The Royal Society of Canada Expert Panel:
The Behaviour and Environmental Impacts of Crude Oil Released into Aqueous Environments
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EXECUTIVE SUMMARY

A panel of leading experts on oil chemistry, behaviour and toxicity reviewed the current science relevant to potential oil spills into Canadian marine waters, lakes, waterways and wetlands. The review, which examined spill impacts and oil spill responses for the full spectrum of crude oil types (including bitumen, diluted bitumen and other unconventional oils), is among the most comprehensive of its kind. It surveyed scientific literature, key reports and selected oil spill case studies, including tanker spills, an ocean rig blowout, pipeline spills and train derailments. The Panel also consulted industry, government and environmental stakeholders across the country.

The Panel found that the dozens of crude oil types transported in Canada exist along a chemical continuum, from light oils to bitumen and heavy fuels, and the unique properties of each of these oil types (their chemical 'fingerprints') determine how readily spilled oil spreads, sinks, disperses, and impacts aquatic organisms, including wildlife, and what proportion ultimately degrades in the environment. Despite the importance of oil type, the Panel concluded that the overall impact of an oil spill, including the effectiveness of an oil spill response, depends mainly on the environment and conditions (weather, waves, etc.) where the spill takes place and the time lost before remedial operations.

The Panel recommends that this critical research should concentrate on seven general high-priority research needs:

High-Priority Research Needs Identified by the Expert Panel

1. Research is needed to better understand the environmental impact of spilled crude oil in high-risk and poorly understood areas, such as Arctic waters, the deep ocean and shores or inland rivers and wetlands.
2. Research is needed to increase the understanding of effects of oil spills on aquatic life and wildlife at the population, community and ecosystem levels.
3. A national, priority-directed program of baseline research and monitoring is needed to develop an understanding of the environmental and ecological characteristics of areas that may be affected by oil spills in the future and to identify any unique sensitivity to oil effects.
4. A program of controlled field research is needed to better understand spill behaviour and effects across a spectrum of crude oil types in different ecosystems and conditions.
5. Research is needed to investigate the efficacy of spill responses and to take full advantage of 'spills of opportunity'.
6. Research is needed to improve spill prevention and develop/apply response decision support systems to ensure sound response decisions and effectiveness.
7. Research is needed to update and refine risk assessment protocols for oil spills in Canada.

Timeframes for conduct of the recommended studies are provided by the Panel. This executive summary highlights these central conclusions and other priority research questions identified in the report chapters.
What happens when crude oil spills into oceans, into lakes or into the waterways that wind through our forests, fields and towns? Canada produces some three million barrels of oil every day, importing hundreds of thousands more, and all of it travels somewhere. In this lake-and-river-rich country with the world’s longest coastline, crossing water is inevitable when oil is transported. Whether in vast tankers traversing the sea or in pipelines, trucks and trains passing countless rivers, lakes and wetlands, oil is on the move. Some is drilled directly from the seabed where offshore rigs perch above ocean waves.

Meanwhile, accidents happen. Headline-grabbing calamities, such as the Deepwater Horizon blowout in the Gulf of Mexico in 2010, the Exxon Valdez spill off Alaska in 1989 and the Arrow spill off the coast of Nova Scotia in 1970, are periodic reminders that oil spills can shock the environment, the economy and the communities affected by them—at least in the short-term. Water is fouled. Wildlife is tarred. Fisheries and other industries struggle to recover.

The good news is that transporting oil at sea is safer than it has ever been. According to the International Tanker Owners Pollution Federation, large tanker spills occurred almost 14 times more often during the 1970s on average than they do today. Undersea blowouts during oil production and exploration are also rare (although Canadian offshore exploration and drilling is expected to increase). Less known is how much oil spilled from pipelines, trains and trucks reaches our lakes, rivers and wetlands (where oil can become trapped and remain concentrated causing more harm or creating more concern because towns and cities are nearby). However, while big oil spills from grounded tankers, oil rigs, pipeline ruptures or train wrecks are guaranteed newsmakers, in truth most of the oil-related chemicals that make it into our oceans arrive from natural seepage, routine tanker maintenance and runoff from land.

Even so, the potential impact of spills into Canadian waters during the transport of oil can be profound.

The Royal Society of Canada Expert Panel report addresses this impact. Its purpose is to better understand what we know and, perhaps more importantly, what we need to find out. Chief among the report’s aims is to provide a roadmap to research questions concerning how crude oils, including diluted bitumen and other unconventional oils, behave and how they affect ecosystems and communities after spilling into the changeable and weather-affected environments of Canada’s vast marine and inland waters.

The Expert Panel has highlighted hundreds of conclusions and identified a long list of research needs in its extensive report. This executive summary highlights only the most pressing of these research priorities. Answers to these research questions are considered by the Panel to be essential for equipping policy makers, oil industry decision-makers, oil spill responders and other Canadians with critical tools to better anticipate spills and their consequences and to better protect Canada’s marine and inland waters from the adverse effects of spilled oil. The Panel has consolidated seven general, high-priority research needs (see the box above) in this executive summary from hundreds of research priorities identified in the report chapters. The rationale for these research needs, and more detailed descriptions, can be found within the report itself.

CHAPTER 1: INTRODUCTION

The Royal Society of Canada (RSC) Expert Panel was established in response to a request from the Canadian Energy Pipeline Association (CEPA) and the Canadian Association of Petroleum Producers (CAPP). The request was the result of a widespread recognition within industry, governments and elsewhere that Canadians should know what to expect in the event of an accidental spill, and that those who move oil and respond to spills have the information they need to protect our environment, economy and communities across the country.
The Panel, composed of international experts on oil chemistry, behaviour and toxicity, reviewed the current science relevant to crude oils spilled into Canadian marine waters, lakes, waterways and wetlands (spills of gasoline, diesel and other refined fuels were not considered). The Panel relied on scientific literature, key reports and selected oil spill case studies, including well-known tanker spills (e.g., the *Arrow* spill in 1970 and the *Exxon Valdez* spill in 1989), the Deepwater Horizon spill of 2010, pipeline spill ruptures and train derailments.

The Panel’s work also involved extensive consultations with key industry, government and environmental stakeholders across the country. These included representatives from CEPA and CAPP, government agencies in Canada (Environment Canada, Natural Resources Canada, Fisheries and Oceans Canada, Alberta Innovates) and the United States (the National Oceanographic and Atmospheric Administration), private sector consultants, oil spill response agencies (e.g., the Eastern Canada Response Corporation), non-government organizations (e.g., Greenpeace), as well as other academics and interested individuals. Formal consultations included public forums involving open, online access held in Calgary in February 2015 and in Halifax in April 2015. A third Panel meeting in June 2015 included informal discussions with attendees at the 38th international Arctic and Marine Oilspill Program (AMOP) technical conference in Vancouver.

These consultations and the scientific review examined spill impacts and oil spill responses for the full spectrum of oil types, from ultra-light condensates and light oils to bitumen, diluted bitumen and heavy fuels. Many of the largest knowledge gaps were found to be associated with the chemical composition and environmental behaviour of emerging petroleum types, including diluted bitumens and other unconventional oils.

**CHAPTER 2: CHEMICAL COMPOSITION, PROPERTIES AND BEHAVIOUR OF SPILLED OILS**

While many Canadians think of the oil travelling by pipeline, train, truck or tanker as much the same, the crude oil crossing the country or plying its offshore waters each day represents dozens of different types. This may seem trivial to some, but if the oil spills into water, the type of oil involved can make a world of difference: How much damage it does, how easy it is to cleanup and how readily the oil degrades in the environment.

Each of the oil types transported in Canada is a complex mixture of thousands of chemicals. While these different types can be thought as existing along a kind of chemical continuum (from ultra-light oil condensates and light oils to heavy crude oils and the thick bitumen commonly associated with Canada’s oil sands), each has its unique ‘chemical’ fingerprint.

The Panel found that this chemical fingerprint is a key predictor of not only the physical properties of the oil (e.g., how heavy or thick it is), but also its behaviour in the environment (e.g., how it spreads, sinks or disperses in water), its toxic effects on aquatic organisms and humans, and its susceptibility to degradation by ‘weathering’ (i.e., changes to the oil caused by exposure to sunlight, waves, weather conditions and microorganisms in the environment). How the fingerprint of each spilled oil type changes in the environment is an important tool for spill responders for monitoring cleanup efforts and setting cleanup goals.

Although the Panel found the chemical composition and behaviour of many oil types have been well-studied, more research is needed to better understand the chemistry, properties and spill behaviour of newer, less-familiar oils, such bitumen, diluted bitumen blends and other unconventional oils.

**CHAPTER 3: EFFECT OF ENVIRONMENT ON THE FATE AND BEHAVIOUR OF OIL**

The unique features of the environment where an oil spill takes place are at least as important as the type of oil in determining effects on aquatic ecosystems.
Saltwater straits, freshwater lakes, running rivers and dense wetlands are home to distinctive combinations of physical characteristics, water and sediment chemistry and natural communities of microorganisms that can transform oil as it spills and spreads. Microorganisms, for example, degrade various hydrocarbons found in different oil types to varying degrees, and their impact is often an important part of oil spill cleanup strategies. Sunlight, wind, waves and weather conditions can physically and chemically transform a spill. Temperature, dissolved oxygen, nutrient supply, salinity and pH also alter the composition and behaviour of contaminating oil. These changes to the chemistry of oil are crucial factors affecting how spilled oil spreads, affects aquatic organisms and people or lingers in the environment.

Indeed, the Panel found that, despite the importance of oil type, the overall impact of an oil spill, including the effectiveness of an oil spill response, depends mainly on the environmental characteristics, the conditions where the spill takes place and the speed of response.

The impact on spilled oil of the characteristics and conditions of a spill site has been carefully studied in some environments, but knowledge gaps remain. In particular, research is needed to better understand what happens to oil spilled into the cold, icy, yet ecologically sensitive waters of the Arctic, where interest in oil exploration, production and shipping is on the rise. Similarly, little is known about the fate of oil and its impact in permafrost areas or in marine environments covered in ice. Microorganisms that break down oil are considered less active when temperatures are near freezing, but this relationship may not be as clear as we think and further study is needed.

**High-Priority Research Need #1**

*Research is needed to better understand the environmental impact of spilled crude oil in high-risk and poorly understood areas, such as Arctic waters, the deep ocean and shores or inland rivers and wetlands.*

i. Research is needed to assess the complex interactions among physical, chemical and biological factors unique to Arctic conditions (e.g., extreme cold temperatures, permafrost ecosystems, snow and ice) and different types of spilled crude oil. *(Timeframe: Within 5 years)*

ii. Research is needed to assess the fate and behaviour of oil spilled into freshwater ecosystems, especially in northern bogs, fens and areas of permafrost. *(Timeframe: Within 5 years)*

iii. Research is needed to evaluate risks associated with the shipment of fuel oil to communities in the Arctic. *(Timeframe: Within 5 years)*

iv. Research is needed to assess the risks of deep sea blowouts in the Beaufort Sea and in areas of the Atlantic coast that support commercial and subsistence fisheries, including research into the behaviour of oil on the surface with and without ice and the effects of subsurface oil plumes, residual oil deposited on deep sea sediments, oil stranded along shorelines and in backwater, marshy areas, and the impact of dispersant additions. *(Timeframe: 5-10 years)*

v. Research is needed to assess the risks of pipelines in Arctic freshwater environments, with an emphasis on the Mackenzie River. *(Timeframe: 5-10 years)*

vi. Research is needed to investigate the fate of unrecovered oil in rivers where it can interact with ice, substrates, woody debris, bed sediments, groundwater and engineered structures. *(Timeframe: 5-10 years)*

**CHAPTER 4: OIL TOXICITY AND ECOLOGICAL EFFECTS**

Oil spills can have significant consequences for aquatic ecosystems. These effects can be both short-lived and long-lasting. In the days following a spill, floating oil smothers mollusks, plants and other species at the shoreline. Oil on birds and mammals destroys their thermal insulation and buoyancy. Some chemical
components of spilled oil dissolve in water and kill fish and other aquatic creatures (before they typically break down quickly and disappear). Other chemicals, such as polycyclic aromatic hydrocarbons (PAHs), can persist in the water and cause chronic health effects for aquatic species that show up months or years later.

Light oils contain more compounds that are acutely toxic to aquatic organisms than medium or heavy oils. On the other hand, heavy oils contain more of the chronically toxic alkyl PAHs. The Panel could not conclude that diluted bitumens present a greater or lesser health risk to most species than other oils because there are too few data available on toxicity. However, there may be a greater risk to bottom- and sediment-dwelling organisms due to the tendency for diluted bitumens to sink in fresh water under certain conditions.

The characteristics of the oil spill location and its environment determine how spilled oil affects aquatic biota. Oil spills into fresh water, for example, are generally smaller than marine spills, but they may have a greater relative impact because the oil can’t be diluted and degraded by the large volumes of water available at sea. Inland shorelines and sediments are more likely to become fouled, and less time is available to contain a freshwater oil spill before it contaminates sensitive habitats.

It is not only the spills themselves that threaten ecosystems, but oil spill cleanup can be damaging as well. Physical cleanup (e.g., removing oiled vegetation or tarred shoreline) destroys habitat and can cause erosion or the buildup of silt. Habitat damage reduces the abundance and productivity of native species and fosters invasive species. Using chemicals to disperse spilled oil often means surface oil is transferred to subsurface water at concentrations that can be toxic to aquatic life (especially to fish embryos). More research is needed on spill cleanup methods that limit habitat damage and the threats to wildlife.

Oil spill impacts on aquatic ecosystems are difficult to measure. In many cases, information about the ecology of a site before a spill occurs (i.e., baseline data) is scarce or missing altogether. Baseline monitoring is typically the responsibility of provincial and federal government departments as part of environmental and natural resource management. Coordination and collaboration is needed between the oil industry and these government agencies to ensure that monitoring addresses the needs for data to assess the distribution and effects of spilled oil in ecosystems most at risks of spills.

Assessment of oil spill impacts on ‘ecosystem services’ should be considered. Ecosystem services are the benefits provided by ecosystems to humans that contribute to making human life both possible and fulfilling. Further research is also required to better understand how the toxicity of spilled oil is affected by its interaction with the environment in which it was spilled.
### High-Priority Research Need #2

*Research is needed to increase the understanding of effects of oil spills on aquatic organisms, populations, communities and ecosystems.*

1. Research is needed to investigate the cumulative and interactive effects of co-exposure to oil and other human-induced and natural environmental stressors, such as industrial and municipal pollution, extreme temperatures, salinity, low oxygen concentrations and elevated concentrations of suspended sediments. *(Timeframe: 5-10 years)*

2. Research is needed on the effects of spilled oil on populations and community structure of aquatic biota. *(Timeframe: 5-10 years)*

3. Research is needed to understand the indirect effects of oil spills on ecological processes, such as interactions within and among trophic levels in aquatic food chains. *(Timeframe: 10+ years)*

4. A program of research is needed on the resilience of aquatic ecosystems affected by oil spills, particularly at sites of past spills and in ecosystems unique to northern Canada (e.g., bogs, fens, etc.) at a high risk of oil exposure. *(Timeframe: 10+ years)*

5. Research is needed to investigate the socioeconomic impacts of oil spills as a first step in implementing an ecosystem services approach to oil spill impact assessments. *(Timeframe: 10+ years)*

### Chapter 5: Modeling Oil Spills in Water

Knowing what to expect and how to respond when oil spills into an ocean, lake or river is no mean feat. The complex chemistry of each oil type makes it difficult to predict how the oil will act and change when it meets the equally complex water chemistry, ecology and conditions at the particular site where a spill takes place. For this predictive work, scientific models are invaluable tools.

Scientific modeling creates conceptual or mathematical representations of complex real-world phenomena that can’t be readily observed. Scientific models of oil spills use what we know from experiments, previous spills and other information to approximate what happens when oil of a particular type spills in particular circumstances. Scientists are constantly adding information and refining these models to improve their accuracy for predicting spill consequences and for understanding the best spill responses.

Early models of oil behaviour and transport relied heavily on experimental observations. Since the early 1980s, advances in oil spill modeling focused mainly on oil dispersion (the formation of oil droplets), the formation of oil particle aggregates, emulsification, evaporation and the general transport of oil in open water as well as in other types of ecosystems. More recently, researchers have developed more advanced numerical models of these various processes to better predict oil’s behaviour and changes in situations where no direct measurements can be made, such as in deep water or in the Arctic.
The Panel found that while scientific modeling has made many advances in predicting how the environment can influence spilled oil and its behaviour (through dispersion, biodegradation, dissolution, etc.), more research is needed to improve models of oil-in-ice effects, oil dispersion by waves, oil droplet formation from blowouts, the formation of oil particle aggregates and the biodegradation of oil droplets under various environmental conditions (such as temperature, salinity, nutrient availability, light and chemical dispersants).

**High-Priority Research Need #3**

*A national, priority-directed program of baseline research and monitoring is needed to develop an understanding of the ecological characteristics of areas that may be affected by oil spills in the future.*

i. Research is needed to collect and evaluate baseline information from high-risk, poorly understood areas, such as the Arctic and other less-studied Canadian environments. (*Timeframe: Within 5 years*)

ii. Research is needed to understand the current status of sensitive and highly-valued species and vulnerable habitats for specific, pre-defined locations in Canada representing a range of human disturbance, from relatively undisturbed to highly disturbed. (*Timeframe: Within 5 years*)

iii. Research is needed to create ecosystem sensitivity maps, prioritized according to recent relative risk assessments, the intensity of current and potential future human use, the relative sensitivity of ecosystems and geographic gaps (e.g., in large areas of inland Canada). (*Timeframe: Within 5 years*)

iv. Research is needed to understand the natural variability of population and community metrics (e.g., abundance, diversity, productivity) across physical and chemical gradients, as well as across time (seasonal and annual). (*Timeframe: Within 5–10 years*)

v. Research is needed to identify other anthropogenic stressors that could influence the effects of oil spills. (*Timeframe: Within 5–10 years*)

**CHAPTER 6: A REVIEW OF SPILL RESPONSE OPTIONS**

Just as types of crude oil are far from uniform and the environments and conditions where spills occur are many, effectively responding to oil spills is complicated. Decisions about what response is best and the likelihood of success depend not only on the oil type, environment and weather conditions, but also on technical and logistical factors (such as the responders’ knowledge and skills, the availability of personnel and equipment, time constraints, regulatory approvals, health and safety criteria, etc.), as well as financial concerns (such as the cost and economic impacts of the spill). Other considerations include the level of community engagement.

There are three main categories of oil spill responses. The first simply relies on natural processes to disperse and degrade spilled oil. For instance, naturally occurring microorganisms can remove or break down some of the hydrocarbons and other chemicals in the oil (called ‘natural attenuation’). Evaporation can also help remove volatile and lighter weight components of spilled oil, while exposure to sunlight and oxygen causes the natural photooxidation of some of the oil’s aromatic compounds. The second type of response involves physically containing and removing spilled oil, often using booms and skimmers on the water or washing and scraping at shore. Thick slicks of oil can also be burned at a spill site. The third response type uses biological and chemical methods. This can involve methodologies to enhance the growth of oil-degrading microbes and/or plants on contaminated sites (phytoremediation) or the application of chemical dispersants that break up oil slicks into small droplets that become diluted into the water column where they are eventually also biodegraded.
Choosing the best response or combination of responses depends on the unique circumstances of each spill. Among these are weather, wave height, ice conditions, daylight and ecological factors, including the risk to fish, invertebrates and other wildlife. Technical and economic factors also play a role, as well as the inherent effectiveness of the response strategy being considered.

The Panel found that most of what is known about oil spill response technologies has been developed through laboratory work and case studies. A better understanding of appropriate spill responses in the Arctic and in snow and ice conditions is vital. The Panel recommends carefully controlled field studies to help close this knowledge gap (without significant negative impact on the environment). Research is also needed to better understand less familiar response methods, such as anaerobic biodegradation in sediments, and emerging technologies (e.g., bioventing, air sparging, etc.) for aiding in the cleanup of anaerobic or anoxic sea floor and lake bottom environments contaminated by sunken oil. What happens to chemically-dispersed oil in both the deep sea and on its surface also needs to be studied using controlled empirical experiments.

**High-Priority Research Need #4**

*A program of controlled field research is needed to better understand spill behaviour and effects across a spectrum of crude oil types in different ecosystems and conditions.*

i. Controlled field experiments on oil spills (sanctioned by the federal government through a new permitting system) with rigorous statistical designs are needed at a variety of sites representing different coastal marine and freshwater ecosystems and conditions. *(Timeframe: Within 5 years and beyond)*

ii. Research is needed at the site of previous oil spills in Canada to increase our understanding of the effects of spilled oil over the long-term and of the extent of natural cleanup. *(Timeframe: Within 5 years)*
High-Priority Research Need #5

Research is needed to investigate the efficacy of spill responses and to take full advantage of ‘spills of opportunity’.

i. Research is needed to help develop effective oil spill response measures tailored to the Arctic, including studies that explore the interactions of oil with permafrost and ice or that examine the microbial degradation of oil at low temperatures. (Timeframe: Within 5 years and beyond)

ii. Advanced planning and contingency funds are needed to support research on the fate, behaviour and effects of real-world oil spills as they occur (‘spills of opportunity’) in the short, medium and long-term, including studies of the relative effectiveness of response measures. (Timeframe: Within 5 years)

iii. Indigenous peoples and their traditional knowledge should be involved in the development of research protocols, in oil spill preparedness, cleanup and remediation/restoration, including involvement in the investigations of ‘spills of opportunity’. (Timeframe: Within 5 years)

iv. Research is needed to address the long-standing remediation question “how clean is clean?” (Timeframe: 5-10 years)

v. Research is needed to develop and improve methods for remediation, reclamation or restoration of damaged marine and freshwater habitats following oil spills. (Timeframe: 5-10 years)

vi. Research is needed on the efficacy and environmental impacts of conventional and new oil spill remediation options, particularly in Arctic and freshwater ecosystems. (Timeframe: 5-10 years)

CHAPTER 7: PREVENTION AND RESPONSE DECISION MAKING

The best way to protect aquatic environments from the sometimes devastating impacts of spilled oil is to prevent spills from happening in the first place. That is, reducing the likelihood of accidental spills is always more effective than managing the risks (to the environment or to the economy) after a spill has occurred. This principle is particularly true in the sensitive ecosystems where spills can cause catastrophic or irreversible consequences, such as in the Arctic where industrial activities (e.g., offshore oil and gas, mining), urban growth and climate-related changes to navigation routes are expected to increase tanker traffic in the years ahead.

All oil spill strategies emphasize prevention as the prior emergency management activity. Effective prevention combines an understanding of the science and technologies associated with oil operations and potential oil spills with a clear understanding of the environment and conditions in which these activities are taking place. For example, properly designed pipelines or tankers can be built to withstand anticipated conditions (waves, wind, ice, etc.) that increase spill risk. Similarly, established procedures, proper inspection and maintenance of equipment and training for extreme and adverse circumstances help reduce the chances of a spill.
High-Priority Research Need #6

Research is needed to improve spill prevention and develop/apply response decision support systems to ensure sound response decisions and effectiveness.

i. A national guidance program for post-spill monitoring is needed to collect reliable, adequate, credible and consistent information on the fate and effects of oil in the environment. This program should be developed based upon consultations among industry, government, Indigenous organizations and community stakeholders. (Timeframe: Within 5 years)

ii. Research is needed to develop methods to support the monitoring of oil spill impacts and the fate of released oil. (Timeframe: 5-10 years)

iii. Research is needed to develop methods for the derivation of comprehensive mass balances for spilled and recovered oil. (Timeframe: 5-10 years)

iv. Research is needed to develop modeling methods to simulate and optimize individual and collective cleanup processes (e.g., booming, in situ burning, skimming, dispersion and bioremediation) for supporting response decision-making. (Timeframe: Within 5 years)

v. Research is urgently required on development and demonstration of oil spill response decision support systems, which can dynamically and interactively integrate monitoring and early warning, spill modeling, vulnerability/risk analysis, response process simulation/control, system optimization and visualization. (Timeframe: Within 5 years)

vi. Research investment is needed on trial tests and field validation of new prevention and decision-making methods to demonstrate feasibility, increase confidence for implementation and improve response capabilities. (Timeframe: Within 5 years)

vii. Research is needed to better quantify modeling uncertainties, evaluate their propagation and mitigate their impacts on spill response decision-making. (Timeframe: 5+ years)

viii. Further research and development are desired on environmental forensics, remote sensing and in situ measurement, early warning and diagnosis, and biological monitoring to improve spill prevention and decision-making. (Timeframe: 5+ years)

ix. Special attention of the above research should be given to some emerging issues (e.g., diluted bitumen, aging/subsea pipelines, railcars and the Arctic) to enhance effectiveness and confidence of prevention and response strategies and decisions. (Timeframe: Within 5 years)

Prevention policies and measures are often best informed by the timely monitoring and analysis of the causes and outcomes of spills when they do occur. Importantly, knowing the characteristics and ecological features of an environment before a spill occurs is central to understanding how it has been affected. Developing baseline data in areas where oil is transported should be an important priority for research.

Indeed, despite the best prevention efforts, spills happen, and then making sound and timely decisions about how to respond is a critical second line of defense. The Panel found that management strategies should be in place to identify the lead decision-making agencies in the case of a spill and to present clearly the steps to contain potential damage to human health, businesses and the environment. Decisions concerning what to do following an oil spill can occasionally mean weighing the potential benefits of a response against its possible harm or against the pros and cons of another approach altogether. Net environmental benefit analysis (NEBA) provides a helpful framework and has been widely used for supporting these decisions. The review also disclosed the limited research efforts in simulating, predicting and optimizing cleanup processes (e.g., in situ burning, skimming and dispersion) individually and collectively and evaluating their effects on response decisions. Inadequate decision support is one of the major challenges that limit the efficiency of current response practices. Due to limited attention and investment, existing decision support systems are rare and lack dynamic and interactive support from other modeling tools (risk analysis, spill modeling, NEBA, process simulation, etc.) and field validation.
In addition, uncertainty is a major hindrance to improving efficiency and confidence of decision-making. These are especially true for the Arctic waters where the window of opportunity for the application of some response measures is significantly short. The Panel also noticed that advances in monitoring and information technologies such as remote sensing, geographic information systems, artificial intelligence and visualization have provided a set of cost-effective and powerful tools that can play a more important role in better addressing complexity and dynamics of spills and supporting sound response making and operations.

**High-Priority Research Need #7**

**Research and work are needed to update, refine and focus risk assessments of oil spills in Canada.**

i. Follow-up relative risk assessments are needed to build upon the Transport Canada assessments of marine spills, focusing on high-sensitivity areas. *(Timeframe: Within 5 years)*

ii. Research is needed to update and refine risk assessment methods to include such things as credible spill scenarios, analyses of seasonal differences in fate, transport and effects of oil (particularly for spills in winter) and the prediction of chronic toxicity. *(Timeframe: Within 5 years)*

iii. A comprehensive national database is needed to track the fate, behaviour and effects of various types of oil spilled and the efficacy of current and emerging oil spill countermeasures over a range of environmental conditions. *(Timeframe: 5-10 years)*

iv. Research is needed to expand species sensitivity distributions (SSDs) for acute and chronic toxicity of oil to aquatic biota. SSDs should be expressed as measured concentrations of total petroleum hydrocarbons and total polycyclic aromatic hydrocarbons. *(Timeframe: 5-10 years)*

v. Research is needed to extend models of chronic toxicity to a wider array of species and environmental (temperature, salinity, etc.) and life history variables. *(Timeframe: 10+ years)*

**CHAPTER 8: RISKS FROM OIL SPILLS**

Learning from history is important to understanding what’s known about the risks posed by potential oil spills in Canada and, most significantly, what needs further study. The Panel reviewed the circumstances and outcomes for selected oil spill cases involving tanker accidents (e.g., the *Arrow* spill in 1970 and the *Exxon Valdez* spill in 1989), a major ocean-rig blowout (i.e., the Deepwater Horizon Gulf of Mexico spill in 2010), pipeline spills and train derailments that occurred in marine and fresh water in Canada and the United States over the past few decades.

Chief among the Panel’s conclusions is that each case was unique in the combination of different physical, chemical and biological factors at the spill location, as well as in the cleanup and recovery measures used in the wake of each accident. These varied combinations of factors were critical for either increasing or decreasing the overall impact for each spill.

Delays in responding to the spilled oil affected the outcome of all case studies examined. Indeed, despite the obvious importance of weather, remote location and technological challenges facing each accident, human error (individuals and organizations) played a dominant role in affecting the impact of the spills across all case studies. Absent or inadequate planning, limited data analysis, inadequate training, poor communication, insufficient personnel and equipment, poor or no information sharing, and lapses in regulatory oversight were common to most, if not all, spill case studies.

From its case study review, the Panel found that the ability of aquatic ecosystems to recover from the shock of an oil spill may be influenced by the presence of other longer-term environmental stresses (e.g., habitat degradation caused by urban development, fishing pressure or water pollution from sewage
discharges or agriculture). In most cases, the lack of pre-spill baseline data (i.e., information about the natural environment and ecology of each area) hampered efforts to predict or monitor the long-term effects of the oil spills on populations and communities of aquatic life. Similarly, monitoring following spills was not conducted according to any standard or consistent national protocols. The Panel’s review of risk assessments of oil spills in Canada revealed a number of challenges, notably the lack of readily accessible data for use in the assessments and the need for increased sophistication of both exposure and effects analyses. In many cases, even if data were accessible, they were extremely limited, particularly for the Arctic and large portions of inland rivers, lakes and wetlands. The Panel found that the assumptions used in the risk assessments sometimes were overly optimistic given the experience gained from oil spill case studies. This was especially true for the spill response times assumed in the assessments.

**CHAPTER 9: CONCLUSIONS**

Crude oil spills are infrequent in Canada’s coastal or inland waters. But the consequences of these spills into sensitive waterbodies can be profound. They can significantly affect not only the environment but also the economy of affected areas as well as human health and safety.

Canada’s offshore oil and gas industry, meanwhile, is expected to grow. The production and transport of unconventional oils, such as diluted bitumens and Bakken crude oil, are likely to increase. Spills of these oils from offshore platforms, pipelines, tankers, rail and other sources will continue to pose risks to Canadian aquatic environments and the communities that rely on them.

The Royal Society of Canada expert Panel prepared this report—based on a review of the science and consultations with key stakeholders—to better understand what is behind these risks. Among the Panel’s many conclusions is a long list of research needs, including seven key research areas that should become top research priorities.

In particular, the Panel recommends that research needs to identify where most oil spills occur and why (e.g., pipeline spills into wetlands are more common than these spills into rivers; oil from truck spills are more likely to enter storm sewers before reaching rivers; etc.). Researchers need to examine past spill response records, current risk management processes and regulations to identify their weaknesses. Other critical knowledge gaps include developing a better understanding of environmental sensitivities that affect the impact of spilled oil. More research is also needed to understand how the type of oil, its source, the environment and the level of preparedness of spill responders combines to influence spilled oil’s fate and effects.

These research gaps are significant. The data needed to assess oil spill risks in Canada are often either absent or widely scattered among government agency, industry and academic sources. Information needed to reliably assess the environmental sensitivity of areas at risk from oil spills is also very limited for large portions of Canada. Input of traditional knowledge from Indigenous peoples and other interested parties is needed.

Examples that demonstrate the need for more research are numerous. Many are documented in the Panel report. While scientific advances have significantly reduced the threat of oil spills in Canadian waters over the past few decades, much about the fate and effects of oil spills remains poorly understood.

To meet the research and oil spill response needs identified in the expert report, the Panel recommends the conduct of coordinated multi-disciplinary research programs between industry, government and academia to further study the effects of oil spills on various marine and freshwater ecosystems, including wetlands. The program should also include Indigenous people for the provision of traditional knowledge and expertise. The science from these studies will provide a much needed database on the interaction and effects of spilled oil with its surrounding environment that will support science-based decision-making following future spill incidents to protect our aquatic environment and its living resources.