak

- Eliminate ignition sources. Ground equipment used when transferring the product.
- Prevent entry into waterways, sewers, basements, or confined areas.
- Use vapor suppressing foam to reduce vapors. Water spray may reduce vapor but may not prevent ignition in closed spaces.
- Dike far ahead of liquid spill for later disposal.

For non-fire spill scenarios (DOT, 2014b):

- Isolate the area and consider evacuation, if necessary.
- If possible, remove or eliminate all sources of ignition.
- Determine the concentrations of any flammable or toxic vapors using air monitoring instruments? What are the flammability and toxicity readings?
- Evaluate the need for continuous air monitoring with technical specialists?
- Ensure adequate foam supplies and equipment available for vapor suppression and scene security.

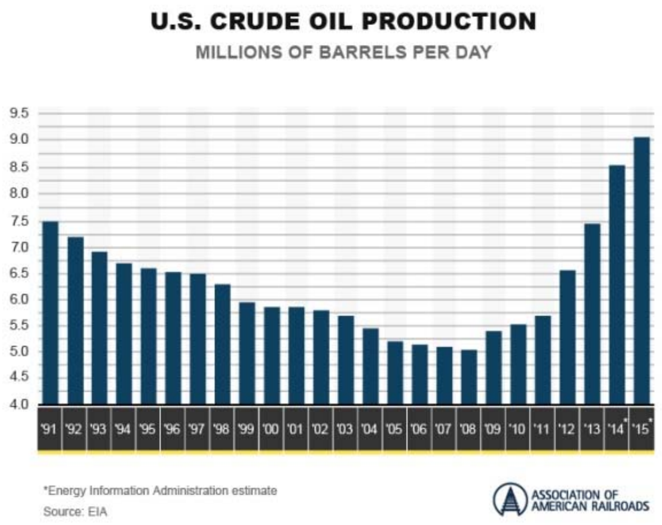
Bakken crude oil has a low viscosity, and will quickly spread and evaporate. It will quickly adhere to suspended solids in the water column, forming unstable emulsions. Recoverable product may persist for only 4 to 8 hours, depending on size of spill. Its lighter components volatilize, posing human health hazard near spill location, and the low molecular weight PAHs (i.e., naphthalene to phenanthrene range) dissolve in the water column causing toxic aquatic effects (NOAA, 2014).

1.0 INTRODUCTION

The intent of this document is to provide a reference for first responders and emergency planners at the local, state, federal level as well as partners in the private sector. The research and production of this document was made possible through a grant from the U.S. Department of Homeland Security through the Massachusetts Emergency Management Agency.

Although crude oil has been produced and transported in large volumes throughout North America for many decades, the continent has experienced a dramatic increase in the overall volume of transported crude oil since 2011.

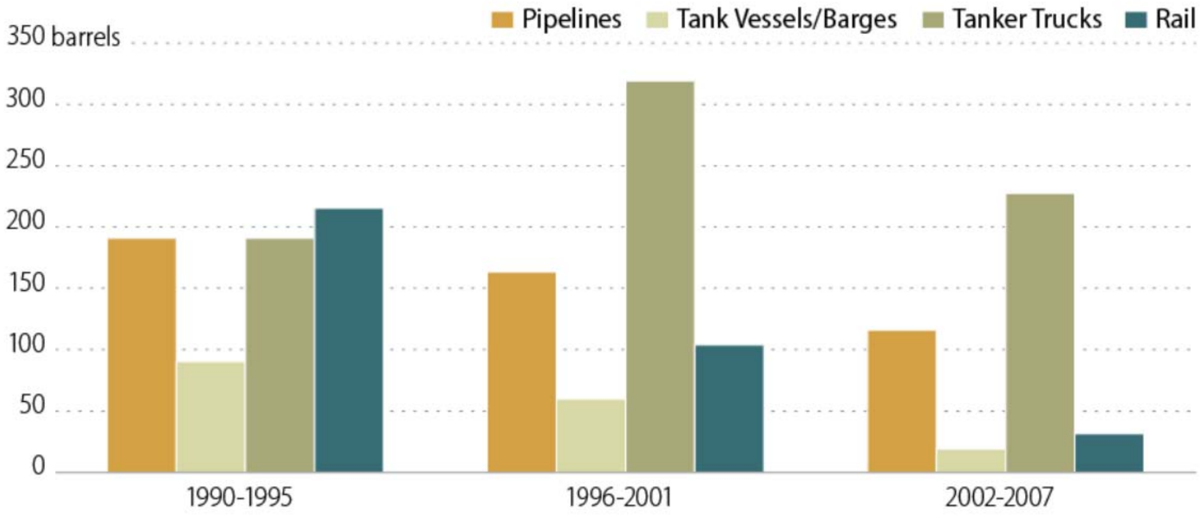
The increase in crude oil production is primarily due to the growth of heavy Canadian oil sands and the recent expansion of shale oil production in North Dakota, Montana and Texas (Congressional Research Service 2014). The increase in crude oil production has not coincided with infrastructure improvements that support transportation of crude oil. Therefore, oil production companies are relying upon an existing rail network to transport crude to refinery locations in the U.S. Gulf States, eastern United States and Canada.



*Energy Information Administration estimate
Source: EIA

Although the overall number of accidents resulting in releases of crude is decreasing, catastrophic accidents and large-scale releases remain a cause for concern. Due to the variability in characteristics of crude oil and the significant increase in the volume of crude oil transported via rail, it is imperative that first responders receive information and training to properly respond to catastrophic releases. Of particular concern is a type of light crude oil from the "Bakken Formation" found in North Dakota, Montana, and Saskatchewan Canada. This area is also known as the Williston Basin. The volatile chemical characteristics of Bakken crude in rail accidents have lead to dramatic fires (DOT/PHMSA Safety Alert 01/02/14).

Crude Oil Spills by Volume
Transportation Mode Comparison
1990-2009



Sources: Prepared by Congressional Research Service; oil spill volume data from Dagmar Etkin, *Analysis of U.S. Oil Spillage*, API Publication
356, August 2009; ton-mile data from Association of Oil Pipelines, *Report on Shifts in Petroleum Transportation: 1990-2009*, February 2012.

Notes: Pipelines include onshore and offshore pipelines. The time periods were chosen based on the available annual data for both spill volume and ton-miles. The values for each time period are averages of annual data for each six-year period.

As a result of these concerns and the need for a well-planned response prior to any potential large scale release, the Massachusetts Department of Environmental Protection (MassDEP) requested that CB&I prepare a document containing information on the environmental impacts of and emergency response techniques for a potential large scale crude oil release. CB&I, with assistance from MassDEP and many associated federal, state and local government agencies and private industry assembled the best information, research and practices available. The anticipated users of this document are emergency planners and responders.

1.1 Scope of Document

As discussed above, domestic crude oil production and transport by rail has been increasing exponentially over the past decade. Domestic crude oil is typically transported in large 80 to 120 mixed unit car trains with each unit car having a capacity of 30,000 gallons. Although crude oil is transported via methods other than rail across the country, rail is the method with the highest risk for a transportation accident in the northeast. There are crude oil ships and barges transporting crude oil on the waters of Atlantic, but responses to releases into coastal waters are not contemplated by this document. In Massachusetts, there are currently very few unit trains traversing the Commonwealth transporting crude oil on a regular basis. This document does not specifically address releases during production, storage, transfer, or during smaller volume transport by highway cargo tankers, although much of the information presented is also relevant to these types of releases.

The material contained in this documents focuses on Bakken crude oil, although the information can be used for heavier and less volatile forms of crude oil.

2.0 EMERGENCY PLANNING & PREPAREDNESS

The foundation of emergency planning and preparedness is risk management. This begins by conducting a risk assessment; a process of comparing potential likelihood of a hazard occurring compared to the consequences of that hazard occurring. In conducting emergency planning and preparedness, it is important to balance various aspects.

Railroads have a "common carrier" obligation to carry oil and hazardous materials. Unlike all other modes of transportation, railroads are required by the federal government to transport these materials, whether railroads want to or not (49 U.S.C. § 11101 of 2006). The response information is not complicated, but the rapid development of crude oil production and transport has outpaced the general dissemination of knowledge to responders and planners in the communities where this material passes.

On May 7, 2014, the US Department of Transportation issues an Emergency Restriction Prohibition Order to all railroads that transport in a single train of 1 million gallons or more (35 or more rail tank cars) of petroleum crude from the Bakken shale formation. This required each railroad to report to the local State Emergency Response Commission certain key information:

- The estimated number of trains covered by this order that are expected to travel through the state;
- The frequency of these shipments;
- A description of the crude oil being transported;
- The emergency response contacts and information needed; and
- The routes to be used.

2.1 Probability

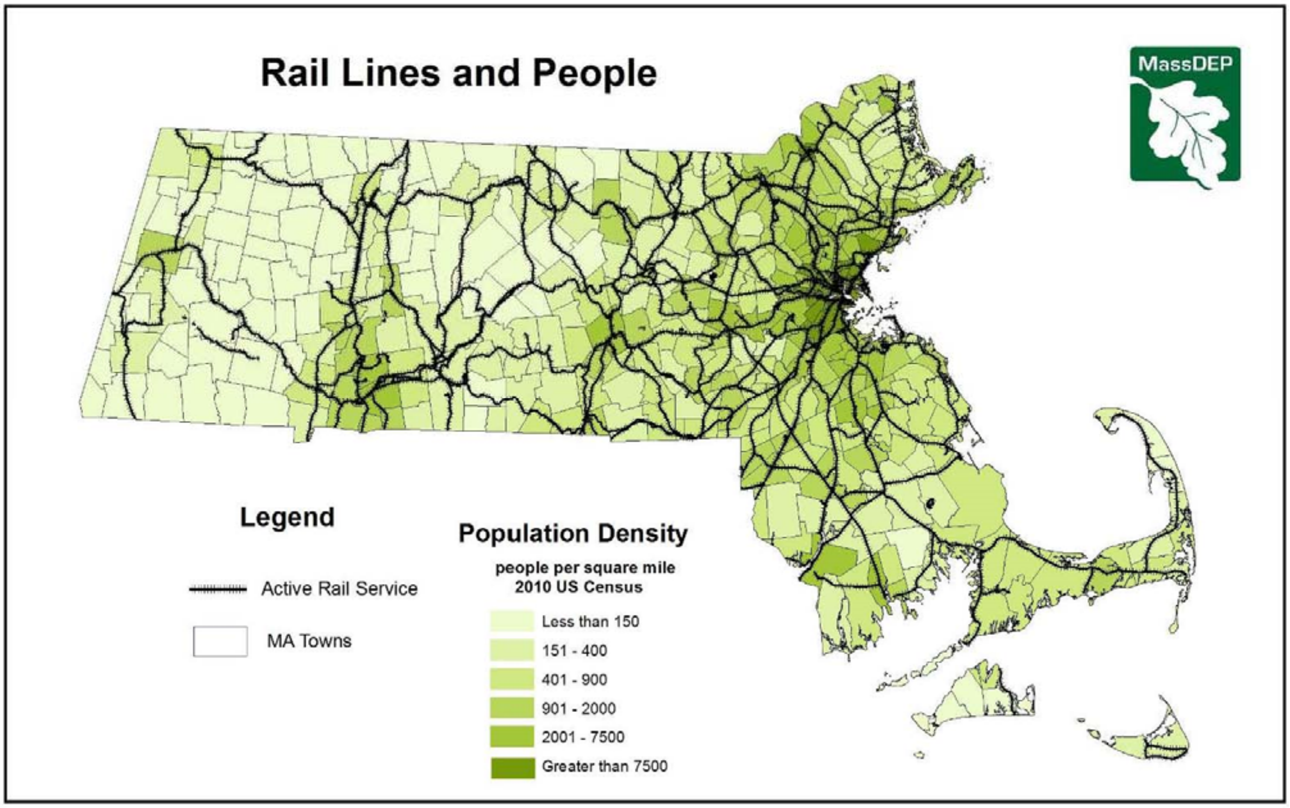
Rail has been repeatedly shown to be a very safe way, per pound of hazardous material per mile traveled, for oil and hazardous material movement (USDOT, 2015). This indicates a low likelihood per shipment of a major release event. That being said, due to the significant increase in the number of Bakken crude oil shipments nationwide, the overall likelihood of an incident has increased.

2.2 Severity

As a substance, Bakken crude oil compared to other chemicals regularly shipped, is relatively less dangerous particularly those identified as "toxic inhalation chemicals" (TICs). When an incident occurs, because of the volume of crude oil being transported is often between 80 to 120 railcars (2.4 million gallons to 3.6 million gallons), the overall potential release volume is significant.

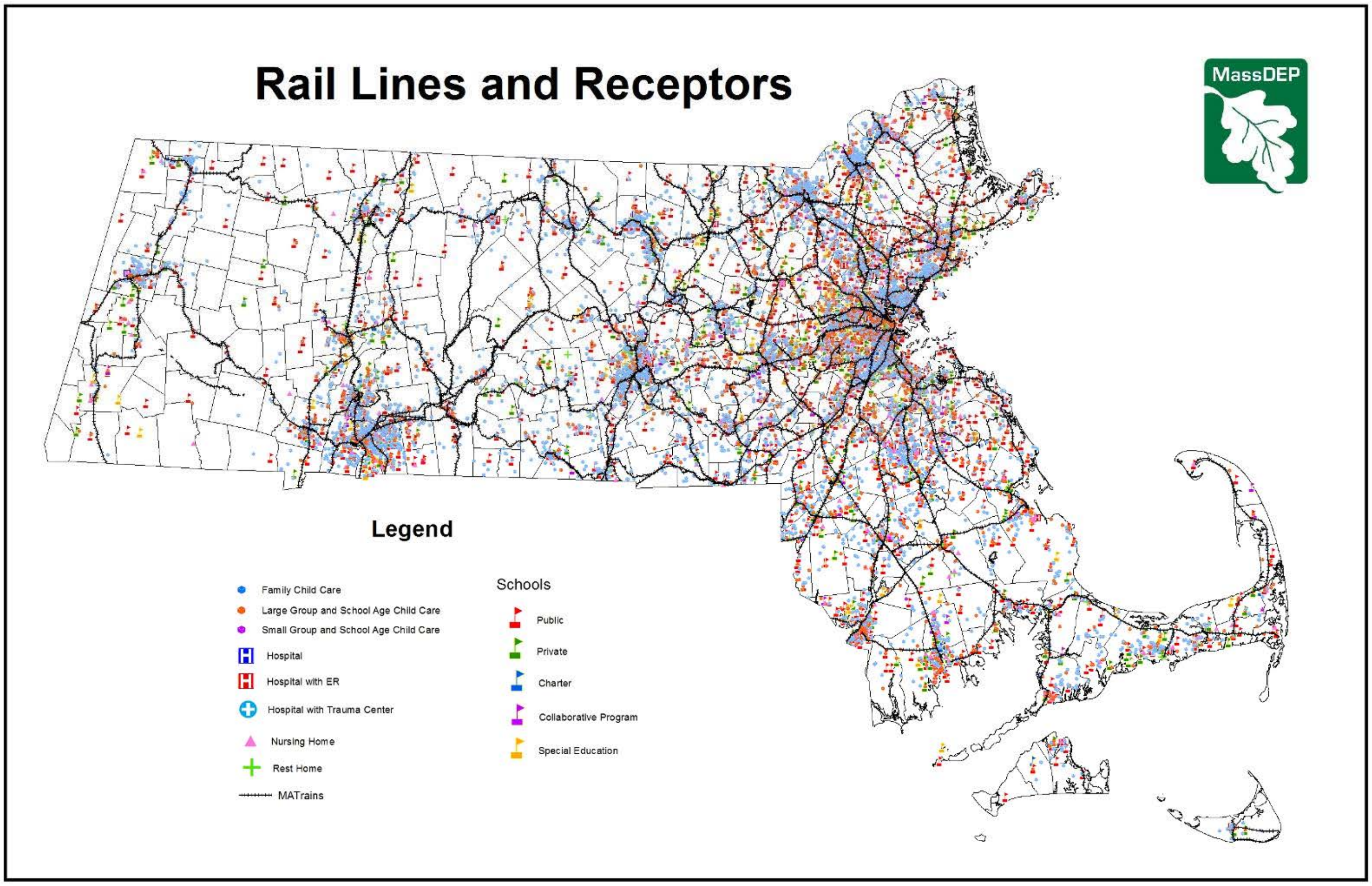
2.3 Vulnerability

Railroads and New England, particularly Massachusetts, developed together. Rail lines connected towns and towns developed along rail lines and rail yards. This has led to dense populations along many of the rail lines, and the safety of these populations need to be addressed through emergency planning (see **Figure 2-1**).



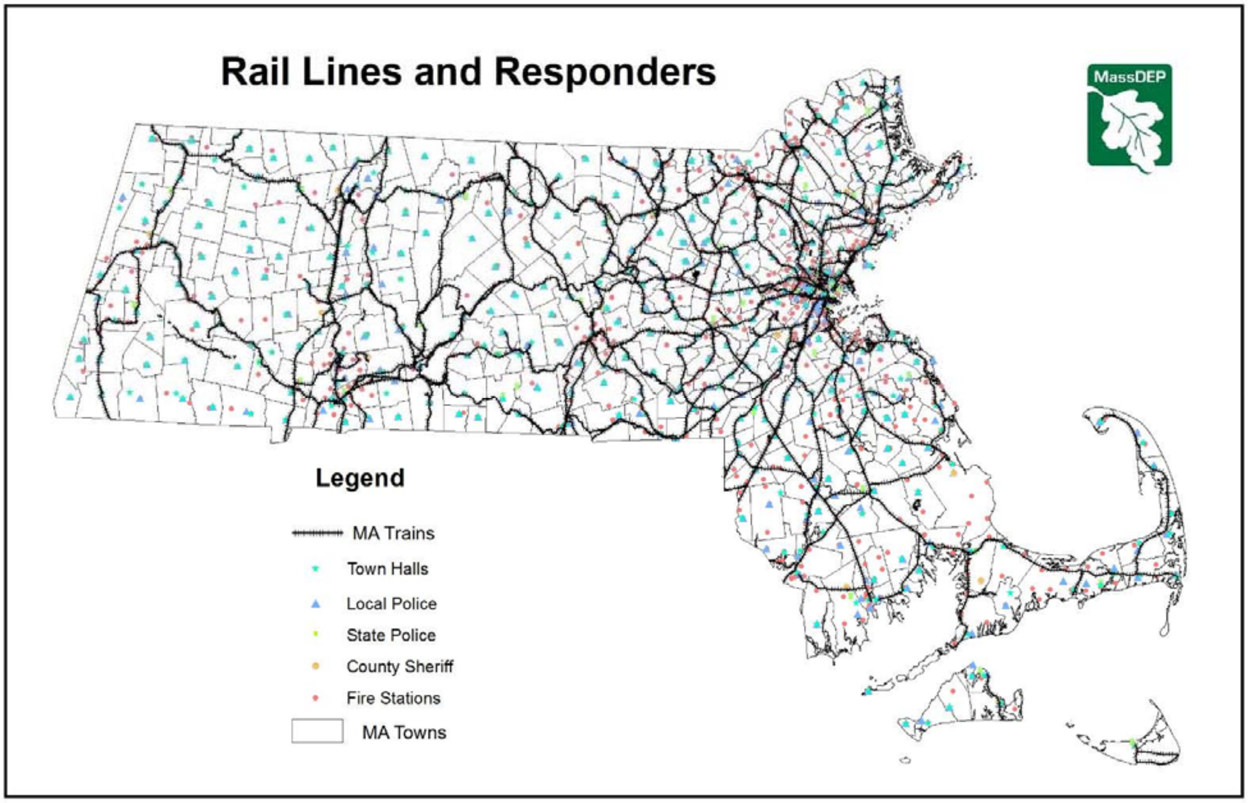
For a full-size view, see Figure section

As with population density, sensitive receptors such as schools, hospitals, daycares, and nursing homes are also clustered near rail lines (see **Figure 2-2**).



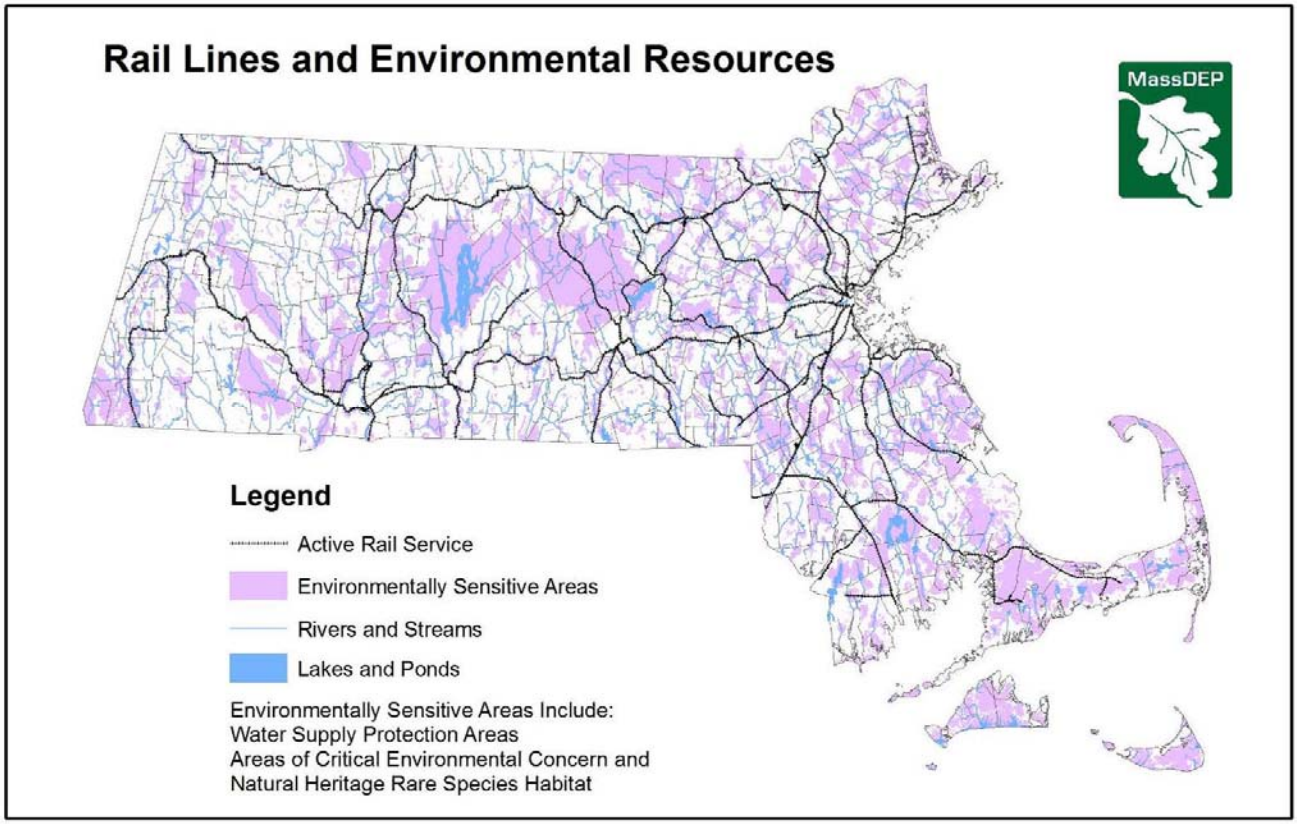
For a full-size view, see Figure section

In addition, emergency responder facilities and assets are also grouped around rail lines and rail yards (see **Figure 2-3**).



For a full-size view, see Figure section

Finally, as with much of the roadways in New England, rail lines often followed waterways as riverfront areas are fairly level and free of obstructions. This means railroad oil or hazardous material releases on a large scale have the potential to impact waterways, threatening public drinking water sources as well as environmentally sensitive receptors (see **Figure 2-4**).



For a full-size view, see Figure section

2.4 Pre-incident Planning

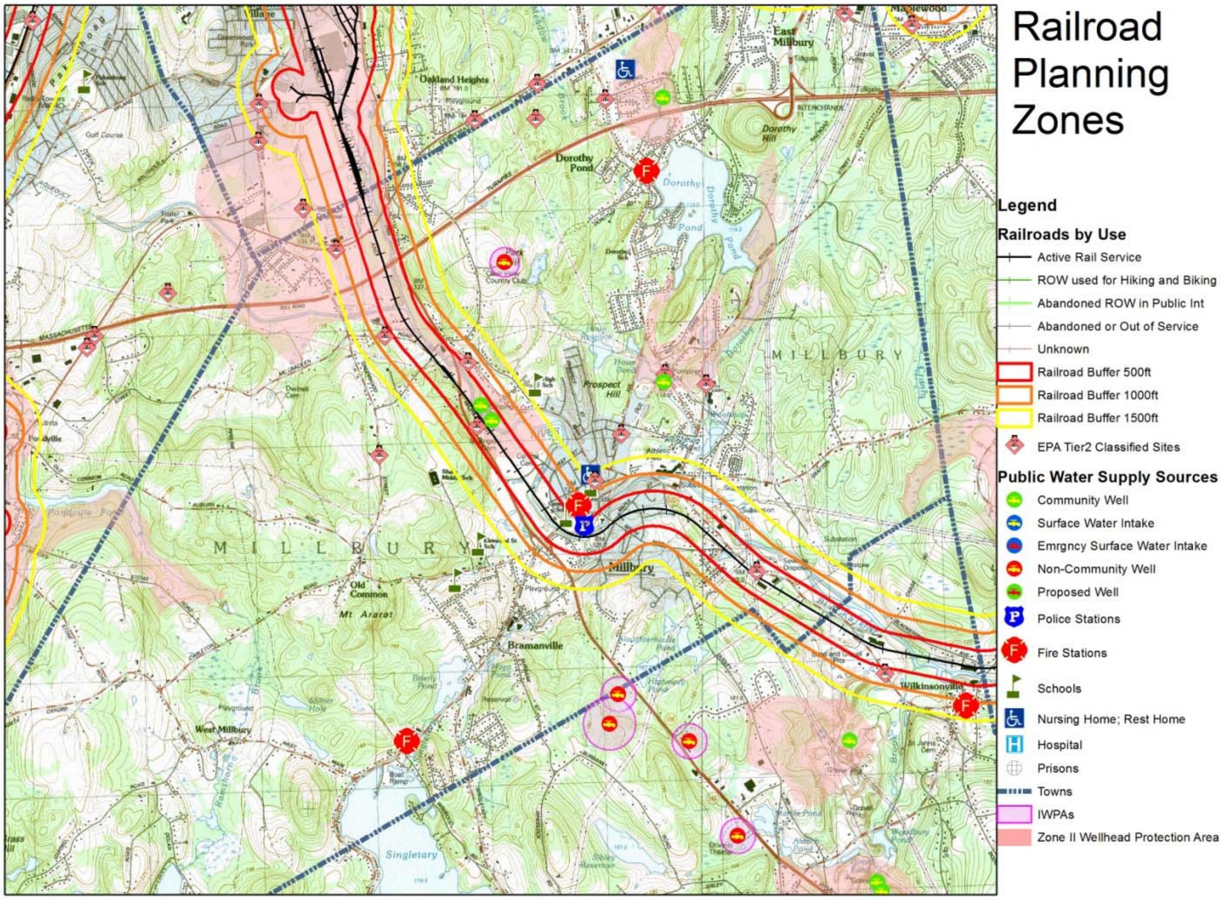
The purpose of pre-incident planning is to review a hazard and response capabilities before a potential incident occurs. Emergency managers and responders should develop transportation route preplans for the multitude of oils and hazardous materials transported on roadways and railways. These types of preplans are typically done for fixed chemical facilities. Some suggested components of a local rail transportation emergency plan would include:

- Rail maps with rail mile posts, crossings, and access points
- Railroad emergency contacts and notifications
- Emergency response resources including railroad assets
- Any critical infrastructure along rail (gas lines, fiber optics, overhead transmission lines, etc.) and points of contact for each.
- Firefighting water supplies, particularly if a waterway has been impacted
- Communications and security (local, state, and railroad police coordination)
- Location/type/quantity of chemicals and their hazards
- Emergency medical support availability
- Contingency plans for fixed facilities
- Vulnerability of surrounding population area/ability to evacuate
- Adjacent chemical/ Tier 2 facilities and other exposures that cannot be evacuated or shut down
- Waterways and storm sewers, particularly those that empty into a waterway
- Public information and notification plans

2.5 Initial Isolation and Evacuation zones

Every fire truck, police car, and ambulance should be carrying the latest version of the Emergency Response Guidebook (Orange book). "Petroleum Crude Oil" / DOT Placard 1267 refers to Guide 128, recommending an initial spill isolation distance of 150 feet in all directions. If a large spill of crude oil has occurred, a recommended isolation and evacuation distance of 1,000 feet downwind. If the crude oil is on fire, a recommended isolation and evacuation distance of 2,640 feet in all directions is recommended (ERG 2012).

Figure 2-5



For a full-size view, see Figure section

3.0 PHYSICAL AND CHEMICAL CHARACTERISTICS OF CRUDE OIL

3.1 Physical/Chemical Properties

Petroleum (crude oil) is a complex mixture whose composition varies widely. Generally, crude oil is divided into three categories (light, medium or heavy). Each category is distinguished by its overall composition. Crude oil is comprised of many materials existing in proportions depending upon the source and can varying across multiple wells within the same oil field.

Light-weight components are characterized by:

- High evaporation rates
- A boiling range up to 150 degrees Celsius
- High water solubility
- High acute toxicity due to constituents such as benzene, toluene, and xylenes.

Medium-weight

- Slower evaporation rates
- Low to no water soluble fraction
- Moderate acute toxicity
- Alkanes which are readily degraded

Heavy-weight

- Low to no evaporation
- Almost no water-soluble fraction
- Potential for chronic toxicity due to poly-aromatic hydrocarbons
- Long-term persistence

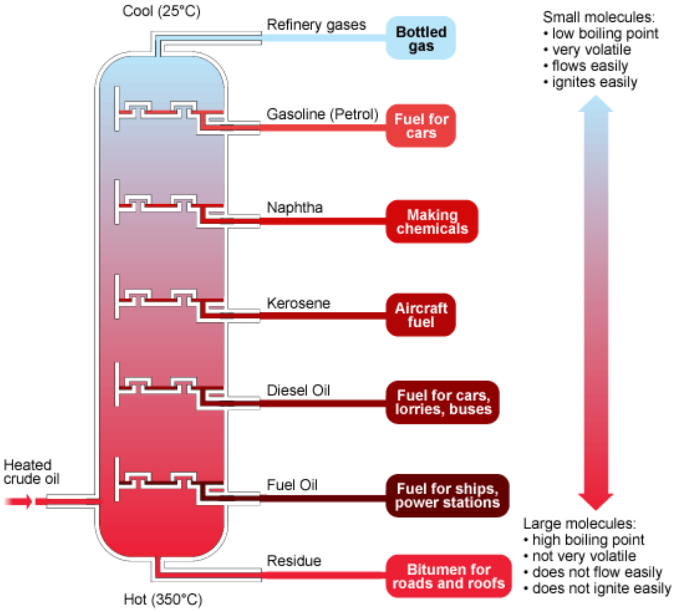


Figure 1 Crude Distillation

Crude oil typically contains smaller amounts of other organic compounds, metals and hydrogen sulfide. Crude oil with high sulfur content is referred to as "sour", while oil with low sulfur content is referred to as "sweet". It is not a uniform substance since its physical and chemical properties vary from oilfield to oilfield and crude composition can even vary within wells at the same oilfield. Due to these variations, challenges often arise in classifying the material prior to transit. At one extreme, it is a light, mobile, straw-colored liquid. At the other extreme, it is a highly viscous, semi-solid, black substance (EPA March 2011). **Table 3-1** depicts the ranges of chemical/physical properties of crude oil.

For this document, we are focusing on Bakken Crude because of its involvement in a significant number of crude oil derailments and subsequent explosions/fires. Bakken is the name given to oil producing rock formation in North Dakota, Montana and adjoining Canadian provinces. The area has become the second largest producer of crude oil in the United States, only behind Texas. (Geology.com)

Bakken Crude is generally considered a light-weight petroleum crude. Lighter-end petroleum constituents often include flammable gases such as methane, ethane, propane and butanes and may also include hydrogen sulfide. These flammable gases can remain in solution thereby raising the vapor pressure, and lowering the flash point and initial boiling point of the material. As ambient temperature increases, gases held in solution can release to the vapor space of tank cars. These gases in the vapor space may create a flammable and inhalation hazard in the event of a spill or catastrophic release.

TABLE 3-1
CHEMICAL/PHYSICAL PROPERTIES OF
BAKKEN CRUDE OIL

Physical State	Liquid
Color	Amber to Black
Odor	Petroleum (rotten egg) Sulfurous
Boiling Point	70 to 110°F (21 to 43°C)
Density	5.83-8.58 lbs./gal bulk
Specific Gravity	0.7-1.03 @ 60° F Reference water =1
Solubility	Generally not soluble in water
Density	5.83-8.58 lbs./gal bulk
Vapor Density	>1 (air=1)
Vapor Pressure	8.5-15 psig @100°F (38.7°C)
Solubility	Negligible solubility in water
Flash Point	<-20°F (<.29°C)

Source: ConocoPhilips Safety Data Sheet

Reid Vapor Pressure - **(RVP)** is a common method specifically designed for the measurement of volatile crude oil and volatile non-viscous petroleum liquids, except liquefied petroleum gases. RVP is a substance or material's vapor pressure or volatility at (100°F) as determined by the test method ASTM-D-323. The presence of lighter end constituents will increase the vapor pressure thereby increasing its flammability. RVP includes the measurement of the liquid and the vapor above the liquid in a closed container.

A similar test method True Vapor Pressure measures only the vapor pressure above the liquid.

Initial Boiling Point - The boiling point of a substance is the temperature at which the vapor pressure of the liquid equals the pressure surrounding the liquid and the liquid changes into a vapor. The boiling point of a liquid varies depending upon the surrounding environmental pressure.

Identifying boiling point of Bakken crude oil is critical due to the high potential that lighter-end constituents may vaporize or volatilize in transit and fill the headspace of the unit car. If these vapors are released during a spill or catastrophic release, the vaporized substances can form vapor plumes in air and/or migrate to an ignition source.

Flammability - Flammability is the ability for a substance to burn or ignite in optimal conditions. The lowest temperature at which a liquid will ignite is its flashpoint. Flashpoint is a criteria used to characterize a substance prior to shipping in accordance with DOT packing regulations. Liquids with a flashpoint of 23° or less are designated as DOT Packing Group I or II **(See Section 4.1).**

Solubility - Solubility is the tendency of a substance to dissolve in a solvent. For this discussion, the term relates to the ability of crude oil to dissolve in water. In very general terms, crude oil is considered to be immiscible in water, meaning that it remains separated from the water. Bakken crude oil, however, in at least the case of a significant Bakken crude oil pipeline subsurface release to the Yellowstone River in Glendive Montana, oil components did impact drinking water intakes located downstream and 14 feet below the surface (USEPA 2015).

Specific Gravity – Specific gravity is the property of a substance to float on water. American Petroleum Institute (API) gravity is the common measurement. In a Bakken crude oil release to surface water, the product is expected to float, spread out to a thin sheen on water, and travel downstream rapidly.

4.0 TRANSPORTATION

4.1 DOT Placards

The proper DOT shipping name, label and identification number (ID) to be used for shipping of petroleum crude are shown below:

D.O.T. Placard 1267 Petroleum Crude Oil, Flammable Liquid, Class 3.

In addition to placarding requirements, DOT requires classification of materials prior to shipping into Classes and Packing Groups. Bakken crude oil is classified as a flammable liquid based upon its flashpoint.

On March 6, 2014, US DOT issued an amended Emergency Restriction/Prohibition (DOT 2014) in docket number DOT-OST-2014-0025. The order requires any person offering UN 1267 petroleum crude oil, Class 3, Packing Group (PG) I, II or III (see table 3.1) in commerce within the United States as described by 49 CFR 172.101 of the Hazardous Materials Regulations the following:

- Mandating the proper testing and classification of petroleum products prior to offering them for transportation.
- Requiring persons offering in bulk for transportation in commerce by rail to treat Class 3 petroleum crude oil as a Packing Group I or Packing Group II hazardous material until further notice.

- Prohibiting persons who ordinarily offer petroleum crude for shipment as UN 1267, petroleum crude oil, Class 3, PG I, II, or III from reclassifying such crude oil with the intent to circumvent the requirements of the Amended Order.

An independent study performed by DOT between August 2013 and May 2014, indicated that the majority of crude oil sampled from locations in the Bakken region displayed characteristics consistent with Class 3 flammable liquids, Packing Group I or II, with a predominance of PG I (i.e. low flash point). The study also suggests that although the crude oil does not display characteristics of a flammable gas, the predominance of PG I conditions makes the materials the most dangerous of Class 3 flammable liquids. Table 4-1 compares the DOT classification of similar petroleum products.

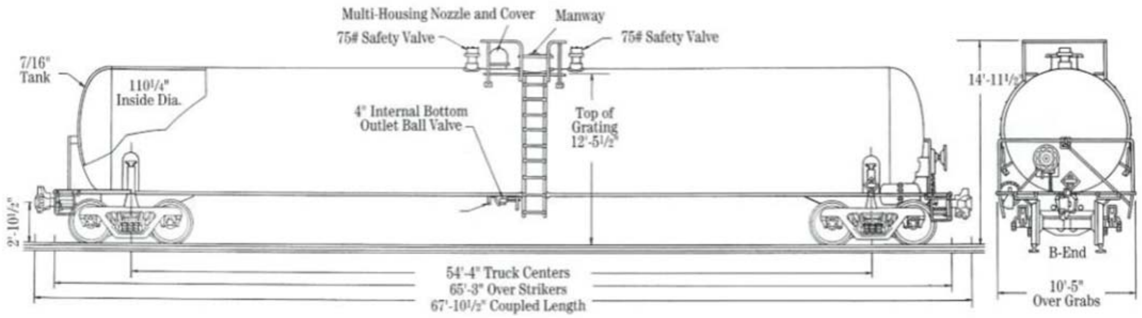
Table 4-1
Hazard Class
Similar Petroleum Products

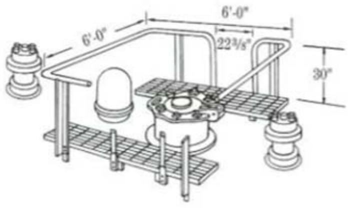
Material	Flashpoint	Class	Division	Packing Group
Gasoline	-45°	3	Flammable	PG I
Bakken crude oil	>73°	3	Flammable	PG I or II
Diesel	100 to 130°	3	Combustible	III
Motor Oil	420-495°	3	Combustible	III

4.2 Tank Car Construction

DOT-111 is a non-pressurized tank car used to transport hazardous and non-hazardous commodities. These tanks vary from 7/16-inch stainless steel shell or a ½-inch at 60 psig or 5/8-inch at 100 psig aluminum alloy shell. (Field Guide to Tank Cars, 2012). Liquid capacity of the DOT 111 is approximately 30,000 gallons depending upon the density of the stored liquid. Tank cars can be pulled in either direction and therefore there is no front or rear. The ends of tank cars are designated by A-end and B-end. The “B” end of the car has the hand brake.

4.2.1 Pre-2015 DOT 111 Unit Car Design





CAPACITY & WEIGHTS

Net Capacity @ 2% Outage – 29,348 gals.

Estimated Light Weight – 67,000 lbs.

Rail Load Limit (100 Ton Trucks) – 263,000 lbs.

COMMODITY MAXIMUM DENSITY

Truck Cpty.	Wheel Base	Non-Coiled Comm. wt./gal.
100 Ton	5'-10"	6.68#

DOT-111A100W1
For Alcohol & Methanol Service
29,947 GALLON CAPACITY –
NON-INSULATED (v. 1)

4.2.2 US DOT 111 Redesigned Unit Car 2015

In July 2014, USDOT issued proposed new requirements for unit rail cars carry hazardous mined gases and liquids. In addition to procedural changes required prior to and during operations, USDOT included specific modifications to the DOT-111 unit rail car construction. Key provisions contained in the May 1, 2015 Final Rule are as follows:

- Standards for tank cars constructed after October 1, 2015 (and that are used to transport flammable liquids as part of a HHFT) (e.g., thermal, top fittings, and bottom outlet protection; tank head and shell puncture resistance).

  1. Tank car option 1 would have 9/16 inch steel, would be outfitted with electronically controlled pneumatic (ECP) brakes and would be equipped with rollover protection.

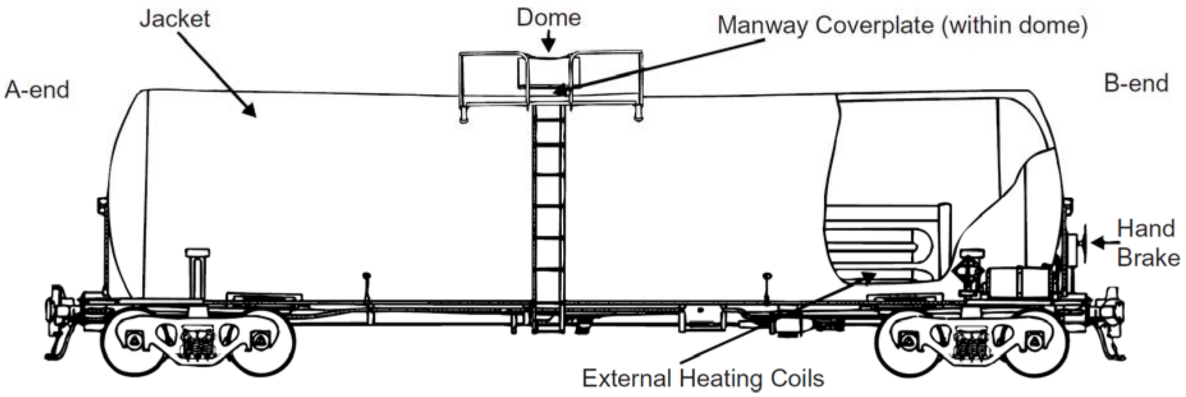
2. Tank car option 2 would also have 9/16 inch steel but would not require ECP brakes or rollover protection.
3. Tank car option 3 is based on a 2011 industry standard and has 7/16 inch steel, and does not require ECP brakes or rollover protection

- Existing tank cars that are used to transport flammable liquids as part of a HHFT must be retrofitted to meet the selected option for performance requirements. Those not retrofitted would be retired, repurposed, or operated under speed restrictions for up to five years, based on packing group assignment of the flammable liquids being shipped by rail. (Transportation.gov 2014)

- Provisions contained in the May 1, 2015 Final Rule, "Enhanced Tank Car Standards and Operational Controls for HHFT," issued by the Pipeline and Hazardous Materials Safety Administration and the Federal Railroad Administration.

    - New tank cars constructed after October 1, 2015 are required to meet enhanced DOT Specification 117 design or performance criteria for use in an HHFT.
    - Existing tank cars must be retrofitted in accordance with the DOT-prescribed retrofit design or performance standard for use in an HHFT.
    - Retrofits must be completed based on a prescriptive retrofit schedule. The retrofit timeline focuses on two risk factors, the packing group and differing types of DOT-111 and CPC-1232 tank car.
    - Complete provisions are available at Final Rule Enhanced Tank Car Standards
    -

The schematic below includes the required changes to DOT-111 tank car.



Source: DOT-111 Wikipedia

Provisions contained in the May 1, 2015 Final Rule, "Enhanced Tank Car Standards and Operational Controls for High-Hazard Flammable Trains," issued by the Pipeline and Hazardous Materials Safety Administration and the Federal Railroad Administration. –

See more at: http://www.transportation.gov/mission/safety/rail-rule-summary#sthash.dyvdAsdI.dpuf

5.0 SUMMARY OF CASE STUDIES

Although crude oil has been produced and transported in large volumes for many decades, North America is experiencing a dramatic increase in overall volume of crude oil transported by rail primarily due to growing production in the Canadian oil sands and the recent expansion of shale oil production from the Bakken fields in North Dakota and Montana as well as oil fields in Texas (Congressional Research Service, December 2014).

Unfortunately, along with the dramatic increase in overall volume, North America has also experienced an increase in the number of very visible catastrophic releases and explosions along its rail corridors. Several of these spills have resulted in significant harm to public safety and the environment.

Some of the more significant incidents that have occurred involving Bakken crude oil are summarized in **Table 5-1**. More detail is presented in **Appendix A**.

It should be noted that according to the American Petroleum Institute (API 2009), the overall volume of spills has been steadily decreasing over the last few decades.

TABLE 5-1 CRUDE OIL SPILL INCIDENT SUMMARIES

Description	Volume	Comments
Railroad Incidents		
2013-Lac-Megantic, Canada Runaway train derailment of 63 30,000 gallon railcars containing crude oil.	Approximately 1.7m gallons either burned or released with an estimated 26,000 gallons into Chaudière River	• Massive fire in town center • 47 residents were killed • Cause insufficient hand breaks • Upward of 70 buildings destroyed as a result of accident • Chaudière River restricted to non-drinking water status. • 7.6 million in initial clean-up costs
2013-Aliceville, Alabama **Derailment of 25 unit cars, 23 breached into wetland.**	630,000 gallons either spilled or burned	• Significant fire permitted to burn out. • No fatalities or injuries • Release to remote wetlands • Response hampered by lack of access to remote area • Significant impact to wetlands. • Environmental site assessment ongoing.
2013-Casselton, North Dakota **Rail car collision caused twenty crude oil tank cars to derail. 18 were breached.**	400,000 gallons of crude oil released	• 1,400 people evacuated • No injuries to the crew or public • Fire allowed to burn itself out • 9,000 cubic yds. of soil removed. GW

		monitoring on-going
2014-Lynchburg, Virginia **13-unit cars of a 105-car train derailed 3-unit cars submerged in James River.**	30,000 gallons released, 3 cars submerged in James River	• No fatalities or injuries • Fire permitted to burn • 17-mile oil slick in James River • Soil and surrounding vegetation coated with crude
2014-Plaster Rock, New Brunswick **19 cars derailed 9 crude oil units and liquefied petroleum gas (butane and propane). Two unit tank cars were breached resulting in fire.**		• Cause: Undesired brake application • No crew or public injuries • 150 evacuated • Fire permitted to burn • Control burn used to speed up burn of LPG • Limited visible impact, minimal environmental impact. • Residents temporarily placed on supplied drinking water
2008-Luther, Oklahoma **14 unit cars of a 110 car train carrying crude oil derailed. 3 unit cars breached and remainder leaked crude.**	80,746 gallons released, 3 cars breached remainder leaked and caught fire.	• Cause-track deflection • No fatalities or injuries • Fire permitted to burn • Evacuation of 35 people
2013-Parker Prairie, MN **14 unit cars of a 94 car unit train derailed. 1 car breached and 2 additional leaked while on their side following derailment.**	30,000 gallons released on to frozen soil	• No fire • No fatalities or injuries • Minimal environmental impact due to frozen conditions

6.0 FATE AND TRANSPORT CHARACTERISTICS

This section provides information regarding the fate and transport of crude oil in various environmental media, including soil, water and air.

Crude oil is not a single chemical; rather it is a complex combination of hydrocarbons and other compounds, with the composition varying significantly between crude oil produced from different geographic regions. Even within individual regions or geological formations, the composition can vary with location and over time. Hydrocarbons (composed solely of carbon and hydrogen atoms in various combinations) are the most abundant compounds found in crude oil. Similar hydrocarbons, heterocyclics, metals and other constituents such as hydrogen sulfide are present in all crude oil although their proportions vary depending on the crude source. As a result, the physical and chemical properties of crude oil can also vary. The fate and transport of crude oil components through the environment is reflective of the variation in the crude oil composition and physical/chemical properties, which are directly related to the carbon range (number of carbon atoms) and therefore the molecular weight of the various components. The carbon range and the molecular weight affect the volatility, water solubility and viscosity of various crude oil components which in turn control the fate and transport of crude oil in the environment (American Petroleum Institute [API], 2011).

6.1 Migration Pathways

In evaluating the potential impact of a crude oil release to the environment following an accident, it is essential to take into account the pathways that crude could travel from the point of release. The major migration pathways include the following:

- Evaporation, volatilization and dispersion into air;
- Infiltration into soil in immediate vicinity of the release;
- Direct surface release or overland runoff from release location to streams, rivers, lakes, coastal water areas, outer harbors, open water, ditches, wetlands and storm/ sanitary sewers; and
- Transport in groundwater, after leaching through soil saturated with crude oil.

Crude oil mass and concentrations of its individual components are expected to reduce over time and with distance from the release location at rates that depend upon the migration pathway, as well as the environmental characteristics such as temperature, soil type and flow rate. In some circumstances, especially where large volume releases create pools of crude oil on soil surface, components of crude oil may leach into the underlying groundwater over a time period of several days to months. A plume of water soluble crude oil components will then be generated in the groundwater near the release site and will migrate in the direction of groundwater flow. Storm drains and utility lines may provide preferential pathways or conduits for the migration of water soluble crude oil components (TPHCWG, 1988).

If large volume releases occur into water, crude oils will typically float to the water's surface as their specific gravity is less than 1. After floating on the water surface for an extended period of time, some components of crude oil will evaporate, dissolve, photo-oxidize, biodegrade and eventually some components may descend to the bottom of the water body and become adsorbed into sediments. These processes are discussed in detail in Section 6.3.

The migration pathways for crude oil depend to a large extent on the physical properties of the crude oil components, primarily molecular weight. The effect of molecular weight on the migration of the various components of crude through various environmental media is discussed in section 6.2

6.2 Partitioning Between Environmental Media

The act of partitioning is the process where a material or compound physically separates or partitions into a different phase (e.g., volatilize into air, dissolves into groundwater or attaches to sediment). This process is critical for first responders to understand for any chemical so they know where to look for the chemical or its constituents. As an example, if the chemical has a high potential to volatilize then special attention should be placed evaluating the compound in the breathing space and/or eliminating ignition sources.

Upon being released to the environment, the various components of crude oil partition into various environmental media depending upon the molecular weight of the components (API, 2001 and API, 2011) as follows:

1. Lighter components with lower molecular weight, containing 1 to 10 carbon atoms (C1 to C10):
    a) evaporate and volatilize into the air readily, or
    b) dissolve readily in water.
2. Intermediate weight components, medium molecular weight, containing 11 to 22 carbon atoms (C11 to C22) :

   a) may slowly evaporate and volatilize into the air, over several days,
   b) may slowly dissolve in water,
   c) readily float and spread out on water surface,
   d) form emulsions with water, or
   e) adsorb to soil and sediment.

3. Viscous, heavy weight components with high molecular weights, containing 23 or more carbon atoms (≥ C23) :
   a) do not evaporate or minimally evaporate into air,
   b) do not dissolve or minimally dissolve in water,
   c) readily agglomerate, and either float or sink in water, or
   d) adhere to soil and sediment.

Crude oil components are likely to partition primarily to air and soil media, unless the release is directly to a water body. After partitioning into various environmental media, the fate of crude oil, controlled by the chemical and physical transformations that occur as the components of crude oil disperse, is again dependent on the molecular weight of the various components.

6.3 Fate and Transport Processes

The environmental fate and transport of crude oil after a release depends upon a variety of site specific conditions, the physical and chemical properties of the crude oil, and the speed and the efficiency of the clean-up processes.

Key factors include the following (Energy East Pipeline, Ltd., 2014):

- volume of the released oil,
- type of crude oil – physical and chemical properties,
- dispersal rate of crude oil,
- receiving media (air, soil and/or water),

- topography of the terrain, and
- weather, especially wind and temperature.

This section discusses the natural fate and transport of the residual crude oil that may not have been removed immediately after the clean-up. After a release, there are several major processes, also called weathering processes that affect the crude oil as it is exposed to the environment and its subsequent fate and transport through the environment. These processes are described in detail in API (API, 2001 and API, 2011), United States Department of Transportation (US DOT, 2014) and Energy East Pipeline Ltd. (2014) documents and are summarized below.

6.3.1 Evaporation

Evaporation is a weathering process that results in transfer of the light and some intermediate weight components of crude oil from liquid phase to the vapor phase. Evaporation begins immediately after a release, and is the single most important process during the first few hours to two days after the release that results in reduction of volume of the spilled crude oil. It is the primary process for natural removal and volume reduction of spilled crude oil from land and water body surfaces, although once oil has percolated through soil into groundwater, evaporation slows down. Windy conditions are conducive to rapid evaporation. Ambient air temperature also impacts evaporation rates, with higher temperatures likely to facilitate evaporation. The expansion of the surface area of the crude oil slick, as well as wave action in case of water releases, also increases evaporation rates.

Light crude oil contains a greater amount of volatile organic compounds and will lose up to 20 to 40 percent of its mass immediately. Up to one-third of medium-grade crude oil will evaporate in the first 24 hours and the material that remains will be much more viscous. Very little evaporation occurs from heavy crude oil (Mason and Gafford, 2015).

The US DOT Pipeline and Hazardous Materials Safety Administration's (PHMSA) and the Federal Railroad Administration's (FRA) testing results of Bakken crude oil, summarized in a report (US DOT PHMSA 2014) indicates that crude oil from the Bakken Shale Formation, which covers approximately 200,000 square miles in Montana, North Dakota and Saskatchewan, Canada, is more volatile than other crude oil produced in the United Sates. Bakken crude is a light crude oil with few heavy hydrocarbon constituents, low sulfur content (sweet crude), high gas content, a low flash point, a low boiling point and high vapor pressure. While this increases risk of flammability and ignitability, it also indicates that a release or spill of Bakken crude is more likely to evaporate rapidly.

6.3.2 Spreading

After a release, crude oil initially accumulates at the release location and then spreads horizontally along the surface of land or water in the immediate vicinity of the release. The spreading of released oil on water surfaces has been studied extensively. Three stages of spreading have been identified in water bodies (US EPA, 2004) and are listed below:

- Stage 1 - gravity and inertial forces control the spreading of oil across the surface.
- Stage 2 - inertial forces become negligible in comparison with viscous drag across the surface.
- Stage 3 - interfacial forces become dominant and provide the driving force to propel spreading.

Eventually, equilibrium is achieved and the floating oil could spread across the surface or it could form a lens. The occurrence of these two types of behaviors depends on the relative magnitudes of the surface and interfacial tension forces. It is expected that low viscosity crude oil, such as the light Bakken crude, when released into water will spread rapidly and form a thin sheen across the surface of the water that provides more exposure to the environmental receptors. This also provides a greater opportunity for evaporation, dispersion and the photo-oxidation process to reduce the crude oil mass and volume.

Crude oil mobility in water increases with wind speed, currents, waves, stream velocity and increasing temperature. Most crude oil moves across the water surface at a rate of 100 to 300 meters per hour (Ramade, 1978 as cited in Patin, 1998), spreading in a complicated fashion depending upon the physical properties of the crude oil and environmental conditions. The spreading is not uniform, with a thick column of oil near the release location eventually thinning to a trailing sheen (Energy East Pipeline Ltd., 2014).

For releases of crude oil on land surface, spreading is similarly controlled by a balance between the effects of gravity, inertia, friction, viscosity and surface tension. Additional criteria include slope of land surface, soil permeability and ambient temperature to a lesser extent. The spreading of crude oil is also impeded by the presence of dense vegetative cover that slows overland flow and provides additional surface area for evaporation to occur (Energy East Pipeline, Ltd., 2014).

Energy East Pipeline Ltd. (2014) provides an approximation to estimate the maximum spread of released oil on land surface. For a 10,000 barrel (bbl.) crude oil spill on flat land, assuming uniform radial flow, the resultant crude oil pool would range between the following:

- 10-cm (4-inch) deep with a radius of approximately 70 m (230 feet)
- 1-cm (0.4 inch) deep with a radius of approximately 225 m (738 feet)

Like evaporation, spreading also occurs during the initial stages of the release and is a critical factor in the resultant dimensions of environmental impact; however it involves the whole oil without partitioning by molecular weight and does not result in volume reduction. Spreading across land or water surface reduces the bulk volume of crude oil at the release location but increases the area of impact. Spreading also increases the surface area of crude oil pools, and as result surface dependent processes such as evaporation, degradation and dissolution may be enhanced.

6.3.3 *Dissolution*

This process directly affects releases to water, where the various components of the crude oil are transferred from a surface spill into solution in the column of water. The overall solubility of crude oil tends to be less than that of its components because solubility is limited to partitioning between oil and water interface. The individual compounds are often more soluble in oil than in water, therefore tending to remain dissolved in oil than in water. Some of the light weight oil components are more soluble and dissolve into water; however, these soluble components are also volatile and evaporate rapidly at rates 10 to 1,000 times faster than dissolution (CONCAWE, 1983; ITOPF, 1987; Lewis and Aurand, 1997 as cited in API, 2001). Therefore, the vast majority of the released oil is removed by evaporation in preference to dissolution. In general, dissolution of crude oil in water increases with decreasing molecular weight. Other environmental factors will also influence dissolution including, but not limited to temperature, salinity, photo-oxidation and dissolved organic matter.

Crude oil released into soil can migrate towards water or partially dissolve in groundwater after leaching through the soil. Dissolution occurs within the first day after the release, and is not a major fate and transport process as most crude oil components are relatively insoluble (Neff and Anderson, 1981, cited in Energy East Pipeline Ltd., 2014).

6.3.4 *Natural Dispersion*

Natural dispersion is a process by which small droplets of the released crude oil become incorporated into the water column as a dilute oil-in water suspension. It typically is caused by turbulent water or waves mixing the “whole” crude oil into the water column. Natural dispersion also occurs in air due to wind action, where crude oil vapors that are initially heavier than air and form a cloud close to the ground are pushed downwind and eventually dissipate over a larger area but at lower concentrations. Dispersion does not reduce the total mass or volume of the released oil. Dispersion spreads the oil over a larger area and diluted concentrations.

6.3.5 Emulsification

Emulsification is a process that affects medium weight crude oil components when spilled to water bodies. The mixing of crude oil with water droplets increases the overall volume of the crude oil by two to four times creating a highly viscous mixture. The heavy weight components precipitate out of emulsion.

Based on the dominance of light weight components, it is expected that although Bakken crude oil will form emulsions with water like other crude oil, the emulsions will be less stable than heavy crudes. These emulsions would be transitory and would release the crude oil back to the water's surface soon after forming (Energy East Pipeline, Ltd., 2014).

6.3.6 Biodegradation

Biodegradation is the transformation of crude oil components into by-products by naturally occurring biologic agents, i.e. microorganisms, such as bacteria and fungi (API, 2001). The end product of biodegradation is carbon dioxide and water. Therefore biodegradation results in reduction of volume and toxicity of the released crude oil. It is a very important fate and transport process that is active over the short term immediately after the release in air media, but takes longer to produce results in soil and even longer in water. Over long term, biodegradation of residual crude oil (left after removal of majority of released crude oil during the initial clean-up process) has been shown to be effective in remediating soil, sediments and water.

The process of biodegradation can be very complex and its extent dependent on the following (TPHCW, 1988):

- presence and types of microorganisms in the environment near the release location,
- bio-availability of nutrients for the microbial population,
- temperature of the environmental media,
- oxygen levels in the environmental media,
- moisture conditions in the environmental media, and
- oil component physical and chemical properties, especially molecular weight and molecular structure.

The rates of biodegradation of various components can be quantified by their half-lives. A half-life is the amount of time it takes for the concentration of a chemical to be reduced by half of the starting concentration. The lighter constituents with low molecular weight that volatilize into air have low half-lives due to their interaction with hydroxyl radicals in the atmosphere and rapidly degrade. For example, crude oil component n-dodecane degrades rapidly with a half-life of 0.4 days while on the end of spectrum is benzene with a half-life of 6.5 days. Both of these are fairly rapid biodegradation rates, especially when compared to the rates in environmental media other than air. After 10 half-life periods, the residual concentration of a chemical is expected to be 1/1,000th (0.1%) of the original concentration at the time of release; therefore the concentrations of various crude oil components in the air are expected to be reduced by a factor of 1,000 between approximately 4 and 65 days.

The heavier crude oil components do not partition into air, but migrate through the soil and water pathways. The heavier components become increasingly insoluble in saturated soil and water, limiting their bioavailability and as a result have very low rates of biodegradation.

Garett et al., 2003 (as cited in API, 2011) indicate that the molecular structure of hydrocarbons in crude oil affects microbial degradation rates, in a wide range of climates, including temperate and arctic summer conditions, with the following order of increasing difficulty of biodegradation:

1. n-alkanes,
2. isoalkanes,
3. alkenes,
4. single ring alkyl benzenes such as benzene, toluene, ethylbenzene and xylenes,
5. polycyclic aromatic hydrocarbons (PAHs), and
6. high molecular weight cycloalkanes.

6.3.7 Photo-oxidation

Upon exposure to sunlight, the hydrocarbons in the released crude oil may be transformed by the process of photo-oxidation (also referred to as photo-degradation) into other by-products. It is a longer term process. Photo-oxidation may occur through two mechanisms:

> **Direct photo-oxidation -** Occurring over several months to weeks after the release, it affects the top surface of the oil pools or impacted sediments and is of relatively minor importance as a fate and transport process. It only occurs at the top surface of the released oil because the hydrocarbon molecules need to be exposed to sunlight for direct photo-oxidation to take place. Some limited degradation of heavy crude oil components, such as PAHs may occur in exposed crude oil pools, although not in sediments or crude oil that

has penetrated deeper in the sediments due to lack of available light. The direct photo-oxidation process is not expected to remove significant mass or volume of crude oil after a release.

Indirect photo-oxidation – It occurs as lighter crude oil components volatilize to air and undergo a gas-phase oxidation reaction with photo-chemically produced hydroxyl radicals (OH^-). The reaction rates are relatively rapid, with atmospheric half-lives of various crude oil components ranging from 0.37 days (naphthalene) to 6.5 days (benzene) [API, 2011]. Indirect photo-oxidation is an important process resulting in removal of mass and volume of the released crude oil components.

6.3.8 Sedimentation

Crude oil begins to degrade through natural processes immediately upon release. Heavier components of the degraded crude oil will adhere to sediment in drainage areas or water bodies. Overall, the process of sedimentation does not remove significant mass or volume of the released crude oil.

6.4 Persistence in Environment

Crude oil components have a wide range of persistence in the environment. Persistent components will tend to remain in the environment for a long time after a release, unless mechanically or otherwise removed during the clean-up process. These components are not affected by the eight weathering / fate and transport processes listed in Section 6.3 to an extent that will facilitate their removal from the environmental media at a rapid rate. Non-persistent crude oil components are rapidly and completely removed from the affected environmental media following the release due to one or more of the eight natural weathering processes. In general, light weight components are non-persistent while the heavier components are persistent (API, 2001). Compared with the other representative crude oil, Bakken crude oil contains a high proportion of light weight components, and therefore any spills or releases of Bakken crude are expected to be less persistent than some of the other heavier crude oil (Energy East Pipeline, Ltd., 2014)

The persistence of the crude oil components in the environment after a release is also related to the biodegradation rates. In general, crude oil is subject to biodegradation although the biodegradation rates vary and whole crude oil is not considered readily biodegradable (API, 2011). Low molecular weight components may biodegrade and therefore they are less persistent while the heavier, high molecular weight components resist biodegradation and persist in the environmental media where they were released.

On average, the medium weight components of crude oil (C10- C20), equivalent to diesel oil in molecular weight, are eight times more persistent than the lightest weight components (C1 – C10), equivalent to gasoline in molecular weight. The heaviest weight components of crude oil (C25- C50), equivalent to fuel oil #6 or bunker oil in molecular weight, are 400 times more persistent than the light weight components (C1 – C10), equivalent to gasoline.

6.5 Potential for Environmental Contamination

6.5.1 Groundwater

Following a crude oil release to surface soil, it is possible that the groundwater resources underlying the release location may become contaminated, although it may take an extended period of time for that to happen after the release and the emergency / clean-up operations occur. Groundwater is especially vulnerable in situations where (Energy East Pipeline Project, 2014):

- The groundwater is unconfined and the water table is relatively shallow, and
- The unsaturated soil overlying groundwater has high permeability that enables fluids such as crude oil to leach vertically fairly rapidly

Crude oil contamination in groundwater water can occur as a distinct layer of oil floating on the top of the water table or as dissolved constituents migrating with groundwater. If the crude oil is not completely removed during initial clean-up operations, the dissolved crude oil constituents will generate a plume of contaminated groundwater. The plume will move in the direction of dominant groundwater flow at a velocity that is less than the groundwater velocity, a phenomenon called retardation. Retardation of the crude oil related plume is caused by adsorption of constituents to soil particles and natural attenuation due to biodegradation and dispersion (Fetter, 1988).

Most crude oil constituents are either not water soluble or have limited solubility. Some of the crude oil constituents that are water soluble may develop into groundwater plumes that include benzene, toluene, ethylbenzene and xylenes (BTEX). For example, the Bakken crude oil contains a high proportion of straight-chained alkanes and BTEX compounds, and releases to the environment can cause impacts such as dissolved BTEX plumes. Over time, these plumes may, begin to attenuate naturally and stabilize at a certain distance downgradient, or may keep expanding and migrating depending upon the volume of the residual crude oil left after the initial clean-up operations. Early intervention during the clean-up operations may protect the environment by removing most of the crude oil and excavating the impacted soil so that a continuing source for the groundwater plume is no longer present.

6.5.2 Surface Water

Crude oil releases may impact surface water bodies such as rivers, streams, lakes, reservoirs and wetlands. These releases may enter directly where the release occurs or via overland flow. The release may also enter indirectly when a surface soil release generates a groundwater plume that eventually discharges to a surface water body. The magnitude of impacts to these surface water bodies would depend largely upon the volume of crude oil released, the volume of water within the receiving water body and the flow velocity if the receiving water body is a stream or a river.

7.0 HEALTH EFFECTS AND ENVIRONMENTAL RISKS

7.1 Health and Safety Considerations for Responders

7.1.1 Recognizing Product Spilled

Section 4.2 discusses the DOT placards used for crude oil. During Size-Up, responders should be identifying the contents and potential product spilled by viewing the placards posted on the all sides of the rail cars. Crude oil is transported from production facilities to the storage depots by rail largely in DOT-111 unit trains. The DOT Placard for crude oil has a red background and a white flame symbol, indicating that it is a flammable liquid. It also shows the North America (NA) code for this substance (1267). Lastly, at the bottom, it shows the hazard class (3). A flammable liquid (Class 3) means a liquid having a flash point of not more than 60.5°C (141°F), or any material in a liquid phase with a flash point at or above 37.8°C (100°F) that is intentionally heated and offered for transportation or transported at or above its flash point in a bulk packaging.

7.1.2 Exposure Limits

The Occupational Safety and Health Administration (OSHA) has established Permissible Exposure Limits (PELs) for work place safety (general industry) for some crude oil constituents, as shown in **Table 7-1**. Other occupational values (the ACGIH Threshold Limit Value) are also shown. PELs are time-weighted average concentrations that must not be exceeded for any 8 hour work shift of a 40 hour week. NIOSH has established a concentration that is deemed to be IDLH. These values are shown for substances for which they are available.

TABLE 7-1 OCCUPATIONAL LIMITS IN AIR (ppmv)

Carbon Number	OSHA PEL	ACGIH TLV	NIOSH (IDLH)
C1-C4		Butane – 1000	
C5	n-Pentane – 1000 (2950 mg/m^3)	Pentane - all isomers - 1000	n-Pentane – 1500

C6	Benzene - 1 Hexane – 500 (1800 mg/m^3) Cyclohexane – 300 (1050 mg/m^3)	Benzene – 0.5 Hexane – 50 Cyclohexane - 100	Hexane – 1100 Cyclohexane - 1300
C7	Toluene – 200 Heptane – 500 (2000 mg/m^3)	Toluene – 20 Heptane - 400	Toluene – 500 Heptane – 750
C8	Ethylbenzene – 100 (435 mg/m^3) Xylenes – 100 (435 mg/m3)	Ethylbenzene – 100 Xylenes - 100	Ethylbenzene – 800
C9	Cumene – 50 (245 mg/m^3)	Cumene – 50 Trimethylbenzene (all isomers) - 25	Cumene – 900
Other	Hydrogen sulfide – 20 (ceiling concentration) Methyl mercaptan – 10 (20 mg/m^3) ceiling concentration Particulates – 15 mg/m^3 (total)	Hydrogen sulfide – 1 Methyl mercaptan – 0.5	Hydrogen sulfide – 100 Methyl mercaptan – 150

7.1.3 Protective Clothing

Due to the potential for toxic and flammable hazards associated with a Bakken crude oil, fire personnel should wear protective clothing consisting of self-contained breathing apparatus and full turn-out gear during initial Size-Up activities, evacuation and firefighting activities. Appropriate protective glasses or splash goggles should be considered, as well as protective gloves (nitrile) and other protective apparel to prevent skin contact during response activities.

7.1.4 Other Health and Safety Considerations

As a result of response to a variety of crude oil releases, a number of specific considerations for care have been identified for first responders (ATSDR, 2011; CDC, 2010), as summarized below:

- Oil in combination with an oxygen rich environment has the potential for explosion
    - Avoid contacting oxygen-using equipment with oily hands
    - Remove oil from head, neck and chest of patient before placing oxygen mask (an oxygen rich environment can exist up to 1 foot from face mask)
    - Sources of ignition, such as a defibrillator, should not be used near oil contaminated persons or clothing
- Oil-contaminated clothing or rags represents a fire hazard and should be stored properly

- Vomiting should not be induced in patients that have ingested oil, as it could lead to aspiration of crude oil into the lungs.

7.2 Environmental Risks – Fire and Explosion

Flammability is the greatest hazard associated with crude oil in a rail incident. As discussed in Section 3.0, the flash point of crude oil is variable, but generally ranges from -59° C to 50° C for Bakken crude. Because of its flammable nature, the crude may ignite resulting in explosions, fireballs, and pool fires. Long duration fires involving crude stored in tanks may result in a boil over, in which the contents of the tank may be expelled beyond the container or containment area (Conoco, 2014). Bakken crude floats on water and can be reignited on surface water (Conoco, 2014).

Explosion may occur following a major tank rupture, spilling fuel which vaporizes, contacts an ignition source, and explodes and also rapidly burns in a fireball. The pressure safety valve may or may not be able to vent the increase in pressure fast enough, resulting in tank failure, fireball, and a partial explosion.

Crude oil fires generally produce dense clouds of soot, liquid, aerosols, and gases. The mixture of gaseous and particulate compounds may include carbon dioxide (CO2), carbon monoxide (CO), sulfur dioxide (SO2), nitrogen oxides (NOx), volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), hydrogen sulfide (H2S), acidic aerosols, and soot. The constituents present in the smoke vary with the source and composition of the oil, and the burning conditions (MnDOH, 2007). The potential health effects associated with smoke particles and gases are discussed in the subsequent sections.

Due to the flammability of Bakken crude, the elimination of sources of ignition (e.g., static electricity, pilot lights, mechanical/electrical equipment, and electronic devices) and the use of explosion-proof electrical equipment is recommended and may be required depending on the relevant fire codes (Conoco, 2014).

As discussed above, explosive hazards can occur in tanks in a spill situation. In addition, spilled material entering low-lying areas, sewers, storm drains, or other confined areas have the potential for the creation of explosive conditions.

7.3 Potential Exposure Pathways in Spill Situations

The potential human exposure pathways during spill situations depend on the nature of the spill. In general, given the volatile nature of Bakken crude and other light crudes, inhalation exposures are the most likely exposure scenarios for both first responders and nearby workers or residents. Skin contact (dermal exposure) is possible, but unlikely, since responders should be wearing appropriate protective clothing (see Section 7.1.3). If a fire occurs following a spill or release, burning can result in inhalation exposures to smoke particles and VOCs in the immediate proximity of the spill, but also at some distance. Ingestion exposure is also unlikely, although if the spill reaches surface water, components of crude oil will dissolve, as discussed in Section 6.0, and could impact a drinking water source. As discussed in Section 5.0 and Appendix A, water supply intakes have been shut down during several incidents. In addition, contact could occur as a result of other uses of surface water, such as swimming or boating, or use for cooling or production water. Given the greater likelihood of inhalation exposures during spill situations, this section will focus on health effects related to this route, with limited discussion of other possible routes of exposure.

7.4 Human Health Effects

This section discusses human health effects of crude oil, in particular Bakken crude, relevant to spill situations. As discussed in Section 3.0, Petroleum (crude oil) is a complex mixture of paraffinic, naphthenic and aromatic hydrocarbons ranging in carbon number from C1 to >C60. Some information regarding health effects is available for the product as a whole. Additionally, extensive information on health effects is available on some of the more toxic constituents, such as benzene, hydrogen sulfide, ethylbenzene, naphthalene and methylnaphthalenes, as well as polycyclic aromatic hydrocarbons (PAHs). The focus of this review is on whole product information, with more limited discussion of specific constituents. This section provides information in summary form and **Table 7-2** provides a summary of effect levels for acute and chronic exposure. **Table 7-3** provides information on effects related to crude oil constituents.

7.4.1 Short-Term (Acute) Effects

Crude oil has been found to have a relatively low acute toxicity. Oral Lethal Doses to 50% of the tested animal populations (LD_{50}) have found to be greater than 5000 mg/kg for a variety of types of crude oil that have been tested. Dermal toxicity tests in animals have shown LD_{50} values of greater than 2000 mg/kg. Skin irritation and eye irritation in rabbits have also been observed (API, 2011). According to OSHA (2010), fresh or weathered crude can cause skin irritation and other irritant reactions in response workers, although these effects may be a result of repeat exposure. **Table 7-2** provides summary information on the acute effects of crude oil.

TABLE 7-2 HUMAN HEALTH EFFECTS OF CRUDE OIL

EXPOSURE ROUTE	ACUTE EFFECTS	CHRONIC EFFECTS
Laboratory Results	**Oral LD_{50}** - > 5000 mg/kg **Dermal LD_{50}** > 2000 mg/kg **Inhalation LC_{50}** > 4 mg/L	**Inhalation NOAEC** – 1507 mg/m^3 - 10,153 mg/m^3. In the absence of H_2S, NOAEC > 1507 mg/m^3. **Inhalation reproductive/developmental toxicity** – NOAECs from 5970 mg/m^3 to 27750 mg/m^3 **Dermal toxicity** – LOAEL – 30 mg/kg-day **Oral developmental toxicity** – LOAEL – 887 mg/kg-day **Dermal Developmental Toxicity** – LOAEL – 125 mg/kg-day **Skin Irritation and Eye Irritation** – observed in rabbits **Genetic Toxicity** – gene mutations and chromosomal aberrations - positive test results.
Crude Oil Exposure Observations/Epidemiology	**Crude oil ingestion in small quantities** - may result in nausea, vomiting, and diarrhea. Vomiting and subsequent aspiration of hydrocarbons can result in significant lung injury. **Review of acute effects in exposure related to oil spill-** effects include respiratory, eye, and skin symptoms, headache, nausea, dizziness, and fatigue **Study of exposed residents in proximity to an oil spill** - evidence of acute symptoms such as headache, throat irritation and itchy eyes.	**Dermal contact to petroleum field workers** - dryness and skin thickening **Studies of worker exposures to crude oil for longer than 15 days** - showed effects on pulmonary function; study of workers involved in cleanup of Prestige spill showed respiratory symptoms 1 -2 years after exposure **Review of chronic effects in exposure related to oil spill-** effects include psychological disorders, respiratory disorders, genotoxic effects, and endocrine abnormalities **Workers employed in the oil industry** - showed excess risk of hematologic neoplasms (blood and bone marrow); general health complaints also reported (cough, runny nose, eye irritation, sore throat, headache and nausea) **Study of exposed residents in proximity to an oil spill** - did not show evidence of pulmonary, hematological, renal, or hepatic damage.

NOAEC = No Observed Adverse Effect Concentration

Acute health effects have been observed in humans studied as part of crude oil spill cleanup activities. Effects on pulmonary function have been observed in workers exposed to a crude oil during a spill cleanup as compared to similar subjects not exposed to crude oil in "control-group" studies. Lung function improved when the subjects were returned to a clean environment (Meo et al., 2008). Interviews of subjects involved in oil cleanup identified significantly higher rates of health complaints associated with cough, runny nose, eye irritation/redness, sore threat, headache, nausea, and general illness compared to controls (Meo et al, 2009). One study included a review of health surveillance information related to a pipeline spill in Michigan, including health care provider reporting, community surveys, calls to the Poison Control Center, and data submitted to the state's surveillance system. The predominant symptoms reported by exposed individuals were headache, nausea, and respiratory system effects, consistent with effects identified with exposure to crude oil in the literature (Stanbury et al., 2010). A study of adults living near a marine spill showed that the occurrence of reported symptoms relating to eyes, respiratory effects, skin and nervous system, and other effects was correlated with distance from the spill site (Janjua et al, 2006).

API (2011) indicates that the acute inhalation hazard associated with crude oil is primarily associated with hydrogen sulfide, for which the lethal concentration to 50% of the population (LC_{50}) in rats is 444 ppmv (parts per million by volume). The IDLH (immediately dangerous to life and health) level for hydrogen sulfide is 100 ppmv. The acute toxicity of VOCs in crude oil is lower than that of hydrogen sulfide, although Bakken crude is typically low in hydrogen sulfide compared to other crude oil.

ATSDR (1999) developed a toxicological profile for Total Petroleum Hydrocarbons (TPH) which considered crude oil, as well as petroleum products made from crude oil. In order to address the wide variety of mixtures and product constituents, ATSDR considered the toxicity of select products and constituents, but also considered health effects associated with carbon fractions found in products in varying amounts. In their reviews, ATSDR establishes Minimal Risk Levels (MRLs) when data are available. MRLs are an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse non-cancer health effects over a specified duration of exposure. ATSDR (1999) identified MRLs for some of the compounds present in various petroleum fractions, based on profiles for those chemicals. Many of the MRLs for these constituents have been updated since that time. Considering these updates, in the EC_5-EC_9[1] aromatic fraction, including toluene and xylene, the lowest MRL is that for toluene (0.8 mg/kg/day). For the $EC_{>9}$-EC_{16} aromatic fraction, the acute oral MRL for naphthalene of 0.6 mg/kg/day is the lowest identified. No acute MRLs are

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1 EC = Equivalent Carbon Number Index

identified for compounds in the $EC_{>16}$-EC_{35} fraction, or for any of the aliphatic fractions. The acute inhalation MRLs for the EC_5-EC_9 fraction ranged from 0.009 to 5 ppmv, with the lowest being for benzene based on immunological effects.

As discussed in previous sections, crude oil contains a complex mixture of chemicals. A brief summary of the health effects associated with some of the primary constituents is provided in **Table 7-3**.

TABLE 7-3 HUMAN HEALTH EFFECTS OF CRUDE OIL CONSTITUENTS

CHEMICAL	**ADVERSE EFFECTS**
Benzene	Inhalation can result in irritation of eyes, skin, and respiratory system. Ingestion of highly contaminated food or water can cause vomiting, dizziness, confusion, convulsions, and death. Long term exposure can cause anemia, and leukemia
Hydrogen sulfide	Inhalation can result in irritation to eyes, skin, and respiratory system, exposure to 500 ppm can result in loss of consciousness; chronic effects can result in headaches, impaired memory or motor function
Ethylbenzene	Inhalation can result in irritation to eyes, skin, and respiratory system, exposure to higher levels can cause dizziness or vertigo
Toluene	Inhalation can result in irritation to eyes, skin, and respiratory system; can also cause tiredness, confusion, impaired memory, nausea, loss of appetite, and loss of hearing. Exposure to high levels can result in unconsciousness and death; long term exposure can affect nervous system or kidneys
Xylenes	Inhalation can result in irritation to eyes, skin, and respiratory system; can also cause headaches, lack of coordination, dizziness, confusion and impaired balance. Exposure to high levels can result in unconsciousness and death; long term exposure can have central nervous system effects, and changes in liver and kidney
Generic alkanes (including octane, hexane, and nonane)	Inhalation of high levels of n-hexane can cause numbness in the feet and hands and weakness in feet and lower legs. Inhalation of high levels of some alkanes can result in asphyxiation; long term exposure to n-hexane can also cause weakness and loss of feeling in the arms and legs
Naphthalene	Exposure to high levels can cause nausea, diarrhea, blood in urine; exposure to extremely high levels can be fatal; long term exposure associated with red blood cell effects, resulting in fatigue, lack of appetite , etc.
Polycyclic Aromatic Hydrocarbons (PAHs)	Inhalation can cause irritation to eyes and skin cancer, possible reproductive effects, immune system effects; Several of the PAHs are known animal carcinogens and probable human carcinogens

Taken from ATSDR (2010)

7.4.2 Long-Term (Chronic) Effects

Limited information is available on the long term effects of exposure to crude oil product. API (2011) concluded that the inhalation studies in rats with gasoline and gasoline blending streams are appropriate to use to evaluate the potential effects of inhalation exposure to crude oil. This conclusion is based on the assumption that there is little difference in the volatile component of the products. Based on this assumption, they identified inhalation NOAECs in laboratory animals ranging from 1507 to 10,153 mg/m^3, however, in the absence of hydrogen sulfide, the inhalation hazards would be lower, with the NOAEC greater than 1507 mg/m^3. API (2011) also indicated that the volatile constituents of crude oil are not expected to pose a significant developmental or reproductive effects hazard and identified NOAECs for inhalation exposure in laboratory animals considering developmental effects from 5970 mg/m^3 to 27,750 mg/m^3, with NOAECs for reproductive effects in a similar range.

Feuston et al, (1997) reported on a study of the effects of the dermal exposure of Lost Hills Light (>38°API, 0.86 wt.% S) and Beldridge Heavy (14°API, 1.05% S) crude oil to rats. This study's LOAEL for both crude oil was the lowest dose tested (30 mg/kg) based on the occurrence of skin irritation and minor thyroid effects. More significant effects were observed with exposure to the Beldridge Heavy crude. API (2011) indicates that the Polycylic Aromatic Compounds (PAC) profile of particular crudes correlate with selected endpoints of mammalian toxicity, with greater toxicity correlated with the concentrations of the 3 to 7 ring PACs. Based on this correlation, they predicted dose response values for 46 crude oil samples. The predicted dose response for hematology effects, liver enlargement, and thymic atrophy to 10% (PDR_{10}) of the exposed population (laboratory animals) ranged between 55 and 544 mg/kg/day. Similar predictions for developmental effects resulting from repeated dermal exposure showed PDR_{10} values ranging from 53 to 2000 mg/kg-day.

Gene mutation has been demonstrated *in vitro* in bacterial assays using extracts of a variety of crude oil (API, 2011). *In vivo* micronucleus tests in laboratory animals with a range of crude oil did not demonstrate cytogenic activity by the dermal route, or the intraperitoneal route (API, 2011).

Information on the potential effects of crude oil exposure in humans is available from the collection of health surveillance information during and after exposure, as well as epidemiological studies of exposed populations and historical cohort studies. This information provides an indication of the potential for effects. However, some of the epidemiological studies are of populations of unprotected workers involved in cleanups and do not reflect exposure with appropriate PPE. Nevertheless, their consideration provides information on the potential for effects, and stresses the importance of PPE in reducing exposure in spill response situations.

Effects on pulmonary function have been observed in workers exposed to a crude oil spill environment during a cleanup as compared to similar subjects not exposed to crude oil in “control-group” studies. Interviews of subjects involved in oil cleanup identified health complaints such as cough, runny nose, eye irritation/redness, sore threat, headache, and nausea. Reviews of health surveillance information from residents in proximity to a pipeline release showed numerous reports of individuals with similar health effects.

Levy and Nassetta (2011) conducted a review of studies documenting adverse health effects related to oil spills. Chronic effects reported include psychological disorders, respiratory disorders, genotoxic effects, and endrocrine abnormalities. The Prestige spill cleanup in Spain involved a large number of people in the cleanup, including volunteers and hired manual workers. Studies of these populations showed evidence of cytogenetic damage in exposed individuals. The chemicals present in the Prestige oil induced alterations in hormonal status, and may be considered an endocrine disrupter. The authors concluded that the study demonstrated the importance of worker protection to preventing effects related to exposure (Pérez-Cadahia et al., 2007).

As discussed above for acute effects, ATSDR (1999) identified (updated as described above) oral intermediate or chronic MRLs for some of the compounds present in the EC_5-EC_9 aromatic fraction, including benzene, toluene, ethylbenzene, and xylene, with the lowest being that for benzene based on immunological effects (0.0005 mg/kg/day). For the $EC_{>9}$-EC_{16} aromatic fraction, the intermediate oral MRL for naphthalene of 0.6 mg/kg/day was identified, based on neurological effects, and a chronic oral MRL for 2-methylnapthalene of 0.04 mg/kg/day, based on respiratory effects. The intermediate and chronic inhalation MRLs for the EC_5-EC_9 fraction ranged from 0.003 to 2 ppmv, with the lowest being for benzene based on immunological effects. The acute inhalation MRLs for the EC_5-EC_9 fraction ranged from 0.009 to 2 ppmv, with the lowest being for benzene based on immunological effects. A chronic inhalation MRL for the $EC_{>9}$-EC_{16} fractions was identified for naphthalene of 0.0007 ppmv, based on respiratory effects. For the EC_5-EC_8 aliphatic fraction, a chronic inhalation MRL of 0.6 ppm was identified for n-hexane, based on neurological effects. A chronic inhalation MRL for the $EC_{>9}$-EC_{16} fraction based on JP-7 of 0.3 mg/m^3 (hepatic effects).

The above discussion of both acute and chronic effects primarily relate to direct exposure to crude oil. However, rail incidents commonly result in burning of crude oil, which may result in emissions and exposure to workers, as well as nearby areas. Lemieux et al. (2004) conducted a review of organic emissions from open burning, including crude oil. They reported on emissions from pool studies (simulations of burning conditions) of crude oil that showed emissions of select organic chemicals as follows:

Compound	Emissions (mg/kg burned)
Benzene	251
Formaldehyde	139
Naphthalene	44
Benzo(a)pyrene	1
Total dioxins and furans	0.000428

In addition to the organic chemicals released, oil fires produce dense clouds of soot, including particulates, metals, sulfur compounds, and nitrogen compounds (MnDOH, 2007). A study of in-situ crude oil burning and calculation of smoke plume dispersion in the vicinity of Cook Inlet, Alaska showed that beyond 5 km downwind of the burn, estimated smoke particulate concentrations near the ground surface did not exceed 150 µg/m^3 (Evans, 1994).

Aristatek (2014) estimated emissions from crude oil fires and protective action distances (PAD), which are downwind distances for exclusion zones based on the data provided by Lemieux et al. (2004) and modeling conducted using their proprietary software. They estimated emissions and PAD for both a 10,000 and 30,000 gallon spill for select constituents (sulfur dioxide, carbon monoxide, particulates, benzene, and formaldehyde). The modeling was based on a wind speed of 5 miles per hour, cloudy conditions, and cropland terrain. They found that the PAD for particulates was 0.75 miles (10,000 gallon spill) and 1.4 miles (30,000 gallon spill) and were slightly less for sulfur dioxide (based on an assumed sulfur content of 2%). The PADs for other constituents evaluated were less than particulates and sulfur dioxide. The estimates for particulates were based on an endpoint concentration of 15,000 µg/m^3, which is the OSHA PEL (see **Table 7-3**). If the NAAQS (see **Table 7-4**) were used, the distances would have been greater.

7.4.3 Health Protective Concentrations

While health protective concentrations have generally not been developed specifically for crude oil, a number of states have developed health-protective concentrations for petroleum in the environment. These concentrations are typically based on petroleum fractions in order to be applicable to a wide variety of petroleum products. The values for fractions are based on consideration of non-cancer hazards. Constituents in petroleum that are known or suspected carcinogens, such as benzene and PAHs, typically have chemical-specific health protective concentrations. Most New England states have developed fraction-based health protective concentrations. It is beyond the scope of this document to inventory such concentrations. However, the table below shows such concentrations developed by the Massachusetts Department of Environmental Protection (MassDEP, 2013, 2014).

TABLE 7-4 HEALTH PROTECTIVE CONCENTRATIONS – PETROLEUM FRACTIONS

Petroleum Fraction	Air (µg/m^3)[a]	Soil (mg/kg)[b]	Drinking Water (µg/L)[c]
C_5-C_8 Aliphatics	200	100	300
C_9-C_{12} Aliphatics	200	1000	700
C_9-C_{10} Aromatics	50	100	200
C_9-C_{18} Aliphatics	Not volatile (see C_9-C_{12} aliphatic fraction)	1000	700
C_{19}-C_{36} Aliphatics	Not volatile	3000	14000
C_{11}-C_{22} Aromatics	Not volatile	1000	200

a) Residential indoor air risk-based concentrations (MassDEP, 2013)
b) Method 1 S-1 (Residential) Direct Contact Standard (MassDEP, 2014)
c) Method 2 GW-1 (drinking water) Standard (MassDEP, 2014)

Health protective concentrations for crude oil constituents are identified in **Table 7-4** based on information from MassDEP (2013, 2014, 2015), and from ATSDR (2010). Information on EPA (2015) drinking water standards (Maximum Contaminant Limits – MCLs) is also included. The AEGL-1 concentrations are also included, if available (National Advisory Committee for Acute Exposure Guideline Levels for Hazardous Substances, (NAC/AEGL, 2014). The values provided are AEGL-1, which are those concentrations that are predicted to result in notable discomfort, irritation, or other non-disabling effects on the general population, including sensitive individuals. They are intended to describe the risk to humans to once-in-a-lifetime or rare exposure situations, such as might occur in spill situations.

TABLE 7-5 HEALTH PROTECTIVE CONCENTRATIONS – CRUDE OIL CONSTITUENTS

Constituent	Air (µg/m^3)	Soil (mg/kg)	Drinking Water (µg/L)
Benzene	MassDEP TEL – 0.6 ATSDR – 10 (chronic), 0.1 (cancer) AEGL-1 – 29,000	MassDEP S-1 – 40 ATSDR – 30 (chronic), 10 (cancer)	MCL - 5
Hydrogen sulfide	MassDEP TEL – 0.9 EPA residential RSL - 2.1 AEGL-1 – 460	EPA residential RSL - 2,800,000	Not available
Ethylbenzene	MassDEP TEL – 300 ATSDR – 3000 AEGL-1 – 144,000	MassDEP S-1 – 500 ATSDR - 5	MCL - 70
Toluene	MassDEP TEL – 80 ATSDR – 300 AEGL-1 – 250,000	MassDEP S-1 – 500 ATSDR – 1,000	MCL - 1000
Xylenes	MassDEP TEL – 11.8 ATSDR – 3000 AEGL-1 - 560,000	MassDEP S-1 – 500 ATSDR – 10,000	MCL – 10,000
Generic alkanes (including octane, hexane, and nonane)	ATSDR – 31,000 (based on decane and white oil)	ATSDR – 600 (based on decane and white oil)	EPA RSL – 320 (n-hexane)
Naphthalene/methylnaphthalenes	MassDEP TEL – 14.25 ATSDR - 3	MassDEP S-1 – 300 (2-methylnaphthalene) ATSDR – 0.7	EPA RSL – 0.17 (naphthalene)
Polycyclic Aromatic Hydrocarbons (PAHs)	Benzo(a)pyrene EPA Residential RSL – 0.00092	Benzo(a)pyrene MassDEP S-1 – 2 EPA residential RSL – 0.015	MCL – 0.2 (benzo(a)pyrene)
Polycyclic Aromatic Hydrocarbons (PAHs)	Benzo(a)pyrene EPA Residential RSL – 0.00092	Benzo(a)pyrene MassDEP S-1 – 2 EPA residential RSL – 0.015	MCL – 0.2 (benzo(a)pyrene)
Particulates (burning)	NAAQS $PM_{2.5}$ 24 hr. – 35 NAAQS PM_{10} 24 hr. - 150	Not applicable	Not applicable

Notes:

ATSDR values from ATSDR (2010)
AEGL-1 (Acute Exposure Guideline Level 1, concentrations that are predicted to result in notable discomfort, irritation, or other non-disabling effects on the general population, including sensitive individuals. Values shown are based on an 8 hour exposure (NAC/AEGL, 2014)
EPA RSL (Regional Screening Level) from EPA (2014)
MCL – Maximum Contaminant Level (EPA, 2015b)
NAAQS (National Ambient Air Quality Standards (EPA (2015a)
TEL – threshold effects exposure limit (24 hour average) from MassDEP (2015)

7.5 Environmental Effects

A spill of crude oil could affect soil and vegetation in the immediate area of the spill and fire. In addition, if the spill results in a release to the surface water, aquatic organisms could be affected. Such effects from marine spills, such as the Deepwater Horizon incident and the Exxon Valdez spill have been extensively documented. However, due to the focus of this report on incidents related to rail transport, the focus of this section will be on terrestrial and freshwater systems, as discussed in the following sections.

7.5.1 Aquatic Systems

Crude oil released to a water body could directly affect aquatic organisms. The most direct effect is the oiling of vegetation, birds, mammals, and reptiles, as has been reported as a result of the Deepwater Horizon spill and numerous others. Oiling of birds can result in the loss of normal activities such as flying, diving for food, and can result in drowning. It also can result in hypothermia through interference with water repellency of the feathers. Ingestion of oil by birds that may occur in grooming can result in death, or lung, liver, and kidney damage (US Fish and Wildlife, 2010). Long term effects on birds and marine mammals can also occur, such as damage to the immune system, organ damage, skin irritation, and behavioral changes. Fish can also be impacted during an oil spill, through gill uptake, or ingestion of oiled prey. Exposure can result in growth, liver, cardiac and respiratory effects, as well as reproductive effects (US Fish and Wildlife, 2010).

In addition to the direct effects on organisms, oil can persist in the environment as a result of sinking into sediments of beaches, tidal flats, and salt marshes (US Fish and Wildlife, 2010). Such persistence has the potential to result in long term effects on wildlife. In Buzzards Bay after the Florida spill, it took more than seven years for fiddler crabs to recover due to the persistence of naphthalene aromatic compounds in the soils in which the crabs burrow (Krebs and Burns, 1978). Michel and Rutherford (2013) reported that the effects of light to medium crude oil on marshes depend on their composition and the degree of weathering prior to reaching the marsh. Crude oil releases directly into marshes result in higher mortality and longer recovery times than those that undergo weathering. Complete mortality of vegetation over 20 hectares was observed upon a spill of 12,600 gallons of Louisiana crude into a brackish marsh, and recovery took four years (Hester and Mendelssohn, 2000).

In the case of the Bakken crude oil spill in the Lower Mississippi, NOAA (2014) reported that the initial oil released was dark, but rapidly changed to a yellowish emulsion and silvery sheen. There were no reports of oiled wildlife or fish kills from this spill, and no shoreline cleanup measures were necessary other than in the immediate vicinity of the spill. The lack of impacts to the shoreline was attributed to river flow. In the Lac Mégantic incident, over 26,000 gallons of Bakken crude were released to the Chaudière River, and eventually extended 50 miles downriver. Efforts were made to clean the riverbanks and sediment, however oil is still present along the bottom of the river (CBC News, 2014).

The literature related to crude oil shows a wide range of responses, in part due to differencing methodologies, but also analytical methods used in determining the exposure conditions. Due to the differing solubilities of various products, API (2011) recommends the use of tests that measure the concentration in the aqueous phase at equilibrium, referred to the water–accommodated fraction (WAF). Acute toxicity tests measure effects observed after a very short period of exposure. Such tests typically result in measures of lethal concentrations in water, such as an LC_{50}, a concentration that is lethal to 50% of the test population. In some cases, other effects are studied after acute exposure, such as growth or reproductive effects. Such studies result in measures of effect concentrations in water, such as an EC_{50}, a concentration has an effect on 50% of the test population. Chronic studies involve longer term exposures, and attempt to identify no observable adverse effect levels.

A large number of studies have been conducted on the effects of crude oil on various species, and considering different types of effects. API (2011) evaluated the data and summarized it in their Category Assessment Document. This document was reviewed by EPA and supplemented by a review of EPA's ECOTOX database. A summary of the effect levels based on their review is provided in **Table 7-6**.

TABLE 7-6 AQUATIC EFFECT LEVELS FOR CRUDE OIL

Fish	96 hour LC50 - 0.73 – 42 mg/L
Aquatic Invertebrates	48 hour EC50 – 0.61 – 28.7 mg/L 21 day EC50 – 0.5 - 6 mg/L

Source: EPA, 2011

Bioconcentration or bioaccumulation of substances in tissues can also be a concern following releases to water and soil. This is the entry and concentration or accumulation of substances in tissues. The VOCs present in light crude oil are unlikely to be accumulated and transferred up the food chain. However, the PAHs also present in crude oil are known to accumulate in exposed zooplankton, which are a food source for a large number of fish species and numerous other animals (Almeda et al., 2013).

7.6.2 Terrestrial Systems

Little information is available on the toxicity of crude in terrestrial settings, although the effects described above on vegetation in marsh setting are also likely to occur in terrestrial systems. In order to identify any available information, an ECOTOX report (EPA, 2015) was run for terrestrial exposures, and no information specific to crude oil was identified. Information on the Alaska Department of Conservation Spill Prevention and Response web site (2015) indicates that crude oil releases can result in damage to vegetation, with the lighter fractions penetrating and destroying plant tissues, and the heavier fractions coating leaf surfaces and impacting the exchange of oxygen and carbon dioxide. Crude oil can also have indirect effects on vegetation by creating hydrophobic conditions in soil, which results in reducing water to the roots. They reported that dry tundra is more susceptible to damage from a crude oil release than moist tundra because the aromatic fractions will be carried into the soil before they can evaporate, resulting in damage to roots and buds.

Baek et al, (2004) found that crude oil had phytotoxic effects on the growth of red beans (*Phaseolus nipponesis OWH1*) and corn (*Zea mays*). Soil containing crude oil at 10,000 mg/kg was phytotoxic to both species. When exposed to concentrations of the aliphatic hydrocarbons such as decane and eicosane up to 1000 mg/kg, no phyotoxicity was observed. However, soil containing concentrations of 10 to 1000 mg/kg of the PAHs naphthalene, phenanthrene and pyrene did have phytotoxic effects, and phytotoxicity increased with the number of aromatic rings.

In general, exposure to terrestrial organisms is likely to be limited in a spill situation. Therefore, significant exposure to terrestrial receptors is unlikely to occur. However, localized effects to the vegetation, and the soil microbe and invertebrate community may occur in the spill area.

8.0 SPILL ASSESSMENT AND DELINEATION

The general spill assessment and delineation process for a crude oil release is similar to a release of petroleum hydrocarbons. Petroleum constituents resulting from a Bakken Crude Oil release behave similar to gasoline. However, as discussed previously, crude oil is unrefined and its chemical and physical properties vary extensively so a more comprehensive assessment may be required to evaluate potential immediate and longer-term risk to first responders and the public.

8.1 Initial Characterization of Response Area

The spill assessment and investigation process should mimic that utilized for a petroleum fuel oil release inclusive of gasoline. This would include screening of ambient air within and outside the release area for the components of interest, visual determination of impacts including stressed vegetation, evidence of impacted aquatic biota, and visual detection of petroleum sheens; statistical determination of appropriate sampling locations and numbers; collection and screening of environmental samples; and the collection and confirmatory analysis of samples.

The topic below summarizes the types of observations and/or samples which may be needed to assess the extent and impact of a release. Details on the actual screening tests and analyses are discussed in Sections 8.2 and 8.3, respectively.

Due to the wide variability in crude oil characteristics and constituent content, first responders must be prepared with a wide array of air monitoring equipment prior to entering a spill zone. Initial screening methods must be used to protect work crews as well as limit the potential for exposure to explosive environments.

Additionally, wind direction, atmospheric conditions, and the general surroundings are important factors that must be considered by the first responders when assessing the initial scene.

Table 8-1 summarizes the sampling objectives and techniques, which are discussed further below.

> **Visual Observation/ "Size Up"** - Due to the nature of crude oil and the extremely dangerous conditions exhibited by crude oil releases involving rail accidents, visual observation or Size Up in the first phases of the response are critical for the safety of the responders, the public and the environment.
>
> Absent fire, careful inspection for evidence of free-phase crude oil, sheens, or evidence of biota impacts (dead fish, stressed vegetation, etc.) will permit immediate activation of the

appropriate support teams to limit the longer term impacts. Generally, crude oil will be identifiable in water, on surface soil, on vegetation, and on man-made structures. Wet spots or staining on soil or solid surfaces should be investigated and screened for properties such as flammability. Pooled liquids and even surface waters can be quickly visually inspected and field screened for flammability.

Although life safety is a responder's primary concern, communications with incident command related to observation of this nature will permit an early response and may prevent longer-term impacts. Safety controls and air monitoring discussed below should be part of the "Size-up" to protect the crews initially involved in any on-scene activities.

Ambient air monitoring – due to the chemical properties of crude oil, ambient air monitoring for multiple toxic and hazardous environments is critical for the safety of the first responders. A multi gas detector ensures safe operations and ensuring that dangerous quantities of escaping gases are detected swiftly so that an appropriate safe response can be implemented. Multi-gas meters also monitor the atmospheric mixture of oxygen and other breathable and toxic gases. Flammability (LEL) can also be used as an indicator of presence/absence of crude oil constituents. Real-time screening of air can be conducted for presence of vapor-phase concentrations of crude oil and flammable gases, and, longer term (8-hour) exposure monitoring can be conducted within and outside spill zone (NIOSH methods). Due to the potential for fire, crews should be prepared to perform perimeter and personnel monitoring for particulates. Due to the potential for fire, crews should be prepared to perform perimeter and personnel monitoring for particulates using air monitoring equipment and potentially laboratory analysis (NIOSH 0600).

Collection of Samples from Environmental Media - grab samples can be collected of site soil, sediments, surface waters, and groundwater, depending upon the extent of release and exposed media. Since volatile compounds of crude oil are rapidly biodegraded, water samples intended for off-site shipment must be preserved at a pH<2. Soil and sediment samples for confirmatory analysis must be collected using acceptable VOC sampling and preservation methods. Sampling for analysis of other petroleum related constituents must utilize approved sampling and preservation methods.

TABLE 8-1 SAMPLING TECHNIQUES

Objective	Matrix	Techniques
Determine immediate extent of spill and impact-including during first responder efforts	Surface water, surface soil, paved surfaces	• Visual observation-sheens from crude oil, visible fires, pooled large volumes of liquid • Stressed vegetation, dead fish or animals • Quick flammability screen
Determine extent and hazard of ambient air in spill area and immediate vicinity	Air- Real-Time Monitoring	• LEL-flammability • Indicating tube-target benzene and other flammable gases • PID-targets crude oil components (BTEX) • FT-IR- can differentiate crude oil components (BTEX)
Determine vertical and horizontal extent of environmental impacts in site surface water, soil, and groundwater	Ground and surface water, soil	• Grab samples for either on-site screening or laboratory analysis. • Water samples to be analyzed for petroleum related constituents including BTEX. Samples must be collected and preserved as for VOCs and SVOCs. • Samples must be collected using closed-loop sampling methods
Determine potential off-site impacts to nearby air-receptors	Air	• 8-hour samples using absorption tube methods (NIOSH 1400)

8.2 Screening Methods

There are a multitude of rapid screening methods for petroleum hydrocarbons. These methods can provide qualitative and quantitative results. Basic field chemistry kits or calibrated monitoring equipment can be deployed within short periods of time. The limitations and the specific applicability should be considered prior to field application of the following methods.

- Head Space Organic Vapor Monitoring
- Immunoassay
- Infrared Spectrophotometry
- Ultraviolet Fluorescence
- Field Gas Chromatographs

Head Space Organic Vapor Monitoring - This method measures vapors emitted from any media in the headspace of a sealed container. The results are limited by the actual method employed. Instruments can include photoionization detectors (PID), flame ionization detectors (FID), and colorimetric tubes. Once the media is placed in two jars, the containers should be shaken for 15 seconds. If the temperatures are below 32 degrees Fahrenheit, the container should be heated to vaporize the volatile material. The method requires consistency in material, jar head space and temperature for comparable data. Once the material has been heated, if necessary, a calibrated instrument is utilized to measure the volatile constituents within the headspace. Most instruments are calibrated to a specific compound.

Colorimetric tubes provide both qualitative and semi-quantitative screening of aromatic hydrocarbons in soil and water using the headspace principal or in ambient air. The procedure requires breaking the ends of a glass tube containing a known quantity of reagent. The tube is inserted into a hand pump and the hand pump is actuated to draw air across the reagent medium. The reagent changes color based upon the concentration of constituent in the space being evaluated.

Immunoassay - EPA Method 4030 Soil Screening for petroleum hydrocarbons by immunoassay is a screening method to determine whether petroleum hydrocarbons are likely present. Deployment of the equipment for immunoassay testing can be completed quickly and the screening results provide consistent results at a release site. If more precise results are required, an on-site gas chromatography or infra-red spectroscopy can be deployed. The available screening methods for Crude Oil are summarized in **Table 8-2**, and discussed below:

Infrared Spectrophotometry (IRS) - This method requires an understanding of basic chemistry for proper application. A specific mass of soil potentially containing the petroleum is added to a silica gel prior to extraction with a method prescribed solvent. The resulting aliquot is then analyzed and the corresponding result is compared to a known standard of the petroleum hydrocarbon analytes.

Ultraviolet Fluorescence (UVF) - This method is used as a tool to detect specific constituents contained within petroleum hydrocarbons. Application of the method can be used for both soil and water, but the method does not provide a concentration, but a mass. A sample can be prepared and tested in minutes. This method requires a trained technician to operate the equipment. Benefits of the equipment are that it is real time data and little sample to no preparation or preservation is required.

Field Gas Chromatographs (GCs) - This method is able to provide the highest data quality for constituent-specific analysis of soil, soil-gas, and water samples for volatile and semi-volatile hydrocarbons. Like the IRS and UVF, the method requires advance training. Field GCs can measure constituent concentration in the part per billion (ppb) range for soil, soil-gas, and water with a lower detection limit of between 1 to 10 ppb, depending on the method and equipment.

TABLE 8-2 CRUDE OIL SPILL SCREENING TECHNIQUES

Method	Technique/Detector	Detection Limit	Comments
Quick Screens for Presence/Absence			
Open flame test	Exposing small volume of material to open flame	Presence/Absence	• Identifies relatively high concentrations of flammable constituents in crude oil (still flammable)
Air			
Real time monitoring for flammability	LEL monitor-calibrated versus methane	1-percent of LEL	• Correction Factor (CF)=.5
Color Tube	Air pumped through reactive sorbent-color change occurs based upon concentration	Benzene-5-40 ppm	• Need separate tubes for each analyte • One-time use
Real-time monitoring w/PID	Air pumped into chamber with a photo-ionization detector-calibrated versus isobutylene	Benzene- 5-20 ppm	• Non-selective • C F =.53 for 10.6ev lamp • CF = .60 for 11.7ev lamp • Response to gasoline components (BTEX) greater
UltraRAE Benzene Monitor	Air drawn into instrument.	Benzene 50ppb to 200pmm	• Selective monitor isolates benzene from other VOCs • 60-sec real time and 15-minute STEL
Real-time monitoring w/FID	Air pumped through chamber, detected via flame ionization	Benzene- 5-20 ppm	• Non-selective

TABLE 8-2 CRUDE OIL SPILL SCREENING TECHNIQUES (cont.)

Real-time monitoring w/FT-IR	Air pumped into chamber where it is subjected to excitation and the resulting infra-red spectral bands are detected. FT-IR peaks are unique to particular compounds	Benzene- 200 ppb	• Selective and can screen simultaneously since bands for BTEX (2500-2000 cm^{-1}) are separated • BTEX in compound library
Water			
Screen for impact in surface water bodies	Dissolved oxygen probe biochemical oxygen demand, chemical oxygen demand per standard methods	0.5 mg/l dissolved oxygen	• Can be used to identify impact to surface water and monitor recovery
Headspace with GC using detection by FID, PID, or MS	Measured volume of sample with known headspace is allowed to equilibrate and a volume of the headspace injected for comparison to similarly prepared standards	Benzene- 5-50 ug/l	• Trained technician required • Minimal preparation, but a stable environment required. • Samples must be heated to consistent temperature
Direct injection onto a GC with detection via FID, PID, or MS	Known volume injected onto the GC and the compounds separated and detected. Comparison to standards	Benzene-250 ug/l	• Trained technician required • Requires use of mobile lab and stable environment.
Portable GC with Purge & Trap system-detection via PID, FID, or MS	Known volume sparged through a sorbent media which is then backflushed under rapid heating to force trapped compounds into the GC. Comparison to standards	Benzene- 5 ug/l	• Trained technician required • Requires use of mobile lab and stable environment
Soil and Sediments			
Headspace with GC using detection by FID, PID, or MS	Measured mass of sample is added to a known volume of water with known headspace and allowed to equilibrate; headspace injected onto the system for comparison to similarly prepared standards	Benzene- 50-500 ug/kg	• See comments above

TABLE 8-2 CRUDE OIL SPILL SCREENING TECHNIQUES (cont.)

Direct injection onto a GC with detection via FID, PID, or MS	Measured mass of sample is added to a known volume of water; injected onto the GC and compounds separated and detected. Comparison to standards	Benzene-250 ug/kg	See Comments above
Portable GC with Purge & Trap system-detection via PID,FID, or MS	Measured mass of sample added to known volume of solvent and then a known volume is placed into a vessel containing water. The sample/solvent/water volume is sparged through a sorbent media which is then backflushed under rapid heating to force trapped compounds into the GC. Comparison to standards	Benzene- 50 ug/kg	• See Comments above

Screening Presence/Absence-Soil and Water - One of the simplest ways to ascertain whether or not crude oil and related constituents are present in media is via a simple open-flame burn test. This can yield valuable information, especially when performing the visual observation/delineation phase of spill site assessment. There are two basic means to perform a quick flame test.

- Place a very small volume or mass of the material into a shallow container such as a watch glass or even a small pie tin and wave a lighted match or a propane torch above the sample; or
- Make a small loop in a length of copper wire, dip it into the sample, and then place it into an open flame.

In either case, if the sample (or wire) burns, sparks, or otherwise supports combustion the spilled product is present in the test sample.

Ambient Air Field Screening - Color-indicating tubes are available for specific constituents present within crude oil. Tubes will provide rapid single analysis for the specific compounds. Benzene, normally associated with most light-end petroleum products, reacts well with the applicable reagents in the tubes. However, tubes can be temperature sensitive, and although manufacturers provide correction data, it is rarely used in the field during a response. This extra step makes tubes difficult for application during a rapid response where immediate data is necessary.

Constituents within crude oil (BTEX) respond well to a PID and a portable FID. FIDs also respond to other volatile organic compounds, including methane. Other air measurement devices will also be useful for immediate evaluation of airborne constituents. A gas detector (4-gas meter) can be used to detect flammable, combustible, and toxic gases (hydrogen sulfide), and oxygen depletion. 4-gas meters are often deployed with first responder hazardous materials teams to evaluate conditions prior to entry.

If real-time and simultaneous detection of specific crude oil constituents is necessary, the best available technology is a portable Fourier Transform Infrared (FT-IR) spectrometer, available from several manufacturers. These instruments are capable of low ppm detection in air, contain pre-loaded compound libraries which include benzene, and can simultaneously screen for up to 25 compounds including the major volatile components of crude oil.

Soil/Sediment and Water Field Screening Environmental matrix samples can be field-screened using typically available portable gas chromatographs (GCs). A PID or mass spectrometry (MS) are also acceptable methods to detect crude oil constituents.

8.3 Analytical Methods

There are many analytical techniques available that measure Total Petroleum Hydrocarbons and the specific constituents that comprise crude oil. There is no single method that captures all constituents of interest so multiple methods must be employed to properly characterize a crude oil release to environmental media (air, soil, sediment, water, etc.). Additionally, there is significant variability from state to state related to analytical methods for detecting specific crude oil constituents and the associated regulatory risk-based standards. Use of the state specific methodologies is a best practice.

The methods discussed in this section are specific to evaluating crude constituents once released into the environment. This is not a discussion related to the proper characterization of crude oil prior to transportation.

Water, Soil, and Sediments - the most prevalent methods for determining constituent concentrations in environmental matrices utilize direct-injection techniques and GC-FID using narrow-bore capillary columns fused silica capillary column. Laboratories usually refer to these methods as 8015M when citing procedures. Direct injection methods yield detection-limits in the low ppm range for both waters and soil/sediment.

Laboratories may also analyze samples for crude oil by GC/MS using the purge and trap techniques (methods 3500).

Air- Perimeter, work zone and personnel monitoring should be conducted to analyze for the presence of petroleum, VOCs (BTEX), PAHs, and particulates (burning fuel). Several methods are available to analyze for these constituents.

- MassDEP Air Petroleum Hydrocarbon (APH) method-APH requires use of a sub-atmospheric pressure canister (SUMMA), flow controllers and GC/MS. The method is designed to support a toxicology approach developed to evaluate the risk posed by petroleum hydrocarbons and related constituents.
- TO 13 requires use of a filter and sorbent material using a high flow rate air sampler and GC/MS for the detection of PAHs. Air is drawn across the sampling material and the material is then prepared at a fixed laboratory for analysis.
- TO-14a or TO-15- requires use of a SUMMA, flow controllers and GC/MS for the detection of VOCs. Both methods include non-polar VOCs. Use of TO-15 when identification of polar (water soluble) constituents are necessary.
- NIOSH 0600- requires use of filters and sorbent material to evaluate respirable dust in the event of burning crude either in personal sampling equipment or perimeter samples.

TABLE 8-3 ANALYTICAL METHODS

EPA Method	**Test Name**	**Instrument**
	Drinking Water	
EPA 200.7	Metals and Trace Elements	Spectrometry
EPA 524-2	Purgeable Organic Compounds by GC/MS	GCMS
EPA 602	Purgeable Halocarbons and Purgeable Aromatics–Field Preserved	GCMS
EPA-610	Semi- Volatile Organic Compounds	GCMS
EPA 624	Volatile Organic Compounds	GCMS
	Soil, Water and Sediment	
EPA-6010, 7000 Series	Metals and Trace Elements	Spectrometry
EPA-8015	Non-halogenated Organics	GCFID
EPA 8021B	Aromatic and Halogenated Volatiles	GCPID
EPA 8260B	Volatile Organic Compounds	GCMS
EPA 8270	Semi- Volatile Organic Compounds	GCMS
MassDEP VPH	Volatile Petroleum Hydrocarbons (VPH) for Massachusetts	GCMS
MassDEP EPH	Extractable Petroleum Hydrocarbons (EPH) for Massachusetts	GCMS
	Air	
MassDEP APH	Petroleum Hydrocarbons using Summa canisters	GCMS
EPA TO-13	Poly aromatic hydrocarbons in Air collected with filter and sorbent materials	GCMS
TO-14a	VOCs collected using SUMMA canisters for non-polar constituents	GCMS
TO-15	VOCs analyzed using SUMMA canisters for polar and non-polar constituents	GCMS
NIOSH 0600	Respirable dust particulates (burning crude oil)	Gravimetric (filter weight)

9.0 RESPONSE OPTIONS

9.1 General Description

The highly variable physical and chemical properties of Bakken crude oil present unique challenges for addressing release scenarios and remediation. In crude oil spills, there is a high likelihood for a layered spill profile, lighter (sweet) crude oil and lighter components behaving like gasoline dispersing on water surfaces and heavier (sour) crude oil and heavier components behaving like diesel fuel remaining semi-solid, requiring two-different clean-up approaches (Mason and Gafford, 2015; DOT, 2014b). Light, sweet crude oil will also normally contain lighter flammable gasses such as butane and propane which can readily ignite if released, when they come in contact with an ignition source (Mason and Gafford, 2015). Bakken crude oil may also contain hydrogen sulfide, a toxic inhalation hazard material, in the vapor space of the tank car (DOT, 2014b).

The review of response action detailed below has been completed for Bakken crude oil releases, but is applicable to the varying ranges of crude oil in North America.

The proper classification and characterization of individual crude oil shipments are necessary to enable the most effective and informed emergency response (DOT, 2014a). The following sections describe short term and longer term response priorities. These sections are followed by media-specific options.

9.1.1 Short Term Response Priorities

The priorities of first responders are life safety, incident stabilization, and minimizing environmental impacts. It is not the objective of this report to provide guidance as to how to conduct these activities in the event of a crude oil spill. Rather, it is to provide guidance as to the potential for long term impacts of various options.

For crude oil assigned to NA 1267 Petroleum crude oil, irrespective of Packing Group, Guide No. 128 of the 2012 Emergency Response Guidebook (ERG) provides a first responder with instructions on what steps to take upon arrival at the scene of an accident or incident (Dangerous Goods Transport Consulting, Inc., 2014). These provide initial response guidance for crude oil incidents only to be revised by incident command (DOT, 2014b). Excerpts from the guide for addressing fire and spills are presented below (Dangerous Goods Transport Consulting, Inc., 2014).

In the presence of a fire involving tanks or car/trailer loads (Dangerous Goods Transport Consulting, Inc., 2014):

- Withdraw from the area and let fire burn if proper equipment is not available
- Utilize water spray, fog, or regular foam. Do not use straight streams. Fight fire from maximum distance or use unmanned hose holders or monitor nozzles.
- Cool containers with flooding quantities of water until well after fire is out to prevent re-ignition and explosion of heated containers.

In the event of a spill or leak (Dangerous Goods Transport Consulting, Inc., 2014):

- Eliminate ignition sources. Ground equipment used when handling the product.
- Prevent entry into waterways, sewers, basements, or confined areas.
- A vapor suppressing foam may be used to reduce vapors. Water spray may reduce vapor but may not prevent ignition in closed spaces.
- Dike far ahead of liquid spill for later disposal.

The following factors should be considered to help estimate the potential impact of the problem spill or release (DOT, 2014b):

1. Is the material on fire?
2. Are other tank cars at risk of becoming involved?
3. Do you have the capability to successfully prevent the fire from spreading, which in some cases may require a minimum of approximately 500 gallons per minute per exposed tank car?
4. Are adequate foam supplies and equipment available for post-fire operations that may last for several hours or days?
5. Has the container been breached? If so, is product flowing?
6. Where will the container and its contents go if released?
7. Why are the container and its contents likely to go there?
8. How will the container and its contents get there?
9. When will the container and its contents get there?
10. What harm will the container and its contents cause when they get there?
11. How much material has been released? What is the proximity of the release to people, property, and the environment?

For non-fire spill scenarios (DOT, 2014b):

- Isolate the area and consider evacuation, if necessary.
- Eliminate or remove sources of ignition, if possible.
- Determine the concentrations of any flammable or toxic vapors using air monitoring instruments.

- Evaluate the need for continuous air monitoring with technical specialists.
- Determine if adequate foam supplies and equipment available for vapor suppression.

Fire Management

In case of fire, use any extinguisher suitable for Class B flammable liquid fires, dry chemical, CO2, or firefighting foam to extinguish. For large fires, water spray, fog, or firefighting foam is appropriate. Isolate area, particularly around ends of storage vessels (Tesoro, 2012).

In the event of a derailment scenario with a spill and fire, confinement and containment operations (i.e., spill control) are a priority. Traditional firefighting strategies and tactics may not be effective in these situations. If fire suppression operations are initiated, responders need sufficient foam concentrate supplies, adequate water supply, foam appliances, equipment, and properly trained personnel to effectively implement and sustain fire suppression and post-fire suppression operations. The strategy that provides the highest level of safety to responders is defensive to protect exposures or non-intervention tactics which allow the fires to burn out. The decision to protect exposures and let the product burn must be considered (DOT, 2014b). Major fires may require withdrawal, allowing the tank to burn (Tesoro, 2012).

Burning unit trains containing crude oil and adjacent cars should be cooled at the vapor space with unmanned hose lines to prevent heat induced tears and further minimize personnel exposure (IAFC, 2014; Tesoro, 2012). Use water fog spray to cool containers, control vapors, and to protect personnel from exposures. There is potential that containers of liquid that are not properly cooled may rupture violently if exposed to fire or excessive heat. Isolate the ends of tank(s) involved in fire, but realize that shrapnel may travel in any direction (DOT, 2014b) and the tank may rupture at any point in the structure.

Do not apply water directly inside a tank car. Apply water to the sides of the tank car from a safe distance to cool tank cars. Use unmanned fire monitors for cooling tank cars when available. Withdraw immediately in case of rising sound from venting pressure relief devices or discoloration of tank. If available, dry chemical extinguishing agents, such as potassium bicarbonate (i.e., Purple K) may also be used in conjunction with Class B foams (DOT, 2014b).

Improper application of fire streams may create a dangerous phenomenon known as a “slop-over”, thereby increasing risks to emergency responders. A slop-over results when a water stream is applied to the hot surface of burning oil. The water is converted to steam causing agitation of the liquid and burning oil to slop over the sides of the tank car. This can occur within 10 minutes of the product becoming involved in fire. Slop-over will not occur in a pool of crude oil on the ground (DOT, 2014b).

Apply Class B firefighting foam as you would on fires involving other hydrocarbons. Alcohol Resistant AFFF, as well as regular AFFF will effectively extinguish a fire. Class B foam blankets prevent vapor production and ignition of flammable and combustible liquids. Foam is most effective on static fires that are contained in some manner. Firefighting foam is not effective on hydrocarbon fuels in motion (i.e., three dimensional fires) that include product leaking or spraying from manways, valves, fractures in the tank shell (e.g., rips, tears, etc.) or spills on sloping terrain (DOT, 2014b).

Agencies should refer to the most recent edition of NFPA 11 – Standard for Low-Medium-and High-Expansion Foam for information concerning the specific requirements for foam application (DOT, 2014b).

As a general rule, do not flush crude oil spills with water. Most crude oil spills are not water soluble and will have a tendency to float on water. Some crude oil will sink and some fractions of crude oil are water soluble. For those fractions that float on water, burning crude oil may be carried on flowing water from the immediate area and may reignite away from the immediate source area (DOT, 2014b).

Vapor Management

In the event of a derailment scenario, foam should also be applied for vapor suppression, if available (DOT, 2014b).

Releases of crude oil may create vapor/air explosion hazards indoors, in confined spaces, outdoors, or in sewers. Remove sources of heat, sparks, flame, friction and electricity, including internal combustion engines and power tools. Use caution when approaching the scene and positioning apparatus. Implement air monitoring as soon as possible to detect the presence of combustible gasses (DOT, 2014b).

Volatile vapors released from the spill area may create flammable atmospheres (DOT, 2014b). Some crude oil vapors may be heavier than air and accumulate in low areas, and travel some distance to a source of ignition and flash back (DOT, 2014b; Tesoro, 2012).

There is also the possibility that the crude oil may contain varying concentrations of benzene or hydrogen sulfide. Products of combustion may also include toxic constituents (DOT, 2014b).

Do not begin foam operations until sufficient quantities of foam are on-site to meet the needs of the incident. Do not mix foam and water streams as this will dilute the foam and destroy the foam blanket integrity. A low expansion nozzle is recommended when using hand lines for crude oil scenarios. Apply foam with roll-on, bank down, or rain down methods. Never gouge the area to be foamed. The roll-on method directs the foam stream on the ground near the leading edge of the liquid pool on fire allowing the foam to flow across the fuel. In the bank-down method, the foam stream is directed off an adjacent elevated object allowing the foam to run down onto the surface of the fuel. The rain down method is less preferred and directs the foam stream into the air above the fire allowing the foam to gently float down onto the surface.

Spill Management

In the event of a derailment scenario with a spill but no fire, containment operations (i.e., spill control) are a priority to limit the size and spread of the release. Damming and diking may be required to limit the potential for the spill to migrate beyond the immediate area and cause extensive environmental damage (DOT, 2014b). Diversion can be applied to divert product from an area of higher harm to lower harm or move uncontaminated clean water away from the contaminated area.

Retention areas may be required to confine a large spill in a depression, pit, pond, or ditch and to minimize lateral spreading. Diking and damming can divert a spill to a location for collection.

Carefully contain and stop the source of the spill, if safe to do so from entering sensitive environmental areas and bodies of water by diking, absorbents, or absorbent booms, if possible. Do not flush down sewer or drainage systems, unless system is designed and permitted to handle such material (Tesoro, 2012).

Absorption is faster for lighter crude oil and components and adsorption is more effective for thicker oil.

If crude oil impacts sewer and drainage systems, water ways or environmentally sensitive areas, containment booms, underflow dams and other means may need to be deployed quickly (IAFC, 2014). Fractions of crude oil are lighter than water and will float on the surface. Spills near waterways may spread rapidly, especially in moving water situations.

Prevent runoff from entering storm/sewer systems and sensitive areas, as this may create a serious hazard and potential environmental impact. Notify proper authorities, downstream sewer and water treatment operations, and other downstream users of potentially contaminated water. Runoff may be flammable and/or toxic and should be contained, treated, and disposed of in accordance with applicable federal, state, and local environmental regulations (DOT, 2014b).

Any efforts by first responders to control or prevent migration of crude oil will have benefits in reducing future response actions to address multi-media impacts.

Wreck Access and Clearing

The railroad can provide expertise and specialized equipment during the emergency phase of the operation. Initially, the railroad will provide the manifest and waybill information for all hazardous commodities onboard the train is available to responders. Heavy equipment specially designed for railroad use can also be called in. Hazards exist from both the spilled material and from physical hazards posed by very large objects under stress. This help can be from the involved railroad, through mutual aid agreements with other railroads, or through contract support. As with any response asset, the earlier mutual aid assets are called, the sooner they can have resources on scene to support emergency operations.

9.1.2 Longer Term Response Priorities

Longer term response priorities are focused on preventing migration of crude oil from the spill site after any fire is stabilized. This can include removal of spilled material, soil removal, damming of creeks or ditches, etc.

Implement a runoff control strategy to control the migration of surface runoff and groundwater downstream of contaminated soil; avoid contaminating clean media; and collect oil and run-off water in trenches for treatment (Golder, 2014). Ditches and dikes may successfully stop the flow of oil over land and into surface waters (Crosby, 2013).

Perform site securing activities to prevent the spread of contamination via preferential paths into water courses. Responders should consider options to plug and re-route sewer lines; installation of bentonite or clay plugs at strategic locations along underground infrastructures; construct temporary ponds at sewer outlets; construct numerous trenches to intercept oil having infiltrated the water table and pump out oily water; installation of recovery wells in sewer fill (hydrovacs); and interventions on surface water bodies (e.g., booms).

Care should be given when plugging sewers and drains and should coincide with recovery operations if necessary so as not to create flammable environments. Migrating crude oil will have a vapor component requiring the implementation of air quality monitoring within enclosed spaces (e.g., sewer lines, basements, etc.) and construction of vents on manholes (Golder, 2014). The remediation techniques employed at the Lac-Mégantic event consisted of mass excavation for restoration of railway operation, construction of temporary soil storage platforms, installation of recovery trenches, runoff control and treatment systems, partial replacement of sewer and water lines, and remediation of shoreline (Golder, 2014).

Clean-up and post-emergency operations include establishing a decontamination corridor, ensuring proper decontamination of emergency personnel, containing all runoff, and properly dispose of PPE and runoff in accordance with applicable federal, state, and local environmental regulations (DOT, 2014b).

9.1.3 Storm Drains and Utility Conduits

Crude oil will travel on a predictable path through storm sewer systems and other utility conduits encased with fill material. Responders should divert crude oil and liquid runoff away from storm drains, manholes, culverts, etc.; plug inlets if feasible; and set up booms at the known outlets (Crosby, 2013).

Do not allow liquid runoff to enter sewers. Gas may form explosive mixture with air in the sewer system (Tesoro, 2012). Establish a runoff control strategy to control the migration of surface runoff downstream of contaminated soil to avoid contaminating the sewer lines and the fill around them (Golder, 2014).

Oil that has entered storm sewers can be removed by vacuum pump or other intrinsically safe equipment.

9.2 Media Specific Options

Oil spill countermeasures include mechanical systems for containment and collection as well as non-mechanical options. Response methodologies in these two general categories are applicable to most oil although the lightest and heaviest ends of the oil spectrum typically limit effective applicability of either (Polaris, 2013). The behavior and character of the weathering oil are important considerations for spill response strategies and tactics.

9.2.1 Soil

Oil spilled to soil, ground, or on shorelines (including river/stream banks) will tend to spread, evaporate, move downslope, and penetrate into the substrate (Polaris, 2013). Barriers are commonly used to mechanically impede oil spreading and movement. On land, these may consist of berms, walls, and trenches (Polaris, 2013).

Contained/Controlled Burn

Under ideal conditions of wind direction and speed, ground cover, distance from structures, and other site-specific elements, the best approach to minimizing movement of oil through soil may be to allow the product to burn and/or conduct a controlled burn of the spilled product. Contained/controlled burns must be conducted with the oversight, guidance, and approval of the local fire officials and appropriate precautions must be taken to protect areas outside the burn zone and conduct sufficient monitoring to both protect and satisfy the public. Monitoring should include both chemical and physical elements, such as particulate matter in smoke.

Burning spilled oil will rapidly convert large quantities of oil into combustion products, carbon dioxide and water, with a small percentage of smoke particulate and other unburned residue products. Because the oil is mainly converted to airborne products of combustion by burning, the need for physical collection, storage, and transport of recovered fluids is reduced to the few percent of the original spill volume that remains as residue after burning (Evans, undated).

Burning oil spills often produce a visible smoke plume containing smoke particulate and other products of combustion which may persist over many kilometers downwind from the burn. Smoke production from crude oil fires varies with the area of the burn and the type of crude oil. Approximately 10 to 15 percent of the mass of crude oil burned in large areas is converted to particulate that is carried in the smoke plume (Evans, undated).

The risks associated with this method include unexpected changes in wind direction and/or speed causing the burn profile to shift, public exposure to the smoke and byproducts, and the overall perception of an outdoor burn of an oil spill. This method is likely not suitable for urban areas due to the toxic vapors likely to be in the smoke plume.

Removal and Off-site Disposal

In spills where the product covers large areas of soil, the pooled oil and impacted soil will need to be physically removed. Excavated soil should be screened for flammability for safety and transport purposes.

Light crude oil tends to penetrate substrate and fresh spills are not adhesive. Heavy crude oil can be highly adhesive but do not readily penetrate substrate (Mason and Gafford, 2015). Thus, removal and off-site disposal of soil impacted by a crude oil release will be most effective for the heavier crude oil.

Crude oil may be absorbed, adsorbed, in-situ treated, pumped, or vacuumed into compatible containers for proper disposal.

In-Place Mixing/Evaporation

For very large impact areas where controlled burning is not possible and off-site disposal is not feasible, the soil can be physically mixed and manipulated to enhance the natural volatilization of the lighter components in crude oil. The objective of this approach is to safely encourage sufficient volatilization to reduce the volume of oil in the soil. In large spills, the work area can be divided into working grids. Although evaporation of spilled crude is not a preferred method of clean-up, encouraging evaporation to eliminate immediate danger to life safety and the environment is acceptable when other alternatives are not readily available during initial response.

The rate of evaporation of crude oil differs significantly within the fractions. The Bakken region produces lighter crude oil and therefore a significant amount of the release material will evaporate immediately (See Evaporation section 6.3.1). In addition to the physical characteristics of the crude oil, atmospheric conditions play a large role in determining the rate of evaporation. Wind and higher temperatures will increase evaporation.

Thus, in-place mixing with soil for evaporation is effective only for the lightest crude oil.

TABLE 9-1 RESPONSE OPTIONS FOR SURFACE SOIL SPILLS

Method	Conditions Required	Issues with Approach
Controlled/contained burn of pooled liquids	• Wind speed and direction away from structures • Open area not near structures or other flammable materials	• Local authorities responsible for public safety • Sudden wind shift could threaten other structures/areas • Not suitable in urban areas due to particulates and toxic vapors in smoke plume • Residue must be managed
Pooled Liquid Removal, Soil Excavation and Off-site Disposal	• More effective for heavier crude oil as slower to penetrate substrate • Viable treatment/disposal facility	• Less effective for lighter crude oil as faster to penetrate substrate • Excavated soil must be screened for flammability
In-place Mixing and Evaporation	• Effective only for lighter crude oil	• Residue must be managed • Must monitor and control work zone for flammability • Large impact areas should be divided into working grids

9.2.2 Groundwater

Poor miscibility of crude oil accounts for accumulation of free oil on the surface of groundwater and this may migrate laterally over a wide distance to pollute other zones (Onwurah, 2007). Where the groundwater table is shallow, responders can dig ditches or trenches to a depth that intercepts the water table. Product can then be recovered from the ditch or trench and directed to appropriate treatment.

Evaluation of appropriate technologies will be necessary to suit the specific site conditions and is beyond the scope of this document.

9.2.3 Water Bodies (Fresh or Marine)

In general, crude oil floats on water until oil densities change through weathering and/or sediment uptake. Crude oil may gradually overwash, become suspended in the water column, or sink depending on the degree of weathering and formation of oil-mineral aggregates (Polaris, 2013).

The strategy for cleaning up a spill in water bodies begins with localizing the spill, using a variety of boom strategies. Booms can be used in several ways: a containment strategy keeps the oil from spreading; collection holds the oil near the source; deflection steers the oil towards collection areas and away from sensitive areas; and protection creates barriers that keep oil from affecting sensitive areas. Booms work best in calm waters and this effectiveness decreases as wave heights and currents increase (API, 2014).

Cleanup tools include skimmers, sorbents, and chemical dispersants. Skimmers are mechanical devices that physically remove the oil from the surface of the water. Sorbents, available as pads, pillows, or booms, remove oil sheens and thin slicks that are too scattered for skimming. Chemical dispersants break down oil in water into small droplets enhancing natural dispersion (API, 2014). Use of chemical dispersants require by law specific regulatory concurrence prior to implementation.

Mechanical Containment and Recovery

Barriers are commonly used to mechanically impede oil spreading and movement. Booms, dams, and weirs are used to contain and concentrate oil on water. Containment challenges with booms include flow relative to the boom (current or towing speeds), turbulence, wave action, oil load in boom, and oil density relative to water (Polaris, 2013).

An underflow dam of gravel and earth or traditional materials for adjustable underflow dams should be considered for use in shallow waters, narrow waterways, calm waters, or low-flow conditions. Contained oil can be recovered with vacuum trucks, skimmers, dredging and other traditional oil recovery techniques.

As oil becomes entrained into the water column, either through turbulence or combination of flow and densities near those of the receiving water body, conventional surface booming becomes less effective. Conventional booms may be effective in containing oil that has only slightly submerged below the immediate surface, but other methods such as trawl nets specifically designed to recover heavy oil may become necessary. Bubble barriers (i.e., pneumatic curtain) have not proven successful in containment tests. Boom with mesh skirts provide moderately improved containment compared to conventional boom but are limited by current speed. Increased current speed and oil density result in less effective containment. The fine mesh successfully traps floating and submerged oil, though some of that oil will gradually extrude from the net (Polaris, 2013).

Containment of heavy oil is most effective prior to significant weathering and before any sediment uptake, hence the need to contain the relatively fresh oil. Once oil is easily overwashed or near neutral density, alternative forms of containment must be considered. As oil weathers and attains high viscosity, enhanced skimming and pumping systems are required to maintain effective recovery (Polaris, 2013).

Responders need to prepare for both a light, floating oil and the potential for a heavy, submerged or sinking oil. In addition, material that initially floats will lose light hydrocarbons to evaporation and mix with fine sediments and may eventually move into the water column and sink to the bottom at natural collection points. The ability to detect, monitor, contain, and recover submerged or sunken oil is limited. Research and development is ongoing to design equipment for responding to sinking or submerged oil spills (Crosby, 2013).

In fast moving water, recovering oil is more difficult as oil tends to entrain in the water column. Oil will flow under containment booms and reduce the efficiencies of most conventional oil recovery equipment. Installing underflow dams, overflow dams, sorbent barriers, or a combination of these techniques will often increase recovery efficiencies. (Crosby, 2013).

High wind or turbulent conditions also present challenges so sufficient length and size of containment booms should be fully considered to contain the oil (Crosby, 2013).

Bakken crude oil has a low viscosity, and will quickly spread and evaporate. It will quickly adhere to suspended solids in the water column, forming unstable emulsions. Recoverable product may persist for only 4 to 8 hours, depending on size of spill. Its lighter components volatilize, posing human health hazard near spill location, and the low molecular weight PAHs (i.e., naphthalene to phenanthrene range) dissolve in the water column causing toxic aquatic effects (NOAA, 2014).

Dispersant Application

Chemical dispersants cause a physical interaction between oil and water that help with oil droplet formation and stability within the water column. Dispersants can be used in conjunction with mechanical recovery and other countermeasures to reduce the overall impact of a spill, although not on the same portion of a slick. For most crude oil, dispersants begin to lose their effectiveness after 24 hours and most oil will no longer disperse after 4 to 5 days (Polaris, 2013). Appropriate regulatory approval is required prior to the use of chemical dispersants.

In-Situ Burning

Controlled on-water burning is a viable response option under appropriate conditions and regulatory approval. Light crude oil has a high burnability with an efficiency range of 85 to 98 percent. Heavy crude oil has a moderate burnability with an efficiency range of 75 to 90 percent. The burnability and efficiency decrease further for weathered crude (Polaris, 2013).

Burning spilled oil from the water surface reduces the chances of shoreline contamination and damage to biota by removing oil from the water surface before it spreads (Evans, undated).

Shoreline Cleanup

Oil spill clean-up operations may cause more harm to a fragile coastal marsh environment than the oil itself. One of the major fates of spilled petroleum in the coastal environment is its incorporation into the sediments (Onwurah, 2007).

Treatment options for shoreline cleanup vary for shoreline types and as a function of oil type. For example, low pressure flushing may be an applicable treatment technique for medium oil on coarse and sand-mixed substrate; however, the technique may be ineffective for heavy oil. Treatment tactics for shoreline cleanup include natural recovery, washing recovery, manual removal, mechanical removal, in-situ mixing relocation, in-situ burning, and bio-remediation (Polaris, 2013).

Shoreline impacts are less likely where current or flow transport the material away from the shoreline. Effects are more likely in calm waters (NOAA, 2014).

Chemical shoreline cleaners are available to treat oil that has adhered to the shoreline (Crosby, 2013). Appropriate regulatory approval is necessary prior to application of these techniques.

TABLE 9-2 RESPONSE OPTIONS FOR SURFACE WATER SPILLS

Surface Water Type	Approaches	Issues
Ditches, Small Creeks, Streams, and Rivers	• Deploy booms or construct earthen dam(s) to block outlets to other waters • Remove/dispose of oil/water mixture	• Earthen dams work best in defined channels with slow-moving water. • Weathered oil may sink and flow under booms. • Removal most effective in ditches and small pools
Large Rivers, Ponds and Lakes	• Deploy booms or construct earthen dam(s) to prevent further migration • Lighter components can be removed by surface boom	• Notify downstream water intake plants so they may take necessary precautions
Wetlands (Freshwater or Saltwater/Tidal)	• Deploy booms or construct earthen dam(s) to prevent further migration • Lighter components can be removed by surface boom • During low-water conditions remove pooled liquids and/or use controlled burn methods to prevent migration	• Tidal flow will increase area and media affected as the turbulence results in sinking and mixing of the oil with sediment and among vegetation.
Marine-inner harbor	• Lighter components can be managed by surface boom.	• Tidal flow will increase area and media affected as the turbulence results in sinking and mixing of the oil in the water

		column
Marine-outer harbor	• Deeper water and varied currents make containment with surface booms difficult • Dispersants • In-situ burning	• Turbulence results in sinking and mixing of the oil in the water column
Open ocean	• Deeper water and varied currents make containment with surface booms difficult • Dispersants • In-situ burning	• Turbulence results in sinking and mixing of the oil in the water column

9.2.4 Wetlands

Spills occurring in wetland environments pose unique challenges. Response options will depend upon factors such as size and depth of the wetland/marsh, proximity to larger open water, and in the case of tidal marshes, the tide stage and resulting water levels. Crude oil impacts fresh and salt water in the same way. Although response actions in wetlands may be similar to shoreline and shallow waters, responders must consider the potential fragile nature of wetland areas prior to implementation.

An underflow dam of gravel and earth or traditional materials for adjustable underflow dams should be considered for use in wetlands to contain the spill and prevent migration. Contained oil can be recovered with vacuum trucks, dredging and a number of other traditional oil recovery techniques.

If a release occurs during low-water conditions in tidal marshes, there are more options including those similar to response and clean-up of soil spills. Crude oil can be recovered from pockets of water surrounded by exposed ground. Failure to adequately remove accessible oil during the low-water condition will simply allow it to disperse once the tidal levels return. Thus, it is critical to address the spill while tidal conditions leave it exposed. Methods in this case can include applying sorbents and controlled burning of the material.

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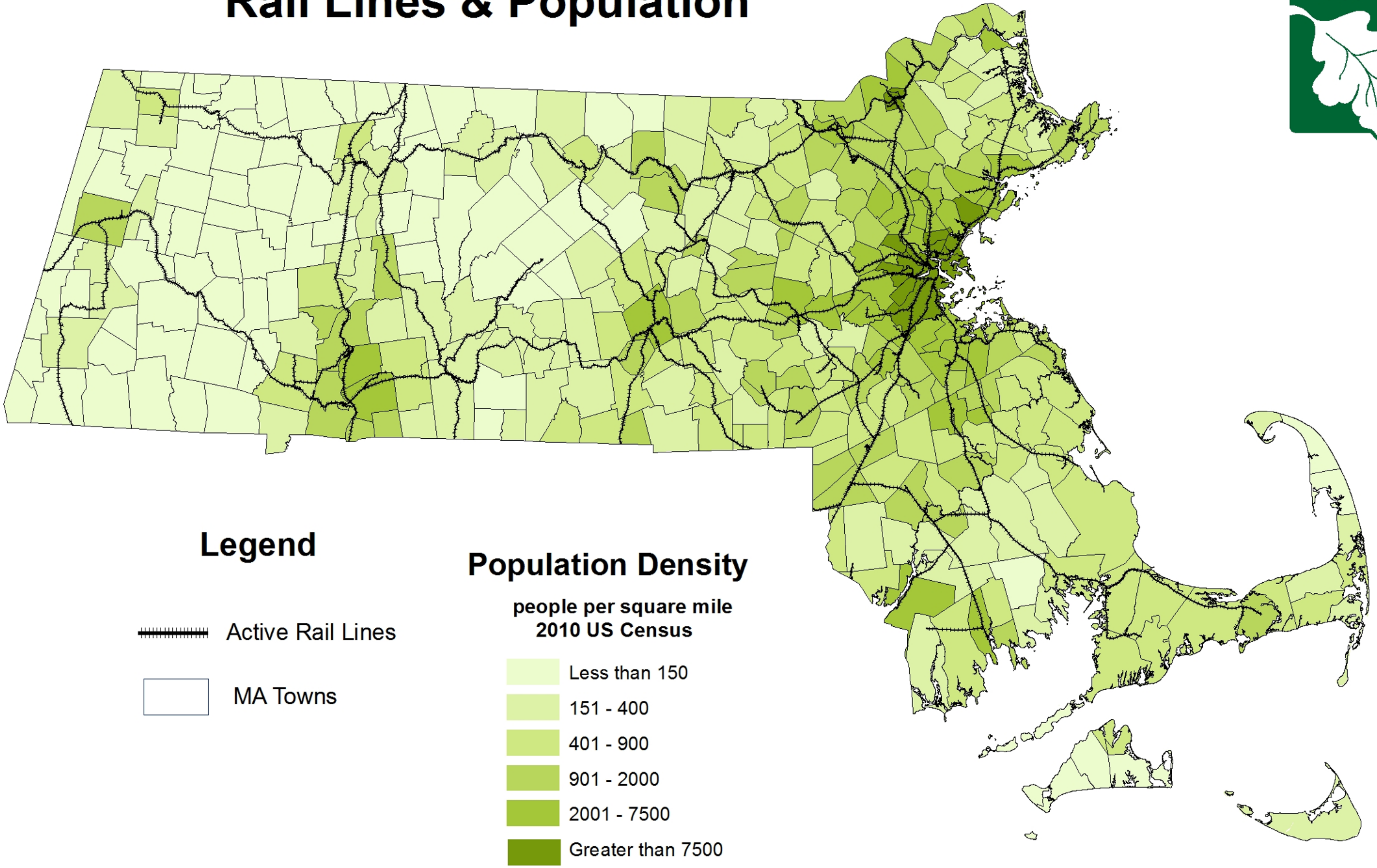
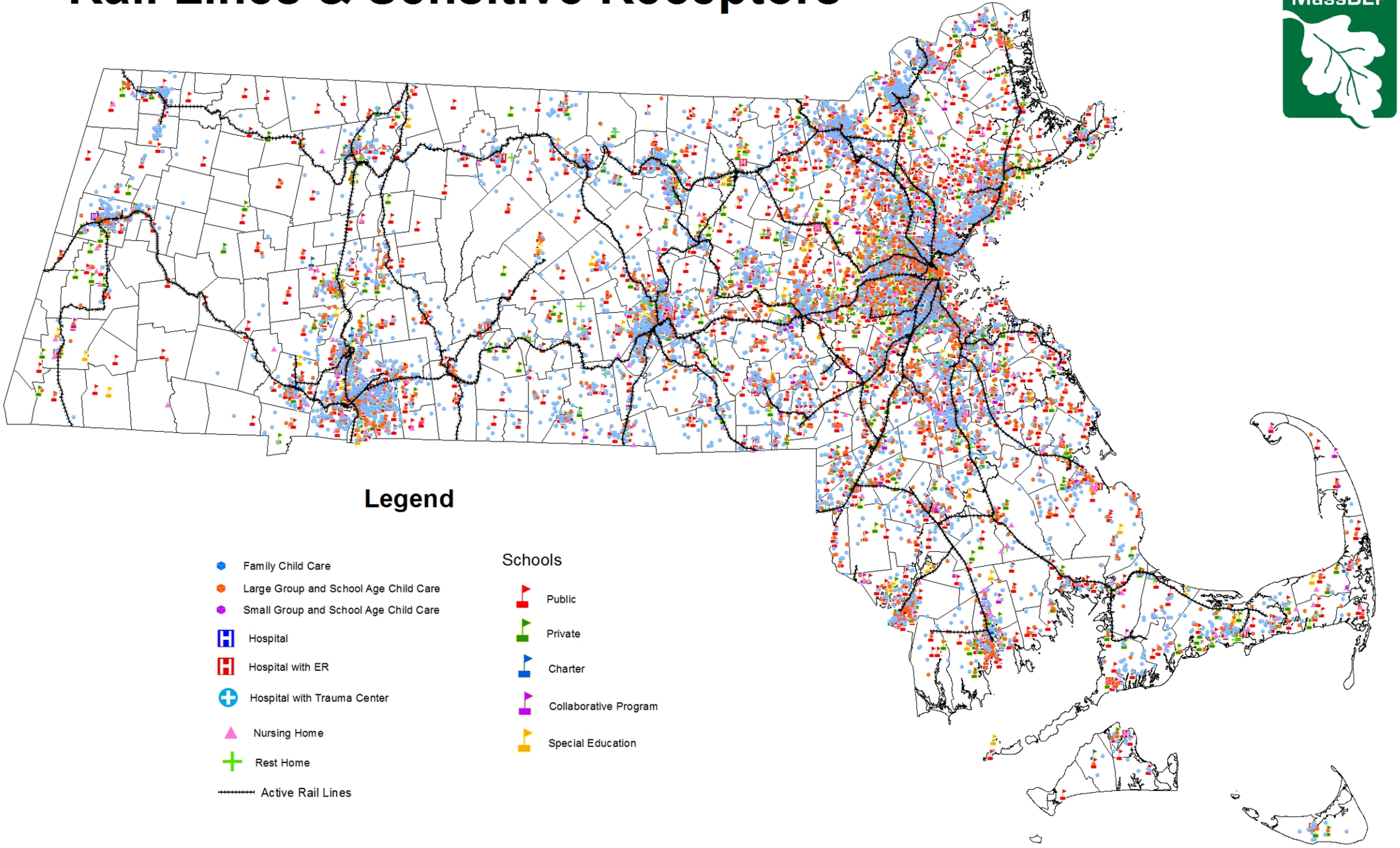
FIGURES

Rail Lines & Population

MassDEP

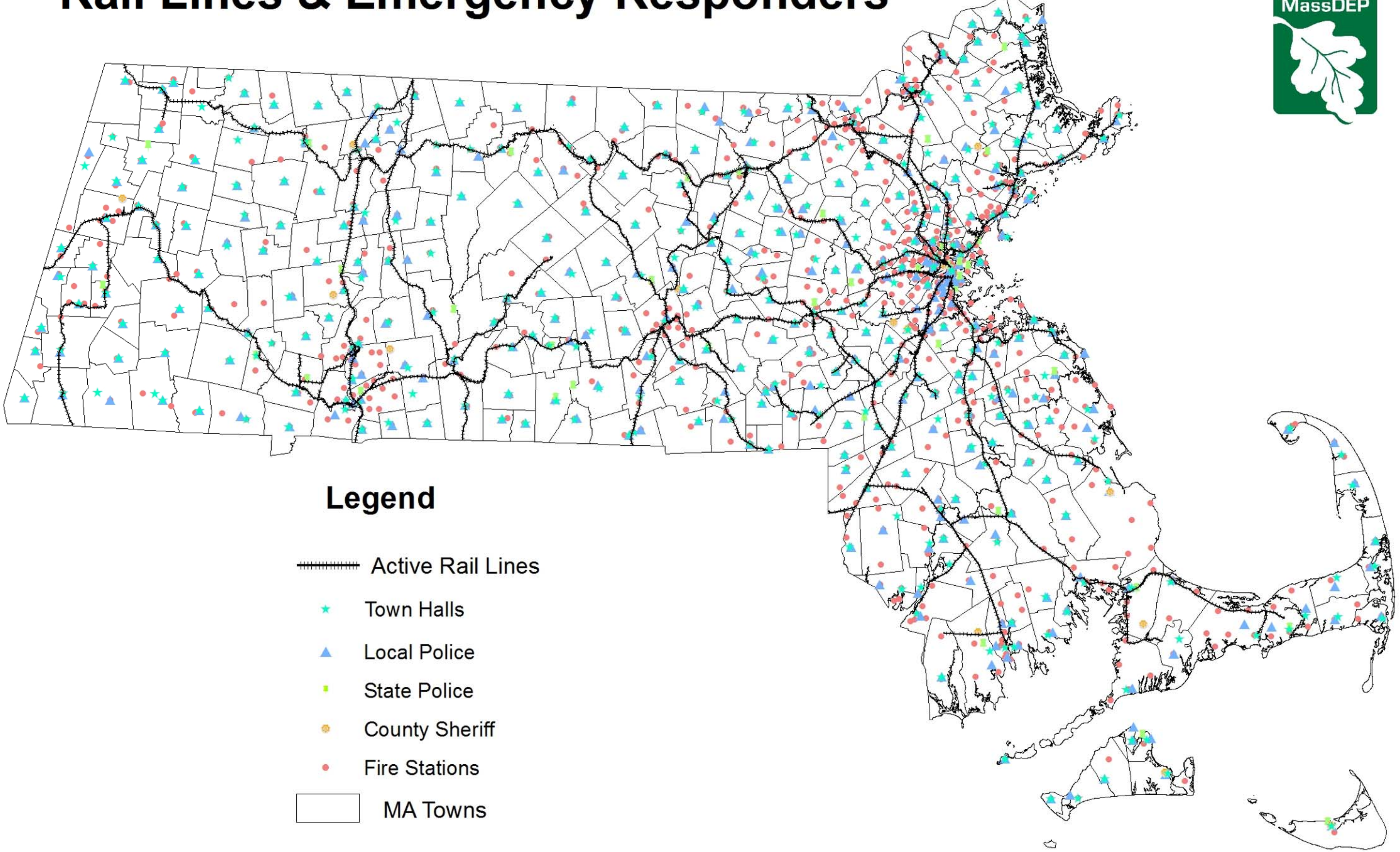


Rail Lines & Sensitive Receptors



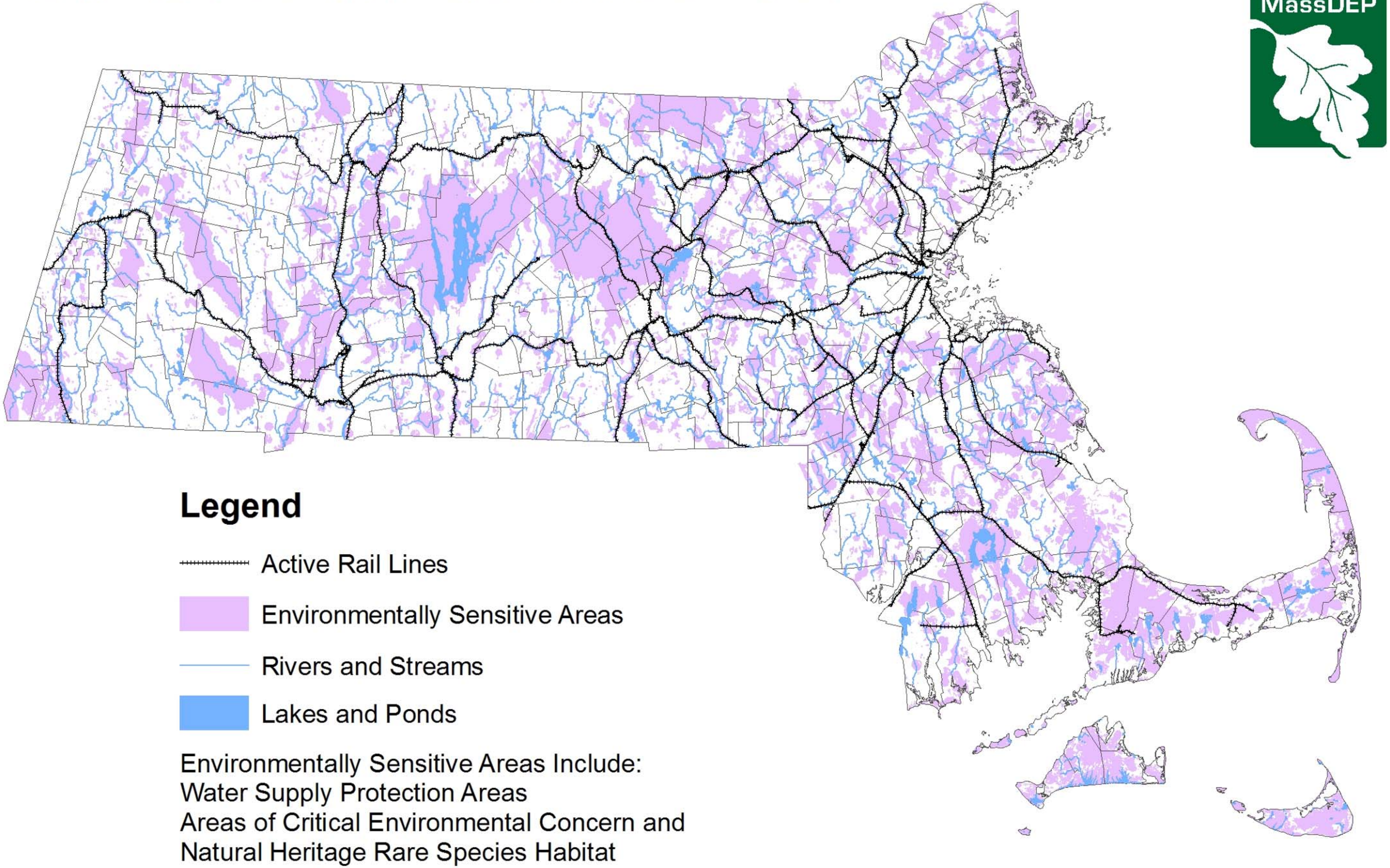
Rail Lines & Emergency Responders

MassDEP

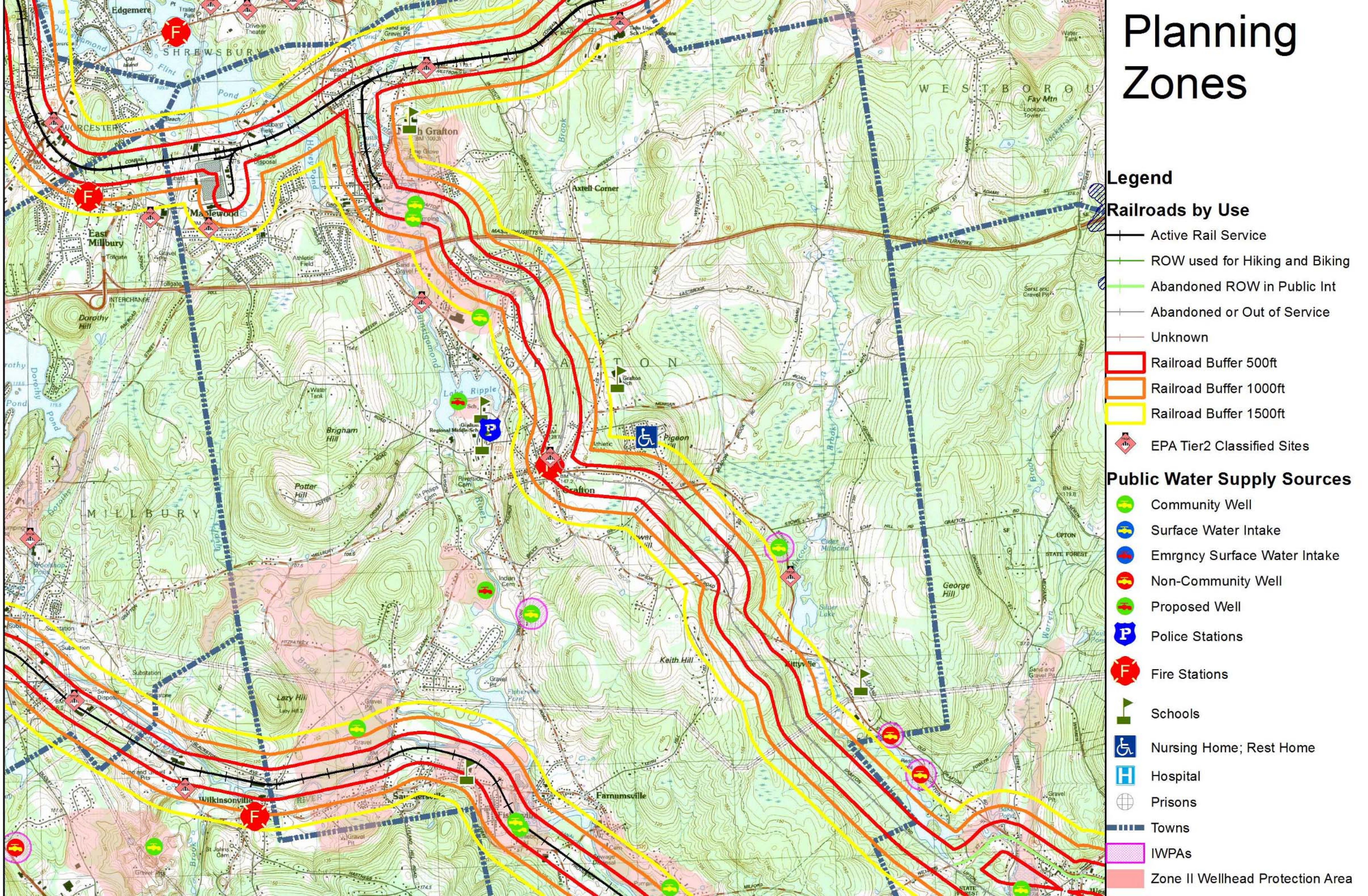


Rail Lines & Environmental Resources

MassDEP



Planning Zones



Appendix A

Case Studies

A1. INTRODUCTION

Although crude oil has been produced and transported in large volumes for many decades, North America is experiencing a dramatic increase in overall volume of crude oil transported by rail primarily due to growing production in the Canadian oil sands and the recent expansion of shale oil production from the Bakken fields in North Dakota and Montana as well as oil fields in Texas (Congressional Research Service, December 2014).

Unfortunately, along with the dramatic increase in overall volume, North America has also experienced an increase in the number of oil spills. According to the American Petroleum Institute (API 2009), volume of spills has decreased over the last few decades, but with the increase of volume transported individual spills have increased. Several of these spills have resulted in catastrophic failure and explosions including significant harm to public safety and the environment.

A2. RAILROAD INCIDENTS

With the dramatic increase of crude oil production and lack of available pipeline capacity from the oil fields to refineries mostly located in coastal locations on the east and gulf coast, rail transportation of crude oil across North America has increased from 9,500 unit cars in 2008 to 435,560 in 2013 (Congressional Research Service, December 2014). Even though several high profile accidents have resulted in significant harm to public welfare and the environment, the overall trend in releases is down. Nevertheless, the potential for a catastrophic release along the rail lines remains high and therefore proper planning and preparedness is necessary.

The following case studies provide a review of large scale accidents, their impact to the public, rail and community infrastructure and the environment.

Lac-Megantic, Quebec

On July 6, 2013, a Canadian Pacific Railway 74-car unit train originating in the Bakken formation area of North Dakota enroute to the Irving Oil Refinery in St John's New Brunswick derailed causing 47 deaths and devastation to a small community in southeastern Quebec.

Events Leading to the Accident
Prior to the accident, the operator, using standard company procedures, parked the train for the night on the main track in Nantes, Quebec approximately 3 miles uphill from Lac Magantic. A local siding designed for leaving a train over night was in use at the time by a local business. The operator set the air brakes on the locomotives and hand-brakes on several unit cars. Airbrakes work as long as the operating locomotive continues to supply air pressure (CTSB 2015).

Prior to departing for a local hotel, the operator contacted rail traffic control to report mechanical problems including heavy smoke from the lead locomotive. The operator and traffic control decided to address the issue in the morning. The operator then reported that the train was secured to his dispatch.

At approximately 2350, a 911 call reported heavy smoke from a locomotive parked on the mainline in Nantes. Local fire and police responded to the train and called rail operations for instructions. Standard operating procedures for the fire department were to shut down the locomotive prior to extinguishing the fire. During the response, the railroad dispatched two field rail engineers to the scene to inspect and provide guidance to the fire department. Once the fire was extinguished, the fire department departed the scene. Apparently, the field engineers were not aware of the limitation of the breaking system and did not perform a full inspection to determine how the train was secured (CTSB 2015).

The Accident

Later investigation of the accident by the Canada Transportation Safety Board determined that once the locomotive was turned off, the air breaks began to slowly bleed out. As brake pressure dropped below a sufficient level to withstand the total load of the 74-unit train, the train began to move toward the town of Lac-Megantic, Quebec approximately 7-miles downhill from Nantes, Quebec. Upon reaching the town, the train was traveling at approximately 65 miles per hour and derailed in a residential and business district. (Wikipedia 2015)

The resulting catastrophic release and explosion caused the death of 47 people and the initial loss of 30 buildings due to fire. Although actual quantities differ depending upon the source, estimates of crude oil released or burned ranged from 1.4 to 1.8 million gallons from the ruptured unit cars during the accident. The initial blast and heat zone covered an area of over 1 mile according to published newspaper reports. (Wikipedia 2015) Flowing oil entered storm sewers, manholes, basements and other structures at grade. Crews attempted to capture oil migrating through the sewer system to prevent it from entering local waterways. Unfortunately, oil flowing over ground and through manholes and the sewer system network also entered the lake (Lac-Mégantic) and the Chaudière River.

The Initial Response

Crews used 3 miles of booms to capture the burning and flowing oil from the lake and river (Golder 2014).
1000 people were initially evacuated from the surrounding neighborhoods due to smoke and fire and an additional 1000 residents were evacuated due to toxic fumes emanating from the release of crude oil. The public water supply was also impacted and residents were put on bottled water.

Due to extreme temperatures and potential for further explosions, crews took up a defensive posture and worked to protect commercial and residential buildings and local infrastructure by controlling the spread of oil and fire. Local construction crews built levees, retention basins, and fire breaks to slow the spread of oil. Once fires had consumed enough crude to enable safe access, first responders used water to cool rail cars and foam to retard burning crude oil that had pooled. 150 first responders were finally able to extinguish the fire after two days.

Photo courtesy of Associated Press

Damage and Environmental Assessment

Once the fires were extinguished, emergency and environmental teams began assessing the impact zone. Due to high weather temperatures and levels of crude oil constituents (benzene) detected above action levels in the ambient air, work times for individual crew members were restricted to short durations. Initial damage assessments revealed significant impacts to buildings, the public water supply, soil, the lake and Chaudiere River. 1,200 soil samples and 127 water and other liquid samples have been collected and analyzed to delineate the impact of the oil release. (Golder 2014)

Estimates since the accident indicate that approximately, 26,000 gallons of crude oil was released to the Chaudiere River impacting the water supply of Lac-Mégantic and Saint Georges 50 miles downstream. Longer-term restrictions including no swimming and fishing were placed Lac-Mégantic and the Chaudiere River. Polycyclic aromatic hydrocarbons and arsenic were detected in river sediments.

Demolition of over 60 buildings resulted from fire damage or during remediation of impacted soil. Nearly 100,000 cubic yards of soil were excavated from the area immediately around the impact zone and surrounding utilities. A total of approximately 150,000 tons of soil removed and over 50mm gallons of water treated during remediation.

Photo courtesy of La Presse Canadienne

Access to the original business district was restricted and most businesses moved to other parts of the community including a newly constructed area of town across the river. Further response actions and returning the area to habitable conditions may require several years.

Note: Investigations by the Transportation Safety Board of Canada discovered that the oil in the unit cars that remained following the accident had been improperly classified as Class 3, Packaging Group III. Analytical testing of the remaining oil indicated a predominance of conditions that required classification of the oil as Packaging Group I or II.

Aliceville, Alabama

On November 7, 2013, 26 cars of the 90 unit train owned by Alabama and Gulf Coast Railway derailed in a swamp near Aliceville, Alabama. Three cars containing crude oil exploded immediately and ignited several additional adjacent cars. The fire burned for three days. Foam was applied to pools of burning crude oil and tank cars. Water was used only to cool the tank cars. A total of 23 cars breached, releasing crude oil directly into an adjacent wetland (USDOT undated).

Although the total volume of oil released to the environment is unknown, it is estimated at 630,000 gallons (USEPA undated). The ensuing fire likely consumed a considerable amount of the released crude, but the wetlands surrounding the incident were also significantly impacted by fire and crude oil.

Photo courtesy of the U.S. Environmental Protection Agency

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Containment booms were used to surround the derailed trains to minimize the spread of oil. 11,000 gallons of oil were recovered and 5,000 tons of impacted soil was excavated from the rail bed and adjacent wetland. Operations and maintenance of containment booms and absorbent fabric began in December 2013. A longer term clean-up plan remains under development. (USEPA undated)

Casselton, North Dakota

On December 30, 2013 at approximately 1410, a westbound BNSF Railway (BNSF) unit train carrying grain derailed 13 cars near Casselton, North Dakota. An eastbound BNSF crude oil unit train consisting of 106 cars collided with a derailed unit car from the westbound train and derailed the first 21 cars. (Preliminary Report NTSB March 2014). Of the 21 cars that derailed, 18 were punctured releasing more than 400,000 gallons of crude oil. The ruptured tank cars exploded 20 minutes following the collision.

Photo courtesy of the U.S. Environmental Protection Agency

No injuries were reported during the incident, but the town of Casselton, population 2400, was placed on a voluntary evacuation order due to concerns about smoke and particulate in the air. First responders took on defensive operations and let the fire consume the crude oil remaining in the ruptured unit cars. This action consumed the bulk of the material and minimized the actual released crude oil to the surrounding soil. Freezing temperatures and only minor elevation changes, and snow covered surfaces also assisted containing the crude oil from migrated outside the impact zone.

Remediation was limited to the removal of approximately 9,000 cubic yards of soil and debris from the impacted area.

Lynchburg, Virginia

On April 30, 2014 at approximate 1345, 13 cars of a 105 car CSXT unit train derailed in the center of Lynchburg, Virginia along the James River. A newer unit car designed to protect from rupture during a derailment exploded causing a large fire ball. 3 unit trains also slide down the embankment into the James River following derailment. Although, the fire was permitted to burn out, a 30-mile oil slick was observed in the James River (Lynchburg News 2014).

Containment booms and sorbent materials were placed in the river surrounding the 3 unit cars to control a further release. Restrictions were also placed on recreational use of the James River for a short-period of time (Richmond Times Dispatch 2014).

Plaster Rock, New Brunswick

On January 7, 2014, 19 unit cars of a 122 unit train owned by Canadian National Railway (CN) derailed in the vicinity of Plaster Rock, New Brunswick. Four of the derailed unit cars were carrying crude oil and four were carrying liquefied petroleum gas (TSBC 2014). Approximately 150 nearby residents were evacuated during the resulting fires to secure the perimeter. A controlled burn was conducted to expedite the burning of the remaining material (WAGM, Dick Palm 2014).

Response action to address the released oil included:

- Excavation of 5,000 tons of contaminated soil with spot excavation in several other arears.
- Collection of water samples from residential wells in the area. Results indicated that private wells were safe to use with the exception of one that may have a problem not related to the derailment.

Luther, Oklahoma

On August 22, 2008 14 unit cars of a 110 car train owned by BNSF, derailed in a remote area three-miles outside Luther Oklahoma. Eight of the 14 derailed unit cars were carrying crude oil and three of the cars breached. The remaining derailed cars carrying crude oil leaked from manways resulting in a significant fire and explosion. No injuries were reported as a result of the derailment. Approximately 30 people were evacuated from residential properties within ½ mile of the fire, but were able to return within 8 hours (USDOT 2008).

Local fire crews provided defensive control until such time as they could get close enough to the fire to apply cooling water to the burning tanks. Following, a minor application of fire suppression foam, the fire eventually burned itself out. Once the potential for explosion had dissipated, BNSF crews began transferring remaining liquids from the derailed unit cars prior to moving the cars away from the tracks.

Parker Prairie, Minnesota

On March 27, 2013 14 unit cars of a 94 car train owned by Canadian Pacific, derailed in the vicinity of Parker Prairie, MN. Three of the 14 cars ruptured, releasing crude oil to the frozen soil. No fire or explosion resulted from the derailment. Approximately 30,000 gallons were released, but due to the low temperatures crude did not impact surface water or soil (Reuters 2013).

Environmental crews used pump trucks and absorbent material to recover crude oil that released from the tanks on to frozen soil.