Crude oil and aquatic ecosystems

Introduction to issue

Crude oil is found in sedimentary rocks which were formed over millions of years by the accumulation of sand, silt and the remains of plants and animals. It consists of carbon, hydrogen, sulphur, nitrogen, oxygen, metals and many potentially toxic chemicals. There are dozens of types of crude oil, ranging from **light** to **extra heavy**, all of which have different physical and chemical properties.

In Canada, crude oil plays a significant role in our economy and society. Canada produces over 3.9 million barrels of oil per day and all of this oil must be transported. Crude oil is transported in Canada using three different transportation systems: **pipeline**, **tankers** (ships) and **rail**. These transportation systems are monitored and regulated by the **Transportation Safety Board of Canada**.

Oil that is accidentally spilled or released chronically can have profound effects on the environment. Each type of crude oil will behave differently in different environments. For example, some lighter oils may float and evaporate, while others may disperse or sink in water. Each of these behaviours will have a different effect on the aquatic ecosystem. Each type of oil also has different levels of toxicity. It has been found that light oils have higher concentrations of **acutely** toxic chemicals or compounds and can kill aquatic life **immediately**, while **heavier** oils typically contain more Polycyclic Aromatic Hydrocarbons (PAHs), which cause **long-term** toxic effects to aquatic species.

The Royal Society of Canada Expert Panel found that the overall environmental impact of an oil spill depends mainly on three things: **environmental characteristics**, the **conditions** of the spill, and the **speed** of response. For example, a small release of oil in fresh water can have a greater impact than if the same volume of release were to happen at sea, due to the larger amount of water available for dilution in the ocean.

References

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Researcher profile

Dr. Vince Palace is a Senior Research Scientist at IISD Experimental Lakes Area. Dr. Palace is an aquatic toxicologist with 25 years of experience in determining exposure, evaluating potential impacts and developing mitigation strategies related to chemical and non-chemical aquatic stressors. Working with industry, government and community stakeholders, Dr. Palace has led projects on the impacts of agriculture, hydroelectric power, the oil and gas industry, and mining on aquatic ecosystems.

Interview with Dr. Vince Palace

How is crude oil transported in Canada? In Manitoba?

In Canada, oil is transported in **tankers** (which is largely relevant to the marine environment) coming from or going to other markets; also in **pipelines** – there are a lot more pipelines than people may think running across North America. In Manitoba specifically we don't have a lot of tanker traffic, although there is potential for that coming with the opening up of Churchill as a more major port. *And what about rail?* **Rail** is increasingly important and has been over the past few years, it's sort of levelling off now, but rail transportation of oil occurs across Manitoba. Some of the oil deposits in southwest Manitoba are transported by rail.

Give the pros and cons, for aquatic systems, of transporting crude oil in different ways.

Transporting oil by tanker in the marine environment used to be a very risky venture. The statistics around numbers of spills, volumes of spills (notwithstanding things like Deepwater Horizon) have declined recently in the marine environment. There's an increasing better safety record for tankers. Pipelines are by far the safest way of transporting oil. If you normalize by the amount of oil transported and the number of incidents, pipelines are a couple of orders of magnitude safer than rail, tanker truck, or even large ocean going vessels. You can flip those statistics around a bit, though. Trucks have far more incidents, but the spills tend to be smaller, more localized, and terrestrial. When spills happen on land it's a lot easier to clean up than it is when it happens in or around water.

How might crude oil might end up in our waterways?

Most importantly it would be by spills. There are natural seeps in some places, and that oil can end up in deep groundwater. But spills are the things that are mostly on our minds, and that can occur from any of the modes of transport I mentioned. The spill can originate on land and then flow into water, or it can be directly into water, such as where a pipeline crosses close to a waterbody, or where you have an incident for example where a rail derailment happens near water.

How does crude oil interact with surface water?

You know the phrase "like oil and water" - oil tends to float on water. The exception to that is some of the heavier crude oils; once they interact with sediment or particles in the water, they can form large tar balls or tar cigar logs, and those can sink. That makes it difficult for cleanup. On land it's a little easier; mostly what we have is the oil interacting with the soil particles. Oftentimes the best remediation strategy is to dig it up, remove the soil and treat it as contaminated waste, and then replace it with clean soil. *And what about groundwater?* Interactions with groundwater are more difficult. Most oil compounds don't dissolve in water, but there are some light molecular weight compounds that can be transported through aquifers.

How might crude oil impact aquatic ecosystems?

The impacts are not all that different in marine and freshwater systems, and can be divided into two categories: **acute** (short-term) and **chronic** (long-term). Immediately after a spill you have acute toxicity, meaning that animals are killed because of exposure to the oil compounds. The reason for that is a lot of the lighter molecular weight compounds I talked about before will dissolve in water, and the animals will bioaccumulate them. What happens is a process called **narcosis**, which really affects the animals acutely. In the weeks and months after a spill, we're more concerned with chronic toxicity, which is due to compounds that will slowly leach out of the oil and bioaccumulate in the animals, leading to growth and reproductive impacts. Largely what is challenged in the organism is their ability to degrade the oil. Once they take it up, how do they metabolize and get rid of it? It puts tremendous strain on their liver.

What are the differences in impacts between flowing and still water? The same types of biological effects are present, but the impacts are far more widespread and less predictable with flowing water. If you imagine a spill reaching into a river, it gets quickly dispersed downstream. If it seeps into a lake, it's more localized, the product tends to float on the surface. The traditional method of recovery, which is really just **mechanical skimming** of the oil off the surface of the water, can be easily accomplished in a lake because you can contain the spill with booms and then you can remove it. Whereas in flowing water, it's the **interactions with the shoreline** that are really important. The farther you flow a product downstream, like in a river, the more shoreline it has the opportunity to interact with.

Are all types of "crude oil" the same? Does the risk factor to the environment depend on the type of oil?

All types of oil are not the same. We tend to call everything from the oil sands "bitumen", but even samples of bitumen from the same area can be quite different. The proportions of lighter molecular weight compounds (which cause **acute toxicity**) and heavier molecular weight compounds (which cause **chronic toxicity**) differ among types of crude oil. There are things like "**light sweet**" crudes which have a lot of the lighter molecular weight compounds and very low sulfur content, and then there are "**heavy sour**" crudes (sour refers to the high amount of sulfur in it) which have the high molecular weight compounds that are slower to disperse and slower to degrade in the environment. It's important to understand that all of these different crude oils are made up of thousands and thousands of different compounds, and it's really the proportion of these compounds that distinguishes one oil from another one. In fact, we can use the distinct characteristics to tell which particular type of oil has been spilled at a site because each type is made up of a sort of fingerprint of different compounds.

What are the main methods used to clean up crude oil spills in aquatic ecosystems?

This is where the differences between the marine and freshwater environments really get accentuated. In the marine environment, one of the main methods we have of cleaning up oil spills is by **burning** the oil. The oil is contained with **booms**, and is then burned. Burning is not generally used in the freshwater environment. Here, **mechanical skimming** is much more prevalent, where the oil is physically removed from the surface of the water. There are **absorbent booms** that can be drawn across or underneath the surface of the water to absorb the oil. For the most part, a lot of the clean-up methods are **mechanical**. If you have a shoreline that is rocky, the best way to clean up the oil is to **wash** it off with water, or sometimes a "**herding agent**" is used which allows it to float and coagulate on the water where it can then be removed by skimming.

How effective are these methods and what side effects might they have?

We are now starting to think about things called "Net Environmental Benefit Analysis" (NEBA) frameworks, because sometimes it's the cleaning up of the oil spill, rather than leaving the oil in place to degrade naturally, that causes the most environmental damage. We've seen this with shoreline cleanups. For example, you have a large portion of a shoreline that has been affected by an oil spill; the company that spills is obligated to clean it up, and they also want to be seen in the public eye as doing something, so they're on the ground cleaning it up. In most cases that includes a lot of machinery, people, and equipment moving along the shorelines, trampling the vegetation, compacting the soil. That really compromises the stability of the shoreline and the vegetation, which leads to longer term impacts such as the residual oil being dispersed further downstream as the compromised shoreline erodes.

Give an example of a recent spill of crude oil in Canada. How was the spill cleaned up?

All those methods of mechanical recovery, absorbents, and herding agents were employed in the cleanup of the recent spill in the North Saskatchewan. That was a case where you had a large portion of shoreline that was impacted (up to 300 km). Now in the North Saskatchewan we see that there is an abatement and oil is not as prevalent along the shorelines. In a spill like Wabumun Lake, AB, where it was much more contained there was a different problem with sinking, so oil remained a problem for years after the spill.

What types of environmental parameters are monitored after an oil spill to assess ecosystem health?

I'd like to say that there's a lot of biological monitoring. There is some, and I think we're getting better at that. Primarily what's monitored afterwards is **concentrations** of oil constituents in soil and water (particularly drinking water). The concentration is mostly on chemistry, asking questions like: What is the concentration of oil? Has it gone down? What is the trajectory of recovery? For biological effects we sort of lean on some excuses sometimes; for example, it can be difficult to determine whether fish were exposed because they can move. We rely heavily on *in vitro* tests. We collect water and do lab tests to see if there is a biological impact, rather than going out and collecting wild animals. *Would water be collected from the actual contaminated site and then used in the lab, or would they mimic the concentrations in the water?* Usually it's a hybrid of that. There have been enough in-lab tests now that we know how a given concentration of oil will affect test species like *Daphnia* or the fathead minnow, so doing the chemistry at the site and then relating those data back to what we know about the toxic effects is usually the best way to do it.

Is there a need for additional research to study the potential impacts of crude oil on aquatic ecosystems?

That's the subject of a huge report recently put out by the Royal Society of Canada. They went through all the different spill scenarios and identified major gaps that remain in our understanding of how oil will behave in freshwater and marine environments. In some cases, the data gaps are enormous and very simple. Things like “does oil sink or float?” We don’t know a lot about trophic interactions. It might have an indirect effect on fish by affecting their food, for example, but we know very little about that. Often when we conduct research at spill sites, the thing that’s lacking there is baseline information. We don’t know what was there beforehand, all we’re doing is reacting to a spill. We can use techniques like going upstream to see what’s there, but it’s not the best case scenario. Ideally you would have information from **before a spill**, information about what happens **during the spill**, and information about how long it takes to **recover afterwards**. The ability to relate post-spill data to pre-spill data allows you to say “Now the system is back to clean, back to its original state.” Without background data it’s very difficult to draw those conclusions.

At IISD Experimental Lakes Area we’re doing some of the research to address some of the data gaps that were identified by the Royal Society of Canada report. We’re doing this in a way that includes people who will use the information (industry, regulators, spill responders), as well as the people who are interested in the findings (First Nations communities, the public, the academic community). Everyone has to be at the table in order for us to generate useful information that we can believe in. Without everyone believing in the information, it’s difficult to include it in any kind of social decisions we make about transporting and using oil, the regulatory limits for producing and transporting oil, and what sort of accountability we hold industrial companies to.