2014 INTERNATIONAL OIL SPILL CONFERENCE

Guidelines to Prepare for Oil Sands Product Spills in Varied Aquatic Environments

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ABSTRACT 299945:

On July 24, 2007, the Westridge Transfer Line in Burnaby, British Columbia, ruptured spilling 1,400 barrels of oil sands product into the area's storm water systems and eventually into the Burrard Inlet at Vancouver Harbor. The response to this spill was considered successful and there is no record of oil sinking. Several years later, in July of 2010, the Line 6B pipeline operated by Enbridge Energy Partners LLP ruptured spilling 20,082 barrels of oil sands product into the Kalamazoo River. In contrast to the Burnaby spill, this response was extremely difficult due to the sinking of large quantities of oil. The variance in fate and behavior of the oil sands products in these two spills demonstrates how environmental factors can result in different response challenges.

Many environmental factors affect the fate of spilled oil sands products in aquatic environments because bitumen, a large component of oil sands products, has a density greater than freshwater. By analyzing specific factors in areas at risk, responders can better prepare for, and expect, submergence in oil sands product spills. Areas identified to have low salinity, rough sedimentation, high turbidity, strong sunlight exposure, high temperatures, and strong currents have a high risk of submergence. Response teams in these areas of high risk should have submerged oil recovery equipment readily available for rapid deployment.

INTRODUCTION:

Oil sands are a source of crude oil that have recently begun large scale production. The rate of production in Alberta, Canada is projected to increase from 1.80 million barrels a day in 2012 to 5.21 million barrels a day in 2030 (Canadian Association of Petroleum Producers, 2013). Oil sands products differ from conventional oil because they are comprised mostly of bitumen. Bitumen is a type of oil that during its formation was not heated enough to pasteurize. As a result, bacteria in the bitumen degraded the smaller hydrocarbons in the forming mixture leaving only large molecules. For this reason, bitumen is very viscous and dense having an API gravity of around 8°, even more dense than fresh water (API gravity of 10°) (Crosby, 2013.) It is important that responders be aware of the high density and be informed of other external factors in their geographic area of responsibility which could facilitate the submergence of spilled oil sands products.

TRANSPORTATION:

Oil sands products are transported throughout North America by three basic means: pipeline, railcar, and shipment. Each of these transportation methods presents its own risks to aquatic environments.

Diluent:

Due to the high viscosity of bitumen, it is often diluted for easier transport. Common diluents are natural gas condensate and synthetic crude oil. These diluents have very low densities and viscosities. Once mixed with a diluent, bitumen acts similarly to conventional oil and the density and viscosity is significantly reduced. When bitumen is mixed with natural gas condensate, the product is called dilbit. Synthetic crude oil is made by thermally cracking bitumen to make lighter hydrocarbons. When it is mixed with bitumen the product is called synbit. If both diluents are used to dilute bitumen, the product is called dilsynbit.

Pipeline:

A diluent must be added to raw bitumen before it can be transported through a pipeline. Pipeline oil sands products spills present unique response challenges because diluent can evaporate from bitumen as it weathers. The evaporation of the lighter hydrocarbons gradually concentrates the larger hydrocarbons making the diluted bitumen more dense. The increased density can result in submergence.

Major pipelines originate in Alberta, Canada and cross into the United States in North Dakota. The pipelines divide and one section, the Keystone pipeline, carries oil sands products south into Texas. A series of pipelines managed by Enbridge Energy Partners LLP carries diluted bitumen east into Missouri. An expansion of the Keystone pipeline, which is currently in debate, would extend the transportation routes across Montana, South Dakota, and Nebraska. A detailed map of the major pipelines is given in Appendix A.

Railcar:

The transportation of oil sands products via railcar does not require bitumen to be mixed with a diluent. Instead, bitumen is loaded into a heated railcar. The advantage of railway transport is that there is a very well developed system of railways in North America, and the oil sands products can be transported virtually anywhere. If a railcar were to spill undiluted bitumen over fresh water, it would sink. However, due to the high viscosity of undiluted bitumen, it would affect a relatively small area only.

Shipment:

The shipment of oil sands products also does not require a diluent. Marine shipment is used primarily to transport undiluted bitumen to Puget Sound, the Gulf of Mexico, and the Gulf of Maine (Crosby, 2013.) A spill of undiluted bitumen from a vessel directly onto ocean water creates a risk of contamination of many vital marine resources and would likely form tar balls which could wash up along the coast.

Shipment can also be used to transport undiluted bitumen along inland fresh water systems. The Great Lakes region and the Mississippi River are expected to see increased barge transportation of undiluted bitumen. A spill of undiluted bitumen from a barge into a major river system has a large risk of submergence.

ENVIRONMENTAL FACTORS:

Weathering is a major factor that determines the behavior of spilled oil. Weathering is the result of evaporation, emulsification, sediment uptake, and photo-oxidation. Evaporation is the transition of oil in a liquid phase to a gas phase and is influenced by temperature, wind, and atmospheric pressure. Emulsification is the physical mixing of two non-soluble substances. In most cases, an oil emulsion is the suspension of water droplets in oil. Water energy, turbulence, and the amount of wind can greatly affect the extent of emulsification. Sediment uptake occurs when oil picks up sediment. This is largely affected by the type of sediment and the turbidity of the water. Photo-oxidation is a chemical reaction caused by the exposure to ultraviolet light. Each of these weathering processes is significantly influenced by a variety of environmental factors which vary greatly among geographic regions.

Sedimentation and Turbidity:

Sediment particle interaction is common in many oil spills, and often causes oil to submerge. Two processes cause submergence: sediment can become trapped in the oil increasing the overall density of the oil, or oil can become adsorbed onto an individual particle and be pulled down as the particle sinks again (Fingas). At a suspended particulate matter concentration of 10 mg/L significant absorption and adsorption occurs. At concentration levels above 100 mg/L, even conventional oils are recorded to submerge (Rymell, 2009.) It is easier for sediment to become trapped in viscous oil sands products than in conventional oils. Rougher sediment is more capable than smooth sediment to adsorb thicker layers of oil due to its increased surface area.

The turbidity of the body of water is an important factor that controls the speed and extent of sediment particle interaction. Rivers and bodies of water with strong currents and waves will carry larger amounts of sediment. Generally, the more sediment that is able to interact with oil the more dense the oil will become.

Salinity:

High salinity in an aquatic environment is important because salt content raises the density of water. Sea water has an API gravity of about 6° (Crosby, 2013). Because seawater is more dense than bitumen, there is less of a chance that oil sands products will completely submerge.

Current:

In a still environment, current will have little impact, but in a fast moving environment like a river, current and turbulence can push oil underwater. When water temporarily covers oil, it is called overwash. Overwash is more likely with oil sands products because of its higher viscosity. Oil with a high viscosity gives a stronger platform for water to push down on, whereas less viscous oils are more easily separated by the force of the water (Rymell, 2009). A strong current also creates a greater chance for the oil to make an emulsion.

Temperature:

Temperature influences many aspects of weathering, especially the rate of evaporation of spilled oil. This is mostly important for diluted oil sands product spills from pipelines, because diluent will evaporate faster than bitumen. As the diluent evaporates, it concentrates the bitumen raising the density and viscosity of the mixture. In a warm environment the diluent will evaporate faster than in a cold environment. However, during the response to the Kalamazoo River spill in 2010, as temperature increased, some of the submerged oil resurfaced because the oil separated from the sediment.

Sunlight:

In the presence of ultraviolet light, the hydrocarbons in oil undergo photo-oxidation. Photo-oxidation is a photo-catalytic process in which ultraviolet light causes oxygen gas to react with hydrocarbons in the oil. The result is a crusty, dense layer on the surface of the oil which can push the oil into the water. (Alberta Oil Sands Workshop, 2013)

BURNABY BAY vs. KALAMAZOO RIVER:

Two well documented spills of oil sands products are the Burnaby Bay spill in Vancouver Harbor and the Kalamazoo River spill in Michigan. The two spills had very different response challenges, highlighting the varied response needs of different environments.

On July 24, 2007, the Westridge transfer line in Burnaby, British Columbia ruptured and 1,400 barrels of oil sands products spilled into the area's storm water systems and eventually into the Burrard Inlet. The response to this spill was relatively easy, as none of the diluted bitumen was recorded to sink. Response teams were able to respond to the spill almost immediately and contain it effectively.

However, when Line 6B ruptured near the Kalamazoo River in July 2010, spilling 20,082 barrels of dilbit into a tributary of the Kalamazoo River, there was a much different outcome. Response teams arrived on the scene late, because the spill was not discovered until 17 hours after the event. Additionally, Enbridge Energy Partners LLP, the responsible party, did not immediately inform the response crews that the spill consisted of diluted bitumen and not conventional oil. The spill was eventually contained 40 miles from the spill point. Some of the oil had submerged in the river calling for extremely difficult, expensive, and damaging recovery techniques such as dredging. The recovery costs of the spill were approximately $1 billion (Alberta Oil Sands Workshop, 2013).

There were many factors which contributed to the increased severity of the Kalamazoo River spill compared to the Burnaby Bay spill. An important reason was due to the differences in environmental characteristics between the two spill sites. First, the Kalamazoo River has different sedimentation than Burnaby Bay. Rivers often carry larger and rougher sediment that have not fully eroded into the smooth pieces found near the shore. Second, the Kalamazoo River was at flood stage and had a more substantial current than Burnaby Bay, facilitating sediment uptake. Third, Vancouver Harbor is cold and the rate of evaporation for the diluent was slower than that of the Kalamazoo River spill. Fourth, the Kalamazoo River is a body of fresh water, while Burnaby Bay, connected to Vancouver Harbor, has a much higher salinity.

These two spills show how different environments can create differences in the fate of spilled oil sands products. Burnaby Bay had many natural characteristics which made the sinking of oil sands products either unlikely or slow. Conversely, the Kalamazoo River had attributes which facilitated the sinking of dilbit, and after a short period of time, the spilled dilbit submerged. The late arrival of the response teams added to the difficulty because the oil sands products were given time to weather. If the spill had been attended to sooner, less of the oil would have submerged.

RESPONSE PREPARDNESS:

Because there is a period when oil sands products act in a similar manner to conventional crude oil, quick response is imperative. Response teams should arrive as early as possible to the scene. In order to have a timely response, Area Committees and responders should identify any means of oil sands product transportation that may pass through their area of responsibility. If one or more are found, the environment around the threat should be analyzed for the key factors which can lead to submergence of oil sands products.

- Low Salinity
- Rough Sedimentation
- High Turbidity of water
- Sunlight Exposure
- Strong Current
- High Temperatures

If one or more of these factors is present in the area at risk, then the area must equip itself with the proper equipment to respond to submerged oil within a few days of the spill. Response plans should be updated accordingly.

These areas at risk should have access to, and be able to deploy, advanced submerged oil detection methods. Current prototypes of seafloor sonar and fluorosensor devices can scan for submerged oil. These machines are not yet completely efficient, and more research is needed to reduce background light interface and interference from topography and murky waters. However, they can detect large areas of sunken oil and can be used as a preliminary detection technique to avoid more labor intensive methods. The simultaneous use of multiple types of sensors can reduce the risk of a faulty detection. It is recommended that more resources be devoted to developing these sensors further. (Hanson, 2009)

If sunken oil is detected, steps must be taken to quickly contain the submerged oil to prevent it from spreading along the seafloor or riverbed. Containment can be accomplished with submerged booms and trawl nets. Submerged oil can be recovered in a variety of ways, most efficiently with divers armed with vacuum pumps. Other methods include using sorbent materials and, in extreme cases, dredging. For a large spill, divers should be deployed as soon as possible (and safe) to clean up the spilled oil before too much accumulates to be cleaned with a vacuum. A swift response can prevent the need for a very costly and environmentally damaging dredging process. If dredging does become necessary, it should be confined to the smallest possible area.

Regions at Risk:

In the United States, there are numerous areas which are under threat of an oil sands product spill. Particularly high risk areas for sunken oil are the Mississippi River, the Arkansas River, the Missouri River, and the Red River, along with their tributaries. These areas are at high risk for oil sands products spills because they intersect major pipelines. These rivers also have fast moving water with high turbidity and low salinity. Responders should expect oil sands products in these areas to sink. Sunken oil detection, containment, and recovery equipment should be readily accessible and deployed soon after the initial response.

The Great Lakes, specifically Lake Superior, Lake Michigan, and Lake Huron, are also at risk of a spill. They have less risk of submergence than rivers because the current is not as strong and less sediment can interact with the oil. They also have lower temperatures which will slow the evaporation of diluent. However, the great lakes are fresh water, so if the spill remains in the water for an extended period there is a chance the oil may sink. The threat of the oil sinking should not be ignored and access to sunken oil equipment should be readily available.

The Gulf of Mexico, the Gulf of Maine, and Puget Sound also face the threat of an oil sands products spill from marine shipment. Due to the salinity of the sea water in these areas, there is a lesser chance of large-scale sinking. However, nearby coastlines should be warned of the potential for tar balls to wash up on shore. Responders should react to spills as if they were conventional oil, but be wary of the differences.

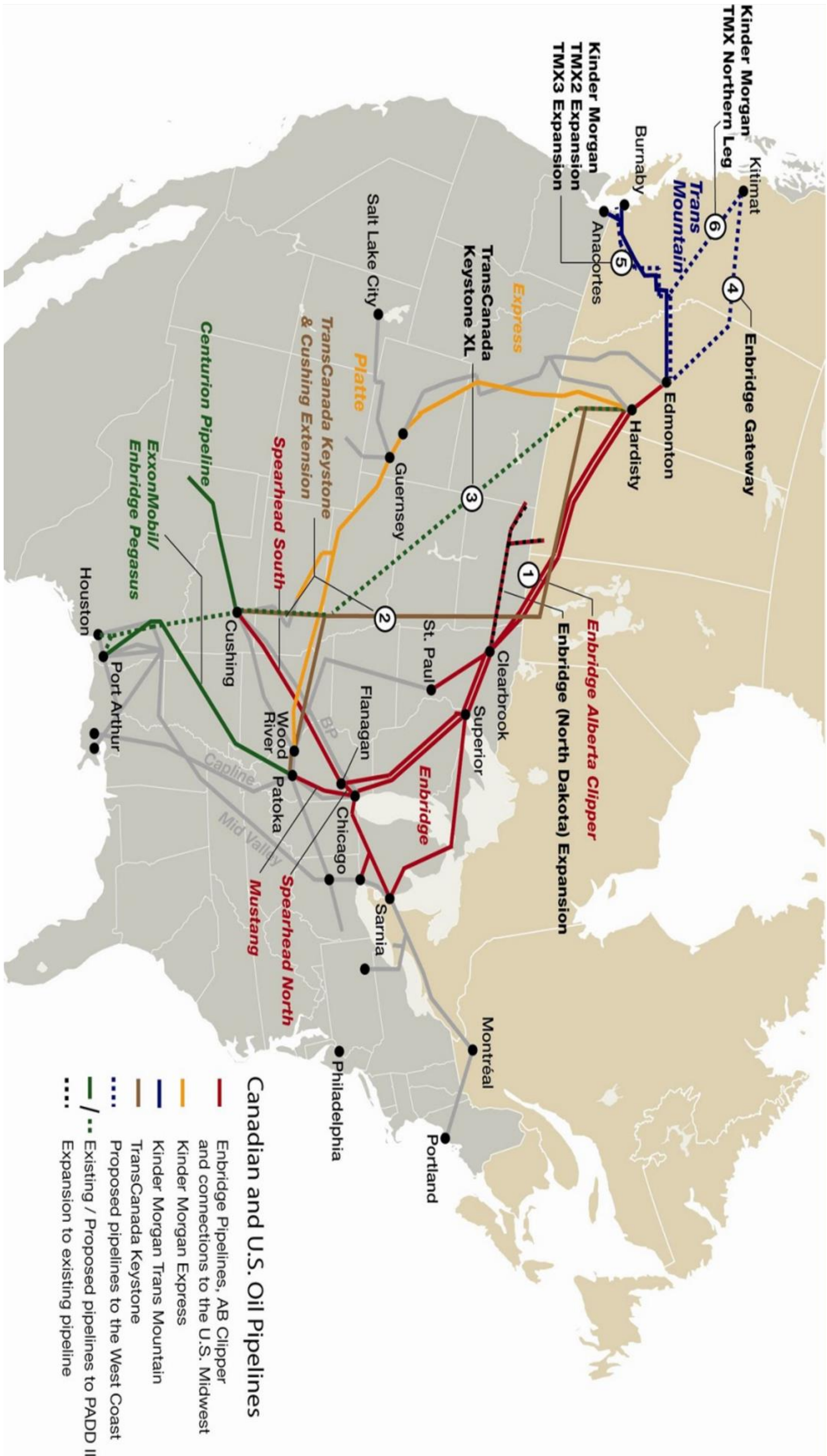
First Responder Health Risks:

Successful response to diluted or undiluted bitumen spills will often require a quick response. It is important that first responders be aware of the health risks involved in a diluted bitumen spill. Higher concentrations of benzene in air were found around spilled diluted bitumen than conventional crude oil. Diluent used to dilute bitumen has a very low flashpoint and creates a flammability risk. Bitumen also has higher sulfur concentrations than most conventional crude oils. (Crosby, 2013) First responders must be prepared with proper safety equipment before attempting to help with the cleanup. Exposure time must also be monitored and limited for first responders.

CONCLUSION:

Oil sands products are becoming an increasingly prevalent source of crude oil for North Americans. Due to its high concentration of large hydrocarbons, they have a density similar to water and a much higher density and viscosity than conventional oil. This leads to different response challenges that are dependent on environmental characteristics. Key characteristics of aquatic environments that facilitate the sinking of oil sands products are low salinity, rough sedimentation, high turbidity, heavy sunlight exposure, strong currents, and high temperature. For any area of responsibility that identifies oil sands products threats in an environment that has any of these key characteristics, responders must prepare to deploy submerged oil equipment quickly to prevent the accumulation of submerged oil.

APPENDIX



Appendix A: A map displaying the current and proposed major pipeline routes in North America which transport oil sands products. (Canadian Association of Petroleum Producers, 2012)

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