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Oil Spill

Response Challenges in Arctic Waters

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WWF Preface

The Arctic is a final frontier for hydrocarbon extraction and is facing renewed pressure owing to high oil prices, rising energy demand, concern over energy security, and retreating ice. There are estimates of significant oil and gas reserves in the Arctic. However, accessing these resources would involve going deeper in colder conditions and into more sensitive and fragile habitats than ever before. Indigenous communities are also concerned over the impacts that oil activities might have on their traditional ways of life.

WWF believes that there are certain places on our planet that are too sensitive to be put at risk from an oil spill. No operator can guarantee 100% that there will not be a spill, and even in ideal conditions oil spills leave their mark. The Arctic offers the highest level of sensitivity and the lowest level of capacity to clean up an accident. This combination makes it unacceptable to expose the Arctic to an unfettered scramble for oil.

WWF is seriously concerned that areas which have previously been protected and off-limits for exploration are now being opened up and considered for hydrocarbon activities. Typical arctic conditions such as extreme temperature, unstable ice, safety and poor visibility create a significant 'response gap' that limits the ability to clean up any spills, thus leaving these special and highly vulnerable places unprotected. The political and economic drivers may have changed but the environmental and social risks are even greater.

The polar bear stands at the top of the arctic food chain and is uniquely susceptible to any ecosystem changes. It is vulnerable to climate change and the associated reduction of sea ice on which the bears live, hunt and breed. The Arctic is home to endangered cetaceans (dolphins, whales and porpoises) that rely on arctic food sources to survive the winters, and are susceptible to noise impacts such as seismic exploration for oil.

The Arctic is at risk of being caught in a vicious cycle. Hydrocarbon extraction is not only a direct threat to the local environment. Growing fossil fuel use results in greenhouse gas emissions that contribute to global warming, which is being felt at its strongest in the Arctic where average temperatures over the last 100 years have gone up 5°C. As a result, sea ice cover is retreating at an alarming rate, opening up new areas for extraction and transport that could potentially accelerate the cycle. September 2007 saw the lowest area of arctic ice cover since records began in 1979.

WWF believes the Arctic Council governments have a duty to ensure the long-term future of the Arctic, as a key element of the sustainable development mandate. This extends to tackling the demand that is driving the rush for resources and addressing the resulting climate change threats to which the Arctic is so vulnerable. A serious effort to decarbonise our energy future is required to limit the push northwards to the Arctic.

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Executive Summary

Arctic conditions can impact on both the probability that a spill will occur from oil and gas operations and the consequences of such a spill. The same environmental conditions that contribute to oil spill risks – lack of natural light, extreme cold, moving ice floes, high winds and low visibility – can also make spill response operations extremely difficult or totally ineffective.

To address the potential for a major marine spill, a system of spill prevention, contingency planning, and response readiness is in place to mitigate or combat oil spills from arctic exploration, production, storage, and transportation operations. This report focuses on the challenges of cleaning up oil spills in the arctic, and considers how those challenges may be addressed during all phases of oil and gas development.

Most oil spill response systems rely on a combination of mechanical recovery and two major non-mechanical techniques – in-situ burning and dispersant application – to clean up or treat spilled oil. However, each of these response options may be significantly limited or even precluded by the harsh environmental conditions that characterise the arctic operating environment. Most of these technologies require the support of aircraft, vessels, and trained personnel to properly deploy and operate them. Remote locations and lack of infrastructure can impede these systems considerably. The cumulative impact of such limiting factors can make marine spill response operations near impossible for long periods of time in arctic and sub-arctic areas.

In nearly all environments, there will be periods during which on-scene conditions may preclude the safe or effective implementation of conventional oil spill response techniques. Such a 'response gap' exists whenever activities that may cause an oil spill are conducted during times when an effective response cannot be achieved, either because technologies available will not be effective or because conditions preclude their deployment due to operational or safety limits.

This report considers how typical conditions may contribute to an arctic marine response gap, and recommends a more formal analysis to quantify this gap for arctic regional seas. The intended audience includes policy makers, environmental stewards, and local stakeholders in arctic and sub-arctic regions who are faced with existing or potential oil development in their marine waters. The purpose of this report is to familiarise readers with the basic components of spill response systems and provide an overview of how environmental factors may limit the effectiveness of spill response options in the arctic.

The authors recognise that significant efforts are ongoing to test and improve spill response technologies for use in arctic conditions. Such efforts are valuable and should continue; however, until such technologies are field-proven and market ready, additional prevention and planning measures are required to eliminate oil spill risks during times when response operations are not feasible.

WWF concludes from this independent study that the only way to avoid the risks of hydrocarbon development is to ensure that no more of the Arctic is opened up to oil and gas exploration until the oil spill response gap is closed. This precautionary approach serves the best interests of industry, government, and indigenous communities.

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1. Introduction

The arctic region can be defined by latitude (the Arctic Circle) or by vegetation, temperature or other geographical or political boundaries (Hassol, 2004 and AMAP, 1998). Figure 1 shows some common delineations of arctic regions. This report uses the term 'arctic' as broadly inclusive of areas where arctic conditions exist for part or all of the year.

Arctic oil and gas development poses considerable threats and challenges to a region already under stress from a changing climate, accumulating pollutants and other types of resource extraction. WWF has developed and commissioned this report to consider the issues associated with effectively containing and cleaning up an oil spill[1] in the arctic marine environment. The report is intended to foster discussion of the realistic limits that arctic conditions impose on oil spill cleanup operations to ensure that such considerations are factored into oil and gas development strategies and contingency plans.

This report begins with a brief discussion of the growing risk that oil spills pose to arctic regions, owing to increased offshore exploration and production and trans-arctic shipping, which are due in part to sea ice retreat. The sensitivity of arctic ecosystems to spilled oil is briefly considered.

The report then discusses the elements of a typical oil spill contingency planning and response infrastructure, and summarises the basic oil spill planning and response systems in coastal arctic regions. Against this backdrop, the report considers how typical arctic conditions may limit or preclude the effectiveness of oil spill planning regimes and response technologies. The potential existence of an arctic oil spill response gap is described and a methodology recommended for quantifying such a gap.

In conclusion, the report offers general recommendations to policymakers who have influence over the environmental safety of arctic oil and gas operations.[2]

[1] Gas spills are treated differently than oil spills, as most of the product is likely to evaporate before safe containment or recovery can be implemented.

[2] While these recommendations include some oil spill prevention measures, the topic of oil spill prevention is not included in the scope of this report.

Figure 1: Select delineations of arctic and sub-arctic regions.

note: based on AMAP 1998

2. Arctic oil spill risks and impacts

As the world population grows and petroleum resources are depleted, increasing attention is being focused on less-accessible supplies, including offshore production in deep water and arctic waters, and the pursuit of 'new' hydrocarbons such as methane hydrates that are concentrated in some arctic regions. Increased exploration and production enhances the probability of a spill occurring from offshore platforms as well as spills from associated pipelines, storage tanks and shipping activities. At the same time, changing sea ice conditions are opening new navigational routes (Hassol, 2004). Spill probabilities increase with a greater number of vessels and volume of oil transported as both cargo and fuel. For existing sea routes, this means more vessel traffic over a longer navigational season; new sea routes will be exposed to vessel traffic and associated spill risks for the first time.

Marine oil spills may result from any phase of oil extraction, storage or transportation. Potential sources of oil spills include well blowouts during subsea exploration or production, acute or slow releases from sub-sea pipelines, releases from on-land storage tanks or pipelines that travel to water, or accidents involving oil transportation vessels or vessels carrying large quantities of fuel oil. Arctic conditions, such as dynamic ice cover, low temperatures, reduced visibility or complete darkness, high winds, and extreme storms add to the probability of an accident or error that might cause a spill to occur (Anderson and Talley, 1995).

There are several characteristics of the arctic environment and arctic wildlife species that exacerbate the potentially negative consequence of an oil spill to arctic waters. Oil persists longer in arctic conditions because it evaporates more slowly or may be trapped in or under ice and is thus less accessible to bacterial degradation. Population recovery after an incident may be slowed because many species have relatively long life spans and slower generational turnover (AMAP 1998). Recent research published in the U.S. suggests that long-term consequences of oil spills to temperate and sub-arctic coastal environments may persist well beyond initial projections (Peterson et al. 2003, Culbertson, et al., 2007. See 'Long-term impacts,' below). Similar impacts could prevail along arctic shorelines as well.

Compared to the world's temperate oceans, arctic marine waters have lower temperatures and lower salinity profiles. Typical winter conditions include cold temperatures, the formation and movement of sea ice, extreme and unpredictable weather conditions, and long periods of darkness. Any of these conditions may increase the risks of a significant accidental oil spill while limiting the potential effectiveness of cleanup options.

The potential consequences of an oil spill (and thus the overall risk) are also impacted by the effectiveness of the spill response and cleanup. If spilled or leaking oil can be effectively contained at its source or promptly removed from the environment, the overall consequences will be much less severe than a scenario where the full spill volume is released, unmitigated, to the environment. In the arctic marine environment, the fact that a catastrophic oil spill might exceed the operating limits of existing oil spill response technologies is significant. The ability to effectively clean up an arctic marine oil spill is a critical component of the risk equation.

Long-term impacts of oil spills:

Two spills in the U.S. show oil impacts may persist for decades

Lingering oil from the 1989 *Exxon Valdez* oil spill (EVOS) in Prince William Sound, Alaska has persisted far beyond initial forecasts (Peterson *et al.*, 2003). In 2005, EVOS oil was found only slightly weathered under beaches across the spill impact area. The lingering oil remains toxic and biologically available, and scientists predict that this subsurface oil may persist for decades to come (Short *et al.*, 2003).

The photograph above shows the presence of EVOS oil in an excavated hole on an impacted beach. The photo was taken in 2001, 12 years after the spill occurred.

The lingering effects of oil spills have also been documented in Cape Cod, Massachusetts, where recent studies published by the Woods Hole Oceanographic Institution found that oil remains in the sediment layer of some coastal marshes from a 1969 oil spill.

The lingering oil continues to impact on the behaviour of burrowing fiddler crabs, which have been observed to actively avoid digging burrows into this oiled sediment layer. The crabs have also been observed to show signs of toxic impacts from the 38-year-old oil (Culbertson, *et al.*, 2007).

3. Oil spill response methods and technologies

The arctic environment poses unique challenges to oil spill response technologies and techniques. While in some limited instances, arctic conditions might prove favourable to spill response, in most cases the arctic operating environment reduces the effectiveness of oil spill control and recovery methods and equipment.

Oil spill response methods are generally divided into three main categories: mechanical recovery, where oil is contained in an area using boom or natural containment and removed using skimmers and pumps; non-mechanical recovery where chemical countermeasures, burning, or bioremediation are used to degrade or disperse an oil slick; and manual recovery, where oil is removed using simple hand tools and techniques such as pails, shovels or nets.

Most existing oil exploration, production, storage, and transportation operations in arctic waters rely on a combination of mechanical recovery and two major non-mechanical techniques – in-situ burning and dispersant application – to clean up or treat spilled oil.

Mechanical recovery contains the spilled oil using booms, and collects it with a skimming device for storage and disposal. Booms are deployed from vessels or anchored to fixed structures or land. A number of different kinds of skimmers exist; they use suction, oleophilic materials or weirs to remove oil from the water's surface. Once the oil has been recovered, it must be transferred using pumps and hoses to temporary storage until it can be properly disposed of.

Therefore, an effective mechanical recovery system requires that sufficient equipment and trained personnel are available and conditions are conducive to contain, recover, pump, transfer and store oil and oily wastes. Ultimately, all recovered wastes must be properly disposed of according to applicable regulations.

In-situ burning of spilled oil on the water's surface involves a controlled burn of floating oil that is contained to the appropriate thickness. The oil is ignited by releasing a burning, gelled fuel from a helicopter onto the oil, or by releasing an ignition device from a vessel or other access point. If successfully ignited, some or all of the oil will burn off the surface of the water or ice. There will always be some residual non-volatile compounds that remain. This residue may float, sink or be neutrally buoyant depending upon the type of oil spilled and the conditions of the burn.

Successful ignition and burning require adequate slick thickness for ignition, minimal wind and waves, and oil that has not emulsified (incorporated water) too much. If a burn is inefficient, a mixture of unburned oil, burn residue and soot will form (NOAA, 2002). As in mechanical recovery, oil containment for ignition can be accomplished either with natural barriers or man-made booms that are both fire-resistant and able to withstand sea ice. Downwind emissions must be below threshold levels for sensitive populations (NRT, 1997). Chemical herders, currently under development, may thicken a slick to allow for ignition (Buist et al., 2006).

Dispersants are a group of chemicals sprayed or applied to oil slicks to accelerate the dispersion of oil into the water column. They do not remove oil from the water, but are intended to limit the amount of oil forming a slick on the water surface or shoreline by driving that oil into a dissolved phase. Dispersants are applied using spray nozzles, pumps and hoses, and can be applied from a vessel or aircraft. Dispersant operations are usually monitored from aircraft to make sure that the application is effective and on target. Dispersants have a limited timeframe for effective application, requiring a prompt, accurate application of the chemicals to the spilled oil with the oil type, emulsification, salinity, weather conditions and sea state all aligned.

Figures 2 through 4 show the typical components of the three response systems described above. All three technologies require surveillance and spill tracking to identify the location, spreading and condition of the spilled oil in order to select and apply the appropriate response equipment and tactics. All three also require logistical support to transport equipment and trained personnel to the spill site, deploy and operate the equipment, and decontaminate the equipment when response operations are complete. Spill responders must be able to safely access the spill site in order to deploy the equipment. Accessing the spill site is often one of the biggest challenges, particularly in remote areas.

Figure 2. Typical on-water mechanical response system

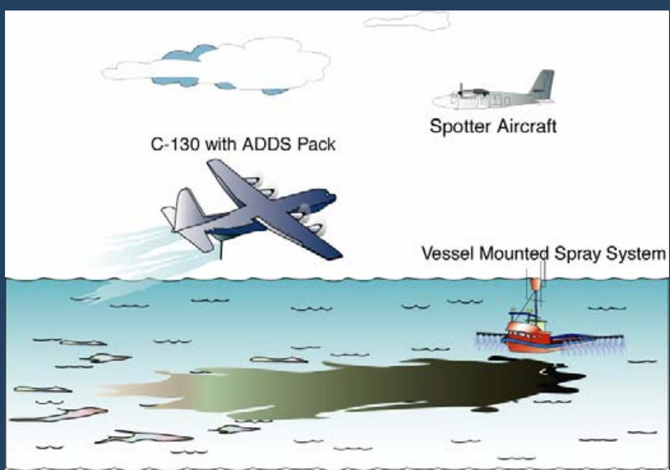

Figure 3. Typical on-water dispersant response system

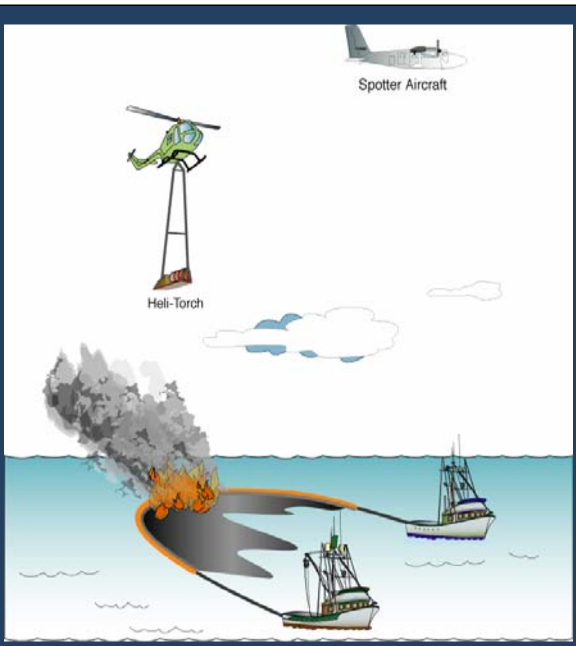

Figure 4. Typical on-water in-situ burning system

With all three spill response options, time is critical. As soon as oil is spilled to water, it begins to spread, evaporate and emulsify. As time passes, it generally becomes more difficult to track, contain and recover or treat spilled oil. Therefore, the quick mobilisation and deployment of response equipment and trained personnel is important to the overall response effectiveness.

4. Oil spill contingency planning

Oil spill contingency plans are an important link between operational risks and response capabilities. These plans describe how available resources would be applied to a release of oil under a range of potential circumstances.

Across arctic regions, the oil spill response planning infrastructure and contingency plan requirements vary considerably. The main arctic petroleum reserves are in Russia, Canada, the US, and Norway (EIA 2006). Of the four major arctic oil-producing nations, all have government-level oil spill contingency plans and resources in place, to varying degrees. In the U.S., Canada and Norway, significant response infrastructure also exists through private response organisations or member-owned cooperatives. In Russia, the development of private response organisations and resources has been more recent, although their response capability is growing as that area experiences increased production. Table 1 summarises the oil spill planning and response infrastructure in arctic nations (based on ITOPF, 2000).

Contingency plans are typically developed, either by individual operators or by national governments or both, to describe the resources and strategies in place to respond to a worst-case oil spill. While the regulations and policies that govern oil spill contingency planning vary among nations and regional seas, most contingency plans include the following:

- Various risk scenarios including a worst-case discharge.
- Prioritisation of sensitive areas for oil spill protection and cleanup.
- A list of response resources available locally and regionally, and the agreements in place to allow their transfer.
- A description of the command and control structure.
- A scenario or scenarios that demonstrate how the available resources would be applied to clean up a worst-case spill under a range of environmental conditions.
- Plans for temporary storage and ultimate disposal of recovered oily wastes.
- Emergency notification procedures.
- Communications equipment and plans to link land, sea and air operations.
- A plan to exercise or test all aspects of the plan and the response system.
- A discussion of how the plan relates to other contingency plans in the region or nation.

Effective implementation of an oil spill contingency plan requires that the operator's policies and strategies for oil spill response be communicated to all response and planning personnel, and that those personnel are in turn committed to carrying out those policies (Hollingsworth, 1991). In the context of arctic oil spill response, this means that the responders identified in the contingency plan must practice deploying equipment in the manner prescribed in the contingency plan, to ensure that planning assumptions regarding response time, recovery efficiencies, and logistical support are realistic. Contingency plans must be continually tested and revised to reflect lessons learned during actual deployments.

Alaskan fishermen observe an oil skimmer. Participants in this fishing vessel training program receive a combination of classroom time, hands-on learning with response equipment, and on-water training.

Table 1. Overview of oil spill prevention and response in Arctic countries (continental Europe and Asia)

	Finland	Norway	Russia	Sweden
Marine-based oil and gas activities	Production, storage, transportation via shipping.	Exploration and production, transportation via shipping routes, bulk storage, refineries.	Offshore exploration and production, transportation via shipping routes, bulk storage, refineries.	Production, storage, transportation via shipping.
Relevant national authority	Finnish Environment Institute (SYKE).	Norwegian Coastal Administration.	State Marine Pollution Control, Salvage and Rescue Administration.	Swedish Coast Guard.
National contingency plan requirements	Rescue Service Authorities have c-plans for municipalities in its area; government has regional c-plans as well.	Companies, municipalities and federal government have integrated c-plans.	Local, regional, and national c-plans; ports, terminals, and harbours also have c-plans.	National response plan; County Administrations have sensitivity atlases.
National response policy	Mechanical recovery (according to Helsinki Convention); no dispersants.	Contain and recover oil as close to the source as possible. Use of dispersants is supplementary and subject to approval.	Treat with mechanical means if weather conditions allow; dispersants and in-situ burning allowed for some spills depending on circumstances and with approval.	Prioritise mechanical recovery; dispersants not used.
Equipment stockpiles	Government has 13 stockpiles and oil recovery vessels; coastal municipalities maintain small recovery vessel and equipment. Terminals have equipment for spills at their facilities.	Government has response vessels and aircraft; also 15 manned equipment stockpiles along coast and islands. Industry (NOFO) has five stockpiles and access to vessels and aircraft.	Stockpiles at ports, terminals, and harbours based on local spill risk; specialised vessels and equipment in larger ports. Two private response contractors nationwide.	Government has oil recovery vessels and equipment at six locations, also aircraft. Oil-handling facilities maintain equipment.
Responders	Government; no private contractors.	Government and industry; stockpiles are manned.	Government and private response contractors.	Government and industry; 25 Coast Guard stations.

Table 1. Overview of oil spill prevention and response in Arctic countries (North America, Greenland, Iceland)

	Canada	Greenland (Denmark)	Iceland	USA
Marine-based oil and gas activities	Exploration and production, transportation via shipping routes, bulk storage, refineries.	Exploration and production, transportation via shipping routes.	Transportation via shipping routes, bulk storage, refineries.	Exploration and production, transportation via shipping routes, bulk storage, refineries.
Relevant national authority	Canadian Coast Guard, Department of Fisheries and Oceans.	Royal Danish Navy.	Environmental and Food Agency of Iceland (EFAI).	Coast Guard, Office of Response.
National contingency plan requirements	Tankers over 150GT and other vessels over 400GT must have c-plans; response organisations have own c-plans.	Greenland-specific c-plan has been developed.	N/A	Tankers and other vessels >400GT require government-approved vessel response plan; regional and response organisation c-plans as well.
National response policy	First transfer oil from damaged tank/vessel, then focus on containment and recovery as conditions permit. Dispersants and in-situ burning of secondary importance; dispersant use must be approved.	Sea conditions prevent most clean-up methods; however, every effort will be made to recover as much oil as possible. Dispersants prohibited.	Contain and recover spill as close to source as possible. Mechanical recovery preferred; dispersant use requires special approval.	Containment and recovery are priorities. In-situ burning and dispersants pre-approved in some States; dispersant use requires approval by Regional Response Team.
Equipment stockpiles	Government-owned equipment in 73 sites nationwide; four private response organisations have various stockpiles sufficient for on-water recovery specified amount in 10 days. Ports and oil-handling facilities also have equipment.	None; would come from Denmark or Canada. There are two stockpiles of equipment in Denmark; also spill response vessels but unlikely that these would reach Greenland in time to be effective, more likely to come from Canada.	Government-owned equipment in five major regional stockpiles; municipalities and regional cooperatives have smaller stockpiles in multiple locations.	Government equipment stockpiled along coastal areas and islands and at naval bases. Private response organisations and oil-handling facilities maintain stockpiles as well.
Responders	Government coordinates Regional Environmental Emergencies Teams; response organisations.	None; would come from Denmark or Canada.	Primarily local, municipal responders as ports are government-owned.	Private response organisations, Coast Guard strike teams on three seaboards.

5. Oil spill planning and response in the arctic environment

Oil spill response systems have distinct capabilities and limitations that should be considered in planning for potential cleanup operations. Most technologies used in responding to oil spills in the Arctic have been adapted from those typically used in temperate regions on open water and land. Environmental conditions in the Arctic are an obvious impediment to the efficacy of most spill response technologies. Typical arctic conditions impacting on oil spill response operations include the presence and type of sea ice, extreme cold, limited visibility, rough seas, and wind (Owens et al.,1998). These conditions may also impact on the fate and behaviour of spilled oil, and thus either improve or reduce the effectiveness of response technologies and systems (Brandvik et al., 2006).

Response limits may also be driven by a combination of factors that, singly, would not affect the response. The cumulative effect of two or more environmental factors is not necessarily equal to the sum of the two factors individually: the interaction of the factors may cause more extreme impacts. For example, the combination of wind and cold can cause the wind chill factor to make air temperatures dangerous to responders, or cause ice to form on vessels and equipment, making them unsafe or unstable. Waves of a certain height or period present a greater obstacle to response operations when there is a strong wind or low visibility.

All spill response requires effective planning, tracking, and surveillance. Visual methods of tracking an oil slick on water can be hampered by poor visibility due to darkness (which can lasts for months) or fog (which can last for several days). Oil that moves under ice is more difficult to track than oil on open water (Brandvik et al. 2006). Any aircraft-based surveillance efforts will be subject to safety limitations in wind or poor visibility. Remote sensing technologies may be impervious to some of these challenges; however, the technology and expertise necessary to operate these systems is not readily available in many arctic regions.

While arctic conditions may reduce the effectiveness of spill response methods, there may be times when these same conditions provide opportunities that may not exist in open water. For example, sea ice can act as a natural containment barrier to facilitate mechanical recovery or burning of the oil contained by ice floes (Brandvik et al., 2006), if it can be accessed safely. Solid ice pack can serve as a platform to support heavy equipment and vehicles in areas that might otherwise be inaccessible (ACS, 2006). Extended daylight during summer months could increase operational periods, if sufficient staffing is available and other conditions allow safe access and operations. Colder temperatures may cause the oil to be more viscous and slow spreading (Brandvik et al., 2006).

Table 2 on the following pages summarises how arctic conditions may impact the effectiveness of mechanical recovery, in-situ burning and dispersant application systems.

Table 2. Typical arctic conditions and potential impacts on spill response options

Conditions	Potential impacts on spill response			
	General constraints	**Mechanical recovery**	**In-situ burning**	**Dispersants**
Sea ice[3]	Ice can impede access to the spill area, making it difficult to track and encounter oil. Remote sensing techniques are being improved and refined to detect oil under and among sea ice, but they are not yet mature. Ice can impede or limit vessel operations, especially for smaller work boats. Boats without ice-capable hulls should not operate in heavy ice conditions. Slush ice may clog seawater intakes or accumulate in vessel sea chests.	Containment boom can be moved, lifted or torn by ice. Skimmer encounter rate may be reduced by ice chunks, and skimmers and pumps may clog. Limited manoeuvrability may prevent or delay accurate skimmer or boom deployment. Attempts to deflect the ice from recovery areas may also deflect the oil. Ice must be separated from recovered oil. Ice may provide natural containment. Reinforced vessel hulls or ice scouts may be required. Ice movement can be unpredictable or invisible. Vessel operators must be experienced in the ice conditions of the area.	Certain ice conditions (i.e. slush ice) may reduce burn effectiveness or impede ignition. Fire boom deployment may become difficult or impossible. Residue recovery requires vessel support. Ice may provide natural containment, and burning in ice leads may be possible.	Oil under ice is inaccessible to dispersant application. Ice can dampen required mixing energy. Dispersants generally less effective at lower salinities. In most regions, dispersants are not considered an operational technology for use in sea ice.

[3] Sea ice is a prominent feature of the arctic marine environment. The generic term “sea ice” encompasses a wide range of ice conditions. Sea ice may be present year-round, or it may follow an annual freeze-melt cycle. Ice conditions may be described in terms of the formation of the ice or the percentage coverage. The World Meteorological Organisation’s ice classification system and terminology are used in this report (WMO, 2005).

Conditions	Potential impacts on spill response			
	General constraints	**Mechanical recovery**	**In-situ burning**	**Dispersants**
Wind	High winds can make it difficult to deploy effectively the crew, vessels, equipment required for a response. High winds can make air operations difficult or unsafe.	High winds can move boom and vessels off station or tear boom off the anchor point (Potter, 2004).	In-situ burning is not generally safe or feasible in high winds.	Accurate application of dispersants is difficult in high wind conditions.
Temperature	Prolonged periods of sub-freezing temperatures can impact personnel safety, or require more frequent shift rotations. Extreme cold temperatures may be unsafe for human operators. Cold may cause brittle failure in some metals. Cold air may freeze sea spray, creating slick surfaces. Icing conditions may make vessels unstable.	Skimmers freeze up. Freezing sea spray can accumulate on boom and cause it to tear, fail or overwash. Increased oil viscosity makes it difficult to recover and pump.	Extreme cold temperatures may make ignition more difficult or ineffective, and may cause burn to slow or cease.	Cold temperatures and increased oil viscosity may reduce dispersant effectiveness.

Conditions	Potential impacts on spill response			
	General constraints	**Mechanical recovery**	**In-situ burning**	**Dispersants**
Limited visibility (including months of darkness in far northern areas)	Any condition that reduces visibility may preclude or limit oil spill response operations, particularly any involving aircraft or vessel operations. Limited visibility may make it difficult or impossible to track the spill location and movement. Fog banks make vessel or aircraft operations extremely dangerous.	Accurate deployment of vessels and equipment requires sufficient visibility to deploy and operate equipment. Work lights may be used during darkness, if safety allows.	In-situ burning is not recommended during darkness (USCG, 2003). Aerial ignition and/or aerial monitoring require visual flight conditions.	Aerial application and/or aerial monitoring requires visual flight conditions. Vessel application requires visual confirmation of slick location.
Sea state	Waves can have varying impacts depending on their form. Short, choppy waves generally have a greater impact on a response than long ocean swells. Currents and tidal changes may also affect response operations.	Booms and skimmers do not function well at high sea states. Equipment must be suitable (rated) for typical sea states. Fast currents, changing tides and short period waves can make it difficult to keep boom and vessels on station. It is dangerous to manoeuvre booms and skimmers in rough seas. A common rule-of-thumb limitation for boom is a 2-3m significant wave height.	High sea states make containment and ignition difficult and potentially unsafe.	High sea states typically enhance the effectiveness of chemical dispersants to disperse the oil.

Bull Seal Bay with melting sea ice in June, St. Matthew Island, Alaska, USA. Sea ice can impede access to the spill area, making it difficult to track and encounter oil. Remote sensing techniques are being improved and refined to detect oil under and among sea ice, but they are not yet mature. Photo © WWF-Canon / Kevin SCHAFER.

6. Considerations for arctic oil spill contingency plans

Contingency plans describe strategies to clean up a worst-case discharge based on available response capabilities and limitations. The information and analysis in a contingency plan may be used to ensure that sufficient equipment, trained personnel and logistical support exist to carry out an adequate response. Part of this analysis includes determining which technologies are likely to be effective in cleaning up a spill under the range of conditions likely to be encountered.

In planning for oil spills in the Arctic, there is little real-world data available regarding the effectiveness of spill response systems, because to date there have been no major arctic marine oil spills. Most of the available information regarding spill response technologies under arctic conditions is based on laboratory or small-scale field trials that focus on individual technologies.

A number of studies and literature reviews attempt to quantify the limits of various response technologies, to provide spill responders and contingency planners with rules-of-thumb about whether mechanical recovery, in-situ burning or dispersants are likely to be effective under certain conditions. Rules-of-thumb are extremely useful to both contingency planners and response managers because they establish a ceiling for response operations. However, the basis for most of these limits lies in small-scale tests that examine the operating limits of a specific technology or type of equipment rather than the entire system. While initial testing in laboratories or test tanks provide valuable data about the operating limits of individual technologies, most tests use relatively small amounts of oil under controlled conditions, and are not illustrative of overall response capabilities (Brandvik et al., 2006).

Response limits for mechanical recovery, in-situ burning, and dispersants can occur when a single piece of equipment fails to perform as intended, or when one or more supporting components break down. Therefore, even if a piece of equipment is engineered to operate in extreme arctic conditions, it may not be safe or feasible to deploy that equipment when it is needed. For example, a laboratory test which demonstrates that a skimmer will not clog until ice concentrations exceed 40% in a test tank under controlled conditions does not mean that mechanical recovery will be feasible, safe or effective in such ice concentrations. The upper limit of a single piece of equipment or an individual technology does not guarantee that the response system required to deploy that technique will have the same functionality.

Field deployments provide an opportunity to delineate the operational limits for spill response systems, because equipment is transported to the scene and deployed under a range of natural conditions. In some cases, a response system may fail not because of a primary equipment failure but because one or more of the technologies or support platforms required does not perform as intended. These support functions may be severely challenged by arctic environmental conditions or by remote locations or lack of infrastructure. During a series of field trials held in the Alaska Beaufort Sea, responders found that the actual limits to a vessel-based skimming and recovery system were realised in much lower sea ice concentrations than previously assumed (NRC 2003). Lessons learned from actual spill responses in temperate and sub-arctic regions are also important reminders of the difficulty of mounting a marine spill response when conditions are unfavourable (see ‘Lessons Learned’ on next page).

An accurate assessment of the capabilities and limits of a response system in its entirety is necessary to anticipate the conditions during which a response may or may not be effective. Once these limits have been defined, they should be applied to the earliest phases of the planning process, to begin to understand the interplay between spill risks and response feasibility. Other decision-making tools, such as net environmental benefit analysis (NEBA), which is used to consider the potential environmental risks and benefits of various response methods, cannot be applied without a thorough analysis of the potential effectiveness of various spill response systems under a range of conditions.

The oil tanker *Seabulk Pride* aground north of Nikiski in Cook Inlet, Alaska, USA, February 2006. Photo courtesy of ADEC and the Prince William Sound Regional Citizens' Advisory Council.

LESSONS LEARNED:

Logistical challenges, remote locations and harsh weather complicate oil spill responses

Lessons from several recent oil spills demonstrate how critical issues of timing, on-scene conditions, logistical support, and pre-planning are to the success of a response. These real-world examples highlight just how difficult it can be to implement an effective spill response in various regions of the world. In remote, undeveloped regions of the Arctic, all of these factors come into play.

Lack of local spill response infrastructure handicaps response

In March 2006, the *Runner 4*, a Dominican-registered cargo ship collided with another vessel and sank off the coast of Estonia. Finnish oil spill response vessels were dispatched over a week later because it was evident that Estonia did not have the resources necessary to mount an effective response in icy conditions, nor had response efforts begun promptly. The delayed response allowed the oil to spread and affect a much larger geographic region than if it had been promptly controlled. Conditions at the spill site hampered response efforts, with wind of 17 metres/second and heavy rain. Soon after the Finnish ships arrived, much of the oil had spread to shallow areas inaccessible to the vessels, further complicating cleanup efforts. (*Baltic Times*, 2006)

Norway spill travels in sea ice and impacts sea birds

Also in March 2006, a fuel oil spill was detected near the Borregaard chemical plant in south-eastern Norway. By the time the oil was discovered – when the ice began to break up – it had been carried on the Glomma River to an ocean inlet near both a major bird sanctuary and a coastal vacation area. According to the local fire chief, ice, cold and strong currents precluded the effective use of traditional spill response equipment (Associated Press, 2006). The International Fund for Animal Welfare reported that 200 ducks and 80 swans were oiled, with hundreds more at risk (IFAW, 2006).

Winter weather slows response to Alaskan freighter spill and leads to significant shoreline impacts

In December 2004, the *Selendang Ayu*, a bulk carrier transiting through the Aleutian Islands, lost engine power and ran aground on Unalaska Island. Immediate rescue efforts focused on the crew; and due to weather conditions, the area most affected by the fuel oil leaking from the damaged ship was not reached for several days. Response equipment stored nearby was depleted within two weeks, and on-water skimming equipment was not on scene until three weeks later, by which time the spilled oil had already begun to affect shoreline areas. The skimmers were used only to remove oil that had remained in the ship. Bad weather also kept the dispersant supply from arriving until three weeks after the accident.

An estimated 1.2 million litres of oil was released into the environment. Other than the oil lightered from the wreck, all recovered oil was collected on shore. In many cases, shoreline impacts were caused by re-mobilised oil that had washed ashore on one beach, then re-floated during subsequent storm events, and spread to new shoreline areas. This continued for several months after the initial release. A total of 666,592 bags of oily waste were removed from local beaches during the spill cleanup. Over 100 local residents, trained in shoreline cleanup, provided assistance. More than 1,600 dead birds were recovered. A local Tanner crab fishery was closed following the spill (ADEC, 2004-2005).

7. The 'response gap' concept

A 'response gap' exists when activities that may cause an oil spill are conducted during times when an effective response cannot be achieved, either because technologies available will not be effective or because their deployment is precluded due to environmental conditions or other safety issues (Robertson, 2007).

A response gap analysis involves a calculation of the response operating limits of spill response systems for a set of environmental factors, such as wind, sea state, sea ice, visibility, etc., and an analysis of the frequency, duration, and timing of conditions that would preclude a response in a particular location. The methodology must account for the cumulative interplay between factors that would cause two or more variables that are individually within the system's limits to exceed those limits when combined. An assessment of the frequency, duration and timing of occurrence of one or more limiting factors or limiting combinations is then performed using either modelled or historical environmental and climate data for a given location or area (See 'response gap analysis', below).

In order to analyse the response gap for a given location, the upper operating limits of the response system or systems in question must be established. This assessment requires analysis and study of the response equipment and procedures beyond stating that they are present on-scene and citing manufacturer ratings; the effectiveness of the system in actual conditions that may exist in the likely operating environment must be demonstrated.

A response gap calculation is by nature an estimate, as it is impossible to predict future conditions exactly, even with extensive historical data. This is especially true in the context of climate change effects in the Arctic. However imperfect, historical data can be used to characterise 'average' conditions over a period of time – a month, season or year – to determine the likelihood that environmental factors will render a spill response ineffective.

A reliable response gap analysis requires data on environmental factors over several years. The data should represent actual operating conditions in a potential spill impact area, such as in the vicinity of a drill rig or a major shipping route. Factors other than those related to environmental conditions can be incorporated as well, such as availability of response resources or existing daily, seasonal or weather-based operating restrictions.

A response gap analysis for a particular location sheds some light on the frequency, duration and timing of conditions during which no response is viable at a particular site. If a response gap exists at a particular location at a particular time, different policy, planning or development options can be explored to bridge the gap, either by improving response capability or limiting operations when the environmental conditions would preclude a response.

Response gap analysis in Prince William Sound (Alaska, USA) shows no response possible for 65% of winter season in one location

A response gap analysis was conducted for two points on the Prince William Sound tanker transit route in Alaska. Datasets on wind, sea state, temperature and visibility were built using buoy observations from the previous five years. The operating limits of the open-water mechanical response system described in the tanker owners' oil spill contingency plans were estimated based on literature, manufacturer ratings and best professional judgement. These limits were applied to the historical datasets in three categories – response possible, response impaired, and response impossible.

Limiting factors were considered both in terms of independent and cumulative impacts. When two or more factors existed to make a response 'impaired,' then response was considered 'impossible' for that time period. The Prince William Sound response gap analysis found that a response gap – during which no oil spill response activities would be safe or feasible due to one of the four environmental factors considered – existed for 38% of the time on average. During the winter season, the response gap existed 65% of the time. This analysis did not consider ice conditions, which could exacerbate the response gap in areas where sea ice may be present.

It is important to note that within the area of study (Prince William Sound), exceptional prevention measures are in place during all weather conditions, including a tug escort system for all laden oil tankers. The main tanker lanes through Prince William Sound are also subject to closure limits when winds and/or sea states exceed a prescribed level. (This was incorporated into the analysis described above.) These systems are both examples of mitigating measures that can be put in place to limit the risk of oil spills when a response gap exists.

A similar analysis is ongoing to determine the response gap for non-mechanical response systems in Prince William Sound.

Based on Robertson (2007).

A tug escorts the Alaska Tanker Company's oil tanker *Alaska Frontier* through fog in Prince William Sound.

8. Analysis and recommendations

In recent years, significant research and development has been underway to define and expand the operating windows for oil spill response systems in arctic environments. Such efforts are valuable and should continue. However, policy makers must also understand that existing technologies face significant limits under normal arctic conditions, that cumulative effects may exacerbate these limits, and that the arctic environment is still new ground for marine spill response technologies and systems.

The response gap in typical arctic conditions is not yet quantified, but is likely to be very large. The lack of real-world experience of deploying and operating spill response equipment in the arctic creates a major challenge to predicting or understanding the response capabilities and limitations of spill response systems. However, a realistic assessment of systemic limitations of oil spill response techniques in arctic regions is critical to understanding and assessing spill risks from oil and gas development.

A multi-year research effort has been initiated by the oil industry, in partnership with research institutions and response organisations, to assess and improve the state of technology for oil spill response in arctic waters. The Joint Industry Programme (JIP) includes research and development initiatives in eight subject areas, including spill response technologies, remote sensing, fate and behaviour of oil in the arctic and contingency planning for arctic oil spills. While this process includes many leading researchers and manufacturers of spill response equipment and several arctic nations, it does not include representation of the environmental community or stakeholder groups, who also have a vested interest in spill response capabilities and limitations.

In addition to the JIP, researchers in the government and private sectors continue to refine technologies to expand the operating window for spill response equipment and systems. International workshops focused on cleaning up oil spills in sea ice were held in 2000 and 2007. As these efforts continue, it is critical that resource managers, local stakeholders, and environmental stewards also contribute to the discussion and analysis of oil spill contingency planning in arctic regions. Strong governance and oversight of oil and gas operations as a whole, and of spill prevention and response in particular, are important to ensure the highest possible standards in protecting public health and resources.

WWF advocates continued diligence on the part of the industry, regulatory agencies and environmental stakeholder groups, to ensure that oil and gas operations in the Arctic acknowledge and plan for the existence of a response gap.

We recommend the following steps to ensure that arctic oil and gas operations — both existing and new — rely on realistic expectations when developing oil spill contingency and response plans:

- Perform a response gap analysis for proposed and existing arctic oil operations to quantify the percentage of time during which local conditions exceed the demonstrated limits of spill response systems.

- Consider the existence and scope of a response gap as a contributing factor to overall spill risks over the life of the operation, and factor the response gap into oil spill vulnerability and risk assessments. Weigh environmental sensitivity data against response gap information for both location and timing.

- Determine an acceptable threshold for response gaps for a specific operation or location. This process must involve local governments and stakeholders, as well as natural resource managers. Establish "no go" zones or closure limits as appropriate for areas where the existence or magnitude of a response gap is found to create an unacceptable level of risk.

- If oil and gas operations are to proceed where a response gap exists, design prevention systems or operating restrictions to improve safety and minimise spill risks during times when no response is feasible.

- Assess local response capabilities. Consider the impact of infrastructure limits and logistical requirements to spill response operations. Remote areas may not have the airstrips, ports, or support services required to mount a large-scale response. Likewise, they may lack the infrastructure to house and feed response personnel for the duration of a response (months to years).

- Develop oil spill contingency plans that contain realistic response scenarios to show the resources and personnel required to respond to a worst-case discharge and provide realistic timeframes for their mobilisation and deployment and realistic estimates of their cleanup capacity. Explain how adverse conditions might affect the response.

- Ensure that research and development efforts to improve spill response technologies also address logistical support and deployment considerations, and that individual technologies are field tested in the context of the overall response system.

9. Conclusion

Any natural resource development in the Arctic over the coming decades will be done in a context of inherent uncertainty. While it is likely that reduced sea ice will make the region more accessible in the long term, unpredictable and short-term changes will challenge development and contingency planning efforts. A production facility located in multi-year pack ice in 2008 will most likely face seasonal ice conditions within its operational lifetime.

Proposed industrial activities in arctic waters should be evaluated thoroughly in terms of their potential impacts during normal operations and in the event of an accidental oil spill. The location, infrastructure, operations and safety measures associated with any means of exploring, producing, storing or transporting oil and gas in the arctic must be carefully scrutinised. The existence of a response gap must be acknowledged and quantified. All of this information must be available *before* any form of petroleum extraction is initiated.

This report reveals substantial gaps in oil spill response capacity that WWF believes must be filled as a pre-condition before any further petroleum development in the Arctic. The risk of environmental and economic damage resulting from major spills in Arctic waters can be greatly reduced if individuals from the private and public sector take action now to address the response gap issue before proceeding with new development.

The oil spill response constraints posed by arctic conditions contribute considerably to the risk of negative impacts from an arctic oil spill. The same dynamic conditions that challenge spill responders have also added to the stresses on arctic species and habitats. A catastrophic event like a major oil spill could permanently tip the balance.

WWF believes that the only way to avoid the risks of hydrocarbon development is to ensure that no more of the Arctic is opened up to oil and gas exploration until the oil spill response gap is closed. In areas where this is not feasible for technical or logistical reasons, extractive operations should not take place. This precautionary approach serves the best interests of industry, government, and indigenous communities.

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