Oil Spill Detection and Modeling in the Hudson and Davis Straits

LOOKNorth Final Report
R-13-087-1096

Prepared for:
Nunavut Planning Commission

Revision 2.0
2014-05-29

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LIST OF ACRONMYS

AHS	Airborne Hyperspectral Scanner
AIS	Automatic Identification System
ATMARIL-3	ATMospheric and MARine LIDAR
AVHRR	Advanced High Resolution Radiometer
AVIRIS	Airborne Visible Infrared Imaging Spectrometer
BAOAC	Bonn Agreement Oil Appearance Code
BOLT	Bedford Institute of Oceanography Ocean Lagrangian Tracking
CCD	Coherent change detection
CCG	Canadian Coast Guard
CECOM	Canadian East Coast Ocean Model
CIS	Canadian Ice Service
CMC	Canadian Meteorological Center
C-NOOFS	Canada-Newfoundland Operational Ocean Forecasting System
CONCEPTS	Canadian Operational Network of Coupled Environmental Prediction Systems
DMC	Disaster Monitoring Constellation
DMI	Danish Meteorological Institute
EC	Environment Canada
ECMWF	European Centre for Medium-Range Weather Forecasts Model
ECRC	East Coast Response Corporation
ECS	Electronic chart system
EMSA	Microwave radiometers
EO	Earth Observation
ERMA	Environmental Response Management Application
eSPACE	emergency Spatial Pre-SCAT for Arctic Coastal Ecosystems
FLIR	forward-looking infrared
GFS	Global Forecasting System
GIS	Geographic Information System
GPS	Global Positioning System
HYCOM	HYbrid Coordinate Ocean Model
IMO	International Maritime Organization
INTA	Instituto Nacional de Técnica Aerospacial
IR	infrared
ISTOP	Integrated Surveillance and Tracking Of Pollution
JIP	Joint Industry Program
LEDs	Light-Emitting Diodes
LFS	Laser fluorosensors
LIDAR	LIght Detection and Ranging
MCT	mercury-cadmium-telluride
MODIS	Moderate Resolution Imaging Spectroradiometer

MSC	Meteorological Service of Canada
MSS	Maritime Satellite Surveillance
MWIR	Mid-Wavelength InfraRed
MWRs	Microwave radiometers
NASP	National Aerial Surveillance Program
NAVGEM	Navy Global Environmental Model
NCP	Nunavut Planning Commission
NEEC	National Environmental Emergencies Centre
NIR	near-infrared
NOAA	National Oceanic and Atmospheric Administration
NOFO	Norwegian Clean Seas Association for Operating Companies
NORDREG	Northern Canada Vessel Traffic Services Zone
NRT	near real-time
OI	Ocean Imaging
OSSAS	oil spill scene analysis system
PPB	parts-per-billion
PPD	Petroleum Products Division
RCM	RADARSAT Constellation Mission
REET	Regional Environmental Emergencies Teams
RMS	root mean square
SAR	Synthetic Aperture Radar
SCAT	Shoreline Cleanup and Assessment Technique
SLAR	Side-Looking Airborne Radar
SWIR	Short Wave InfraRed
TC	Transport Canada
TEK	traditional ecological knowledge
TIR	Thermal InfraRed
UAV	unmanned aerial vehicle
UV	ultraviolet
VIS	visible
VNIR	Visible and Near InfraRed
WRF	Weather Research and Forecasting Model

EXECUTIVE SUMMARY

This project was carried out to assess current capabilities for oil spill detection and impact prediction in the Hudson and Davis Strait areas. To this end, a series of literature reviews were conducted covering the movement and weathering of oil in Arctic waters, the use of remote sensing technologies for Arctic oil spill monitoring, and the modeling of oil fate and trajectories in the presence of sea ice. An assessment of local capabilities and gaps to respond to oil spills was performed, and recommendations formulated to increase the local capacity for effective oil spill response.

Although a significant body of knowledge exists to describe the use of remote sensing technologies for oil spill detection and monitoring on open water, there is little research available to describe their performance in ice-affected marine environments. Dedicated research is therefore required to fully assess the utility of remote sensing technologies under Arctic conditions. As no single technology will likely fulfill the needs of all aspects of oil detection in the complex and dynamic Arctic environment, using a suite of multiple sensors may improve detection performance. Current and upcoming satellite missions should be incorporated into the operational monitoring of oil spills and other relevant environmental parameters.

The behavior of oil in ice is complex, and although research efforts over the past decades have resulted in models that satisfactorily forecast the fate and trajectories of oil spills in open water conditions, modeling of oil spills in ice-covered waters is relatively little advanced. Sea ice is not considered in most existing oil spill models; when it is, the formulations are simple and arguably over-simplify the problem. To improve forecasting of oil fate and trajectory in sea ice, models should incorporate current and new generations of operational coupled ocean-ice models and atmospheric models, assimilate near real-time data, consider oil weathering processes and uncertainty, and model oil-ice-interaction using the discrete-element method over smaller geographic areas.

Opportunities to increase local response capabilities include improved coordination between territorial and federal government agencies, and training of local staff and community members. Recommended capacity building activities include training in oil spill awareness, shoreline protection and data gathering, as well as formalized training in advanced remote sensing methods to extract oil spill and environmental information (e.g. sea ice and wind) from current and future satellite missions. In order to facilitate effective shoreline cleanup in the event of a spill, the Hudson and Davis Straits should be mapped to identify environmentally sensitive shoreline areas, as defined by Environment Canada criteria, traditional knowledge and community importance. A central point of reference should be established within the territorial government to handle all elements related to oil spill response in Nunavut, including training, community outreach, interaction with local, territorial and federal stakeholders, as well as the building of resident scientific and technical expertise.

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1 INTRODUCTION

As a result of changing environmental conditions and ice regimes, the Arctic is becoming more accessible, and it is anticipated that economic activities, resource development and shipping will increase throughout Canada's north in the coming years. This, in turn, raises concerns about heightened risks of marine pollution due to accidental spills of oil and other harmful substances.

The Hudson and Davis Straits are critical corridors for marine transportation in Nunavut. The Hudson Strait is the primary access point for the delivery of goods and diesel fuel to the Baffin Island communities of Kimmirut and Cape Dorset. The Davis Strait provides the eastern access to the Northwest Passage, and as a result is not only important for connecting communities by sealift, but also a main transportation hub for commercial shipping and moving of natural resources including minerals, and potential oil and gas. Funded under the Nunavut General Monitoring Plan (NGMP), this study was undertaken in an effort to increase the ability of relevant Federal and Territorial Government Agencies and community stakeholders to respond and how to prepare for marine oil spills in the Hudson and Davis Strait areas. To this end, the following tasks were carried out:

- Review and summarize the behavior of oil in the Arctic marine environment;
- Review the current capabilities of remote sensing technologies to detect and monitor oil spills in Arctic waters;
- Review current approaches to the modeling of oil fate and trajectories in Arctic marine conditions;
- Assess local spill response capabilities in the Hudson and Davis Strait areas and identify gaps; and
- Formulate recommendations to close capability gaps and increase the level of local involvement in spill response.

1.1 AREAS OF INTEREST

The principal areas of interest covered by this investigation are presented in Figure 1. The corresponding communities located along the Hudson and Davis Straits include the following:

- Cape Dorset;
- Kimmirut;
- Iqaluit;
- Pangnirtung;
- Qikiqtarjuaq;
- Clyde River and
- Pond Inlet.

Source, Canadian Geographic, 2014

Figure 1. Map of Hudson and Davis Straits, Nunavut

1.2 CONTRIBUTION TO VALUED COMPONENTS

This investigation provides information applicable to a number of valued components identified in the NGMP. The link between each valued component and relevant sections in this document is provided in Table 1.

Table 1. Value Component (VC), Associated Indicators and Remote Sensing Capabilities

Valued Components and Indicators	Relevant Sections in Document
Valued Ecosystem Components: • Marine Water Quality • Sea Ice	• Section 2: Oil in the Arctic Marine Environment • Section 3: Remote Sensing for Arctic Oil Spill Monitoring • Section 4: Predictive Models for Fate and Trajectory of Oil in Ice • Section 6: Conclusions and Recommendations
Socio Economic Components: • People - Health and well being, food security • Economic – Employment	• Section 5.1: Spill Risks and Scenarios • Section 5.3: Current Response Capabilities in Nunavut • Section 5.4: Identification of Gaps and Needs • Section 6: Conclusions and Recommendations
Valued Activities and uses of Land and water: • Traditional use areas • Contaminated sites • Transportation • Infrastructure • Parks and protected areas	• Section 5.2: Current Monitoring Programs • Section 5.4: Identification of Gaps and Needs • Section 6: Conclusions and Recommendations

2 OIL IN THE ARCTIC MARINE ENVIRONMENT

This section describes the movement and weathering of oil in the Arctic marine environment on ice-free waters, on and under a solid ice cover, and in moving pack ice.

2.1 OIL ON ICE-FREE WATERS

For a spill on open water, as would be the case for an Arctic marine spill during late summer, the oil spreads into a relatively thin slick on the surface. The thickness of the slick depends on the type of oil, with heavy oils forming thicker slicks (on the order of a few millimeters). The movement and thinning of the slick are affected by sea state with the oil being moved along the surface by surface currents and wind (Fingas, 2011).

If oil emanates from a subsurface leak or blowout, it migrates up through the water column. The movement of oil through the water is complex, depending on physical properties including oil and water densities, water depth, ocean currents, and the molecular composition of the oil (Yapa and Zheng, 1997). In the case of a pipeline rupture or a blowout, the oil is introduced into the ambient water as a jet. It may be accompanied by natural gas which will also affect the nature of the spill. As the jet propagates up through the water column, it entrains the denser seawater which increases the density of the jet/plume.

Depending on the stratification and depth of the water the plume may become neutrally buoyant before reaching the surface. Under these circumstances the oil will form small, millimeter-sized droplets and eventually float to the surface (Yapa et al, 1999). In this instance, however, it is possible that oil may become entrapped between the stratified water layers, remaining suspended in the water column (Adalsteinsson et al., 2011). For typical ocean conditions most of the oil makes it to the surface. Once on the surface, oil spreads horizontally forming a thin slick. Under the influence of ocean currents, the slick will experience a lateral displacement from the initial release point.

From the moment oil is discharged into the ocean, it continually changes in both shape and in chemical properties. These processes are known as weathering, which involves spreading, evaporation, dispersion, emulsification, dissolution, oxidation, sedimentation and biodegradation (Jordan and Payne, 1980), illustrated in Figure 2.

Weathering processes such as evaporation, water-in-oil emulsification and natural dispersion in the water column are subject to environmental conditions, described by parameters such as sea surface temperature and sea state, as well as the physical properties of the released oil. For an Arctic spill on open water in late summer, which is influenced by tidal mixing and relatively high sea surface temperatures, (order of 5-10 °C, depending on the locations, which is considerably colder than other areas of the world where oil spills occur at a higher frequency) weathering rates can be significant (Payne et al., 1991, Fingas, 2011). Weathering of an open water spill can greatly reduce the effectiveness of spill clean-up countermeasures, making it crucial that countermeasures be deployed quickly before the oil emulsifies.

Generally, there is good knowledge of the behavior of oil in temperate waters; however, detailed knowledge of its behaviour in cold water is limited. The knowledge gaps, which include limited field information about Arctic oil spills, are discussed with particular reference to the challenges presented by ice. The influence of local factors (e.g., bathymetry, currents, etc.) on the movement of oil in the context of Hudson and Davis Straits are addressed in Section 4.

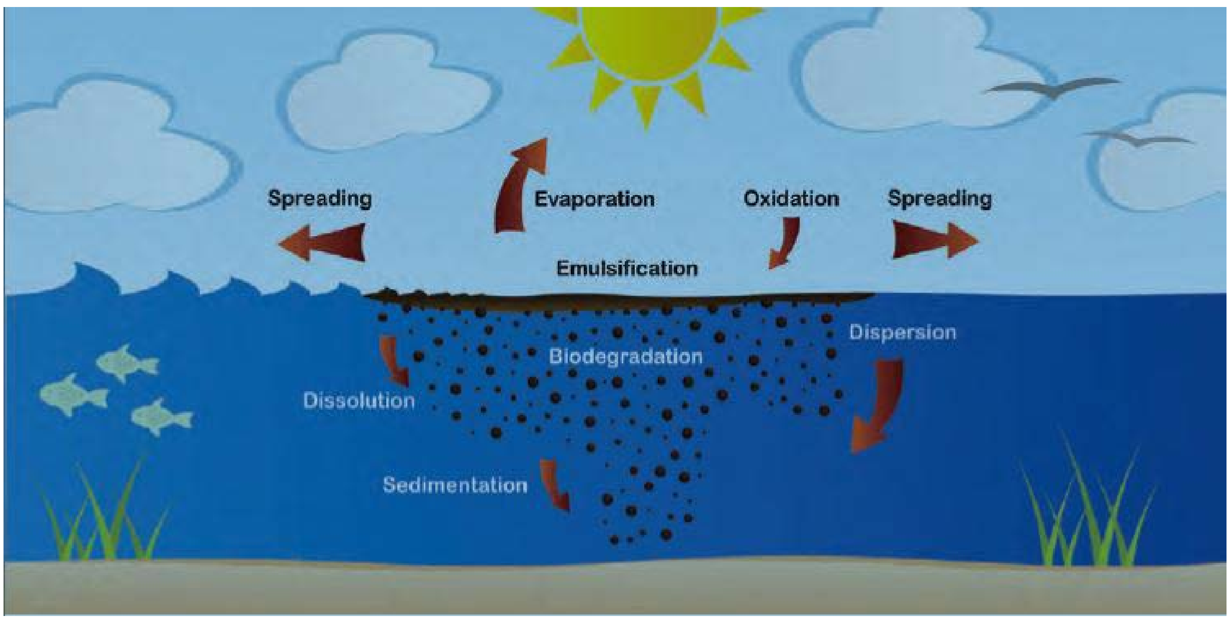


Figure 2. Oil weathering processes in temperate waters (ITOPF, 2011a).

Spreading, evaporation, dispersion and emulsification are the most important during the early stages of an oil spill, while oxidation, sedimentation and biodegradation are longer-term processes that ultimately determine the fate of the oil. As soon as oil is released, it begins to spread over the sea surface at a rate that is dependent on the viscosity of the oil and the volume spilled (ITOPF, 2002). For ship discharges, the first few hours are the most important for monitoring purposes, due to the rapid interaction of oil with seawater (Pavlakis et al., 2001). The more volatile components of oil will evaporate quickly; the rate of evaporation is dependent upon the air and sea surface temperatures and wind speed. The rate of dispersion is dependent upon the nature of the oil and the sea state, occurring more rapidly with low viscous oils, especially in breaking waves. Many oil types can form water-in-oil emulsions, which can increase the volume of pollutant up to five times. The rate and extent to which the oil dissolves also depends upon the oil composition, spreading, water temperature, turbulence and dispersion. Oxidation or photo-oxidation is promoted by sunlight and occurs when hydrocarbons react with oxygen, which can lead to the formation of soluble products or tars.

Sedimentation and sinking occurs when dispersed oil droplets interact with sediment particles and organic matter suspended in the water column that become dense and slowly sink to the sea floor. Oil compounds can also metabolize with the marine micro-organisms in the ocean, which are dependent upon the oxygen, nutrients and temperature (ITOPF, 2002).

In addition to these processes, an oil slick's fate is also affected by local wind and currents. It has been found empirically, as a crude rule of thumb, that oil floating will move with surface currents about 3% of the wind velocity. Tidal currents near the coast also have to be considered, whereas farther offshore, ocean currents predominate over the cyclic nature of the tidal movement. Therefore, if the local winds and currents can be measured, then it is possible to roughly estimate the velocity of the movement of oil in open water from a known geographic position, as shown in Figure 3 (ITOPF, 2011b).

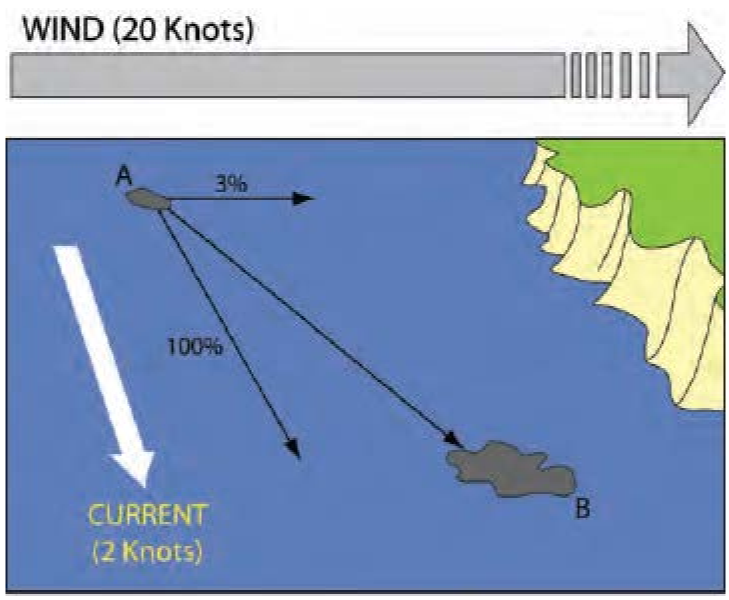


Figure 3. Influence of wind and currents on oil at sea. (ITOPF, 2011b)

2.2 OIL ON/UNDER ICE

The fate and behavior of an oil spill in ice-affected water differ significantly from a spill in open water. Snow and ice tend to reduce the rate of spreading and weathering processes. When subjected to lower water and air temperatures, oils become highly viscous and do not spread as easily resulting in thicker oil being present. Snow and ice impede oil movement and the oil may become encapsulated and the oil may become encapsulated as ice cover grows (Bobra and Fingas, 1986). For oil spills on or under ice, the movement of the spill is largely dictated by the roughness of the ice interface, with oil pooling in undulations. Furthermore, oil weathering rates are slower due to lower evaporation losses and, for oil spilled under sea ice, a decrease in the rate of emulsification stemming from reduced wave-action compared to open-water conditions. Overall, the way oil spreads and weathers are subject to the ice and snow conditions, thus, is influenced by the time of year and the geographic region. Oil trapped under ice can be tracked using buoys deployed on ice floes (Goodman, 1978). Figure 4 illustrates possible scenarios for how oil interacts with ice and snow.

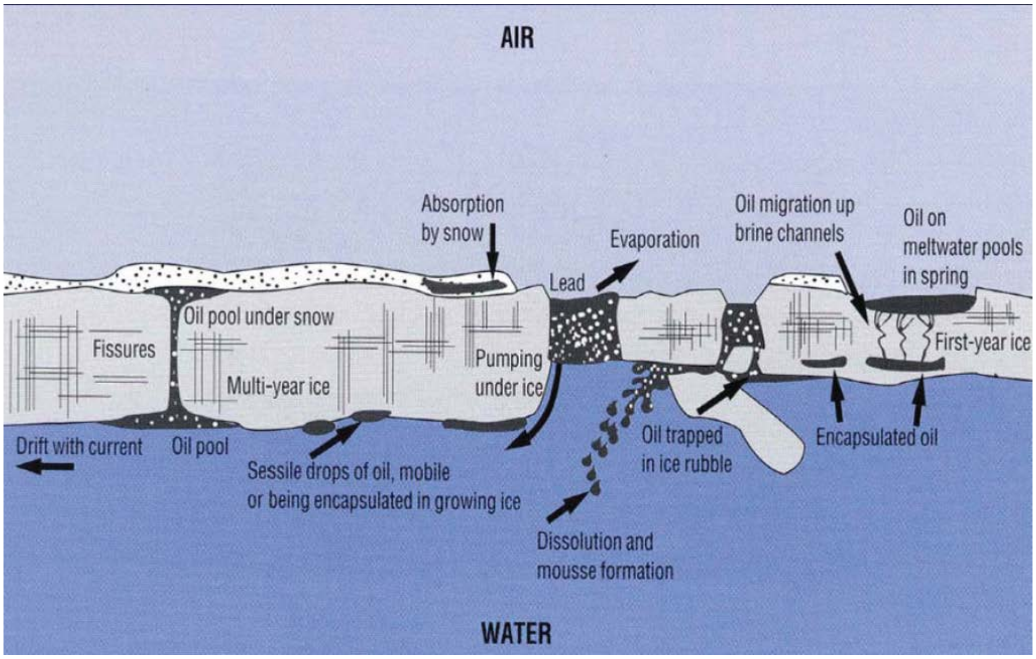


Figure 4. Oil behavior in ice-affected water (from Bobra and Fingas (1986) adopted Allen, 2008)

Like spills on land, the fate of oil on ice is largely dependent on the nature of the surface with large amounts of oil being retained in depressions and irregularities in the ice (Fingas, 2011). The resulting oil layer is typically approximately 2 cm thick, but can be over 30 cm thick in areas where the oil is contained by ice deformation features such as rafting and pressure ridges (Dickins and Buist, 1999; Fingas and Hollebone, 2003), although this is very much dependent on local under-ice profiles. Additionally, if ice is covered by snow, oil may spread along the ice-snow interface. For dry snow, approximately 25% of the oil may be absorbed into the snow cover. Under high wind conditions the oil-snow mixture may be distributed over large distances.

For a subsurface leak under ice, the nature and fate of the oil depends on ice conditions at the surface. In the case of solid ice coverage, the oil forms a relatively thick layer (on the order of a few centimeters) which pools in undulations on the underside of the ice. The oil movement is impeded by the interface roughness and, therefore, may remain relatively localized. Studies have found that a current with an approximate speed of 0.5 m/s is required to force the oil out of undulations (Dickins and Buist, 1999; Fingas and Hollebone, 2003). Additionally, if the oil is accompanied by an abundance of natural gas, the buoyant force resulting from gas build-up may crack the ice cover allowing oil to flow onto the ice surface (Fingas and Hollebone, 2003).

If the leak occurs during winter freeze-up, pooled oil at the undersurface of the ice can become encapsulated in the growing ice sheet. Studies have shown that the time for encapsulation is on the order of two days (Buist et al., 1983), occurring more quickly under first-year ice than under multi-year ice because of the large differences in thickness. Oil remains trapped until spring when the ice warms and brine channels open, at which time oil migrates to the surface (Potter et al., 2012). Once at the surface, the oil floats on the melt pools and, due to the low rate of weathering it has experienced, the exposed oil is relatively "fresh".

For spills on and under solid ice cover, the ultimate fate of the oil is largely dictated by ice behavior. If the ice breaks up, the oil will be carried along with the floes (Deslauriers et al., 1977). The oil may then be distributed into the water through tidal action on the broken ice.

When oil is released into ice-covered waters, many of the same weathering processes are in effect; however, the different forms of sea ice can drastically change and control the rates of these processes. The temperature-dependent properties of viscosity and pour point are important because they affect the spreading of oil on the water surface and the dispersion of whole-oil droplets into the water column (Jordan & Payne 1980; Payne et al., 1987). Oil weathering processes in cold waters were examined by Payne et al. (1991) in laboratory and field studies of the physical and chemical changes that occur when oil is released in open-ocean and ice-covered waters. Seawater wave-tank experiments in a cold room at -35°C and studies in the Chukchi Sea provided data on oil fate and effects for potential oil spill scenarios in the Arctic. This study concluded that when oil was released in a slush ice field during late fall or early winter it might become stranded in an upper ice pan and hence increase the water-in-oil emulsification. If oil is contained in the upper-ice surface of pans and smaller ice floes, diffusion controlled evaporation weathering is predominant; however, for the oil that remains in the ice/water matrix, the emulsification processes may quickly occur before significant evaporation and dissolution weathering can reduce the oil toxicity and affect the overall size of the slick. Similarly, if oil is released in a subsurface existing ice canopy it is subject to encapsulation before evaporation weathering, although dissolution of aromatics has been demonstrated. Once it is encapsulated in the ice, the oil is no longer subject to further weathering until the spring and ice breakup (Payne et al., 1991).

There have been many laboratory and field experiments performed in US, Canada and Norway (NORCOR, 1975; Ross and Dickins, 1987; Vefsmo and Johannessen, 1994) that are similar to the one described above, but there is comparatively little known about the weathering processes of Arctic oil spills in the presence of ice. During the past 30 years, there has been extensive research into the weathering processes of oil spilled in ice from laboratory studies, but only to a limited degree in the field. Compared to the available in-depth knowledge about weathering processes of oil spills in open water and temperate conditions, knowledge regarding Arctic oil spills is very limited. Bandvik and Faksness (2009) performed a series of meso-scale field experiments on Svalbard, Norway in 2005, which investigated oil behavior with different ice conditions (slush ice 30% and 90% ice coverage). It was shown that several weathering properties were strongly influenced by low temperatures, reducing oil spreading and wave action. The reduced water uptake, viscosity, evaporation and pour point in dense ice conditions extend the operational time window for several contingency methods compared to treating of oil spills in open waters (Bandvik et al., 2006).

Colder water temperatures can also have an effect on visually estimating the volume of oil spilled during aerial observation (ITOPF, 2002). For instance, some oils with high pour points which solidify into unpredictable shapes and floating oil portions may conceal the total volume that is present. Ice floes and snow can obscure large amounts or all of the oil and make it difficult to quantify how much oil is actually present on the water surface. An example of oil spilled in icy waters is presented in Figure 5.

Figure 5. Oil spilled in icy waters (ITOPF, 2011b).

During the last 30 years, there has been some research into the weathering processes when oil is spilled in ice including field tests, observations in real oil spills and laboratory tests. However, most of this work is more than 20 years old now, as concluded in a more recent review on the behavior of oil in freezing environments and some of these methods have improved to the extent that older results may not be valid (Fingas and Hollebone, 2003). In this more recent article, it stated that many of the algorithms proposed in the literature were based on limited laboratory experiments and there is a need to verify these experiments on a larger scale. Other recommendations included that the spreading of oil on ice and snow requires larger-scale verification and oil spreading under ice requires further tank testing followed by larger-scale testing. Oil spreading under ice used different algorithms from various tests and often the results were contradictory. In addition, some of these tests did not consider the effect of under-ice roughness. Oil spills in ice affected waters contains complex processes and the understanding of these indicate significant gaps. More quantitative research is needed before there is a real capability to predict oil behaviour and fate in ice affected environments.

2.3 OIL IN MOVING PACK ICE

Not surprisingly, the behavior and fate of oil in pack ice is heavily influenced by the concentration of ice cover. The presence of close-pack ice (i.e., fractional area of ice cover greater than 6/10) reduces the spread of oil and results in a thicker spill. This contained oil moves with the ice floes. As ice concentration decreases the oil behavior changes, approaching that of an open-water spill for ice concentrations less than 3/10. Oil spreads more freely as ice concentration decreases (Dickins and Buist, 1999).

The spreading of oil between broken ice is influenced by the presence of slush and brash ice between the ice floes. While light hydrocarbon components surface to the water-air interface, heavier components will incorporate into the slush and brash ice (Dickins, 2011). In turn, lighter hydrocarbons are more readily evaporated than the heavier components, which are suspended in the slush.

There have been a number of experiments conducted to determine the behavior of oil in open water leads. As suggested by MacNeill and Goodman (1987), lead closures redistribute the oil. In particular, at low closure rates, oil is pushed under the ice surface while at high closure rates (i.e., above 12 cm/s) oil is pushed up onto the ice surface. Further field analysis found that the lead closure rates under normal conditions were insufficient to push oil onto the ice. In fact, this mechanism of “lead pumping” may only be encountered in the case of ice closing behind ships (Fingas and Hollebone, 2003). Consequently, this may be important for oil spills from ice-bound vessels.

3 REMOTE SENSING FOR ARCTIC OIL SPILL MONITORING

This section summarizes the state-of-knowledge of sensors, platforms, challenges and techniques related to oil spill monitoring in the Arctic environment, with emphasis on operational satellite and airborne sensors. It is modified from a recent comprehensive technology review generated under the Arctic Oil Spill Response Technology Joint Industry Programme (Puestow et al., 2013).

3.1 SENSING PLATFORMS

Sensors for detecting and monitoring oil can be deployed on satellite, airborne or in-situ platforms. Table 2 provides an overview of platforms, distance from the surface, sensor coverage and spatial resolution. The distance from the surface is an important consideration since it indicates whether information must be collected in situ or not. For example, airborne platforms can provide coverage up to 1000 km^2 with a resolution on the order of meters or better depending on the system and its distance from the surface. These platforms are capable of carrying a range of relevant sensors and decisions must be made regarding trade-offs between resolution, coverage and reliability of detection.

Table 2. Remote sensing platforms

Platform	Distance from the Surface	Sensor Spatial Coverage	Sensor Spatial Resolution
Satellite	Several hundred kilometers	~100-10000 km^2	From 0.5 to >250 m
Airborne (helicopter, airplane, Unmanned Airborne Vehicle, aerostat)	From tens meters to kilometers	up to 1000 km^2	From centimeters to meters
In-situ: deployed on vessels, rigs, etc.	Centimeters to meters	Up to km 10s km^2	From centimeters to meters
In-situ: deployed on the water, oil or ice surface	N/A	Point measurement	From millimeters to meters

A number of remote sensing platforms have proven effective for detection and monitoring oil spills on open water. For example, a new compact aerostat system "Ocean Eye" can carry a high resolution camera and infrared (IR) sensor to monitor spills from altitudes up to 150 m (Jensen et al., 2012). Both airborne and space-borne sensors, including Synthetic Aperture Radar (SAR), Side-Looking Airborne Radar (SLAR), IR - and visible-range imaging, microwave radiometers, and laser fluorosensors, can be used (Fingas and Brown, 1997; Jha et al., 2008). The various sensors use different physical attributes of the oil and the surrounding environment to detect the presence of oil. The applicability of a given detector depends on such factors as the size of the spill, ambient weather conditions, time of day, and accessibility of the geographic region. Overall, remote sensing has been an effective surveillance technique for oil spills on open water.

Various technologies have been developed and tested for application to remote sensing of oil under ice and snow. Satellite-based sensors, such as SAR, are less effective for direct detection of such spills since the returned signal does not have a distinct signature when oil is present. Contact based methods (e.g., acoustic) require deployment of instruments on the clean snow or ice surface; therefore, it is reasonable to consider if these methods offer an advantage compared to drilling a hole in ice. As described by Goodman (2009), using mechanical equipment to drill a hole in the ice and visually detecting oil is the only proven technology. There have been very few oil spills under ice in the past few years, thus little opportunity to test new technologies. Some sensors mounted on surface and aerial platforms, including ground-penetrating radar, acoustic sensors, as well as laser-based systems that measure either a fluorescence signature or thermal emission from the trapped oil were experimentally tested. There are a number of extensive reviews of this early work (Dickins, 2000; Fingas and Brown, 2000).

3.2 Arctic Environmental Constraints

In the event of an oil spill in ice-affected waters, the effectiveness of clean-up counter measures, including detection, will be subject to the ice and environmental conditions. In particular, ice conditions vary considerably from region to region, so necessary oil treatment and removal operations may also vary. Furthermore, the behaviour and fate of the oil will be dictated by ice and environmental conditions as described in Section 4. In addition to ice conditions, detecting and monitoring in Arctic waters is hampered by low visibility due to clouds and fog, precipitation, blowing snow and darkness. This applies particularly to passive optical sensors.

In general, much of the Arctic sky is covered by low (up to 2 km high) stratus and stratocumulus clouds (NSIDC, 2012). Total cloud cover combines low, middle (2-8 km), and high clouds (8-15 km). Low cloud cover is more common and uniform and increases over the Arctic Ocean. The increase reflects the dominance of low-level stratus, which forms as warm air masses moving over the ocean are chilled by the cold, melting sea ice. Total cloud cover extent is lowest in December and January (65-80%). Starting in May, cloudiness is within 73-78% with average 75% (Wang et al., 2012). Autumn months exhibit cloud cover in the range from 72-84%. For certain Arctic regions these numbers are even higher; a 10 year record from National Oceanic and Atmospheric Administration (NOAA) Barrow Observatory in Alaska, for example, showed annual average of 76% cloud coverage with 80-90% from May to October (Dong et al., 2010).

Low level stratus clouds form and persist through the spring and summer due to the presence of warm air over the water adjacent to ice, frequent temperature inversions, and fog. Evaporation fog, called Arctic sea smoke, is produced when air above open water within Arctic ice is stable and relatively cold. Arctic haze in Arctic regions reduces horizontal and slant visibility and which may extend to a height of about 10 km.

Precipitation, such as rain, snow, hail, dew and hoar frost, is an important component of the hydrological cycle. Precipitation is low over much of the Arctic (NSIDC, 2013). Some areas are referred to as polar deserts and receive as little precipitation as the Sahara desert. However, the Atlantic sector of the Arctic between Greenland and Scandinavia receive higher precipitation due to winter storms originating in the Atlantic Ocean.

Almost all precipitation in the central Arctic and over land falls as snow in winter. More than half of the precipitation events at the North Pole are snowfall. Over the Atlantic sector, snow is very rare in summer and rain can occur on rare occasions during winter in the central Arctic Ocean when warm air is transported into this region.

Wind speeds over the Arctic Basin and the western Canadian Archipelago average 14 and 22 kilometers per hour, respectively, in all seasons. Stronger winds are present in these areas during storms with wind speeds up to 90 km/h. During all seasons, the strongest average winds are found in the North-Atlantic seas, Baffin Bay, Bering Sea and Chukchi Seas, where cyclone activity is most common. On the Atlantic side, the winds are strongest in winter, averaging 25 to 43 km/h, and weakest in summer, averaging 18 to 25 km/h. On the Pacific side they average 22 to 32 km/h year round. Maximum wind speeds in the Atlantic region can approach 180 km/h in winter (Przybylak 2003).

Blowing snow accompanied by high wind (above 30 km/h) reduces visibility to 800 m or less and to less than 400 m for wind speeds of 40 km/h (Environment Canada, 2013). Sensors operating in ultraviolet (UV), visible, and near-infrared (NIR) bands have decreased effectiveness in blowing snow.

By definition, Polar night means that it is absolutely dark and occurs between November to January when the sun is below the horizon. On a clear day, however, the sky is often illuminated by flares of northern lights. During Polar night active remote sensing systems which illuminate the observed scene are preferred.

The role of a surface remote sensing technology may be considered within two broad categories: (a) direct detection and monitoring of spills and (b) monitoring the surrounding environmental and ice conditions.

3.3 OIL SPILL MONITORING AND DETECTION

3.3.1 Cameras and Multispectral Sensors

The visual interpretation of oil spills by trained operators remains an important method for detecting oil on water (Bonn Agreement, 2009). The primary sensors include digital still or video cameras mounted on aircraft, vessels or rigs (Jha et al., 2008) which are sensitive to reflected visible light (i.e., corresponding to wavelengths ranging from 400 to 700 nm) as well as the NIR range (i.e., from 700 to ~1000 nm) (Campbell and Wynne, 2011). Since the amount of oil is a critical parameter to guide response actions, it is important for operators to relate the visual appearance of oil to layer thickness and volume. Figure 2 shows an aerial photograph in which oiled and clean water are discernible, an example of the appearance of oil on different types of water is presented in Figure 7. An aerial photo of an oil sheen and slick observed during the Deepwater Horizon blowout (from Leifer et al., 2012).

Figure 6. An aerial photo of an oil sheen and slick observed during the Deepwater Horizon blowout (from Leifer et al., 2012)

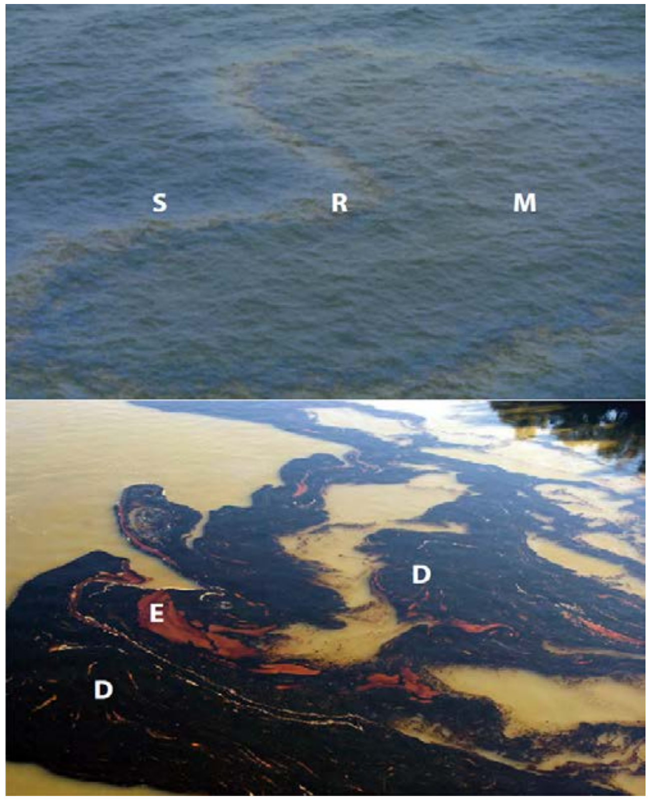


Figure 7: Aerial digital photography of oil spilled on (top) the ocean and (bottom) the Mississippi River. S: silver/gray; R: rainbow; M: metallic; D: dark or true color; E: emulsified (from NOAA, 2012)

The letters describing the appearance of oil on water were assigned according to modified Bonn Agreement Oil Appearance Code (BAOAC), presented in Table 3. BAOAC is used operationally as an interpretation key to relate the brightness and colour of oil on water to layer thickness.

Table 3. Relationship between oil thickness and appearance (from Bonn Agreement, 2009)

Code	Appearance	Layer Thickness (μm)
1	Silvery/gray sheen	0.04 to 0.30
2	Rainbow	0.30 to 5.0
3	Metallic	5.0 to 50
4	Discontinuous true oil colour	50 to 200
5	Continuous true oil colour	>200

Silver/gray and rainbow sheens are due to optical interference effects over the thin oil film, while the metallic appearance is caused by the reflection of skylight. For thick layers, the true colour of the oil dominates (Bonn Agreement, 2009; Leifer et al., 2012). In addition to colour, shape, size, contrast and context are used to interpret oil on open water (NOAA, 2012).

Since oil does not have specific absorption bands in the visible and NIR spectral ranges, detecting oil on water relies on differences in contrast between the oil and the surrounding oil-free water. The difference in reflectance between oil and water increases for shorter wavelengths and the contrast may be enhanced by filtering out any response above 450 nm and by using cameras positioned at the Brewster angle of water (i.e., at an incidence angle of 53^{o}) in conjunction with a horizontal polarizing filter (O'Neil et al., 1983; Ahmed et al., 2006; Fingas and Brown, 2011).

Recent work by Svejkovsky and Muskat (2009) and Svejkovsky et al. (2012) used multispectral airborne imagery to map oil on water and characterize oil thickness. Using a portable spectrometer with four spectral channels, oil slicks were categorized into different thickness classes in two stages. A neural network algorithm was used to replicate the visual interpretation process based on contrast and shape parameters to classify oil and oil-free water. A second step used the reflectance ratios between water and oil pixels to extract thickness classes, from which volume estimates can be derived.

Visible sensors, such as still and video cameras, are widely used for aerial reconnaissance of open water spills as they are readily available, inexpensive and easy to use. However, visible imaging of oiled water is affected by false alarms. Oil sheens can be confused with sun glint and wind sheens, while biogenic materials such as seaweed, sunken kelp beds and fish sperm can be confused with thicker oil slicks (Jha et al., 2008; Fingas and Brown, 1997; Fingas and Brown, 2011). While typical camera systems are limited to use during sunlight hours, visible-range detection of spills may be extended into dark and low light conditions using night-vision technology. Although, the capabilities of the current low-light systems for detecting oil on water have not been thoroughly documented (Brown et al., 2005).

Optical satellite imaging has also been used to monitor and map oil slicks on water. However, the dependence on cloud cover, infrequent revisit and low spatial resolution makes optical satellite imagery an ancillary rather than a primary data source. Interpretation of satellite data requires specialized expertise and may take too long in tactical situations (Fingas and Brown, 2011). Liefer et al. (2012) completed a comprehensive review of space-borne and airborne sensors for oil spill monitoring. An overview of select operational optical satellite systems is presented in Table 4.

Table 4. Operational optical satellite systems

Instrument	Resolution (m)	Swath (km)	Revisit (days)
LANDSAT 5, 7, 8	15 - 30 (MS) and 120 (TIR)	185	16
MODIS	250 to 1000	2330	1-2
MISR	275 to 1100	360	2-9
DMC	20 to 30	600	Near daily
SENTINEL-2	10 to 60	290	Near daily; to be launched 2014
QuickBird	0.6-2.4	16.4	1-3.5 days
Worldview-1/2	0.5-1.8	16.4	Near daily
Geoeye	0.41-1.35(MS)	15.2	2.1 days

Despite limitations, optical satellite surveillance has been used successfully in conjunction with radar-based oil spill monitoring to identify areas of algal blooms and remove them as sources of false alarms from SAR images (e.g., Brekke and Solberg, 2005; ASL, 2012). Image products from MODIS, MERIS and LANDSAT were generated every few days to support cleanup efforts of the Deepwater Horizon spill (Leifer et al., 2012). Given the size of the spill, which covered a surface area on the order of 10^4 km^2, the oil was readily discernible in relatively low spatial resolution data (i.e., >30 m). A true color image of the Deepwater Horizon spill collected by MODIS is shown in Figure 8.

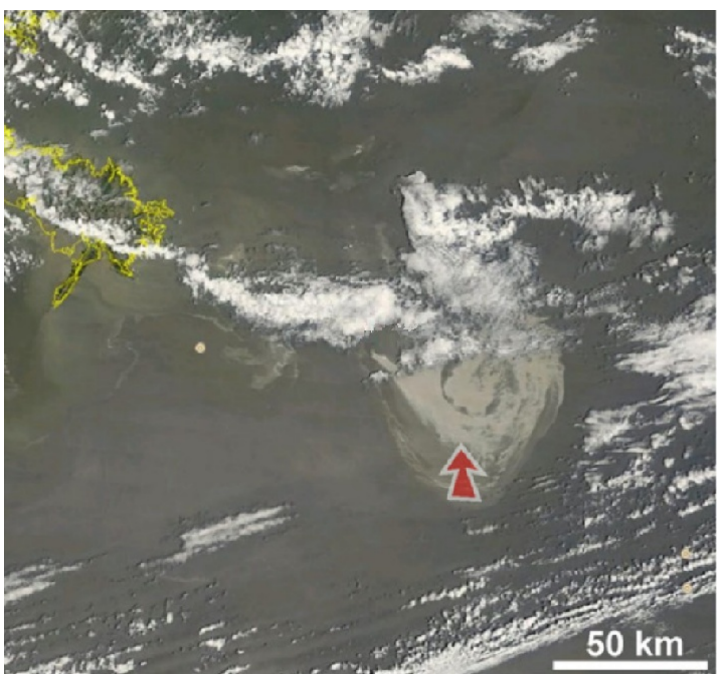


Figure 8. MODIS true color image of the Deepwater Horizon spill collected on May 8, 2010. The red arrow denotes the position of the spill (from Leifer et al., 2012)

Given the high rate of false positives from sun glint, kelp beds, jellyfish, cloud shadows and changes in water depth (NOAA, 2012), the need for specially-trained, experienced personnel is essential. Due to the relatively long imaging and data processing time required for both aerial and satellite-based sensors, observations by trained personnel will probably remain more timely and cost effective for rapid surveys of large spills (Svejkovsky et al., 2012).

Optical detection methods are hindered when ice is present. Optical signals are attenuated in ice and snow making passive optical sensors ineffective for characterizing oil encapsulated in ice and under snow or ice (Fingas and Brown, 2000). Dark melt pools as well as sediment and dirt on ice during the break-up season can be confused with oil on the ice (Dickins and Andersen, 2009). Even with oil on snow or bare ice, visible detection may be difficult due to synoptic conditions in Arctic regions, including the presence of fog, marine layer, low cloud ceiling and long periods of darkness (Potter et al., 2012). Newly formed ice may also be misinterpreted as oil (Dickins and Andersen, 2009). In relatively high ice concentrations, oil is contained within the ice and remains fairly localized. Under these conditions, the equilibrium thickness of the oil can be quite large (i.e., on the order of millimeters) and, in accordance with Table 3, the oil appears in its true colour. An example is presented in Figure 9, where the oil is clearly visible through its colour contrast with ice and water.

Figure 9. Photograph showing oil being released between ice floes during the SINTEF JIP field experiments carried out in 2009 (from Dickins, 2010)

In the case of open ice (<3/10 concentration), the oil spreads more freely and the oil sheen may appear similar to that expected in open water conditions (Wang et al., 2008). The limitations of optical systems are most severe for satellite-based systems, whereas aerial and ship-borne systems may be operated in cloudy conditions. Due to these restrictions optical sensors need to be combined with other technologies to offset their limitations. To this end, currently available optical sensors and processing methods should be subjected to a thorough performance evaluation and validation in a range of representative ice conditions and spill scenarios. Training oil observers specifically in the interpretation of optical imagery in ice conditions should also be considered.

3.3.2 Ultraviolet Sensors

The ultraviolet (300 nm to 400 nm) reflectance of oil is greater than that of water (Hurford and Buchanan, 1989). Aerial passive UV scanners have been engineered to collect and analyze UV sunlight reflected from the water surface and discriminate oiled water from oil-free water through observed variations in the electromagnetic intensity. UV sensors have detected sheens as thin as 0.1 μm (Fingas and Brown, 2011; Jha et al., 2008).

The level of expertise required to operate a UV detector is comparable to that of a Thermal InfraRed (TIR) system, although the technology is not as well developed as TIR or visible-range sensors (Fingas and Brown, 2011). Due to the high attenuation of UV light by fog and clouds, oil spill detection with UV requires clear atmospheric conditions (Jha et al., 2008) and the need for ambient sunlight further limits use of the system to daylight hours. UV-based oil spill detection is also susceptible to false alarms caused by sun glints, wind slicks, and biogenic material (Fingas and Brown, 1997).

UV and TIR sensors are frequently used together to assess thinner and thicker parts of an oil slick (Jha et al., 2008). In addition, the false positives observed in TIR images are often different from those for UV images and the results obtained from using both offsets individual limitations (Fingas and Brown, 1997). An example of concurrently acquired UV and TIR data is presented in Figure 10.

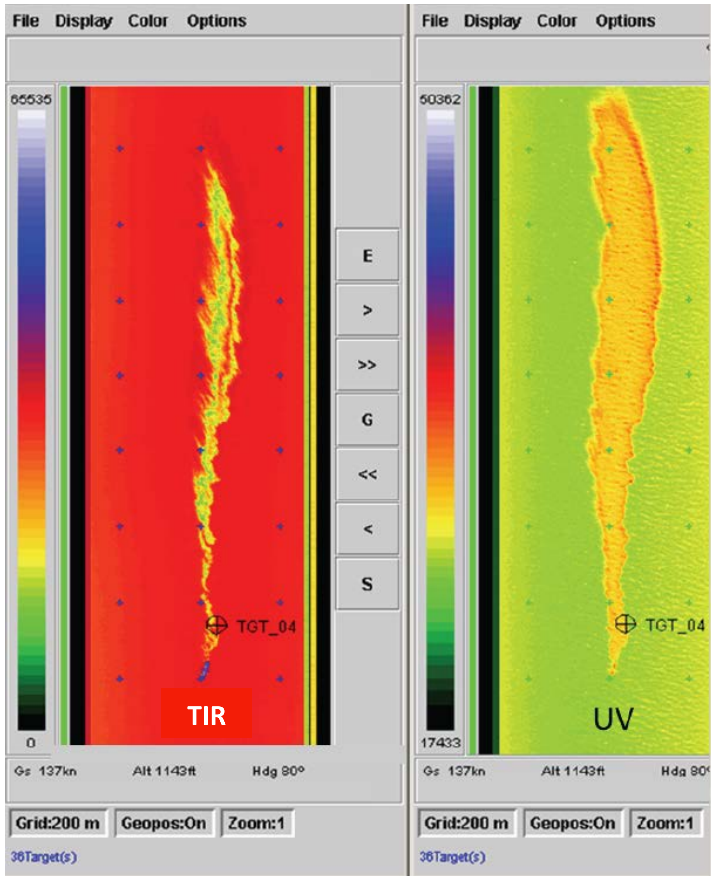


Figure 10. Concurrent aerial Thermal Infra-Red (TIR) and UV images of a slick (Robbe, 2012).

The effectiveness of airborne UV sensors for detecting oil in ice-affected water is not well understood, and assumptions have been made about their capabilities in such situations based on how they performed in open water spills. UV imaging could be useful for detecting thin oil layers on melt ponds as well as oil between floes (Dickins and Andersen, 2009). Attempts were made to test an aerial UV/IR line scanner during the SINTEF Joint Industry Program (JIP) field experiment, but poor weather and fog over the test site did not allow these measurements to be taken (Dickins, 2010). Weather is a significant factor that must be considered in sensor selection. The performance of UV sensors for detecting oil in slush and brash ice is also unknown. Additional testing under field conditions is required to determine the capabilities of UV sensors for detecting oil in a variety of ice conditions (i.e., oil on ice and snow, oil between ice floes, etc.).

3.3.3 Hyperspectral Sensors

Hyperspectral sensors registering reflected electromagnetic radiation over tens or hundreds of spectral bands have been used to detect oil on water (Salem and Kafatos, 2001; Plaza et al., 2005; Leifer et al., 2012). Hyperspectral sensors typically operate from the UV to the mid-infrared part of the electromagnetic spectrum (i.e., ~2500 nm). A number of hyperspectral sensors are commercially available, such as the MEIS, CASI, AVIRIS, CAESAR and AISA systems (O'Neil et al., 1983; Salem et al., 2002; Wang and Stout, 2006; Clark et al., 2010). There are also a number of new hyperspectral sensors becoming available in the future, including two upcoming Canadian missions. It should be noted that there are hyperspectral sensors which also provide coverage of the infrared spectral range. The Airborne Hyperspectral Scanner (AHS) instrument has 80 spectral bands covering the Visible and Near InfraRed (VNIR), Short Wave InfraRed (SWIR), Mid-Wavelength InfraRed (MWIR) and TIR spectral range. The instrument is operated by Instituto Nacional de Técnica Aerospacial (INTA) and it has been involved in several field campaigns since 2004 (Sobrino et al., 2009). HyMap, another airborne hyperspectral sensors developed in Australia, has contiguous spectral coverage of visible (VIS), NIR, SWIR, MWIR, and TIR spectral regions with a spectral bandwidth of 10-20 nm and spatial resolution of 2-10 m (Cocks et al., 1998).

The increased spectral resolution of hyperspectral imagers allows them to assess spectral signatures specific to oil. For example, Clark et al. (2010) demonstrated that the NIR portion of the spectrum is sensitive to oil thickness and the water-to-oil ratio in an emulsion. An example of laboratory spectra of oil emulsions sampled during the Deepwater Horizon spill is presented in Figure 11. The emulsion exhibits clearly defined spectral features in the NIR, and the shape of the spectrum depends on emulsion thickness. The black lines/arrows highlight spectral regions corresponding to the absorption bands in the oil.

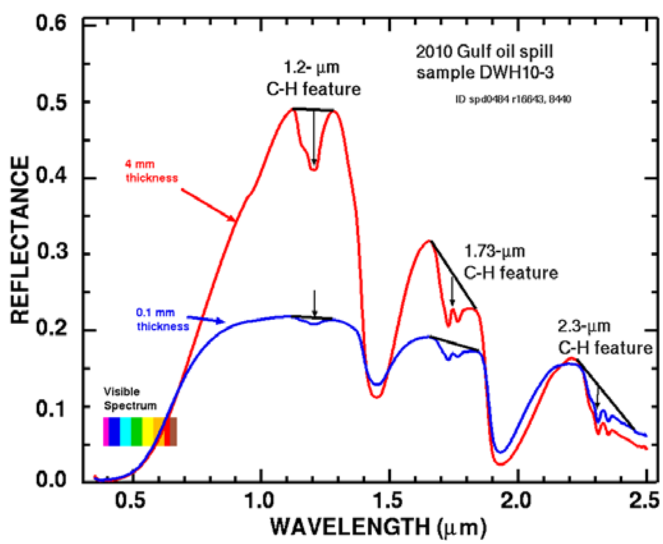


Figure 11. Laboratory spectra collected from a sample of oil emulsion (from Clark et al., 2010)

Analysis of field data collected over the Deepwater Horizon spill using the Airborne Visible Infrared Imaging Spectrometer (AVIRIS) provided quantitative values for oil thickness and oil-water ratio (Leifer et al., 2012). Clark et al., (2010) generated maps of oil thickness and emulsion ratio (as shown in Figure 12) using emulsion ratios of oil absorption bands. This information was subsequently used to estimate oil volume.

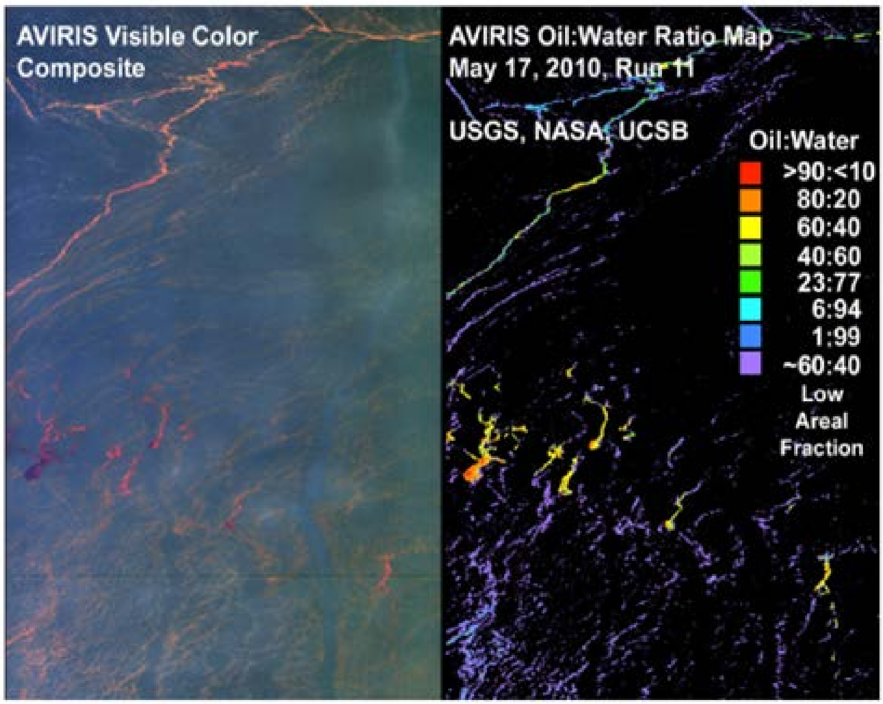


Figure 12. Colour composite and corresponding oil-water ratio map generated with AVIRIS (from Clark et al., 2010)

Other field experiments suggest hyperspectral measurements could be used to differentiate between light and heavy oils (Salem and Kafatos, 2001). While the products resulting from hyperspectral measurements can be generated relatively quickly when compared to optical satellite products, the analysis can be quite complex. The raw hyperspectral image is typically processed using spectral unmixing algorithms and the spectra deduced from each image pixel is compared to a spectra library to classify the surface material composition (Plaza et al., 2005). Classifying the surface material (i.e., in this case, oil on water) requires *a priori* knowledge of the spectral response of the material being probed, which means that in-situ field measurements must be taken before classification can be carried out. In contrast to the preceding sensors, operators require a higher level of expertise to use and interpret hyperspectral measurements. Additionally, these detectors can be quite large and are not readily deployed.

An oil spill determination system using airborne/spaceborne hyperspectral sensors for detecting oil spills and other contaminants on a water surface is described in Alawadi (2011). Such systems consist of a moderate resolution imaging spectrometer (e.g., MODIS for satellites) and provide high radiometric sensitivity in two spectral bands (i.e., one in the NIR and the other outside of the NIR) within the wavelength range of 0.4 micron to 14.4 micron. Maximum and minimum spectral radiance values are 649 nm and 869 nm, respectively, corresponding to MODIS bands 1 and 2 of the 250 m product. Oil spills are assessed based on the calculation of the spectral contrast shift between two bands. A cloud mask is required for satellite data, but not for data collected from aerial platforms.

Hyperspectral imaging of oil in ice-affected waters has not been field tested. Given the high spectral resolution and approximately 1 m spatial resolution it is expected that this sensor would be at least as effective as a low spatial resolution, multispectral visible range camera for detecting oil around ice. Analysis of hyperspectral data can be complicated. Future operational applications will need to consider automation to generate products that can be easily interpreted in near real-time (NRT) for tactical spill response.

Similar to the approach taken for oil spill detection in open water, there is a potential to use hyperspectral measurements to quantify oil spill characteristics (e.g., thickness, oil-to-water ratio, etc.). In order for this technology to be a viable method for oil-in-ice detection, spectral libraries corresponding to the applicable surface conditions need to be developed. The necessary reflectance spectra will depend on the oil, the ice conditions (e.g., is the oil mixed with brash ice), visibility and atmospheric state.

Upcoming hyperspectral satellite missions may provide useful information in the context of spill response and should be evaluated for their possible contributions. Planned missions to be launched within the next five years are presented in Table 5.

Table 5. Future hyperspectral satellite missions

Instrument	Spectral Range (nm)	Number of Bands	Spatial Resolution (m)
ENMAP	420-2450	155	30
HYSPIRI	380-2500	213	60
PRISMA	400-2500	211	20 - 30

3.3.4 Thermal Infrared Sensors

The nature of energy radiated from an object is dependent on its temperature and TIR sensors are sensitive to the radiant energy emitted by objects according to their kinetic temperature. Absorption in the atmosphere affects most of the TIR spectrum except for atmospheric windows from 3 to 5 µm and 8 to 14 µm where most TIR sensors are designed to operate.

Oil and water have different emissivities causing a thermal contrast that can be identified using TIR sensors (Goodman, 1989; Salisbury et al., 1993; Fingas and Brown, 1997). During daylight thick spills appear warmer than the surrounding water since they absorb solar radiation faster (Fingas and Brown, 2011). By contrast, thin films tend to appear cooler than oil-free water. The apparent decreased temperature of a thin slick is not well understood but it may be due to electromagnetic interference effects over the oil film (Fingas et al., 1999). For night-time TIR imagery this pattern is reversed, with thin slicks appearing warmer than the water background and thicker oil acting as a thermal insulator thus appearing cooler (Goodman, 1989). While TIR imagery does not rely on solar illumination, Dickins (2010) reports that the contrast between oil and water tends to be higher during daylight hours.

Many TIR sensors used in maritime oil spill detection operate in the 8 to 14 µm spectrum since past research suggests that the 3 to 5 µm atmospheric window is of limited utility (Salisbury et al., 1993; Fingas and Brown, 2000). Hover and Plourde (1994) evaluated the day and night imaging capabilities of ship-mounted TIR sensors operating in 8 to 15 µm range, as well as hand-held sensors exploiting the 3 to 5 µm interval and found both types of systems useful in the identification of oil slicks, although the performance of individual sensors depended on environmental conditions and sensor tuning. The 3 to 5 µm spectral range is also used by operational TIR sensors embedded in APTOMAR's SECurus system (FLIR, n. d.; see Section 7.1).

TIR sensors are available as cooled (cryogenic) or more recently, un-cooled systems. Older cooled systems required liquid nitrogen which limited the period of operation to several hours. Newer systems use cooling based on gas expansion (Fingas and Brown, 2011). More recently, un-cooled systems have become available that are smaller and more easily operated and maintained (Svejkovsky et al., 2012). Cooled systems, however, have a lower noise floor and greater sensitivity to detect thermal contrast, resulting in longer operating ranges and higher spatial resolution compared to un-cooled systems (Veprik et al., 2012).

TIR sensors are relatively inexpensive, easy to deploy and commercially available as handheld or airborne units. TIR sensors are used widely for oil spill detection and response as they can operate day or night and provide information on relative slick thickness (Fingas and Brown, 2011). Svejkovsky et al., (2012) confirmed the quantitative extraction of oil thickness up to 2 mm based on the correlation of oil thickness and measured radiant temperature. TIR sensors can be paired with UV sensors to capture slicks thicker than 20 µm, while UV scanners are used to map thinner accumulations of oil.

Although TIR sensors do not rely on solar illumination, they are adversely affected by fog, poor weather and rough water. TIR imagery may also generate false positives from aquatic vegetation, shoreline and oceanographic phenomena (e.g., fronts). Early research suggested that TIR systems were not able to identify emulsions due to reduced thermal contrast with surrounding oil-free water. However, Svejkovsky et al., (2012) were able to successfully map emulsions with a water content of 60% using an un-cooled microbolometer. Figure 13 shows an example of emulsified oil captured by thermal and multispectral imagery.

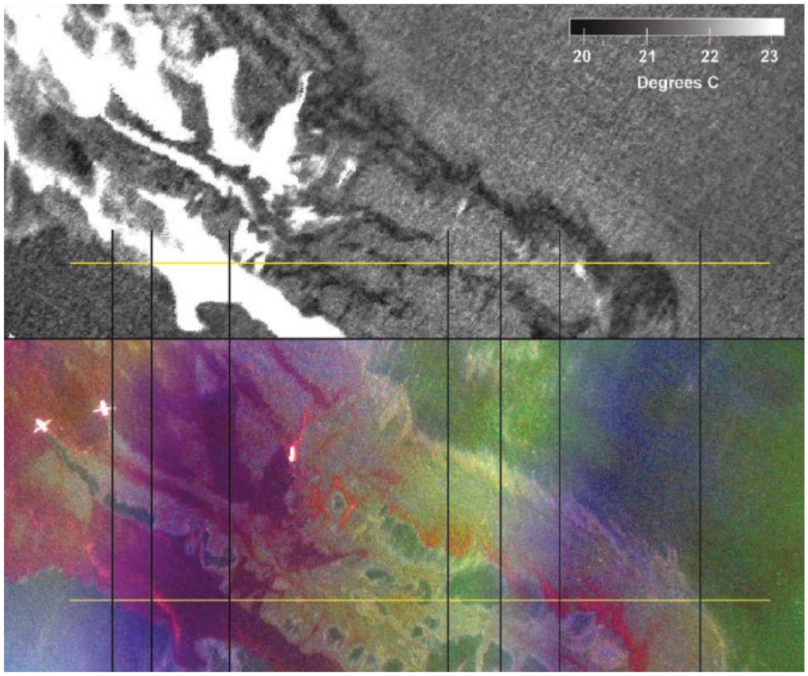
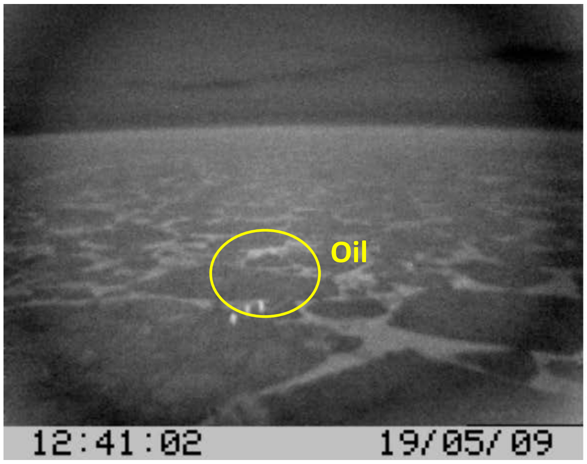


Figure 13. Emulsified oil of the Deepwater Horizon spill captured by thermal (top) and multispectral (bottom) sensors (from Svejkovsky et al., 2012)

In addition to nadir-viewing line scanners, forward-looking infrared (FLIR) is frequently used in aerial oil spill surveillance (e.g., Trieschmann et al., 2001). FLIR sensors perform similarly to TIR scanners, although varying viewing angles make area and distance measurements less feasible (Potter et al., 2012). FLIR systems are also routinely used in other maritime surveillance applications, such as vessel detection and search and rescue missions.

Since the emissivities of ice and water are similar over much of the TIR spectrum (S.L. Ross et al., 2010), it is expected that TIR will be suitable for detecting oil in ice-affected waters. The results of a recent study undertaken to evaluate the performance of several remote sensing systems in ice conditions suggest that TIR sensors are promising tools for detecting oil on water between ice floes (Dickins et al., 2010). However, TIR sensors will likely not be effective in detecting oil in ice or under snow since the radiation emitted by the oil is absorbed during its passage through the overlaying ice and snow. Figure 14 shows images of a hand-held TIR sensor (left) and an optical camera (right), with oil from a controlled release clearly visible in both images.



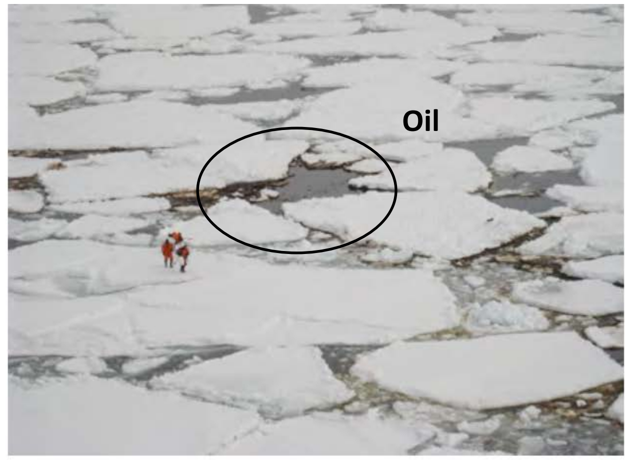


Figure 14. Oil between ice floes imaged by TIR (left) and optical camera (right) (adapted from Dickins, 2010)

Additional research is required to fully test and validate the performance of TIR imaging systems in different ice conditions, such as brash and grease ice. The detection of oil on ice as well as on surface melt ponds should also be investigated. These investigations may include sensors mounted on vessels or platforms, as well as airborne TIR scanners and FLIR systems.

Satellite-based TIR sensors are unlikely to provide valuable tactical information for detecting oil in ice environments due to their limited spatial resolution (e.g., 30 m for LANDSAT, 1-2 km for Moderate Resolution Imaging Spectroradiometer (MODIS) and Advanced High Resolution Radiometer (AVHRR)).

3.3.5 Microwave Radiometers

Microwave radiometers (MWRs) measure emitted radiation with wavelengths in the range of millimeters. As with TIR detection, observed differences in the surface microwave emissivity facilitate discrimination between different surface materials in a scene. In the microwave range oil has a higher emissivity than water (Fingas and Brown, 2011) and can appear brighter than oil-free water in MWR images (Jha et al., 2008). Microwave emission from oil slicks can be influenced by interference over the oil layer and is greatest when the round-trip electromagnetic phase difference over the oil layer is equal to a multiple of π (Jha et al., 2008). The brightness measured by the MWR sensor can theoretically be related to estimates of oil slick thickness. In practice, signal ambiguities have been reported as a result of the cyclic nature of the constructive interference condition and the resulting thickness estimation (Lääperi and Nyfors, 1983; Skou, 1986; Goodman, 1994). Attempts to resolve this issue include the use of multi-frequency scanning radiometers (McMahon et al., 1997) and relating oil thickness to variations in polarization of the microwave signal (Pelyushenko, 1995).

Although not in widespread use, multi-frequency MWR sensors are used for operational pollution surveillance in Germany (Trieschmann et al., 2001; Dickins and Andersen, 2009). OPTIMARE's MWR is capable of detecting, measuring, and mapping oil layers with thicknesses in the range from 0.05 to 3 millimeters (OPTIMARE Product Sheet, 2013). Trieschmann et al., (2001) reports that MWR instruments enable oil film thickness measurement in the range of 0.05 to 2.5 mm when flying at an altitude of 300 m. MWR systems operating at 18, 36 and 89 GHz, provide complementary information at varying spatial resolutions as follows:

- 18 GHz: sensitive to thicker films, spatial resolution is 22 m;
- 36 GHz: compromise regarding spatial resolution (11 m) and all-weather capability; and
- 89 GHz: sensitive to thin films, spatial resolution is 5 m.

An example of an oil slick imaged by multi-frequency MWR as well as TIR and UV instruments is presented in Figure 15.

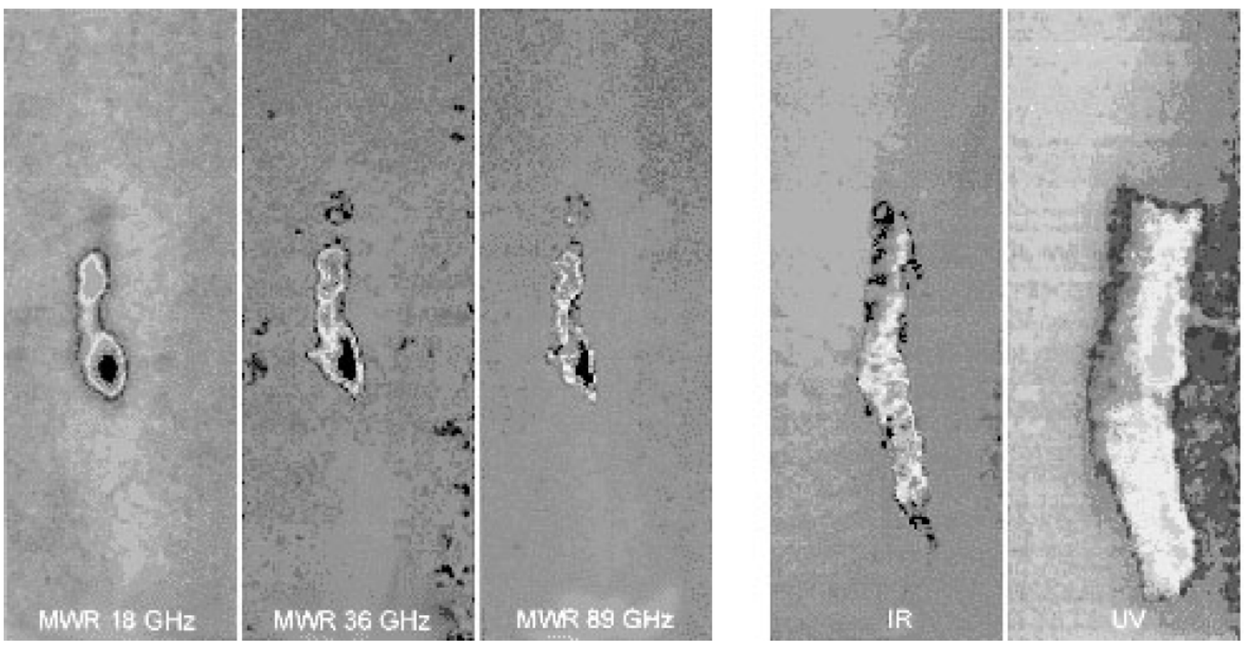


Figure 15. Oil spill on water imaged by three-frequency MWR, IR and UV sensors (from Trieschmann et al., 2001)

MRWs can operate in conditions of low visibility (e.g., fog, rain and night), although false positives can be generated by waters of different temperatures, seaweed and biogenic material (Pelyushenko, 1995; Fingas and Brown, 2011). MWR systems can be costly and require a dedicated aircraft to accommodate a special antenna (Jha et al., 2008).

MWR systems have not been tested or validated in ice conditions, and their potential for characterizing oil in ice-affected waters remains unknown. Research on the utilization of MWR sensors in ice environments, especially in low ice concentrations (<3/10), can be useful to evaluate capabilities of this technology for operational application.

3.3.6 Airborne and Satellite Radar Systems

Radar systems operate in the microwave spectrum, are largely weather-independent, can acquire images day and night and are available on airborne and satellite platforms. Radar backscatter signal depends on the parameters of the imaged surface such as target material and conductivity and system characteristics, such as wavelength, incidence angle and polarization (Campbell and Wynne, 2011). Radars use an antenna to emit and collect the microwave signal and spatial resolution improves as the length of the antenna increases (Van Zyl and Kim, 2011).

Due to the large antenna size, SLAR is restricted to aerial platforms, typically fixed-wing planes. SAR by contrast, uses the forward motion of the sensor platform, while taking into account Doppler shift of the collected signal to synthetically increase antenna aperture (Gade et al., 1996). Imaging satellite radars rely on SAR, although airborne SAR sensors are also used. SAR satellite sensors are emerging as the predominant means of ice surveillance over large areas and are widely used by national ice centers around the world.

Oil slicks on water are detectable by radar imagery because of the dampened capillary waves which correspondingly reduces backscatter compared with the surrounding oil-free water (Solberg et al., 1999). Oil on water appears as dark patches on radar images (Topouzelis, 2008). Capillary waves are also reduced by other phenomena (see Section 4.1.1) and verification by other means is required to identify oil unambiguously.

Most current radars operate in C-Band (wavelength ~5 cm) or X-Band (wavelength ~3 cm), although L-band (15 to 30 cm) and P-Band (30 to 100 cm) systems have been used on airborne and satellite platforms. Radars can be configured to transmit and receive horizontally or vertically polarized radiation and vertical antenna polarizations for both transmission and reception (VV) have been shown to yield better results than other configurations for oil detection (Brekke and Solberg, 2005).

Wind speed is a major factor in detection of oil with radar. At low wind speeds, there is relatively little wave activity and almost no Bragg scattering from the ocean surface, minimizing the contrast between oil-affected and oil-free areas (Solberg et al., 1999). On the other hand, at very high wind speeds the larger waves are substantial enough to overcome damping effects caused by the oil. Again, under these conditions the brightness contrast between the oil and surrounding water is diminished, and the presence of oil cannot be detected. In general, wind conditions between approximately 3 and 10 ms^{-1} are favorable for detecting oil on open water using SLAR or SAR sensors (Gade et al., 1996; Solberg et al., 1999; Brekke and Solberg, 2005; Babiker et al., 2010).

False alarms are possible from areas of low wind, biogenic slicks, fresh water inclusions, grease ice, shear zones and internal waves, all of which may have a radar signature similar to oil on water (e.g., Fingas and Brown, 1997; Solberg, 2012). Discriminating oil from the water background typically relies on analysis of local image contrast as well as shape and distribution of observed dark patches (Brekke and Solberg, 2005; Topouzelis, 2008).

In the last decade, satellite-based oil spill monitoring has become an integral part of national pollution control programs in Europe and Canada (Ferraro et al., 2010). In Europe, the European Maritime Safety Agency (EMSA) administers satellite-based monitoring through a network of service providers, while in Canada the Integrated Surveillance and Tracking Of Pollution (ISTOP) program is executed through the Canadian Ice Service (CIS). Figure 16 shows an example of a satellite SAR image with oil and ship signatures acquired and analyzed by CIS.

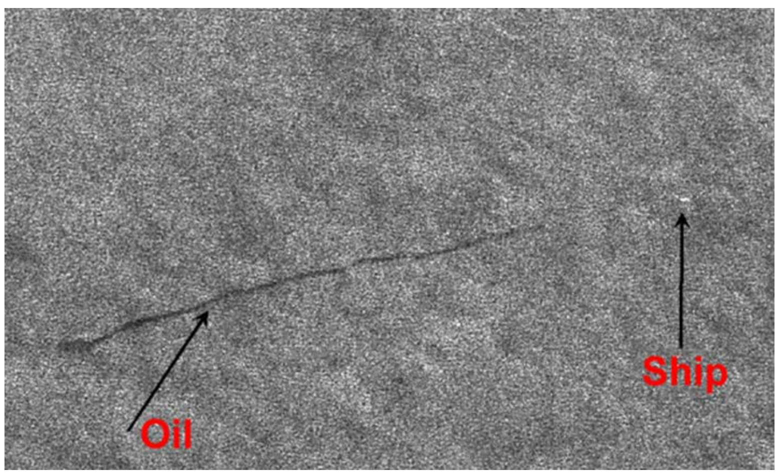


Figure 16. Satellite SAR image acquired on January 30, 2009 in Cabot Strait, Canada with oil and ship signatures (from http://www.ec.gc.ca/glaces-ice/default.asp?lang=En&n=C5EE0C9F-1)

The approaches and algorithms used to extract potential oil slicks are typically divided into two major stages. In the first stage areas of low backscatter are identified in the image either through manual interpretation or automated segmentation. In the second stage the characteristics of the low-backscatter areas are evaluated to determine if it is likely an oil slick. Classes of features used in this context are slick geometry and structure, appearance of the edges, brightness contrast to surrounding areas, known sea state, known presence of algae blooms and locations of ships or platforms (Brekke and Solberg, 2005; Solberg et al., 2007; ASL, 2012).

The presence of oil slick look-alikes remains a constant issue, with false alarm rates ranging from 15 to 85% (Tarchi, 2005), however, recent research indicates that automated algorithms are increasingly able to differentiate between oil slicks and look-alikes, with classification accuracies ranging from 73% to 92% (Brekke and Solberg, 2005; Bogdanov et al., 2005; ASL, 2012). Present operational oil spill monitoring using satellite SAR is based on manual or semi-automatic interpretation with significant input from operators (Ferraro et al., 2010), suggesting that automated algorithms may not yet be able to fully take account of environmental conditions, look-alikes and slick characteristics encountered in the routine surveillance of large areas.

Fully-polarimetric SAR has been recently investigated for characterizing oil slicks. Minchew et al. (2012) examined polarimetric SAR imagery acquired with an unmanned aerial vehicle (UAV) over the Deepwater Horizon spill. The results show that radar backscatter from both clean water and oil in the slick is predominantly due to single bounce surface scatter. The most reliable indicator for slick detection was found to be the major eigenvalue (λ1) of the coherency matrix, which is approximately equal to the total backscatter power for both oil and oil-free water see (Figure 17).

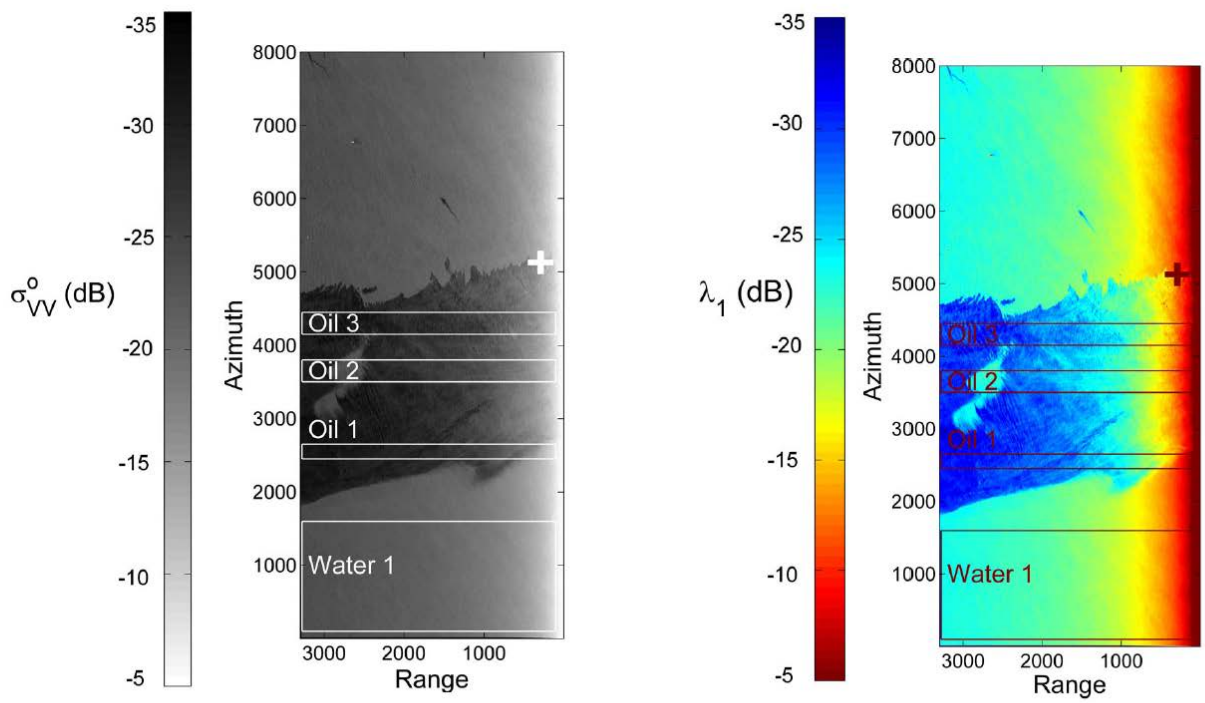


Figure 17. Vertical co-polarized normalized radar cross section, σ_{VV}, image (left) and major eigenvalue (λ1) images (right) of oil spill (from Minchew et al., 2012)

Other polarimetric parameters studied in the context of oil slick characterization include the circular polarization coherence, the co-polarized phase difference standard deviation, polarimetric entropy and anisotropy, among others (Solberg, 2012). Recent work has indicated that polarimetric entropy is a promising area to consider (ASL, 2012). An overview of current and future SAR satellites is provided in Table 6.

Table 6. Current and future SAR satellites

Sensor	Band	Polarizations	Spatial Resolution [m]	Swath Width [km]	Revisit Frequency	Status
RADARSAT-2	C	HH, VV, HV, VH	1 to 100	50 to 500	2 to 3 days	Operational
COSMO-SKYMED	X	HH, VV, HV, VH	1 to 100	10 to 200	2 days	Operational
TERRASAR-X	X	HH, VV, HH/VV, HH, HV, VV, VH	1 to 18	10 to 150	3- 4 days	Operational
SENTINEL-1	C	HH, VV, HH/VV, HH, HV, VV, VH	20	250	1 to 3 days	Launch in 2013
RCM	C	HH, VV, HV, VH	1 to 100	50 to 500	Daily	Launch in 2018

Reduced wave activity in areas filled with broken ice limits the utility of radar for detecting oil spills within moving pack-ice. Recent studies found that SAR or SLAR were not able to detect oil contained between close-pack ice (Dickins et al., 2010). While it was suggested that radar may be useful for imaging spills in open pack ice, where the ocean wave behavior is closer to that of open water conditions, this assertion has not been validated in the field. Additionally, new ice may dampen ocean waves in a fashion similar to that of oil, resulting in potential ambiguities in spill assignment when analyzing radar images, especially with single-band SAR data (Babiker et al., 2010).

SAR cannot penetrate thick ice cover due to the high attenuation of saline ice. The ice thickness is particularly critical when operating at high SAR frequencies (e.g., X-band, 8-12GHz), as the attenuation coefficient increases with frequency (Fingas and Brown, 2000). While attempts to detect oil within high ice concentration during the SINTEF JIP project were unsuccessful, it was suggested that there was no technical reason why such sensors could not detect oil in open ice (1/10 to 3/10) (Dickins, 2010). Further work is required to determine the full capabilities of SAR and SLAR systems in ice.

3.3.7 Fluorosensors

Certain hydrocarbons have fluorescent properties. For these materials, when ultraviolet light (typically between 300 nm to 400 nm) is incident on an oil sample visible light within the range of 500 nm to 600 nm is produced through a sequence of energy transitions in the hydrocarbon molecules. This fluorescence signal is unique to oil and can be used to differentiate a probed oil sample from materials such as chlorophyll, kelp, water, ice, and snow (Fingas and Brown, 2000). In fact, the fluorescence peak is unique for each oil sample and can be used to classify oil (Turner Designs, 2012). For thin slicks on water (i.e., approximately 1 micrometer thick), information on the oil thickness can be deduced through intensity analysis of the Raman spectral peak observed from the water beneath the oil. As the oil thickness increases, the intensity of the Raman peak (stemming from inelastic light scattering in the water) decreases (Brown, 2011).

Fluorosensors can be deployed from aircraft or the surface. For the former, a UV laser pulse is emitted from the bottom of an aerial platform (typically a plane). The laser is scanned across the flight track to cover a horizontal swath of land. The visible-range spectral response is monitored and a spectral peak between 400 nm to 600 nm clearly indicates the presence of oil. This spectral analysis may be done in real-time on the aircraft (Brown, 2011).

While fluorosensors can be used to detect oil on a variety of backgrounds, the relatively high attenuation of UV light in water renders the system ineffective in fog, low cloud-ceiling, and inclement weather. The system requires a dedicated aircraft with an open belly hatch and depressurized cabin (Fingas, 2011).

There are only a small number of airborne laser fluorosensors in routine operation due to the difficulty of operation as well as the relatively high cost to maintain the system. Systems are being operated in Germany and Estonia (Trieschmann et al., 2001; Babichenko, 2008) and Environment Canada (2007) has a long history in developing and operating a laser fluorosensor (LFS), but this program has been discontinued (Fingas, Pers. Comm., 2012).

Recent field-tests using an airborne Raman laser spectroscopy system reported that methane and hydrogen sulfide leaks could be detected with concentrations as low as six parts-per-billion (ppb) and two ppb, respectively (Alimov et al., 2009). The system was based on a pulsed UV laser, however, the authors suggest that it may be modified to be integrated with a flurorosensor.

Fluorosensors operating in the UV spectrum are not suitable for detecting oil under snow since light in the UV to visible range is highly attenuated in snow. The attenuation in ice is not as high over this spectral range suggesting that fluorosensors may be able to penetrate ice covers. Past research suggests that this approach works well with snow-free ice up to about 1 m thick (Goodman, 2008).

In 1992 Environment Canada conducted a field test to evaluate the capabilities of laser fluorosensors (LFS) to detect oil in various environments including vegetation, water, ice and snow (Dick et al., 1992). The results demonstrated that LFS were capable of detecting oil on different surface types (Figure 18). While LFS would be ineffective for detecting oil under ice and/or snow, they have future potential for discriminating between oiled and un-oiled surfaces.

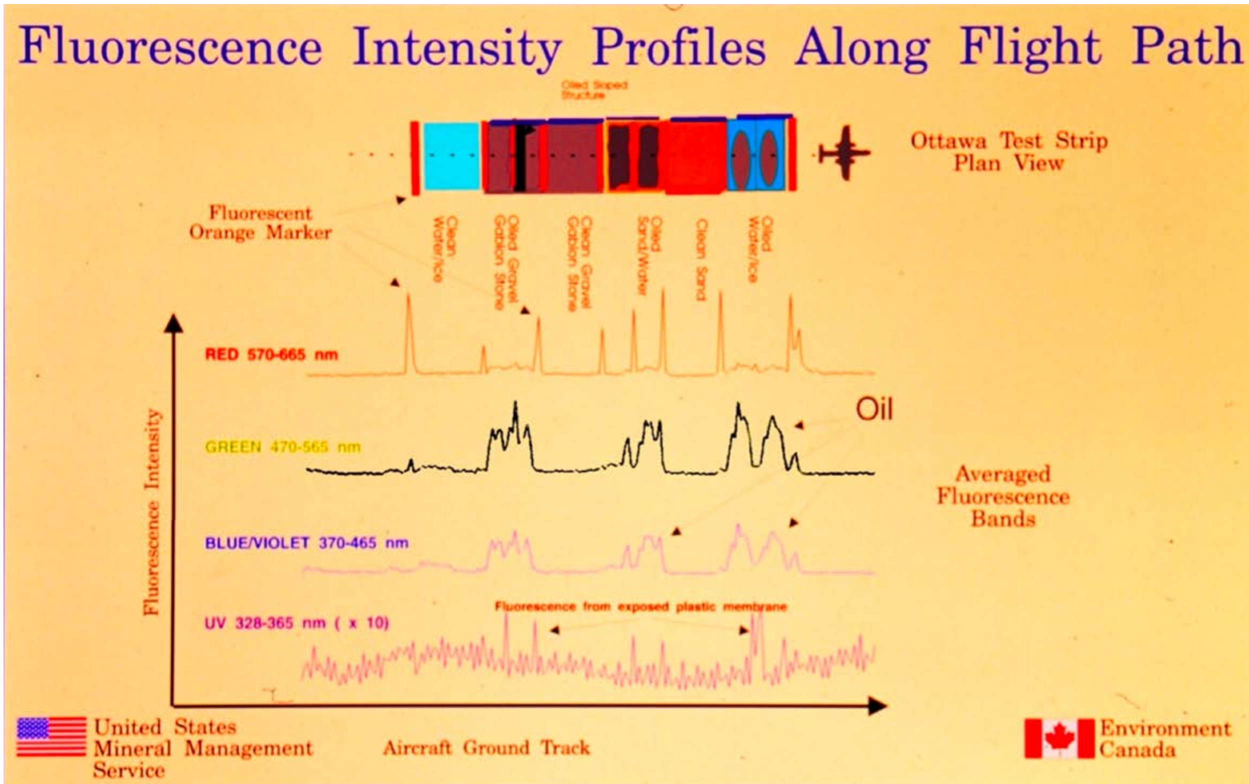


Figure 18. Oil detection using fluorosensor (Environment Canada, 1992).

Surface-based fluorosensors have lower power requirements and compact continuous-wave UV lasers or Xenon lamps have been used as the active source (Turner Designs, 2012; Goodman, 2008). These detectors have been used to detect oil on the ground, in water, on snow and on ice. Research been conducted to implement laser-based fluorosensors from vessels (Brown and Fingas, 2003a), but the utility of these systems is not well understood.

3.3.8 LIDAR Sensors

LIght Detection and Ranging (LIDAR) systems are based on laser technology (similar to fluorescence sensors). A number of airborne and ship-based LIDAR systems which operate in visible (i.e., non-UV) and IR ranges using CO_2 lasers were developed and tested in USSR (Kozintsev et al., 2002).

The results indicate that it is possible to detect oil on the water by analyzing the backscattered LIDAR signal (Figure 19). Oil is easily detected on lakes and rivers provided that wave heights are low, which suggests that the system may function in ice covered water where there are no waves. Experiments in the Baltic Sea in high winds (up to 50 km/hour) have demonstrated that ship-based LIDAR systems using a CO_2 laser are effective (Kozintsev et al., 2002). Figure 20 shows signal scatter from a diesel fuel spill and sea water with winds about 1-5 km/hour.

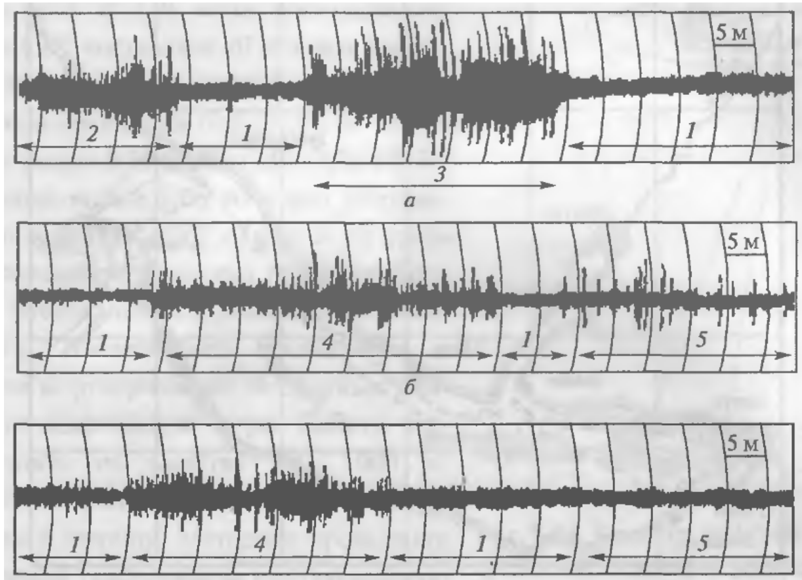


Figure 19. Recorded signal of optical LIDAR acquired on the test sites: river (top), lake (middle and bottom). Section of the signal: 1 - clear water, 2 and 4 – oil film with thickness of 0.2-0.5 micron, 3 - oil slick 3 micron, 5 – biological film (from Kozintsev et al., 2002).

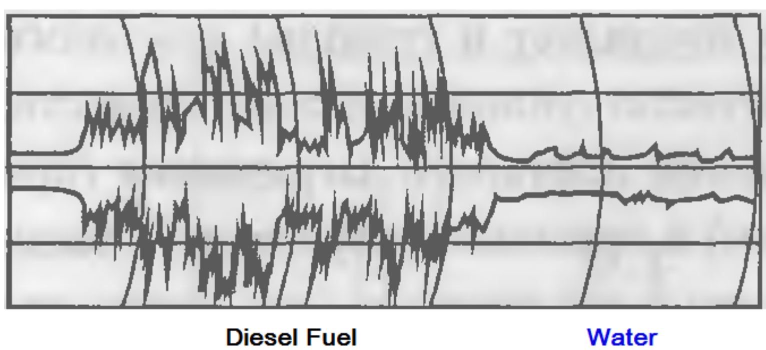


Figure 20. Backscatter from CO_2 LIDAR for the Baltic Sea (from Kozintsev et al., 2002)

Lumex (2012) has developed an active IR sensor for environmental monitoring and detection of oil pollution on water. The KRAB-1 detector is based on three infrared Light-Emitting Diodes (LEDs) to generate light beams (similar to laser) and a single channel receiver system. Signal processing capabilities are built into the microprocessor of the unit and the detection of oil on water is based on the difference in the coefficients of light reflection for oil and water. The device can be calibrated for different environmental conditions to reduce the impact of wind waves and background light on the measurement results. The instrument can be mounted on vessels or platforms and detect oil slicks with thicknesses greater than 0.5 µm over distances up to 25 meters. The instrument supports the generation and transmission of information products in real-time using wireless communications.

The experimental LIDAR system, called ATMospheric and MARine LIDAR (ATMARIL-3), was developed for atmospheric-optical and hydro-optical measurements from the carrier platform (e.g., aircraft, vessel, etc.). This LIDAR is capable of revealing an oil film on the water surface and chlorophyll/phytoplankton in the water. When short laser radiation pulses enter the water they are dispersed and illuminate various heterogeneities (e.g., polluting hydrosols, fish), which are detected by the laser locator. The optical signal reflected from the heterogeneities is received, detected and processed by various algorithms. The LIDAR consists of an opto-mechanical transmitter-receiver, a laser with power supply and cooling systems, an analog-digital converter and a computer. The system makes it possible to account for the influence of above-water atmosphere, including atmospheric precipitations, to reduce the effect of mirror glares resulting from micro-roughness and to adjust the LIDAR parameters to changing conditions and different tasks.

3.4 Integrated Monitoring Approaches

The concurrent use of multiple sensors with complementary characteristics can minimize uncertainties associated with single sensors and facilitate the generation of enhanced, comprehensive information products, while allowing visual interpretation of imagery to remain a central element of oil spill surveillance (Fingas and Brown, 2011). Leifer et al*.,* (2012) reports the importance of trained observers during early stages of a spill to deploy clean-up resources in the most effective and efficient manner. Visual analysis and interpretation by a trained operator implicitly integrates information from different sources according to the cognitive abilities and experience of the observer.

While visual interpretation works well for extracting qualitative information, generating quantitative information from diverse data sources and their dissemination to downstream users requires the use of automated systems. Data fusion provides a useful framework for integrating observations from multiple remote sensors (Pohl et al., 1998). Fusing information from various sources generates meaningful information products of higher quality than could be obtained from single data sources only and requires a range of methods to accurately integrate co-registered or geocoded image data sets at pixel, feature and decision levels (Solberg, 2006; Zhang, 2010).

Integrated systems of multiple sensors are increasingly used for operational monitoring of oil spills and discharges. Specially equipped and dedicated aircraft using a combination of SLAR, UV/IR, FLIR, photo cameras, and video have emerged as a typical payload for maritime monitoring (Brown and Fingas, 2005; Baschek, 2007; Armstrong et al., 2008). In some cases, the basic sensor suite is extended by LFS and MWR systems, and the integration of other datasets, such as satellite imagery and Automatic Identification System (AIS) data, is increasingly enabled (Bonn Agreement, 2009).

In Germany, maritime oil spill surveillance in the North Sea and the Baltic Sea is accomplished using two dedicated and specially equipped Dornier Do 228 aircraft (Tufte et al., 2004; Robbe and Hengstermann, 2008). Equipped with OPTIMARE's MEDUSA maritime surveillance system, the sensor suite comprises SLAR, UV/IR, FLIR, MWR and LFS, together with FLIR and digital still and video cameras (Robbe and Zielinski, 2004; Gade and Baschek, 2013). In this configuration, the SLAR is used for far-range detection of potential slicks with a swath width of 60 km, while the other sensors are used in the near range to describe the slick and extract oil properties, including classification and thickness with swath widths of 500 m (UV/IR, MWR) and 150 m (LFS), respectively. The data streams are displayed on a central operating console, which is the primary interface with the operator for data manipulation and product generation. An example of an oil slick captured by the five different sensors is presented in Figure 21.

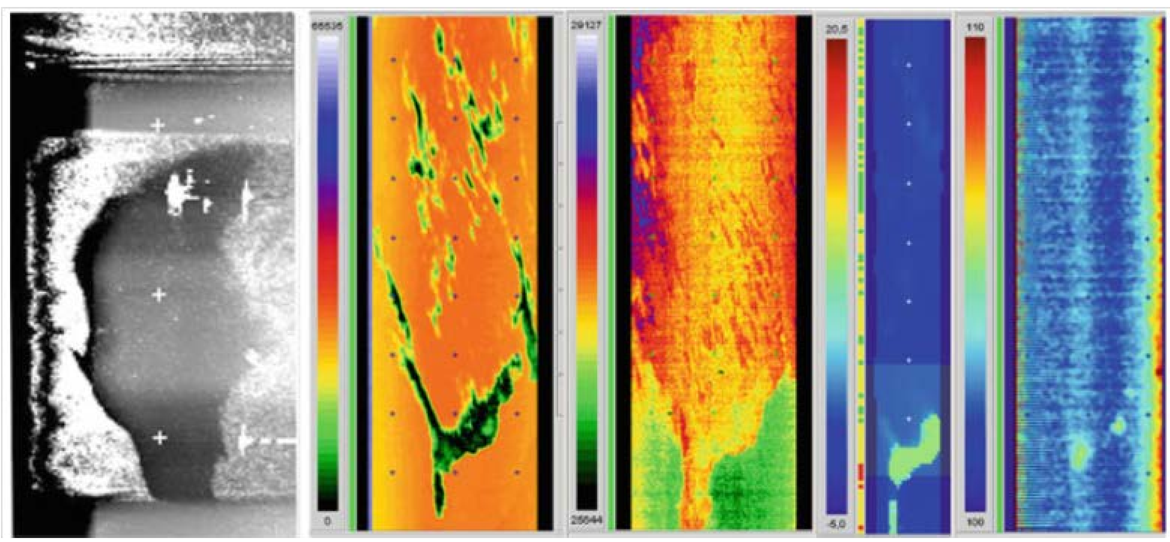


Figure 21. Oil pollution event observed using the MEDUSA system with concurrent acquisition of SLAR, IR, UV, LFS and MWR imagery (Gade and Baschek, 2013).

To prevent operators from being overwhelmed by incoming multi-sensor data streams, the MEDUSA system's automated oil spill scene analysis system (OSSAS) module automatically generates a range of information products including raw UV/IR imagery, area of the oil spill, maps showing intermediate and thick areas within an oil slick, the centre of its area and specific size parameters (Robbe and Hengstermann, 2008). OSSAS also generates higher-order oil thickness products by merging UV/IR and LFS data. In this case, the UV signal is correlated with LFS-derived optical thickness and scaling-up is performed from the narrower LFS swath (150 m) to the spatial coverage of the UV sensor (500 m) (Robbe and Zielinski; Bogdanov et al., 2005). Figure 22 shows an example of the fused UV/IR and LFS data, with extrapolated optical thickness as a measure of oil film thickness and UV and IR spill contours.

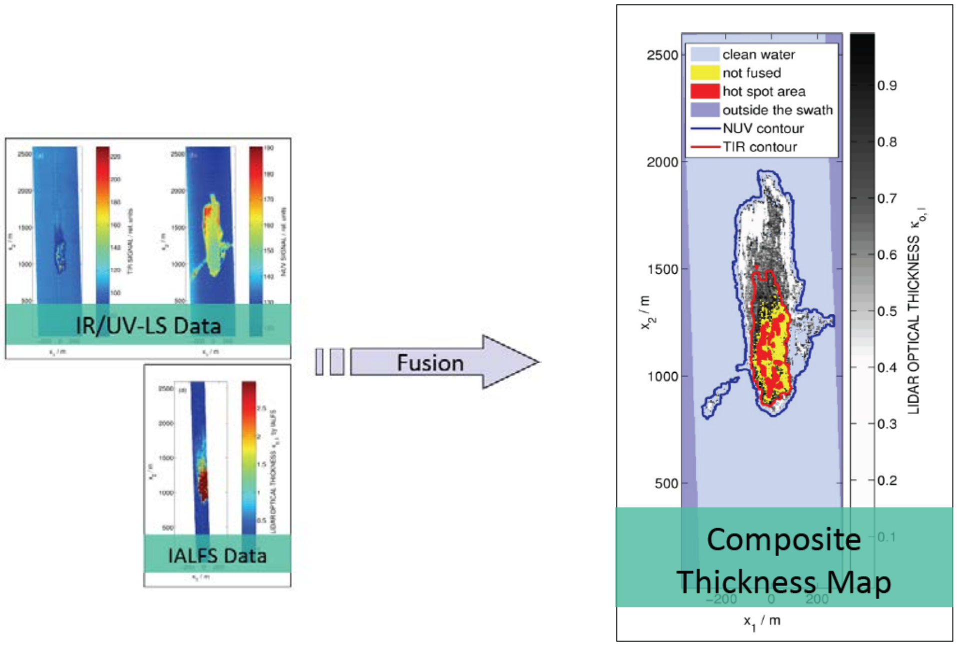


Figure 22. MEDUSA composite thickness map generated with OSSAS (from Robbe, 2012)

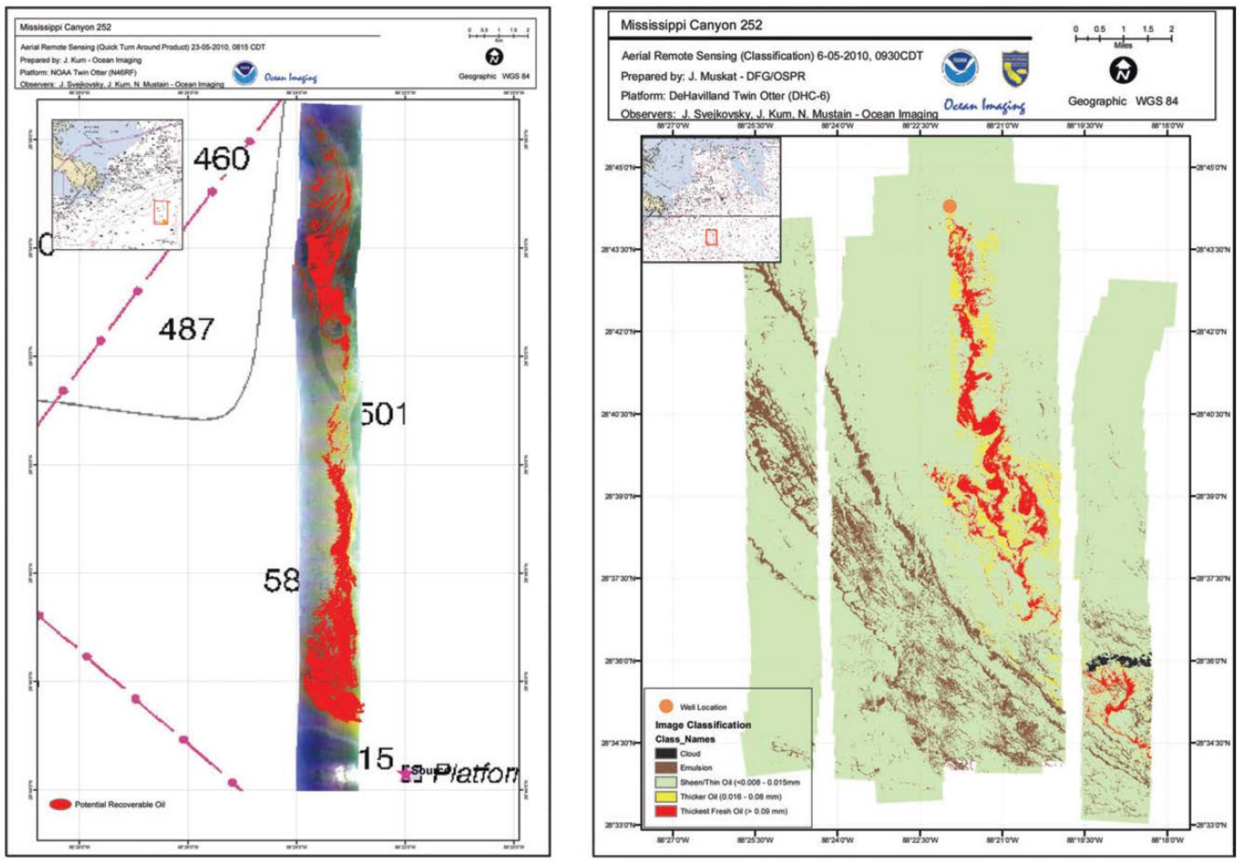
The Swedish Space Corporation has developed and installed more than 80 operational aerial monitoring suites since 1976 (Domargård, 2012). The latest Maritime Satellite Surveillance (MSS) 6000 comprises a combination of SLAR, FLIR, IR/UV-LS, as well as still and video cameras. Data flows from imaging sensors and other equipment, including direction finder, search radar and AIS, are accessible to the operator via a dual operator console (Armstrong et al, 2008). The system further supports the integration of digital nautical charts and satellite SAR images. Depending on user requirements, information products can be generated in a variety of formats, including reports, map products, image maps and video feeds. All information generated can be disseminated in real-time to command centers and ground crews using high-speed INMARSAT communication. In addition to oil slick products, MSS 6000 supports vessel tracking and identification. An example of different data streams integrated within the MSS 6000 operator console is presented in Figure 23.

Figure 23. MSS 6000 Integrated system (from Domargård, 2012)

While MEDUSA and MSS 6000 are examples of permanent installations on dedicated aircraft, Svejkovsky et al. (2012) describe a mobile system by Ocean Imaging (OI) that combines multispectral and TIR sensors and can be mounted on aircraft of opportunity. The system consists of a DMSC MK2 progressive-scan Coherent change detection (CCD) camera with four selectable narrow (10 nm) spectral bands within the spectral range of 400 to 950 nm, together with an IR-TCM640 un-cooled micro-bolometer measuring emitted radiation from 7.5 to 14 µm. The spatial integration of the two sensors is based on a combined differential Global Positioning System (GPS) and inertial measurement unit with a circular positional error of 2 m, resulting in an root mean square (RMS) error of less than 6 m. At an altitude of 3800 m, the ground resolutions are 2 m (multispectral) and 4 m (TIR), with a swath width of 2048 m.

Building on established principles of visual interpretation, the system uses a two-tiered process to generate oil spill information products with up to six oil thickness classes. In a first stage, a neural network is used to differentiate oil and water, while a second step involves extracting oil thickness classes using a fuzzy ratio-based classification. Field and experimental validation results confirm that the combination of multispectral and TIR imagery enables characterization of oil thickness of up to 2 mm (Sveikovski and Muskat, 2009).

Figure 24 shows example products generated in-flight (a) and post-flight (b) during the Deepwater Horizon spill. The generation of detailed thickness classes requires additional calibration and operator input, and the final product includes a series of thickness classes as well as areas covered by emulsion. By contrast, the in-flight product, generated in NRT, shows only areas of thicker oil that are likely recoverable.



(a) (b)

Figure 24. In-flight product for rapid turn-around (a) and fully processed post-flight product (b) with detailed oil thickness classification (from Svejkovsky et al., 2012)

OI information products are fully compatible with Geographic Information System (GIS) typically used in oil spill response, such as NOAA's Environmental Response Management Application (ERMA) online mapping tool (noaaerma.org). During the Deepwater Horizon response, repeat coverage with the OI system was also used to provide situational awareness with respect to vessels in the spill area, verify the effectiveness of sub-surface dispersant application and assess the impact of aerial dispersant application and the mapping of beached oil.

APTOMAR's SECurus system is a ship-mounted situational awareness and decision support tool comprising TIR and digital video sensors installed on a stabilized pointing unit that allows for images to be collected in all weather conditions (Hänninen and Sassi, 2010; Skjelten et al., 2011; Buffagni et al., 2012). A xenon searchlight is synchronized to point in the same direction as the cameras. The TIR camera uses a cooled mercury-cadmium-telluride (MCT) detector with a resolution of 640 x 512 pixels and operates in the spectral range of 3 to 5 µm (FLIR, n. d.). At a sensitivity of 18 mK, the TIR camera generates estimates of relative oil thickness at distances of up to two nautical miles to support response measures. The video and TIR data streams are georeferenced and integrated into an electronic chart system (ECS) and displayed on a touch-input bridge console operated by a dedicated high-speed processor (see Figure 25).

Figure 25. View of bridge console depicting spill location on ECS, digital video and TIR imagery

An open sensor communication interface allows for the integration of inputs, such as radar-based oil spill detection systems and AIS and information and can be generated and shared with other stakeholders in real-time. System performance was validated through planned exercises in collaboration with The Norwegian Clean Seas Association for Operating Companies (NOFO), and the system complies with NOFO requirements for oil recovery vessels on the Norwegian continental shelf (NOFO, 2009). In addition to spill response, the SECurus system is applicable to maritime surveillance and search and rescue operations.

Across the Arctic and other ice-affected areas, national ice services rely routinely on satellite imagery to generate ice information products in NRT. While the primary data source for ice charting is SAR imagery, data from optical and passive microwave satellites are used as well to aid interpretation, especially if radar images are not available. For spill response in ice-affected areas, satellite imagery can provide useful information on ice conditions and provide situational awareness. Depending on sea state and illumination conditions, it can also provide a synoptic view of major spill events (e.g., Leifer et al., 2012). A number of satellite systems acquire data systematically (e.g., LANDSAT, MODIS and AVHRR). Automated systems can be implemented to download and georeference all available imagery for a given area of interest. An example is presented in Figure 26 showing the online database operated by the Danish Meteorological Institute (DMI) for satellite images for the coastal zone of Greenland.

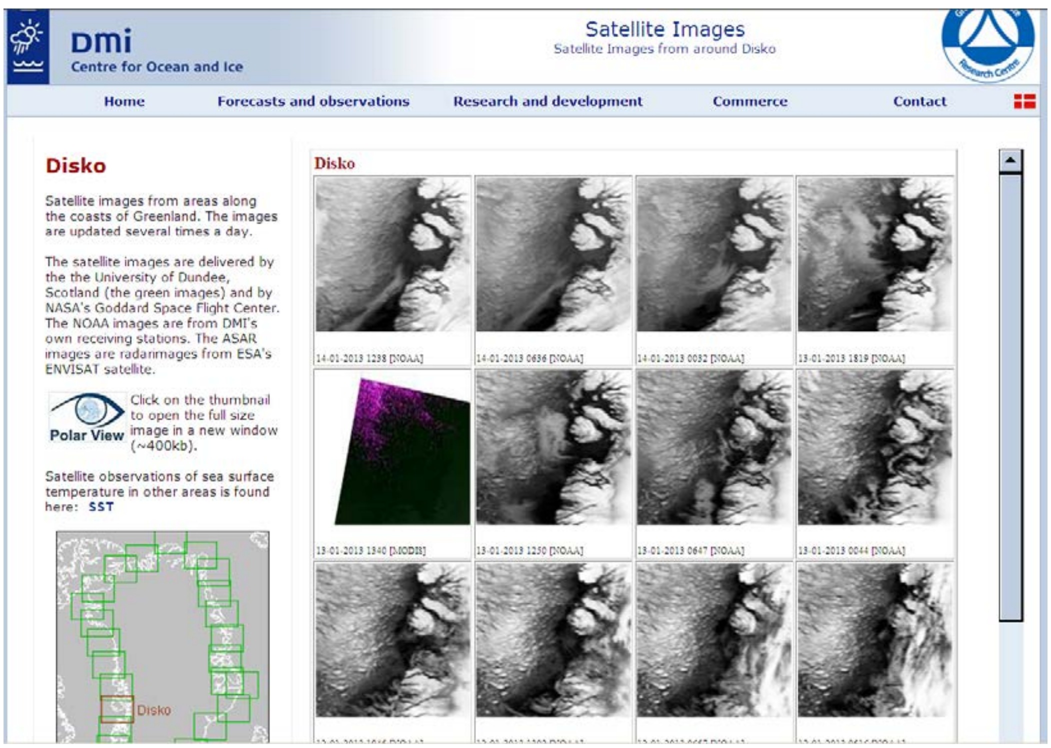


Figure 26. Online database of satellite images for the Disko Bay area, Greenland (DMI, 2013)

Ongoing acquisition of satellite imagery can be useful during response activities, since a search for imagery would not be required and the data are already readily available in a GIS compatible format. The future European satellite missions SENTINEL-1 (SAR) and SENTINEL-2 (optical) will be designed to collect data systematically and will be available in NRT via online archives. A steady stream of optical satellite imagery could also be exploited by developing nested approaches to extrapolate high-resolution observations from ship-borne or aerial sensors to the larger spatial footprint of a satellite image.

3.5 Outlook

Although a significant body of knowledge exists to describe the use of remote sensing technologies for oil spill detection and monitoring on open water, there is little research available to describe the performance in ice-affected marine environments. Dedicated research is therefore required to investigate the performance of remote sensing technologies under Arctic sea ice conditions. Promising sensing technologies to be considered for further research include hyperspectral sensors with a spectral range from UV to TIR, active laser-based systems (i.e. LFS, LIDAR), as well as microwave radiometers.

As no single technology will likely fulfill the needs of all aspects of oil detection in ice environments, a suite of multiple sensors is required to improve detection performance. Recommended sensors should not be used in isolation, but integrated within a suitable architecture to achieve effective data acquisition, information product generation and product dissemination to other stakeholders. Depending on the needs of the individual operations, the sensor networks may include different sensors mounted on a single drilling rig (e.g., radar, optical and TIR), or multiple sensors on multiple platforms, including rigs, vessels, satellites, aerial platforms and underwater vehicles.

The data streams from all sensors should be integrated using accurate geopositioning and accessible from one or more central interfaces (e.g., on the bridge of a vessel, incident command post). Ideally the generation of value-added information products (e.g., spill location, thickness estimates) should be accomplished in an automated fashion with limited quality control to facilitate the dissemination of products in real time over existing communication channels and allow response personnel without specialized knowledge of the sensors involved to interpret output products. Automated detection algorithms may need to be customized for specific geographic areas due to differing environmental conditions (e.g., sediment load, water depth, algae, etc.).

As the number of satellites used for remote sensing is steadily growing, new and emerging satellite sensors should be incorporated in ongoing research activities. In the Arctic context, EO satellites on sun-synchronous orbits provide the added advantage of frequent repeat coverage with multiple image acquisitions per day at high latitudes. Of particular interest are the future C-Band SAR missions SENTINEL-1 and RADARSAT Constellation Mission (RCM). The contribution of optical satellite missions should also be considered. For example, the currently operational Disaster Monitoring Constellation (DMC) provides LANDSAT-type multispectral imagery at 30 m and 20 m resolution and a maximum swath width of 600 km, resulting in near daily global repeat coverage. SENTINEL-2, scheduled for launch in 2014, will have near daily coverage at high latitudes with multispectral data provided at a spatial resolution ranging from 10 m to 60

m. The hyperspectral mission ENMAP, expected to be launched in 2016, will collect hyperspectral imagery from 420 to 2450 nm at a spatial resolution of 30 m and a swath width of 30 km. The investigation of satellite imagery should also include the utility of nested approaches to scale-up airborne or in-situ observations to the larger spatial coverage provided by satellite sensors. Table 7 provides an overview of operational and planned satellite missions, as well as selected airborne technologies, available in Canada.

Table 7. Remote sensing technologies available in Canada

Sensor/Mission	Type	Platform	Status	Provider/Information
RADARSAT-2	C-Band SAR	Satellite	Operational	Canadian Space Agency (CSA) http://www.asc-csa.gc.ca/eng/satellites/radarsat2/
COSMO-SKYMED	X-Band SAR	Satellite	Operational	e-GEOS http://www.e-geos.it/
TERRASAR-X	X-Band SAR	Satellite	Operational	Airbus Defence and Space http://www.astrium-geo.com/en/65-satellite-imagerynd Space
SENTINEL-1	C-Band SAR	Satellite	Launch in 2014	European Space Agency (ESA) https://earth.esa.int/web/guest/missions/esa-future-missions/sentinel-1
PALSAR-2	L-Band SAR	Satellite	Launch in 2014	ESA https://directory.eoportal.org/web/eoportal/satellite-missions/a/alos-2
RCM	C-Band SAR	Satellite	Launch in 2018	CSA http://www.asc-csa.gc.ca/eng/satellites/radarsat/
LANDSAT 8	PAN, MSS, TIR	Satellite	Operational	US geological Survey (USGS) http://earthexplorer.usgs.gov/
MODIS	MSS	Satellite	Operational	USGS http://earthexplorer.usgs.gov/
DMC	MSS	Satellite	Operational	DMC International Imaging http://www.dmcii.com/
SENTINEL-2	MSS	Satellite	Launch in 2015	ESA http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-2
QuickBird	PAN, MSS	Satellite	Operational	MDA Geospatial Services (MDA) http://gs.mdacorporation.com/SatelliteData/SatelliteData.aspx
Worldview-1/2	PAN, MSS	Satellite	Operational	MDA http://gs.mdacorporation.com/SatelliteData/SatelliteData.aspx
Geoeye	PAN, MSS	Satellite	Operational	MDA http://gs.mdacorporation.com/SatelliteData/SatelliteData.aspx
ENMAP	HS	Satellite	Launch in	http://www.enmap.org/

Sensor/Mission	Type	Platform	Status	Provider/Information
			2015	
HYSPIRI	HS	Satellite	Launch in 2016	NASA http://hyspiri.jpl.nasa.gov/
PRISMA	HS	Satellite	Launch in 2015	Italian Space Agency (ASI) http://www.asi.it/en/activity/earth_observation/prisma_
Aerial surveillance	MSS6000	Aircraft	Operational	Transport Canada (NASP) http://www.tc.gc.ca/eng/marinesafety/oep-ers-nasp-2195.htm
Aerial surveillance	Optical, TIR and radar	Aircraft	Operational	Provincial Aerospace (PAL) http://www.provincialaerospace.com/
Aerial surveillance	HS	Aircraft	Operational	ITRES http://www.itres.com/products/imagers/ ASL Remote Sensing http://remote-sensing.aslenv.com/ Hyperspectral Imaging Ltd. (HIL) http://www.hyperspectralimage.com/1801.html

4 PREDICTIVE MODELS FOR FATE AND TRAJECTORY OF OIL IN ICE

The objective of this section is to review current modeling techniques and existing models for forecasting fate and trajectories of oil spills in cold environments, in which ice is present and to identify the related context relative to Nunavut. The review includes techniques and parameterizations used for modeling (1) oil and ice interaction processes; (2) oil weathering processes in cold water; (3) the atmosphere-ocean-sea ice system; and (4) oil spill trajectories in ice-covered waters.

The behavior of oil in ice is complex. Although research and developments efforts over the last several decades have permitted the development of models that perform satisfactorily for forecasting fate and trajectories of oil spill in open water conditions, the state-of-the-art in oil spills modeling in ice-covered waters is relatively little advanced. Sea ice is not considered in most of the existing oil spill models and when it is, the formulations are simple and they arguably over-simplify the problem. In operational coupled sea ice-ocean models, it is not possible to directly model the behaviour of a potential oil spill. The ability to forecast the location and characteristics of an oil spill in ice is essential for risk assessment, planning spill response and assisting in the response and clean-up efforts (Drozdowski et al., 2011).

Oil and ice interact at different spatial scales. Oil can be found on the surface of ice floes; on the snow; in melt pools; under ice; encapsulated into the ice following ice growth; within the cracks and brine channels; between floes of a broken ice field and within brash ice; and in open water leads. Ice prevents the oil from spreading over large distances (Sørstrøm et al., 2010). Oil can drift either with surface currents or the ice (partially or entirely). The big challenge is to determine how much is moving with the ice or not (Drozdowski et al., 2012).

The inherent difficulty in modeling oil fate and trajectory in ice lies in the fact that these processes have to be determined quantitatively. Coupled sea ice-ocean models are resolved at a much larger spatial scale (typically tens of km) than that for which the oil-ice interactions occur (less than 1 km). As a result, the specifics of these oil-ice interactions are generally ignored in oil spill models in ice because it would become too computationally expensive not to do so.

4.1 MODELING OF OIL AND ICE INTERACTIONS

4.1.1 Oil Spreading in Cold Open Water

The spreading of oil is the process by which the oil patch thins and covers a larger area due to the action of viscous, gravitational, buoyancy and surface tension forces (Drozdowski et al., 2011). Oil spreading is slowed in cold water (higher viscosity) and the presence of ice further limits the spreading by containing the oil between ice floes. This results in a thicker oil accumulation than in open water.

The well-known Fay's three-phase (i.e., inertia-gravity, gravity-viscous and viscous-surface tension) parameterization for oil spreading on warm water (Fay, 1969; Fay and Hoult, 1971) has been modified by many authors for oil spreading on colder water (at or near the freezing point), for which the equilibrium thickness of the oil slick is larger and is reached sooner than on warm water (Venkatesh, et al., 1990). In cold water the surface tension spreading phase is absent (spreading ceases before the surface tension phase is entered (Schultze, 1984; Venkatesh, et al., 1990) and ignored in parameterizations. Ross and Energetex Engineering (1985) proposed a formulation for the gravity-viscous spreading equation to determine the radius of the oil slick in which the oil viscosity is used instead of the water viscosity. S.L. Ross and Dickins (1987), after showing that Fay's equations overestimate the radius of the spill (by orders of magnitude) and the time of maximum spread, proposed an empirical relation originating from a linear fit and a very limited set of data points, to calculate the equilibrium thickness.

4.1.2 Oil Spreading in Brash Ice

Heavy hydrocarbon components incorporate into slush and brash ice (Dickins, 2011). Spreading oil in the presence of brash ice has been investigated by some authors that provided formulations to estimate the radius and thickness of the oil slick, some of which are presented in Venkatesh et al. (1990). It should be noted that for the same ice floe size, the area covered by the oil spread could be less by a factor of five in brash ice than in open water (Venkatesh et al., 1990).

S.L. Ross and Dickins (1987), after carrying out small size field tests of oil in brash ice concluded that Fay's equations could not be used for predicting the observed radius and thickness of the oil patch. They used an equation developed for oil spreading in snow developed by Kawamura et al. (1986) to predict the final area of the oil spill in brash ice. This formulation could not reproduce observed oil thicknesses from other experiments (computed thicknesses differed by a factor of 2-20, Venkatesh, et al., 1990).

S.L. Ross and Dickins, (1987) also proposed a linear relationship with oil viscosity to predict oil thickness, based on their data. Sayed and Løset (1993) used laboratory tests to propose a slightly more complicated equation for predicting the radius of the oil spread in brash ice. It is suggested in Fingas and Hollebone (2003) that this equation might not be appropriate to apply at a larger scale in the field, as it originates from laboratory tests, and that a modified Fay's equation for spreading might represent the most suitable analysis to date. This, however, requires more verification to use with confidence.

4.1.3 Oil Spreading in Open Water Leads

Oil 'trapped' in open water leads between broken ice is re-distributed as the leads close. At low lead closure rates the oil is pushed under the ice while at high lead closure rates it is pushed over the ice (Gjøsteen et al., 2003; MacNeill and Goodman, 1987). Simple rules have been defined in terms of lead closure rates thresholds to determine the oil behaviour in these cases

(MacNeill and Goodman, 1987; S.L. Ross and Dickins, 1987). Buist et al., (1987) have investigated oil in leads in tank tests and have developed a simple equation to calculate the thickness of 'wind-herded' oil slicks in leads, as a function of the original thickness and wind speed. Fingas and Hollebone (2003) points out that lead closure rates in nature under normal conditions were insufficient to push oil onto the ice, except for ice closing behind ships.

4.1.4 Oil Spreading in Broken Ice

Spreading of oil spilled in a broken ice field is largely dependent on the surface ice concentration (i.e., areal fraction of ice coverage), since the latter defines the amount of open water available and hence a path for the oil to spread (Venkatesh, et al., 1990). It is typical of oil-in-ice spill models to account for this by dividing the ice concentrations into three classes: (1) low ice concentrations (generally less than 30%); (2) high ice concentrations (generally 60-80% or more); and (3) medium ice concentrations (in between).

In existing models, at low ice concentrations, the spreading of oil is treated as in cold open water. Venkatesh et al., (1990) proposed to calculate the spread area simply as the ratio of the volume spilled to the product of the thickness of the oil patch and the fraction of open water (this assumes that no oil is trapped under the ice). The thickness of the oil can be calculated with equations for oil spreading in cold water already discussed. At medium ice concentrations, Venkatesh et al. (1990) proposed to calculate the amount of oil trapped under the ice and within the slush/brash ice and to subtract that volume to the total volume spilled. The remaining volume of oil is then to be used to calculate the thickness of the spread, as was proposed for low ice concentrations. For high ice concentrations, they propose to calculate the volume trapped between ice floes as the product of the open water fraction, the area covered by the spill and the oil thickness. These are more conceptual than practical considerations, as the authors did not provide any indications as to how the thickness or area of the spill might be estimated in different circumstances.

For all three concentrations classes, S.L. Ross and Dickins (1987) proposed to use their equation for oil spread in cold open water, but to correct it as a function of oil and water viscosities ratio and ice concentration (Fingas and Hollebone, 2003).

All existing methods for calculating the spreading of oil in broken ice are highly empirical and data or evidence of their performance is either unpublished or non-existing. It should be noted that models consider ice concentration to assess the likelihood of oil drifting independently of, or with the ice.

4.1.5 Oil Spreading on Ice and Snow

Oil on the ice surface exhibits little spreading at cold temperatures because of its higher viscosity (Chen, 1972; Fingas and Hollebone, 2003) and most often the presence of a snow cover will absorb the oil and further reduce spreading. The nature of the ice surface is very important in determining the amount and thickness of oil 'trapped' in surface depressions and irregularities. The resulting oil layer thickness can be anywhere between 2 to over 30 cm thick (C-CORE, 2013; Dickins and Buist, 1999; Fingas and Hollebone, 2003).

According to Fingas and Hollebone (2003), theoretical models of oil spreading on ice are generally based on Fay and Hoult's (1971) three phase semi-empirical model of oil spreading on open water. Glaeser and Vance (1971) have proposed a simple equation to calculate a characteristic dimension of the oil spread that is a function of the volume of oil spilled and the spreading time. Chen (1972) found no spreading below -19°C (Fingas and Hollebone, 2003). McMinn (1972), based on Fay's equation, concluded that gravity is the only important spreading force and developed a parameterization for the radius of the oil spill as a function of the average leak rate, average surface roughness and time, as well as a fit equation to experimental data, the latter of which was revised later by McMinn and Golden (1973). Chen et al. (1974) developed a quasi-empirical equation for the radius of the oil spill that is a function of time, volume, density and viscosity of the oil spilled. The equation was found to work only for laboratory-scale spreading on smooth ice surfaces (Fingas and Hollebone, 2003). Kawamura et al. (1986) proposed a similar empirical relationship, based on experimental data that accounts for the oil final spill thickness. No published study exist where these formulations are compared and evaluated, but according to Fingas and Hollebone (2003), the formulation by Kawamura et al. (1986) can predict field results to some degree, this has not been quantitatively defined or verified in any available published material.

Parameterizations for oil spreading on snow are scarce. Kawamura et al. (1986) extended the oil-on-ice equations to predict the spreading on snow with a very similar formulation that accounts for the snow density and type. Their formulae can be used to calculate the final area and thickness of the oil spilled on snow. No comments on performance or comparisons with field data are given or available.

4.1.6 Oil Spreading Under Ice

The movement of oil under ice is largely dictated by the roughness of the ice interface, with oil pooling in undulations (C-CORE, 2013). Oil spread under ice is the least well understood and most complex to model (C-CORE, 2013; Stanovoy et al., 2012; Drozdowski et al., 2011) because oil hydrodynamics depends on the under-ice shape and profile of the ice, which are unknown during operating/forecasting activities and on the hydrodynamics of the water flow. Oil trajectory modeling in the presence of ice is still an active field of study and is being further investigated through the Arctic Response Technology in a Joint Industry Program (JIP)[1].

The spreading rate under ice depends on the oil spill rate, the under-ice depression fill rate, the under-ice roughness, gravitational forces, and ocean currents. Under-ice roughness or variation

[1] Arctic Response Technology JIP: www.arcticresponsetechnology.org

in ice thickness which occurs in nature could provide large oil storage volumes and limit the spread of oil under ice. A field study by Dickins and Buist (Dickins and Buist, 1981) revealed that under low currents and relatively flat under-ice profile, the oil spread mechanism is mainly governed by gravitational forces due to the difference between oil and sea water densities. Oil is trapped under ice by two mechanisms (Izumiyama et al., 2004): gravity and interfacial tension. The typical holding capacity of oil under ice is shown in Figure 27.

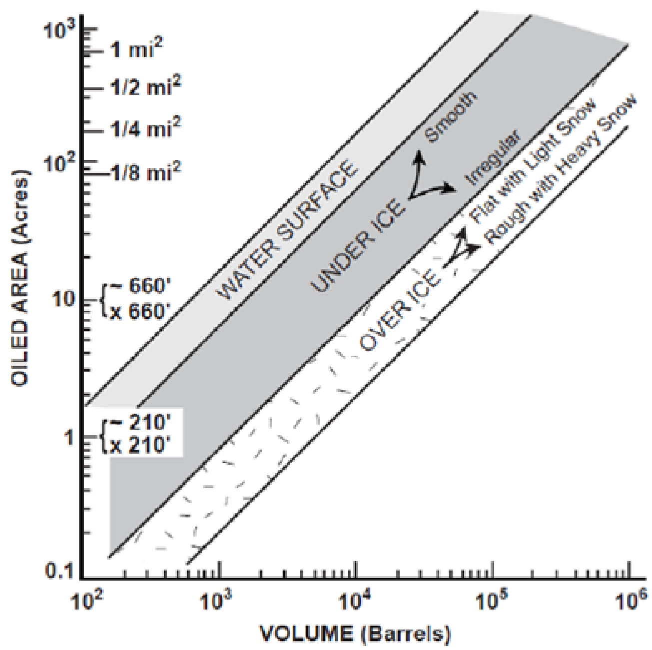


Figure 27. Typical Arctic holding capacity (after Potter et al., 2012)

Oil is stored under the ice in the cavities, which are defined and parameterized on three scales:

Global scale: This type of roughness usually contains ridges or rubble fields bounding level ice areas, which are impermeable enough to prevent or limit oil spread and corresponds to large scale under-ice storage volumes. The complex nature and distribution of global-scale roughness patterns under ice has been studied by several researchers (Hoare et al., 1980; NORCOR, 1977; NORCOR, 1978; Comfort and Edwards, 1978) and found to be highly site specific. Varying from poorly consolidated first-year porous ridges to highly consolidated multi-year ridges. Modeling of oil spreading under ice with global-scale roughness needs to perform with respect to local ice profiles.

(A) *Macro scale*: Significant oil volumes are also stored under ice at this scale. This type of roughness is defined as under-ice roughness with areas of tens of square meters. The storage volume of macro-scale roughness can be modeled as a function of roughness size and the filling depth. Comfort (1986) has developed a model for estimating storage volume of macro-scale roughness based on the data provided by Kovacs et al. (1981). However, Comfort (1986) argued that the model by Kovacs et al. (1981) may underestimate the available storage volume due to the fact that for large spills there is an encompassing boundary that is deeper than the mean. This leads to an increase in the storage volume, and will be discussed later in the present review.

Micro scale: Roughness scale that is expected in the growing ice sheets with area scales of less than one square meter. While there are studies conducted in this field such as the study by Wotherspoon et al. (1985) for a range of default under-ice profiles representative of micro-scale roughness (providing a range of storage volumes from 0.007 to 0.027 m^3/m^2), the significance of this type of roughness is still unclear.

Some simple rules of thumb (in terms of ocean currents thresholds under the ice) can be used to determine whether the oil will be forced out of an undulation or not (Buist et al., 2007; Cammaert, 1980; Dickins and Buist, 1999; Fingas and Hollebone, 2003; Potter et al., 2012). Most parameterizations for under-ice spreading typically predicts a slick radius and, although some formulations account for the ice roughness (e.g., Izumiyama et al., 2004), most do not consider the under-surface irregularities and ridges (e.g., Izumiyama et al., 1999; Yapa and Chowdhury, 1989). They are all reported to perform better for flat ice rather than rough ice under-surface profiles.

Winter under-ice currents in most Arctic areas are not sufficient to move spilled oil beyond the initial point of contact with the ice under surface (Fingas and Hollebone, 2003). In existing oil-in-ice spill models, oil under the ice is generally assumed to drift with the ice (e.g., Cox et al., 1980; Liu and Leendertse, 1981).

4.1.7 Oil Encapsulation, Vertical Migration and Oil Release

Oil trapped under the ice surface can become encapsulated into the ice layer (especially under first-year ice) as the latter grows. It has been observed that it can take as little as 48 hours for the oil to be effectively encapsulated (Buist et al., 1983). When ice disintegrates during the break-up period, oil can be released at the surface or migrate vertically to the surface through brine channels or between disintegrated columnar ice crystals (Dickins and Buist, 1981; Fingas and Hollebone, 2003; Potter et al., 2012; Wilkinson et al., 2013). The amount of encapsulated oil over large areas is not clearly known and their fate and drift are usually not modeled.

4.2 Modeling of Weathering Processes of Oil under Cold Conditions

4.2.1 Oil Evaporation in Ice Environments

Evaporation losses are reduced in cold environments, in the order of half as much or less (20% in broken ice – by weight – compared to 40% in open water, Brandvik et al., 2004) when compared to warmer environments (Brandvik et al., 2004; Potter et al., 2012). There are not many equations or parameterizations available to estimate oil evaporation in ice conditions. Buist et al. (2009) used an equation developed by Stiver and Mackay (1983) to calculate evaporation of oil on ice, on snow and in broken ice. Their experiments were made at a small scale, using Petri dishes. The evaporation fractions calculated with the Stiver and Mackay equation match their data well. It is not clear how this can be extrapolated to larger scales, including full scale. Evaporation losses are not normally accounted for in existing oil in ice models.

4.2.2 Emulsification and Natural Dispersion in Ice Environments

Emulsification is the process of mixing water droplets into spilled oil forming highly viscous mixtures that have reduced weathering capabilities and are usually more difficult to burn, disperse and mechanically recover (Potter et al., 2012). Natural dispersion is the process of breaking waves forcing oil droplets into the water column, which can result in at least a portion of the droplets small enough to remain in the water (Potter et al., 2012). These processes are less important in ice environments (order of 4-5 times less water content than in open water, Brandvik et al., 2004), as ice tends to damp waves and dissipate turbulent energy. Because of this, they are generally ignored in existing oil trajectory models in ice.

4.3 Modeling of Oil Drift and Trajectory in Ice Conditions

The current techniques used for modeling oil drift and trajectory in ice conditions have been in use for over 30 years. The models use a kinematic approach, in which the oil motion is calculated as a vector sum of the current velocity and a fraction of the wind velocity (3-5%), rotated at an angle from the wind direction to account for the Coriolis effect. There are three main approaches used for discretizing the oil (Drozdowski et al., 2011), i.e., using (1) particles; (2) tracers; or (3) spillets.

In the *particle* approach (a Lagrangian approach), the oil is discretized as a finite number of particles. Each is assigned a series of properties, such as position, mass, thickness, velocity, viscosity, etc. The area and thickness of each particle does not change in time. Each particle is advected independently using the velocity field of the ocean or the ice. Spreading and dispersion are accounted for by adding random movements to the particles at each time step.

In the *tracer* approach, the area of the oil spill is discretized into a fine Eulerian grid, with less than 1 km grid spacing (Drozdowski et al., 2011). Each cell is then either assigned oil/water properties to best represent the physical geometry of the oil spill. The advection-diffusion equation is solved on each grid cell using local ocean currents and ice drift velocities. Diffusion coefficients are used to simulate spreading. This method can be computationally expensive because the number of cells is large.

The *spillets* approach is essentially the same as the particle approach, with the exception that spillets are allowed to change their area and thickness over time. As explained in Drozdowski et al., (2011), the total spill is represented by a number of smaller spills, each with the ability to spread. Spread can be modeled by equations presented earlier (e.g., Fay's equations). The spillets approach can be regarded as a compromise between the particle and tracer methods (Gjøsteen et al., 2003).

Most existing models either use a particle or spillets approach. Some models use a probabilistic approach, in which the oil-ice interactions are described according to probabilities for a particle to, for example, go from one state to another, become trapped under ice or not, spread or not, etc. (Gjøsteen et al., 2003).

Forcing used in oil spill trajectory models in ice environments come from atmospheric models, ocean models and ice models (or a combination of these, in a coupled manner). Oil trajectory and weathering models are not coupled to these (i.e., it is a one-way transfer of information from the atmosphere-ocean-ice system to the oil, without transfer of information from the oil model in the other direction). The quality of the oil trajectory modeling effort is directly dependant on the quality of the data used from the atmosphere-ocean-ice modeling system.

Typically, the oil is assumed to move with the ice at relatively high sea ice concentration (>50-70%). At low concentration (<30%), the oil is assumed to behave as in open water (Dickins and Buist, 1999; Potter et al., 2012; Spaulding, 2013; Venkatesh et al., 1990; Wang et al., 2008). Quality of ice motion and ocean currents fields is crucial in modeling oil trajectory.

4.4 Ice-Ocean Modeling

Ice motion, thickness and concentration are obtained from sophisticated coupled sea ice-ocean models (e.g., Hibler, 1979; Coon, 1980; Coon et al. 2007; Neralla et al. 1988; Sakov et al., 2012). Ocean currents or coupled sea ice-ocean models typically use advanced data assimilation techniques, in which different parameters, measurements and observations are included in the simulation (in NRT when producing forecasts), to produce better quality results (e.g., Hunke et al., 2013; Sakov et al., 2012). These models provide estimates of ice concentration and average thickness for predetermined ice thickness categories (three to 10, typically) in each model cell. The spatial discretization (10-100 km) is insufficient (partly because of computational limitations) to resolve oil-in-ice processes involved in oil spreading and weathering in ice as these occur at a much smaller scale (scale <1 km). Because of that, ice motion cannot be described in sufficient detail (Gjøsteen et al., 2003), and crude approximations for oil-in-ice processes need to be used. Although ultra high resolution models might be available for the atmosphere and ocean, such as the Weather Research and Forecasting (WRF) model, their use is only practical regionally, in a very limited geographical area. Another difficulty is that ice models all tend to over-predict ice velocities. This is due to a number of factors including the manner in which large scale ice rheology is modeled.

A multitude of operational atmospheric forecast models exist, including the: Canadian Meteorological Center (CMC, Canada); Global Forecasting System (GFS, U.S.A.); US Navy Global Environmental Model (NAVGEM, U.S.A); and the European Centre for Medium-Range Weather Forecasts Model (ECMWF, Europe). These models provide global coverage and most of these are accessible at no charge.

Operational ocean models are also numerous. Models of interest include: Canadian East Coast Ocean Model (CECOM, Canada); Canadian Operational Network of Coupled Environmental Prediction Systems (CONCEPTS, Canada); and the Canada-Newfoundland Operational Ocean Forecasting System (C-NOOFS, Canada). CONCEPTS will be operational in the short-term and is intended to replace CECOM.

The only known, publically available, operational ice-ocean system available is the TOPAZ4 model from Norway (Sakov et al., 2012). TOPAZ4 uses the HYbrid Coordinate Ocean Model (HYCOM) ocean model (Bleck, 2002), coupled with a modified version of the CICE sea ice model (Hunke and Lipscomb, 2010) and the ECMWF atmospheric fields. It covers the Arctic, including the Hudson and Davis Straits.

Considering an oil slick's fate is affected by local winds and currents, these are important environmental parameters that need to be measured. However, there are no Environment Canada Meteorological Service of Canada (MSC) buoys measuring real-time marine information in the Hudson and Davis Straits. Therefore, models have to be used to obtain marine forecast bulletins for Nunavut[2]. Marine forecasts for day 1 and day 2 are derived from the Regional model, while forecasts for days 3, 4 and 5 are from Global models and are available on the Environment Canada (EC) website[3]. Further real-time measuring capabilities can also be provided by the Federal government (i.e. Canadian Coast Guard) (CCG)) and private oil spill response corporations in the event of an oil spill.

There are EC Weather Stations at the local airports in seven communities along the Straits (Figure 28). These stations record standard meteorological parameters measured at all of EC stations across Canada (i.e., air temperature, relative humidity, winds, visibility, etc.). Because these measurements are very localized, they would be of little help if one was to try to predict oil movement in ice using this data.

[2]Marine Forecast Bulletins for Nunavut: http://weather.gc.ca/marine/marine_bulletins_e.html#NU
[3] Environment Canada Forecast Models: http://weather.gc.ca/model_forecast/index_e.html

Figure 28. Environment Canada Weather Stations

4.5 Ice Conditions in the Hudson Strait and Davis Strait

Ice conditions in the Hudson and Davis Strait are well documented and described in Department of Fisheries and Oceans Canada (DFO, 2012) and S.L. Ross (2011). The following is a summary of these.

Figure 29 shows the ocean currents within Baffin Bay, Davis Strait and Hudson Strait. Warm, saline currents flow in the northwest direction off Greenland and converge with the cold and less saline waters that flow south off the coast of Labrador. Some of these waters enter the Hudson Strait.

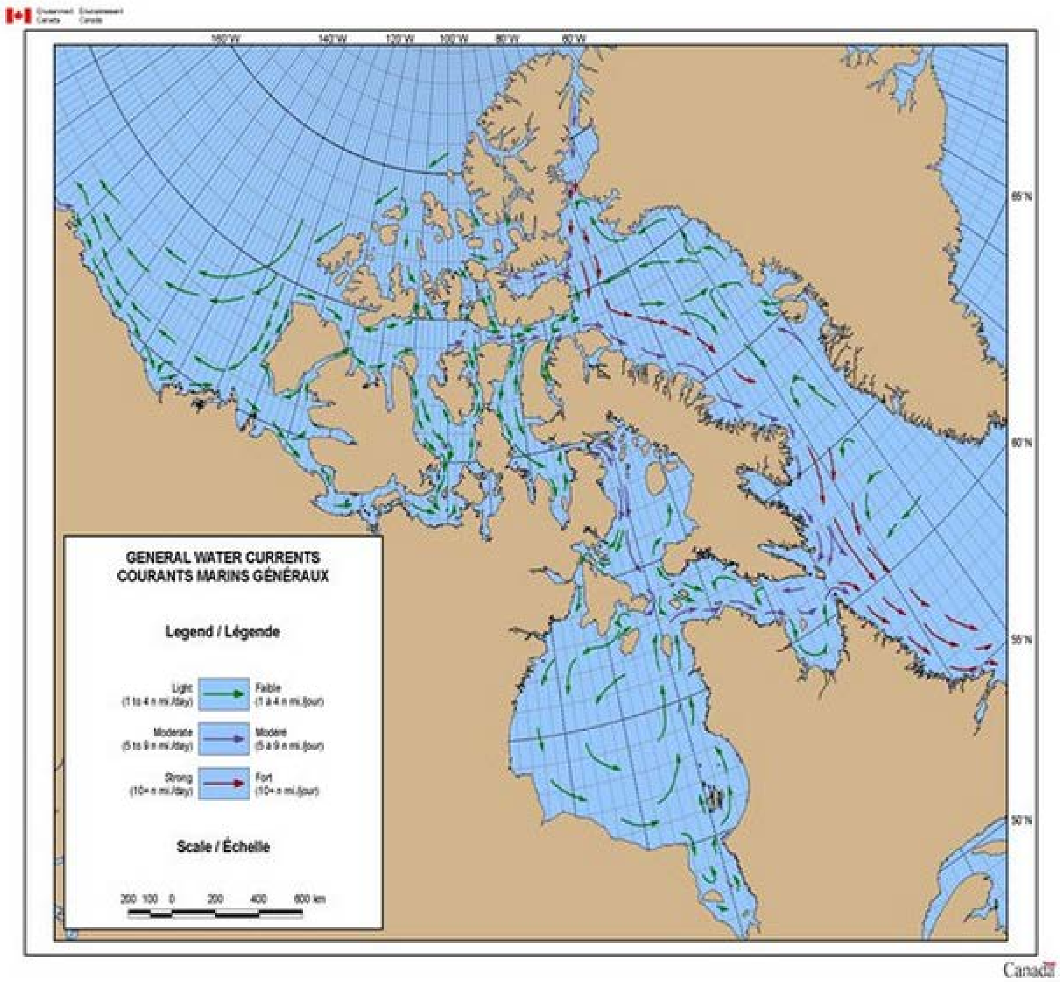


Figure 29. Main surface currents (DFO, 2012).

The western portion of the Strait is generally ice-free between August and early October. Ice concentrations quickly reach 100% during the freeze-up period (mid-October to mid-November) and there is very little open water between January to July (S.L. Ross, 2011). First-year ice is predominant north of Cape Dyer near mid-November (DFO, 2012). Polynyas (see Figure 30) are present at the entrance of Frobisher Sound and Cumberland Sound (DFO, 2012). Ice freeze-up at the entrance of Frobisher Sound and Hudson Strait happens later, in early December or later. On average, the southern extent of sea ice achieves equilibrium near a line from the Greenland Coast near latitude 68°N generally southwestward to a point some 200 kilometers off Resolution Island (DFO, 2012). Average freeze-up dates are presented in Figure 31.

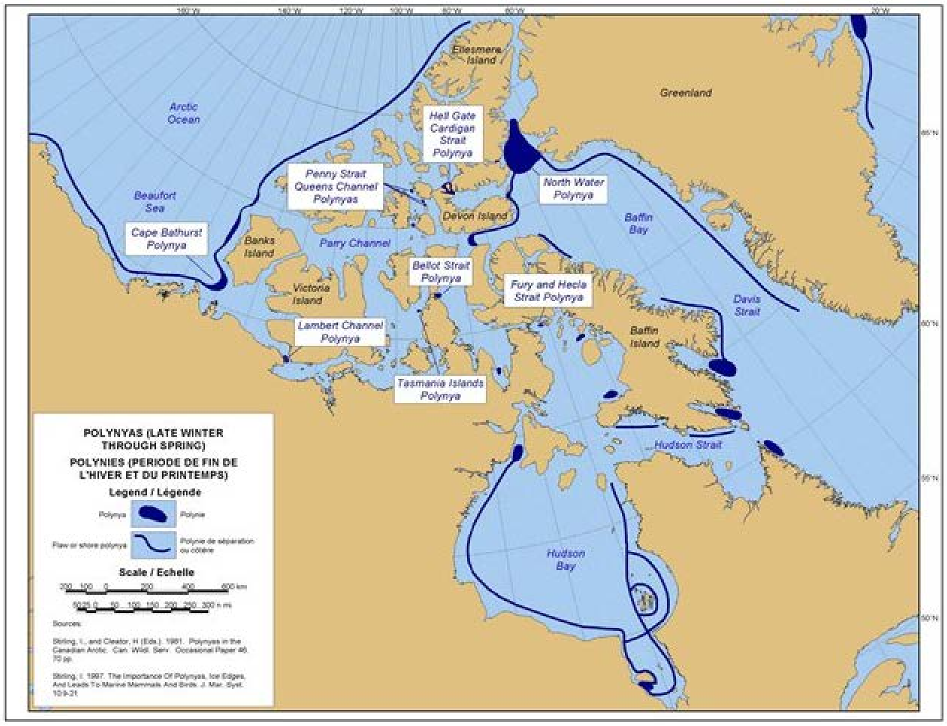


Figure 30. Location of polynyas (DFO, 2012).

Ice in Baffin Bay and the Davis Strait is mostly first-year ice (1-2 m in thickness), although some multi-year ice with thickness up to 3.0 m may be present on the western side of Baffin Bay, originating from the Lancaster Sound and Smith Sound. Ridging, rafting and hummocking are significant, and icebergs abound (DFO, 2012).

Break-up in Baffin Bay starts early June and progresses on two fronts: (1) from Smith Sound (starting in the North Polynya) southwards; and (2) off Frobisher Sound northwards. Ice disintegrates more quickly on the eastern side (off Greenland) and break-up occurs earlier than off Baffin Island. At the beginning of August ice remains near the coast from Cape Dyer to Clyde River and in central parts of the Bay northward to near latitude 74°N – ice clearing occurs on average by late August (DFO, 2012). Average break-up dates are presented in Figure 32.

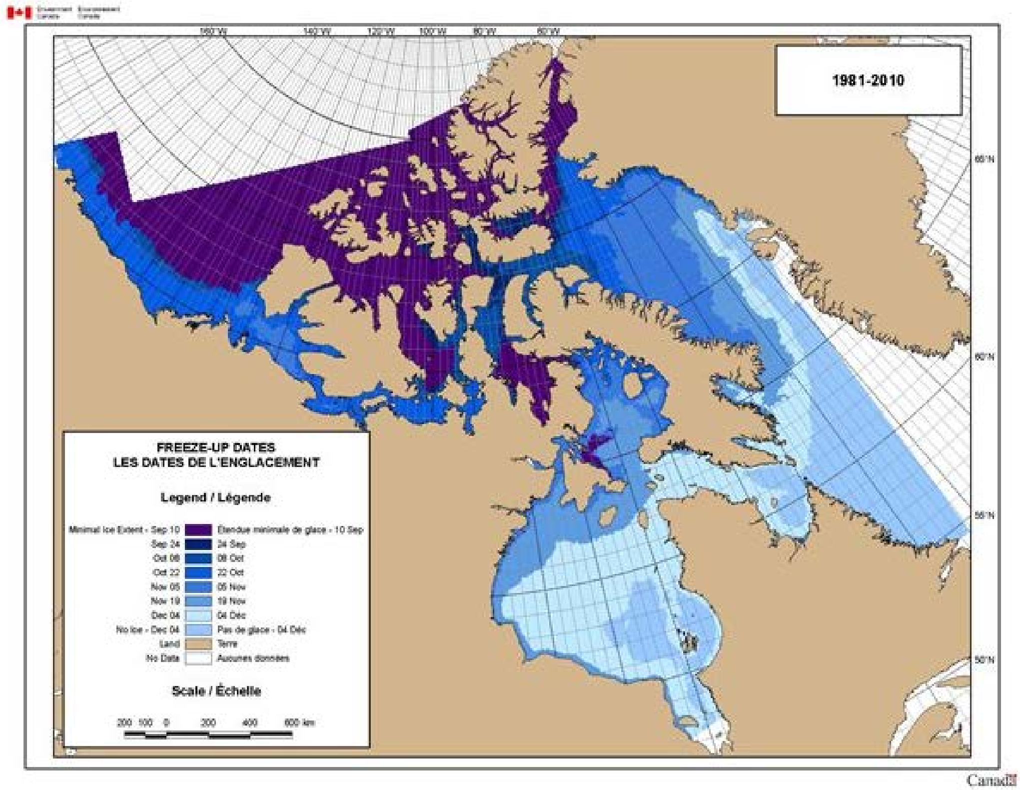


Figure 31. Average freeze-up dates between 1981-2010 (DFO, 2012).

Ice freeze-up in the Hudson Strait happens earlier to the west (mid to late November), in proximity of the Foxe Basin, than is does to the east (mid-December of later). Ice forms near the shore first and progresses to cover the entire Strait. By mid-December, first-year ice predominates (DFO, 2012). Ice conditions are very dynamic in the Hudson Strait (strong currents and frequent gale force winds). Ridging, hummocking and rafting are continually taking place and ice congestion often affects Ungava Bay and the south side of Hudson Strait. Conversely, a shore or flaw lead is frequently present on the north side of the Strait. At times small concentrations of second year ice drift into the area from Foxe Basin. Multi-year ice also enters eastern portions from Davis Strait (DFO, 2012).

During break-up, most of the Hudson strait is generally ice-free by early July. The western side and the Ungava Bay usually breaks-up later (mid to late July), although heavy deformed ice, with some embedded old ice may remain. Complete clearing of the Strait has taken place as early as mid-July and as late as the end of August (DFO, 2012).

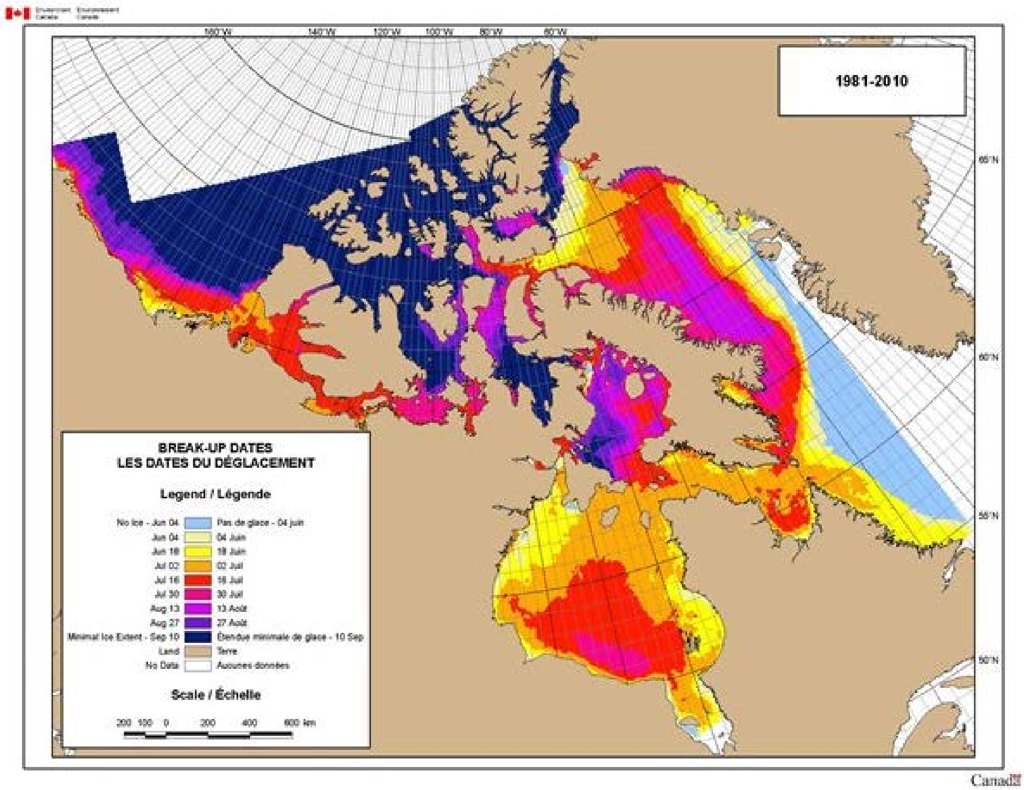


Figure 32. Average break-up dates between 1981-2010 (DFO, 2012).

4.6 Existing Oil Spill Fate and Trajectory Models and Commercial Packages

State-of-the-art oil spill models generally handle a reasonable range of different spill scenarios, weathering, advection and spreading processes, albeit using parameterizations that are relatively old and simple, as described in previous sections. A multitude of oil spill fate and trajectory models exist, although their few intrinsic differences do not necessarily justify their number being so large. Only a few are presented here.

Petit (1997) has developed an oil spill model for the Antarctic. The model includes drift and spread of oil as well as weathering and storage of oil under ice (proportional to ice thickness) and is coupled to a sea ice model. The oil is assumed to drift with the ice at high sea ice concentrations and independently from the ice at low sea ice concentrations. There is a continuous transition between the two regimes. Oil spreading is modeled using horizontal diffusion, for which the coefficient varies with sea ice concentrations. Diffusion stops when concentrations exceed 80% and linearly increase to a maximum at 30% and less. Weathering processes are modeled using parameterizations developed for cold conditions as presented in Whiticar et al. (1993). The model applies the spillets approach.

OILMAP™ (Applied Science Associates) is a commercial package for the trajectory, behaviour, fate and countermeasures of oil spills. It indirectly accounts for sea ice by applying an ice concentration correction. The model applies the spillets approach. Weathering processes do not explicitly consider ice.

OSCAR™ (developed by SINTEF) is another commercial package that includes various oil-ice interactions states. It also indirectly accounts for ice by applying a correction factor based on ice coverage. The interaction between ice and oil is described by assigning a state (e.g., under ice, on ice or surface-oil) to the oil particles and by defining probabilities for the particle to go from one state to another. The model applies the particles approach.

The DMI has developed a model for oil spill trajectory in ice called DMOD (Christiansen, 2003; Nielsen et al., 2006; Nielsen et al., 2008; Ribergaard, 2012). The model uses the particle approach. Only recently was the ice incorporated into the model. Oil drift velocity is a linear combination of the ocean surface current and the ice velocity weighted by the ice concentration. Weathering processes do not explicitly consider ice.

Bedford Institute of Oceanography Ocean Lagrangian Tracking (BOLT) is a Canadian model (Nudds et al., 2013). BOLT can be used to simulate spills in both water and ice. It is coupled with an ocean-sea ice model (NEMO and LIM2). BOLT is in early stages of development and weathering processes have not been considered yet. It is unclear how oil trajectory in ice is modeled.

Many other models exist, but in essence, they are all similar. These models have many important gaps for modeling of oil in ice, including their inability to account for weathering processes in cold regions properly and the manner in which they account for the presence of ice and its influence in the oil trajectories.

4.7 Summary and Paths Forward

A short review of modeling techniques and available parameterizations and models for modeling oil spill fate and trajectory in ice environments was presented in this section. Processes such as emulsification, natural dispersion, dissolution, biodegradation and entrainment are typically not accounted for in models of oil spill and fate in ice conditions. It has been shown that most of these processes do not have a significant impact on the overall rate of oil weathering (Potter et al., 2012; Spaulding, 2013) in ice-covered waters, with the exception of biodegradation, which can be significant in cold waters (Potter et al., 2012). Oil encapsulation and vertical migration through an ice sheet are typically not modeled either, these processes act at smaller different scales than the ocean and ice models, making them extremely difficult to account for in present models.

Existing parameterizations for oil spreading and other weathering processes in ice are simple and based on very few data points. They are often inaccurate and can hardly be extrapolated to field conditions with confidence as long as they have not been tested with field data, as they were developed either from laboratory data or from field tests of limited sizes. Although these are useful to some extent, there is a need for a more physically-based theoretical framework (Venkatesh et al., 1990)

A difficulty in modeling oil-in-ice processes as well as oil trajectory is the discrepancy between the scales at which these processes occur: weathering, spreading, dispersion, etc. occur at small scales whereas ice drift and oil spill drift occur at much larger scales. As noted in Spaulding (2013), a key problem in achieving any improvement in modeling these processes lies in the ability to model the behavior of the ice itself at the necessary spatial scales, which are on the order of meters. To do so, it is paramount to adequately model the ocean currents as well, for which scale is also an issue. The complexity of the patterns that describe the surface currents is generally not captured in models. Olascoaga and Haller (2012) have presented a method in which they used mathematical constructs called Lagrangian Coherent Structures (LCSs) to capture the details of the ocean circulation driven by the eddies and they have used LCSs to model the Deepwater Horizon oil spill in the Gulf of Mexico in 2010 with an unprecedented accuracy. However, this method could not be applied in ice-covered areas because it requires knowledge of the current field, which is not known in ice-covered waters.

Most oil spill models that account for ice are based on open water spill models and incorporate the presence of ice by applying a correction factor that is a function of ice concentration to the oil drift component (e.g., Potter et al., 2012; Venkatesh et al., 1990). This approach has been used for more than three decades and the validity of this procedure is unclear. As noted in Gjøsteen et al. (2003), the only model that has been developed for ice conditions is that of Petit (1997). For other models, spreading in broken ice is merely an extension added to an existing model.

There is an evident lack of model validation and few comparisons with field data are presented/published (Drozdowski et al., 2012; Spaulding, 2013). Errors in models are rarely reported and most often unreported (C-CORE, 2013). Overall, although some models might, in specific cases, be reported to offer reasonable performance, the current ability to model oil spill fate and trajectory in ice conditions is inadequate.

Ways to improve the oil spill fate and trajectory models in ice include:

- Using current and new generations of operational coupled ocean-ice models (such as TOPAZ4) and atmospheric models (e.g., CMC, GFS, ECMWF), to provide real-time information to the oil models (such as also suggested in Brandvik et al., 2006);

- Developing a comprehensive framework in which near real-time data (remote sensing data or other type of data) would be assimilated into the modeling system to correct any existing bias and improve forecasts of the oil spills;
- Ensuring all important weathering processes for oil in ice are accounted for in models and are representative of most recent laboratory and field tests of oil in ice. Models must better reflect the reality of oil-in-ice);
- Including an assessment of the uncertainty in model predictions and the incorporation of a probabilistic framework to the models so that a distribution of model outputs that defines its variability can be assessed (C-CORE, 2013; Drozdowski et al., 2012; Spaulding, 2013); and
- The modeling of oil and ice interactions at a smaller scale, in regions of interest, potentially using the discrete element method (DEM, also suggested in Spaulding, 2013). This could alleviate to some extent the weight carried by the simplifications necessary when estimating the spreading of oil in ice and the transport of oil with or without the ice in present models (i.e., ice concentration corrections and simplified spreading equations based on a diffusion coefficient).

5 ASSESSMENT OF LOCAL RESOURCES AND THREATS

The Hudson Strait is the main gateway to many Baffin Island Communities and the Davis Strait provides the eastern access to the Northwest Passage, serving as an important link for connecting communities by sealift and is the main transportation hub for commercial shipping and moving natural resources including minerals, and potential oil and gas. This section outlines the potential risk of oil spills, current oil spill related programs along with present response capabilities and possible gaps.

5.1 SPILL RISKS AND SCENARIOS

There are several possible oil spill scenarios that can occur in the Hudson and Davis Straits based on the vessel traffic during ice-free conditions. From August to November the west-central Davis Strait is basically ice-free and from December through July there is little open water). The ice conditions in the Central location is less distinct, but there still exists a well-defined boundary between open water and sea ice with August to November virtually ice-free, 25 - 30 % open water in July and December and no open water from January to June (S.L. Ross, 2011).

Vessel traffic is the only possible risk in these two areas, as currently there is no ongoing oil exploration or development in Nunavut. The specific numbers on vessel traffic along the Hudson and Davis Straits, specifically, could not be obtained only the number of vessels travelling in the Arctic as a whole based on Northern Canada Vessel Traffic Services Zone (NORDREG) statistics. However, the vessel positional information from each of the geographic locations can be obtained through space-based AIS data archives, if later required. Larger ships that are more 300 gross tonnes that intend to enter Canada’s northern waters must report their geographic position under the NORDREG. This is a regulation that falls under the Canada Shipping Act.[4] The Government of Canada helps prevent spills through regulatory inspections, and enforcement measures. When vessels travel in the Arctic, (North of 60°), Transport Canada’s (TC) regulations and standards apply such as the Canada Shipping Act, 2001 and the Arctic Waters Pollution Prevention Act,[5] in addition to International Maritime Organization (IMO) regulations. There are a variety of ships travelling in the Arctic from large tankers, bulk carriers, general cargo vessels, fishing vessels to small tugs. There are less than 150 vessels travelling through Canada’s Arctic waters each year, with tankers accounting for less than 10 per cent of these vessels.[6] Therefore, there are potential risks of illegal ship discharges of oily bilge water and other possible ship accidents though physical damage or malfunction, potentially leaking fuel cargo (Transport Canada, 2014). The estimated volume of spilled oil

[4] Canada Shipping Act: http://www.tc.gc.ca/eng/marinesafety/rsqa-csa2001-menu-1395.htm
[5] Arctic Waters Pollution Prevention Act: http://www.tc.gc.ca/eng/acts-regulations/acts-1985ca-12.htm
[6] Tanker Safety and Spill Prevention, Transport Canada Website: http://www.tc.gc.ca/eng/marinesafety/menu-4100.htm#

from large accidents is less than that released from illegal "operational" discharges, which originate from tank washings, dirty ballast, and bilge pumping (Oil Spill Hazard Team, 1997). A typical oil tanker carries approximately 140,000 metric tons of oil (based on ~1M barrels of oil) on board with three to five holding tanks and a small tug holds approximately 500 metric tons of oil.[7] Therefore, these types of vessels can produce varying oil spill risks, which also depend on ship structure and dynamics.

5.2 Current Monitoring Programs

TC keeps a watchful eye over ships travelling through waters under Canadian jurisdiction through its National Aerial Surveillance Program (NASP), which performs aerial surveillance to detect pollution from ships. NASP performs regular aerial surveillance that is a widely recognized and an effective deterrent in reducing illegal oil discharges since potential polluters are aware that Canada has heightened surveillance. In 2011-2012, TC crews observed more than 12,000 vessels and detected 135 pollution occurrences nationally, with an estimated total volume of 1,014 litres of oil. There is an obligation for vessel owners and operators of oil handling facilities to report marine spills to the Canadian Coast Guard (Transport Canada, 2014).

TC also uses satellite surveillance to detect illegal discharges at sea. Satellite images are provided by EC's Integrated Satellite Tracking of Pollution (ISTOP) program. ISTOP is an early warning real time oil pollution detection program, which uses satellite SAR imagery to provide wide scale monitoring and day and night surveillance of Canadian waters. The program is funded and staffed by the CIS of EC and operates in conjunction with TC, Fisheries and Oceans and Environmental Emergencies and Enforcement. The Hudson and Davis Straits are monitored through ISTOP under their Arctic zone, as shown Figure 33.

[7] Tankers International Vessel List: http://www.tankersinternational.com/fleet_list.php?type=1&order=year_down
Northern Transportation Company Ltd: http://www.ntcl.com/operations/fleet/

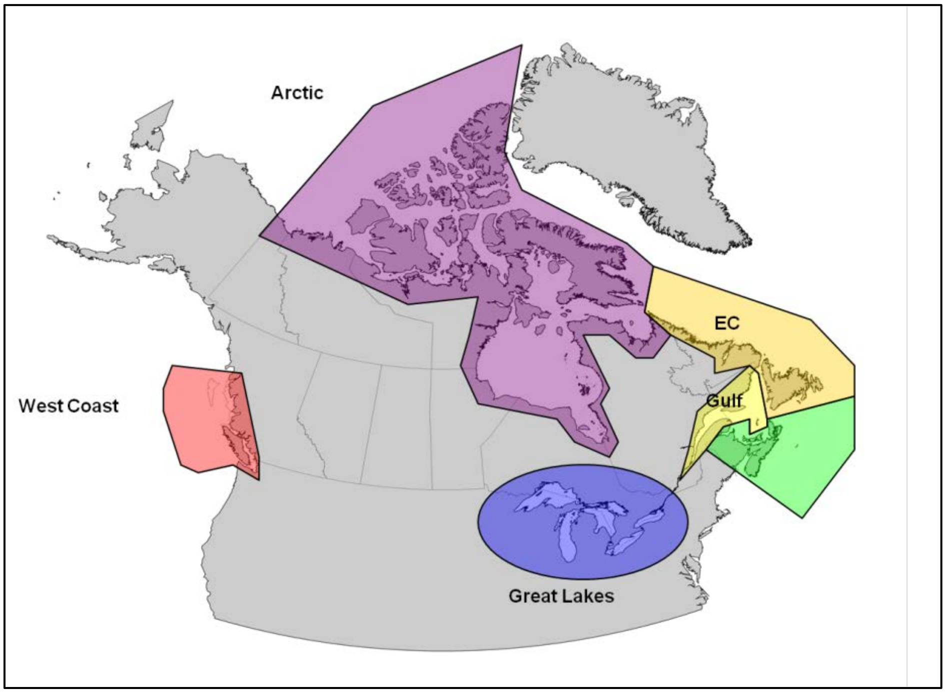


Figure 33. ISTOP Oil Pollution Monitoring Zones (EC, 2011)

Satellite images are used to search for oil-like signatures or anomalies on the ocean's surface. Once these anomalies are detected on the satellite imagery, the aircraft is tasked to the geographic location to confirm the presence of an oil slick and once verified, evidence is gathered for prosecution. TC's investigations have led to numerous successful prosecutions against marine polluters over the years, with some financial penalties reaching more than $100,000. In the Arctic, enforcement occurs through aerial surveillance, as well as reports from government ships and reporting through the Long-Range Identification and Tracking system, which automatically transmits the identities and positions of vessels to authorities (Transport Canada, 2014). In 2013, NASP flew approximately 500 hours in Arctic waters and there were 106 satellite images captured over the entire Arctic as part of the ISTOP program (Pers. Comm., Armstrong, 2014).

In May 2013, TC commissioned GENIVAR, a leading professional services firm and SL Ross, a consulting firm specializing in the behaviour of oil and chemical spills to conduct a Canada-wide risk assessment on ship-source spills and perform a comparative analysis of risks between regions of Canada. There are two phases to the project "Risk Assessment for Marine Spills in Canadian Waters". Phase one examined the likelihood and potential impacts of oil spills in Canadian waters south of 60° north latitude and Phase 2, which is currently ongoing is investigating at the oil spills risks in the Arctic and spills of hazardous and noxious substances (Transport Canada, 2014).

5.3 Current Response Capabilities in Nunavut

5.3.1 Local Concerns

In order to address community concerns that increased marine traffic could lead to future oil spills in the Canadian High Arctic, the Canadian Coast Guard maintains pollution response kits in 17 communities throughout Nunavut (Pers. Comm., Munroe, 2014). This equipment is designed to respond to small coastal and land-based spills, such as those that might occur when barges deliver annual fuel supplies to the communities. The pollution control assets comprise the following elements:

- Arctic community pack: minimum of 500 meters of boom, 5 meter aluminum boat;
- Delta 1000: 3,200 meters of boom, 3 skimmers (2 of which are for heavy products), various open top-tanks, pumps, generators and pressure washers;
- Shoreline Kits: rakes, shovels, pitch forks, sorbents, tarps, pool, etc.;
- Beach flush kits: pump, wands, hoses.

The specific composition of the kits varies with location and is tailored to the needs of each community as shown in Table 8. At this point, access to the equipment caches is provided via the local RCMP detachments, since planned training[8] for response personnel from each community has yet to be completed.

Table 8. Pollution response equipment in Nunavut communities

Community	Type of Equipment
Arctic Bay	Arctic community pack, shoreline kit
Baker Lake	Arctic community pack, shoreline kit
Broughton Is. (Qikiqtarjuaq)	Arctic community pack, shoreline kit
Cambridge Bay (Ikaluktutiak)	Arctic community pack, shoreline kit
Cape Dorset	Arctic community pack, shoreline kit
Chesterfield Inlet	Arctic community pack, beach flush kit, shoreline kit
Clyde River	Arctic community pack, shoreline kit
Coral Harbour	Arctic community pack, shoreline kit
Hall Beach	Arctic community pack, shoreline kit
Iqaluit	Delta 1000, shoreline kit
Kimmirut	Arctic community pack, beach flush kit, shoreline kit
Pangnirtung	Arctic community pack, beach flush kit, shoreline kit
Pond Inlet	Arctic community pack, shoreline kit
Rankin Inlet	Arctic community pack, shoreline kit
Kugluktuk	Arctic community pack, shoreline kit
Resolute	Arctic community pack, shoreline kit
Gjoa Haven	Arctic community pack, shoreline kit

[8] Arctic Oil Spill Response Training Planned, CBC, May 3, 2010: http://www.cbc.ca/news/canada/north/arctic-oil-spill-response-training-planned-1.962352

Recent community consultations carried out by the Nunavut Planning Commission (NPC) indicate that all of the Nunavut communities in this study area have raised concerns about oil spills in their areas (Nunavut Planning Commission, 2013). The Environmental Emergency Plan for land-based spills for Resolute Bay was updated by the Government of Nunavut in late 2013, see Appendix A. This plan was developed by the Petroleum Products Division (PPD), who is also in the process of updating Oil Spill Response Plans for all the twenty seven communities in Nunavut and adding more information on marine spill scenarios. Further to this plan, the local PPD in Resolute also use a land-based 24-hour spill response website, Hazardous Materials Spills Database[9], where people can go to report an oil spill, which is immediately followed with the proper response measures.

5.3.2 Arctic Oil Spill Response Processes

The processes that are followed if an oil spill occurred in the Arctic, such as in the Hudson and Davis Straits, are in common with response in other areas in Canadian waters. Several federal departments would become involved and co-ordinate their resources to respond and clean up the spill as quickly as possible.

Nunavut is responsible for land-based spills and any spills that occur along the Nunavut coastlines. However, oil spills that occur in the ocean are the responsibility of the ship owners or polluters. Under Canada's Marine Pollution Preparedness and Response Regime managed by TC, the polluter is always responsible for paying the cost of an oil spill cleanup, including third party damages. This means that if a ship causes a spill, its owner is liable for losses and damages.

While the Canada Shipping Act[10] assigns the responsibility to respond to marine oil spills to certified response organizations[11] for all areas south of 60°N, the Canadian Coast Guard (CCG) is the lead federal agency responsible for an appropriate response to ship source spills in Canadian waters north of 60°N, including the Arctic. Under international maritime law, oil tanker operators must have their own ship-board plans to deal with a spill. They also must have a contract arrangement with a TC-certified, private, oil spill response company. The oil transport industry funds these private businesses that have spill cleanup equipment strategically located along the coasts of Canada. Once satisfied with the polluter's response plan, the CCG will monitor the response efforts. In this scenario, a private response organization, contracted by the oil tanker's operator, typically leads the oil spill cleanup.

As there is no private oil spill response corporation operating out of Arctic to help clean up a potential spill, TC or CCG would have to request a response agency, such as East Coast

[9] Hazardous Materials Spills Database: http://www.enr.gov.nt.ca/_live/pages/wpPages/Hazardous_Materials_Spill_Database.aspx
[10] Canada Shipping Act: http://www.tc.gc.ca/eng/acts-regulations/acts-2001c26.htm
[11] Canada's Response Organization: http://www.ecrc.ca/en/can_ro/general_info.asp

Response Corporation (ECRC) first before they can operate and clean up an oil spill North of 60° (Pers. Comm., Predham, 2014). The CCG will lead the spill response to ensure protection of the marine environment. The CCG has environmental response barges to trained CCG personnel and environmental response equipment, such as skimmers and booms to carry out oil spill response operations (Transport Canada, 2014).

EC's weather service provides important meteorological information to oil spill responders. Aboriginal Affairs and Northern Development can provide advice about pollution incidents in the Arctic, and on or near Aboriginal lands, and about land claims agreements, cultural and other issues. Provincial, territorial and municipal governments, have laws, mandates and expertise that can contribute to the overall response. Aboriginal Groups may provide local knowledge, and can identify environments at risk during the response to marine pollution incidents (Transport Canada, 2014).

The Nunavut Planning Commission has collected traditional ecological knowledge (TEK) specific to Inuit land use which is available in the form of Community Meetings Summaries on the Draft Nunavut Land Use Plan. These summaries are available on their website. [12] The Geomatics and Cartographic Research Centre at Carleton University in Ottawa have also been collecting TEK in Nunavut and transforming into geographic databases and atlases[13]. This social science mapping contains information on sea ice and routes, sensitive areas, place names, etc. It is a place where the local people and elders in various communities can contribute their knowledge and help preserve their rich culture and traditional practices through GIS databases. These community members who live off the land and ice and also Canadian Rangers would be the first responders if there is an oil spill that reaches the shore. (Pers. Comm., Hayes, 2014). This TEK data model for communities could be used as baseline structure for future demonstrations on oil spill surveillance data integration.

5.3.3 Pre-Spill Shoreline Mapping

A key concern of marine oil spills is the impact of oil on sensitive on shorelines. A significant body of knowledge from world-wide cleanup activities has resulted in documented best practices in the form of the Shoreline Cleanup and Assessment Technique (SCAT) and a SCAT manual for Arctic applications (Owens and Sergy, 2004). While the pre-spill mapping of shorelines has been accomplished for much of southern Canada, carrying out shoreline sensitivity mapping in the Arctic remains a work in progress. Using a combination of aerial video and satellite imagery, Demers et al. (2013) developed a methodology for carrying out pre-spill mapping in Canada's northern regions under Environment Canada's National

[12] Community Meeting Summaries on the Draft Nunavut Land Use Plan: http://www.nunavut.ca/en/downloads
[13] Carleton University Atlases on Nunavut: https://gcrc.carleton.ca/confluence/display/GCRCWEB/Atlases

Environmental Emergencies Centre's (NEEC's)[14] emergency Spatial Pre-SCAT for Arctic Coastal Ecosystems (eSPACE) initiative. Where available, TEK information is included as a thematic layer within the NEEC shoreline database. To date, shoreline mapping under eSPACE has been completed in some areas in the Canadian Arctic, but does not include the Davis and Hudson Straits (see Figure 34).

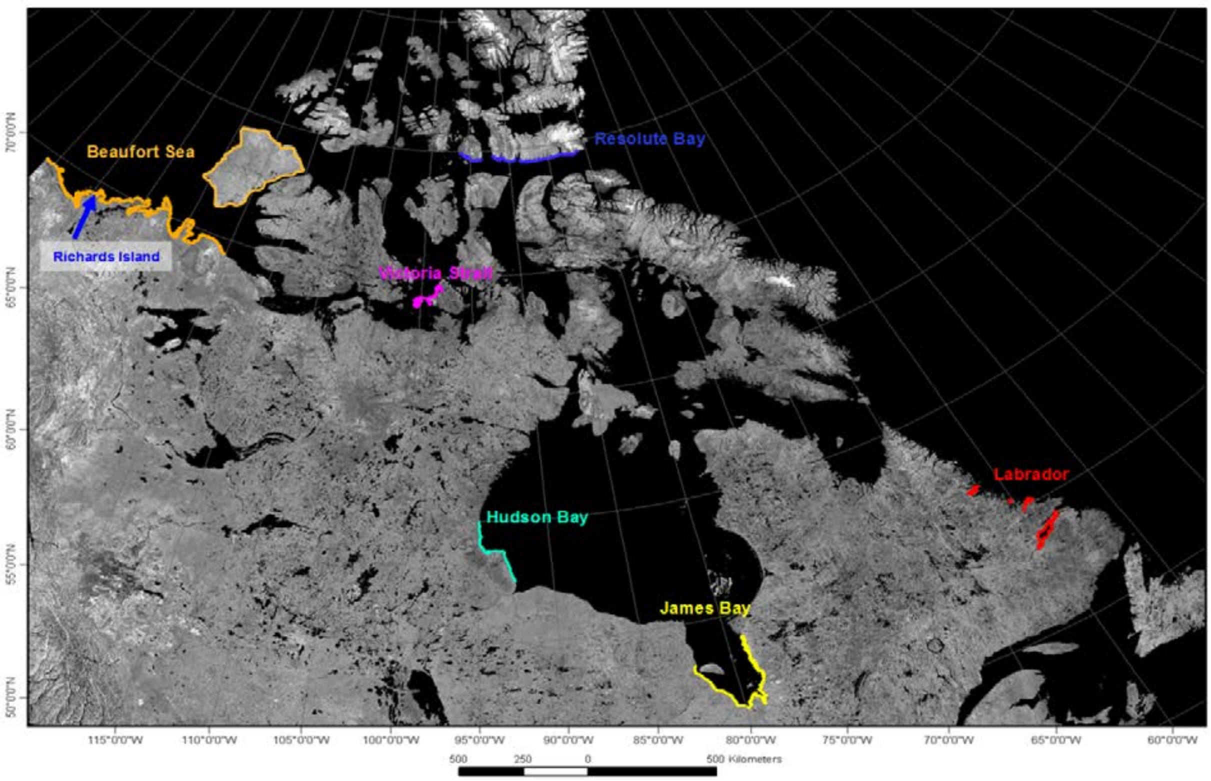


Figure 34. e-SPACE pilot sites (from Demers et al., 2013)

[14]Within the emergency response structure of Environment Canada, a single National Environmental Emergencies Centre (NEEC) replaced the Regional Environmental Emergencies Teams (REET): http://www.ec.gc.ca/ee-ue/default.asp?lang=En&n=FDBFAF6B-1

5.4 Gaps and Opportunities for Local Involvement

The formal responsibilities for responding to oil spills in Nunavut are divided between the Canadian Coast Guard for marine spills and the Nunavut Petroleum Products Division for land-based spills. The protection and cleanup of shorelines comprises the major intersection of both areas of responsibility. A key element of local spill response and shoreline protection, spill kits have been delivered to 17 communities throughout Nunavut (see Section 5.3.1).

It is important to instruct community members in the operation and maintenance of the pollution control equipment to enable effective, community-based spill response. The training regime should involve a suitable number of individuals in each community and include regular field exercises as well as the effective coordination with response teams in other communities. A central point of contact should be identified for each community to control access to the equipment caches and mobilize the response team as required. Access to the equipment should also be possible for the Nunavut Petroleum Products Division. Contact details, level of training and training schedule for each community response team should be communicated to relevant authorities (e.g. Hamlet officials, RCMP, Nunavut Petroleum Products Division).

In order to protect shorelines effectively using established and proven protocols, pre-spill mapping must be completed to identify the sensitivity to oil spills for different shoreline types. Ideally, pre-spill mapping would also include traditional knowledge and other elements of critical interest to communities. While research on community-based mapping and traditional knowledge is ongoing, pre-spill sensitivity mapping has not been completed for most of Nunavut, including the Hudson and Davis Strait areas.

As described in Section 5.2, the routine monitoring for oil spills in Nunavut waters is currently carried out solely under the federal government mandate by the NASP and ISTOP programs. Since these initiatives monitor major shipping routes throughout the Canadian Arctic, the coverage of the Hudson and Davis Straits is necessarily limited. This opens up opportunities for additional surveillance by local resources, which may include shoreline-based observations by community members, marine observations by vessels of opportunity, as well as satellite-based observations using new and upcoming satellite resources by trained analysts.

In the context of Arctic shoreline response, the use of trained dogs to detect oil buried under snow or sediment may contribute positively to the engagement of local stakeholders, since dogs constitute an important element of the social and economic fabric of northern communities. Recent studies have shown that trained dogs are effective for locating oil spills in soil (Huppunen et al., 2012) as well as in ice and snow (Brandvik and Buvik, 2009).

6 CONCLUSIONS AND RECOMMENDATIONS

The Arctic poses unique challenges for the monitoring and modeling of marine oil spills. There is a significant body of knowledge surrounding the use of remote sensing for oil spill detection and monitoring on open water, but little research is available that documents performance in ice-affected marine environments. Therefore, dedicated research is required to fully understand the applicability of different remote sensing technologies under Arctic conditions.

Weathering processes as well as the drift of ice and oil occur at different scales, and the discrepancy between these scales is one of the principal difficulties when modeling oil-in-ice processes and trajectories. The performance of models to characterize the movement of oil in the presence of sea ice depends directly on the capabilities of ocean and coupled ice-ocean models. These models do not generally operate at a sufficiently high spatial resolution to support the modeling of oil spills in sea ice. In addition, the limited availability of field observations results in inadequate model validation.

Targeted training activities should be implemented to increase the awareness of suitable monitoring, modeling and response techniques and understand their potential contributions to community-based spill response efforts. In order to engage local communities in oil spill response and maintain a high level of response efficiency, it is recommended to establish a database of responders in each community, together with a plan for regular training, assessment of capabilities and check of equipment operations. This information should be shared between territorial and federal stakeholders.

In addition to the training of responders, it should be considered to hold community-based workshops to increase the level of public engagement in response activities. These general workshops would constitute the first step in sensitizing communities to issues surrounding oil spills and provide an overview of oil in the Arctic environment, oil spill countermeasures, as well as potential impacts on local ecosystems and traditional livelihoods.

A second level of training could focus on building local capacity in recognizing oil in the environment, collecting ancillary information (e.g. location, land cover, sediment type) and reporting sightings of spills to the appropriate authorities. This would cover both land-based and vessel-based observations and may include appropriate technologies for information gathering (e.g. GPS, tablets, apps) as well as the training of dogs to detect buried oil. The training of observers and operators of vessels-of-opportunity may be integrated into the formal training of responders and the use of the community spill kits.

In an effort to complement existing surveillance programs, it is recommended to build a formal capacity to acquire and analyze satellite imagery. To this end, the European Sentinel missions are particular appropriate due to their systematic acquisitions (i.e. no planning required) and freely available data. In addition to routine surveillance for pollutant spills, satellite imagery would also be useful for a number of other applications of relevance to Nunavut, such as shoreline sensitivity mapping, land cover and resource mapping, sea ice, etc. The training of remote sensing analysts could be integrated into existing educational institutions.

Local capacity in remote sensing could also contribute to improved oil fate and trajectory modeling by providing near real-time satellite-derived information as model inputs (e.g. wind speed and direction, sea ice flow). In this context it would be important to build and maintain close links with operational and research-oriented modeling groups at Environment Canada, DFO and NEEC.

In order to complete shoreline sensitivity mapping for the Davis and Hudson Strait areas, it is recommended to launch a dedicated program that follows the established methodology used by NEEC (Demers et al., 2013). In this context, it would be beneficial to include NEEC as a formal partner in any project related to shoreline sensitivity mapping. Additional efforts should be made to integrate TEK information elements into all pre-spill shoreline mapping activities.

Arctic oil spill response, impact and mitigation are the target of significant research interests worldwide (USARC, 2012). The Arctic Oil Spill Response Technology Joint Industry Programme[15] is a comprehensive industry-led effort established to improve knowledge and capabilities in a wide range of technical areas, including the use of dispersants, environmental effects, fate and trajectory modeling in ice-affected waters, detection and monitoring of oil in Arctic conditions, mechanical recovery and in-situ burning. In Canada, the Environmental Studies Research Fund (ESRF)[16] is currently in the process of implementing major research activities to address key environmental and socio-economic questions applicable to hydrocarbon exploration and production in northern (i.e. Beaufort Sea) and eastern Canada. It is recommended to establish links with applicable research initiatives to keep abreast of new scientific developments, assess their relevance for the Nunavut context and, where appropriate facilitate their translation into operational practices. The Nunavut Research Institute would be ideally suited to build linkages and realize opportunities for research coordination and collaboration.

Given the operational, scientific and regulatory complexities of responding to Arctic spills, it would be helpful to establish a central point of reference within the territorial government to deal with all elements related to oil spill response in Nunavut, including the training of responders and technical staff, education and outreach to communities, interaction with local, territorial and federal stakeholders, as well as the building of resident scientific and technical expertise.

[15] http://www.arcticresponsetechnology.org/
[16] http://esrfunds.org/index_e.php

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APPENDIX A – NUNAVUT ENVIRONMENTAL EMERGENCY PLAN

Environmental Emergency Plan

Bulk Fuel Storage & Dispensing Facility for Petroleum Products

Resolute Bay

(EC00021865, EC00021866, EC00021868)

Petroleum Products Division Rankin Inlet
Department of Community & Government Services
Government of Nunavut

Resolute Bay

Table of Contents

Plan Development ----- Background

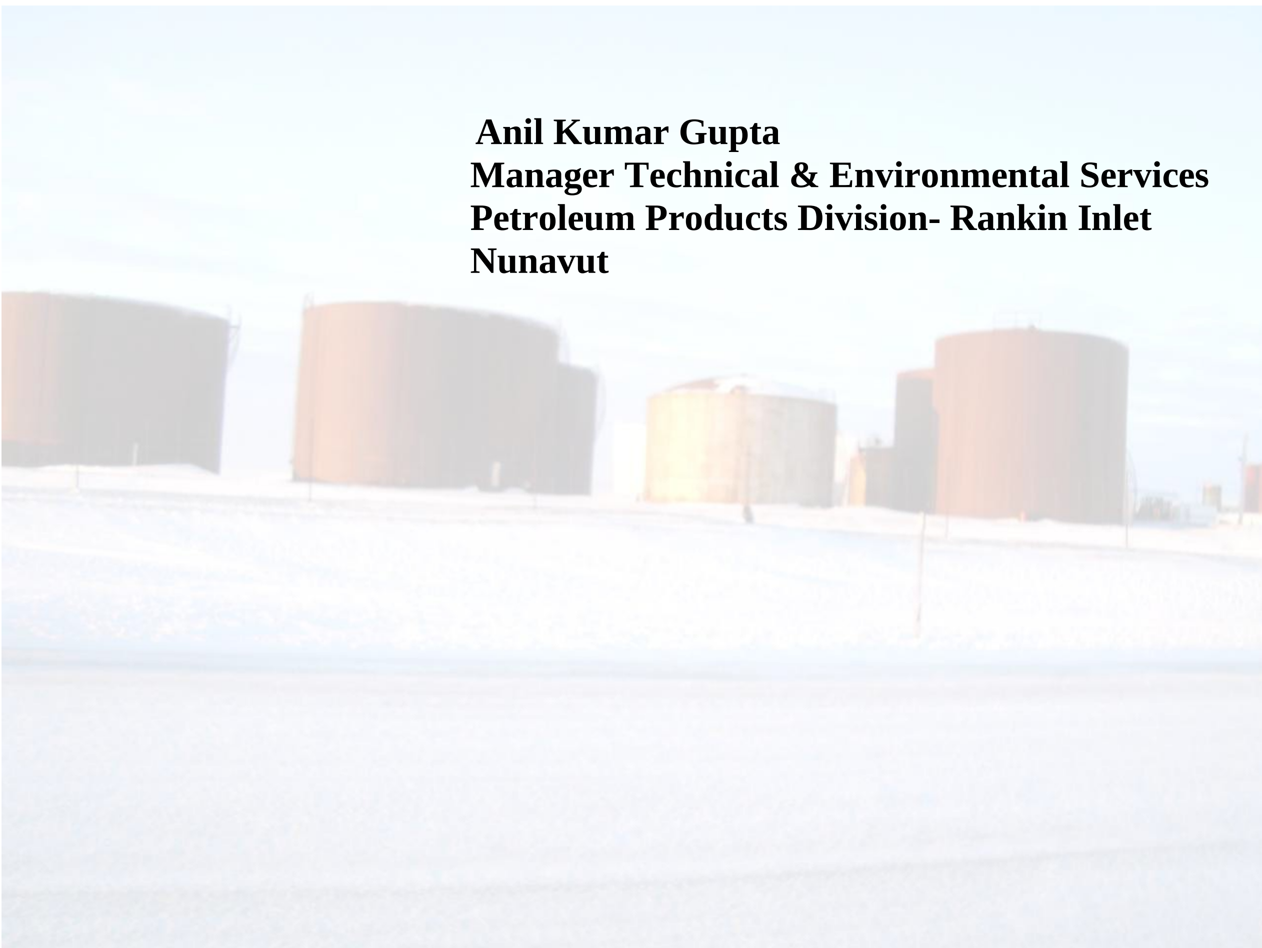
Developing an emergency plan helps owner/operator anticipate and take steps to prevent the most likely accidents, and it allows responding quickly and efficiently if an accident does occur. A quick response limits damage and reduces clean-up costs. We must assess, for our system, the potential emergencies that could result in harm to the environment or endanger human health, then create a plan to prevent the occurrence, prepare for, respond to and recover from each emergency scenario. An emergency plan that is adapted to a particular system and surroundings while at the same time meeting the requirements in the regulations is considered the right document.

The Petroleum Products Division (PPD) of Government of Nunavut is responsible for purchase, transportation and storage of fuel in a well-organized and environmentally friendly manner. At the same time PPD is constrained to abide by all regulations and pieces of legislations governing fuel related activities. In the past environmental emergency plan (OPEP) was to be prepared on voluntarily basis but now Environment Canada made it mandatory. Traditionally PPD kept Oil Pollution Prevention Plan, OPEP which was originally created in 2001.

PPD's fuel delivery contractor as operator of fuel storage facility is among the community stakeholders to deal with community wide emergency. Under the direction of GN Emergency Preparedness Iqaluit, Hamlet of Resolute Bay prepared its own Emergency Plan in 2010, at the same time all the other departments including PPD were encouraged to develop their own plans that could fit into the Hamlet's Plan.

PPD prepared its Emergency Plan in 2010 under the guidance of GN Emergency Preparedness and copies of the plan were provided to fuel delivery contractors and other community stakeholders including Hamlet. This plan was generic in nature. On the other hand Environment Canada had imposed a deadline to prepare and put in place an emergency plan compliant with EC requirements. PPD opted to use the already existing generic plan to comply with the sections 199 and 200 of the part 8 of Canadian Environmental Protection Act 1999 but by examining the plan later in 2013 by EC representatives, it was found neither site specific nor covering the broad range of emergencies so PPD got an Order of Compliance to revise the plan. Now PPD has revised it and made it site specific that will comply with the *Storage Tank Systems for Storage of Petroleum Products and Allied Petroleum Products Regulations and Environmental Emergencies Regulations*. At community level fuel delivery contractors represent PPD and are trained to implement emergency plan when need arises but PPD as an owner of the facility got the responsibility to update the plan, ensure its implementation and arrange necessary training for the personnel to carry out the plan. This plan will be updated and tested annually.

The PPD's Environmental Emergency Plan has been prepared by PPD's Manager Technical & Environmental Services with the information from PPD's operation and PPD's local fuel delivery contractor, Resolute Bay. The selection of the contents and format of the document has been developed under the directions laid out in Storage Tanks Systems for Petroleum Products and Allied Petroleum Products Regulations, Tank Tips fact sheets, Environmental Code of Practice for Aboveground Storage tanks, Canadian Environmental Protection Act 1999, Guidelines for E2 Planning, CEPA Registry and Nunavut Guideline for Contaminated Site Remediation. The contribution of Derek Williams, Environmental Services Specialist is also acknowledged.



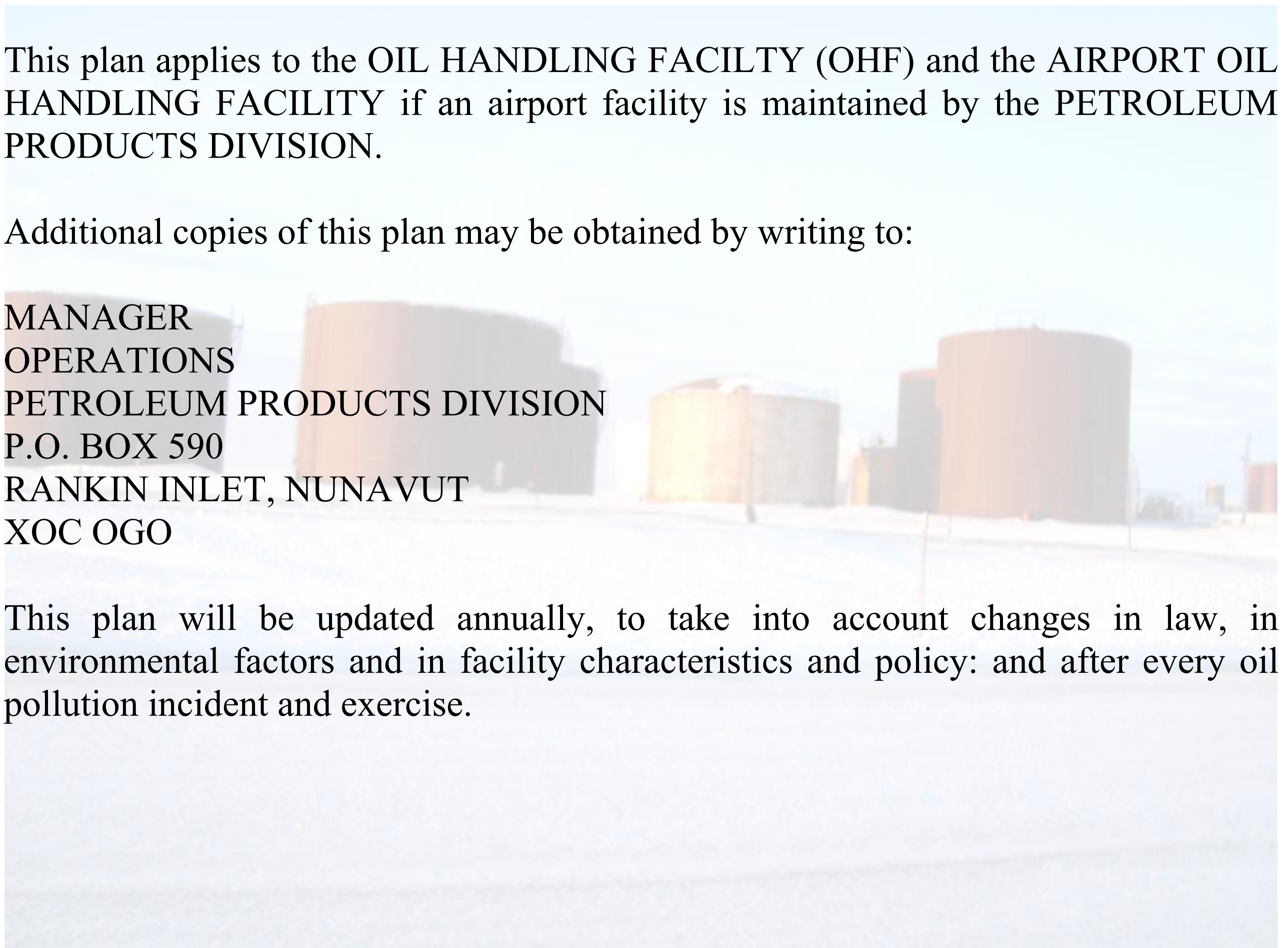
Anil Kumar Gupta
Manager Technical & Environmental Services
Petroleum Products Division- Rankin Inlet
Nunavut

Effective Date of Emergency Plan

This ***OIL POLLUTION EMERGENCY PLAN*** is effective from:

DD	MM	YY
01	12	2013

This plan will remain IN EFFECT until advised otherwise by the DIRECTOR, PETROLEUM PRODUCTS DIVISION of COMMUNITY AND GOVERNMENT SERVICES.



This plan applies to the OIL HANDLING FACILTY (OHF) and the AIRPORT OIL HANDLING FACILITY if an airport facility is maintained by the PETROLEUM PRODUCTS DIVISION.

Additional copies of this plan may be obtained by writing to:

MANAGER
OPERATIONS
PETROLEUM PRODUCTS DIVISION
P.O. BOX 590
RANKIN INLET, NUNAVUT
XOC OGO

This plan will be updated annually, to take into account changes in law, in environmental factors and in facility characteristics and policy: and after every oil pollution incident and exercise.

Control Page

On Receipt of Revisions or Updates, the plan holder will complete this section to ensure that the plan is always current.

Revision Number	Date Inserted	Description/Purpose	Signature

Distribution of Oil Pollution Emergency Plan

MANAGER
Operations
Petroleum Products Division
Rankin Inlet, NU

HEAD OF OPERATIONS
Petroleum Products Division
Region: Kitikmeot
Kugluktuk, NU

CANADIAN COAST GUARD

ENVIRONMENTAL PROTECTION SERVICES REGIONAL OFFICE
Region: Kitikmeot
Kugluktuk, NU

DIRECTOR, COMMUNITY AND GOVERNMENT SERVICES
Region: Kitikmeot
Kugluktuk, NU

FACILITIES MANAGER, COMMUNITY AND GOVERNMENT SERVICES
Region: Kitikmeot
Kugluktuk, NU

MAYOR
Resolute Bay, NU

FIRE CHIEF
Resolute Bay, NU

RCMP DETACHMENT
Resolute Bay, NU

LOCAL CONSERVATION OFFICER
Resolute Bay, NU

PETROLUEM PRODUCTS DIVISION FUEL CONTRACTOR
Resolute Bay, NU

EMERGENCY CONTACT INFORMATION

EMERGENCY CONTACT PERSONNEL & TELEPHONE NUMBERS

24 – HOUR SPILL REPORT LINE:
Telephone Number: (867) 920-8130
Fax Number: (867) 873-6924

OPERATOR OF FACILITY (PPD FUEL CONTRACTOR)

BUSINESS NAME: Atco Structures and Logistics
Telephone Number: (867) 252-3737
Fax Number: (867) 252-3838

FACILITY OPERATOR Bob Mitchell
Residence Telephone Number: (867) 252-3925

PETROLEUM PRODUCTS DIVISION – HEADQUARTERS – RANKIN INLET

DIRECTOR, PETROLEUM PRODUCTS DIVISION
Business Telephone Number: (867) 645-8403
Business Fax Number: (867) 645-3554

MANAGER, REGIONAL OPERATIONS
Business Telephone Number: (867) 645-8443
Business Fax Number: (867) 645-3554

MANAGER, TECHANICAL & ENVIRONMENTAL SERVICES
Business Telephone Number: (867) 645-8411
Business Fax Number: (867) 645-3554

MAINTENANCE CO-ORDINATOR
Business Telephone Number: (867) 645-8442
Business Fax Number: (867) 645-3554

COMMUNITY AND GOVERNMENT SERVICES – HEADQUARTERS - IQALUIT

MANAGER, CONTRACTS AND PROCUREMENT
Business Telephone Number: (867) 975-5436
Business Fax Number: (867) 975-5450

ASSISTANT DEPUTY MINISTER, OPERATIONS
Business Telephone Number: (867) 975-5403
Business Fax Number: (867) 975-5452

COMMUNITY AND GOVERNMENT SERVICES – KITIKMEOT REGIONAL OFFICE – CAMBRIDGE BAY

DIRECTOR, COMMUNITY AND GOVERNMENT SERVICES
Business Telephone Number: (867) 983-4161
Business Fax Number: (867) 983-4123

FACILITIES MANAGER
Business Telephone Number: (867) 983-4153
Business Fax Number: (867) 983-4123

PETROLEUM PRODUCTS OFFICER
Business Telephone Number: (867) 983-4135
Business Fax Number: (867) 983-4123

ASSISTANT PETROLEUM PRODUCTS OFFICER
Business Telephone Number: (867) 983-4134
Business Fax Number: (867) 983-4123

ENVIRONMENTAL PROTECTION SERVICES

RESOURCES, WILDLIFE AND ECONOMIC DEVELOPMENT (RWED) GOVERNMENT OF THE NORTHWEST TERRITORIES – YELLOWKNIFE

HAZARDOUS SUBSTANCE SPECIALIST
Business Telephone Number: (867) 873-7654
Business Fax Number: (867) 873-0221

DEPARTMENT OF SUSTAINABLE DEVELOPMENT ENVIRONMENTAL PROTECTION DIVISION GOVERNMENT OF NUNAVUT – IQALUIT

MANAGER, POLLUTION CONTROL
Business Telephone Number: (867) 975-5907
Business Fax Number: (867) 975-5980

DEPARTMENT OF SUSTAINABLE DEVELOPMENT – NUNAVUT

ENVIRONMENTAL PROTECTION OFFICER - KITIKMEOT REGION
Community of Residence: Kugluktuk
Business Telephone Number: (867) 982-7445
Business Fax Number: (867) 982-3701

LOCAL CONTACT AUTHORITIES: *COMMUNITY OF RESOLUTE BAY*

HAMLET OFFICE
Telephone Number: (867) 252-3616 or 252-3689
Fax Number: (867) 252-3749

SENIOR ADMINISTRATIVE OFFICER (FIRST CONTACT)
Name: Martha Kulluq
Telephone Number: 867-252-3616

MAYOR (SECOND CONTACT)
Name: Tabitha Mullin
Telephone Number: 867-252-3746

FIRE
Emergency Telephone Number: (867) 252-3333

AMBULANCE
Emergency Telephone Number: (867) 252-3844 (Health Centre)

RCMP
Emergency Telephone Number: (867) 252-1111

SUSTAINABLE DEVELOPMENT OFFICER
Business Telephone Number: (867) 252-3879

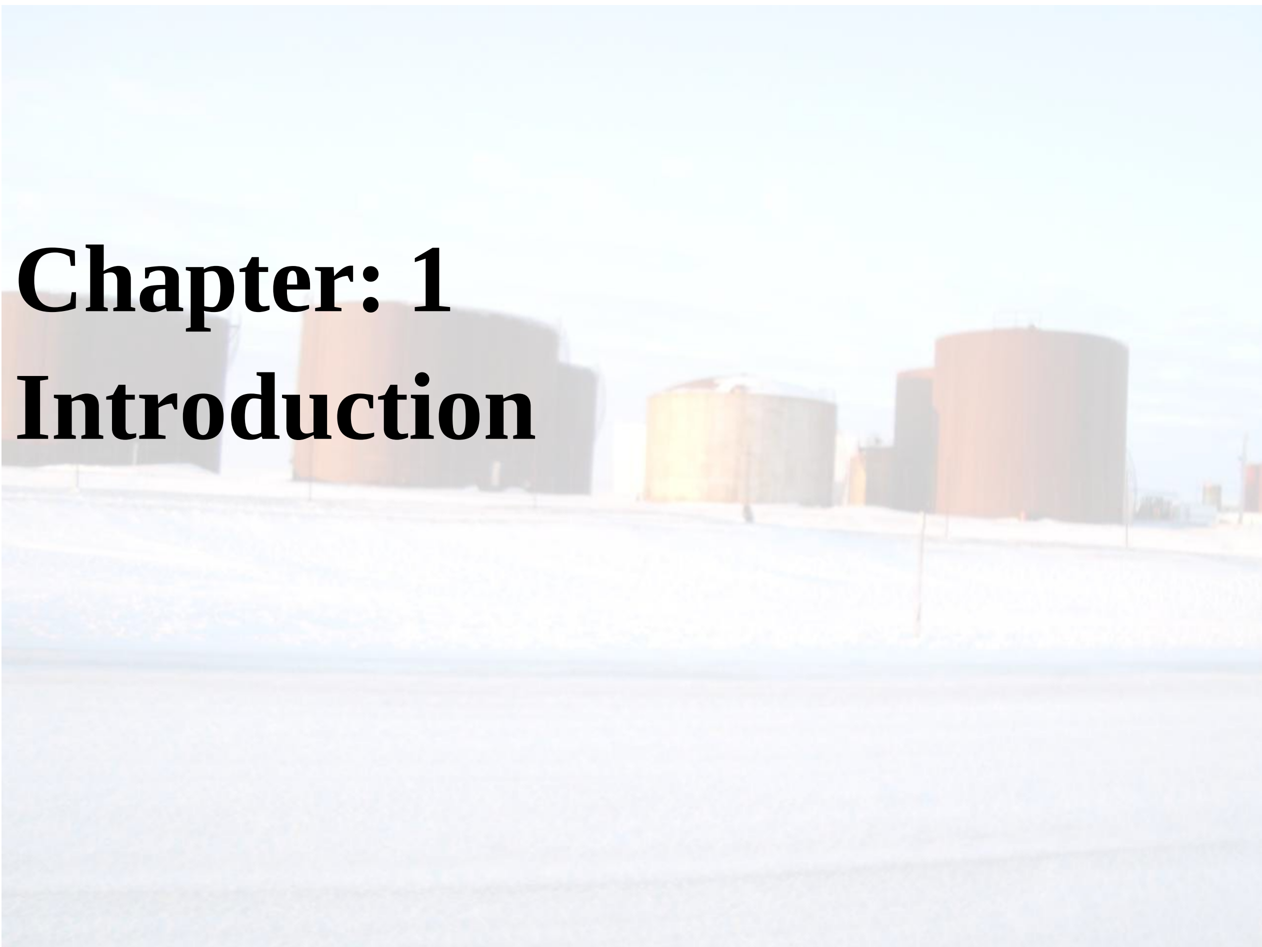
COMMUNITY AND GOVERNMENT SERVICES
Emergency Telephone Number: (867) 983-4125 (Cambridge Bay)
Emergency Fax Number: (867) 983-4123 (Cambridge Bay)

GOVERNMENT OF CANADA EMERGENCY PHONE NUMBERS

CANADIAN COAST GUARD (CCG)
Operations Centre (Spills)
105 South Christina
Sarnia, Ontario
Spills Reporting 1-800-265-0237

<u>NORDREG</u>
TRANSPORT CANADA
Chief, CANUTEC, Regulatory Affairs
Transport Dangerous Goods
Ottawa, Ontario
K1A 0N5

Information	(613) 992-4624
Emergencies	(613) 996-6666



Chapter: 1
Introduction

Introduction – Brief History

Petroleum Products Division of Government of Nunavut owns fuel storage and related infrastructure in twenty seven communities of the territory. Mainly three petroleum products i.e. diesel, gasoline and jet fuel are purchased, stored and dispensed in bulk quantities. Since similar kinds of emergencies are associated with transporting, storing and dispensing these three products so a single emergency response plan has been prepared for a community but it covers full range of emergency situations associated with all of three petroleum products. “Emergencies” as defined by Environment Canada, are “situations or impending situation caused by the forces of nature, accident or an intentional act that constitutes a danger of some proportions to life and property and/or damage the natural environment, land, water and air.” These emergencies can have the potential to affect people’s physical and emotional health, harm property and interfere with normal business operations, as well as affect the economic and environmental well-being of people.

This PPD’s Emergency Response Plan is intended to provide direction to the PPD’s fuel delivery contractor on the procedures to follow in the event that an emergency or disaster occurs that has the potential to affect all or a significant portion of the PPD’s operations in the community of Resolute Bay. Local PPD fuel delivery contractor shares the responsibility with PPD to guarantee the safe and smooth running of fuel distribution operation, safety of field staff and environmental protection. However there are extraordinary situations which can occur and are outside the realm of PPD’s capabilities so all community stakeholders are to be actively involved to respond to such situations. This PPD Emergency Response Plan is intended to guide the PPD’s response to everything from a minor incident through to a facility-wide disaster originating from fuel storage and distribution operation. A major part of the plan is intended to function as the umbrella plan for all locations but each site is being provided with the plan meeting the specific needs of the facility and community. Our plan is in the form that makes the most sense for PPD’s organizational and operational requirements; it aims at reducing the potential risks and addresses the following elements:

- The properties and characteristics of the three petroleum products stored at the facility in bulk quantities
- The maximum expected quantities of these products at the tank farm at any time during a calendar year
- The characteristics of the place where these products are stored and of the surrounding area that may increase the risk of harm to the environment or of danger to human life and health
- The potential consequences of an environmental emergency on the environment and on human life and health

The identification of any environmental emergencies that can reasonably be expected to occur at the place and that would likely cause harm to the:

- environment or constitute a danger to human life or health, and identification of the harm or danger
- A description of the measures to be used to prevent, prepare for, respond to and recovery from the emergency situation
- A list of the individuals, identified by name and position, which are to carry into effect the plan in the event of an emergency and description of their roles and responsibilities
- Identification of the training required for each of the those individuals

Research shows that an emergency response plan gives responders an enhanced ability to react to an event with a substantial reduction in property damage and casualties. The PPD Emergency Plan will build upon existing structures and routine activities of the organization; it will also require PPD and local fuel delivery contractor to assume responsibilities that never before realized fully. New functions must be performed and existing relationships must integrate with those that emerge to manage the event. A variety of emergency response roles and functions are described in this plan and the situations in which they are recommended.

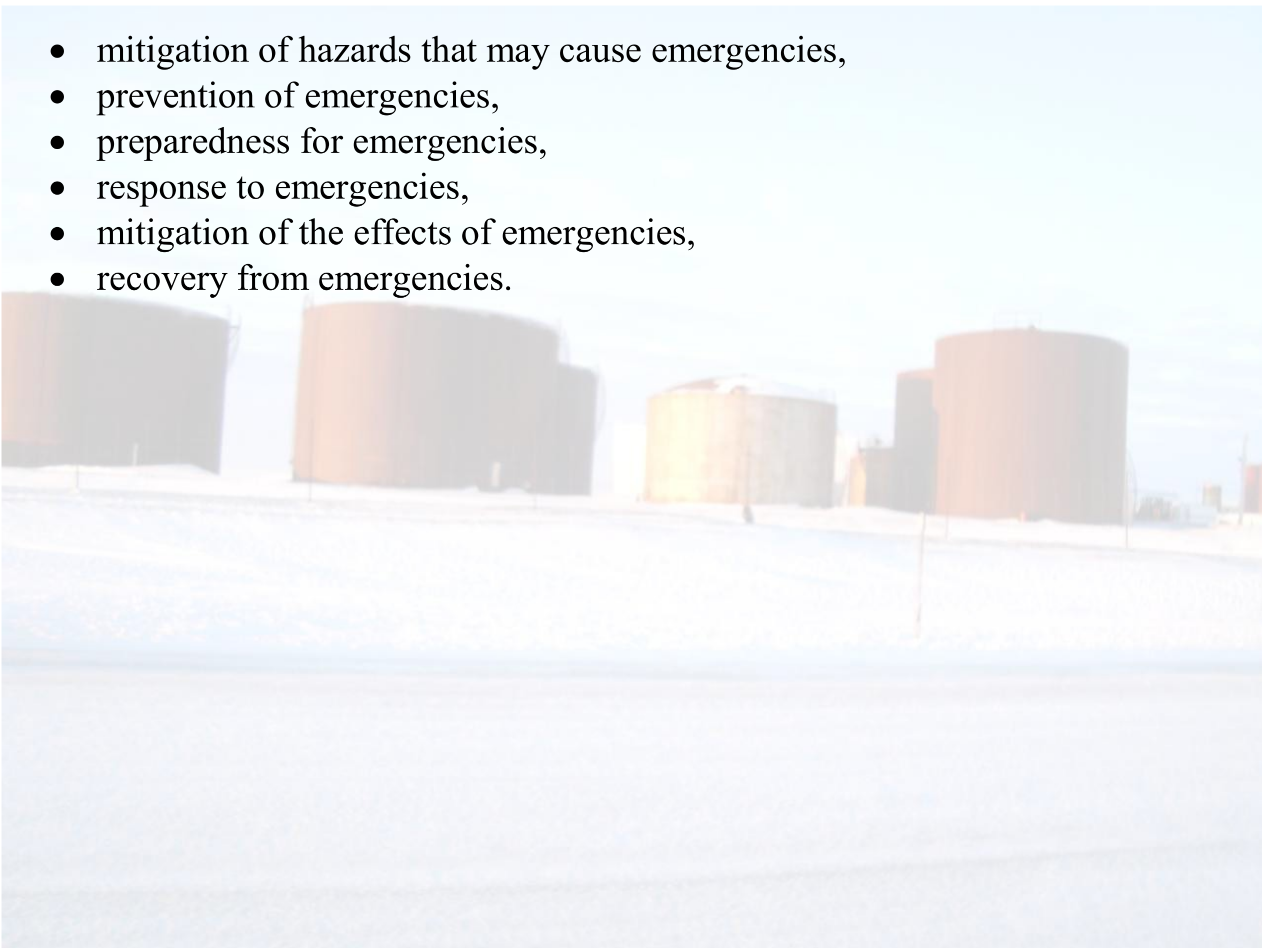
The Emergency Management Team, comprising of PPD staff, has undertaken the responsibility to oversee the plan's development under the leadership and direction of the Manager of Technical and Environmental Services. For the plan to serve its purpose it contents must be known and understood by those responsible for its implementation, that is the point where staff of fuel delivery contractor needs to be trained and adequately prepared to execute the plan when emergency situation arises. The PPD's Emergency Plan has several objectives. A large focus of the plan is outlining the role and responsibilities of field staff and administration on how to manage the emergency. The plan also lays out the ways to prevent emergency situation. As well, the plan addresses the wide issues to ensure that PPD and its contractor are equipped and fully prepare to respond. The PPD Emergency Response Plan is designed to assist the staff in being proactive, coordinated, and effective during an emergency situation by helping to:

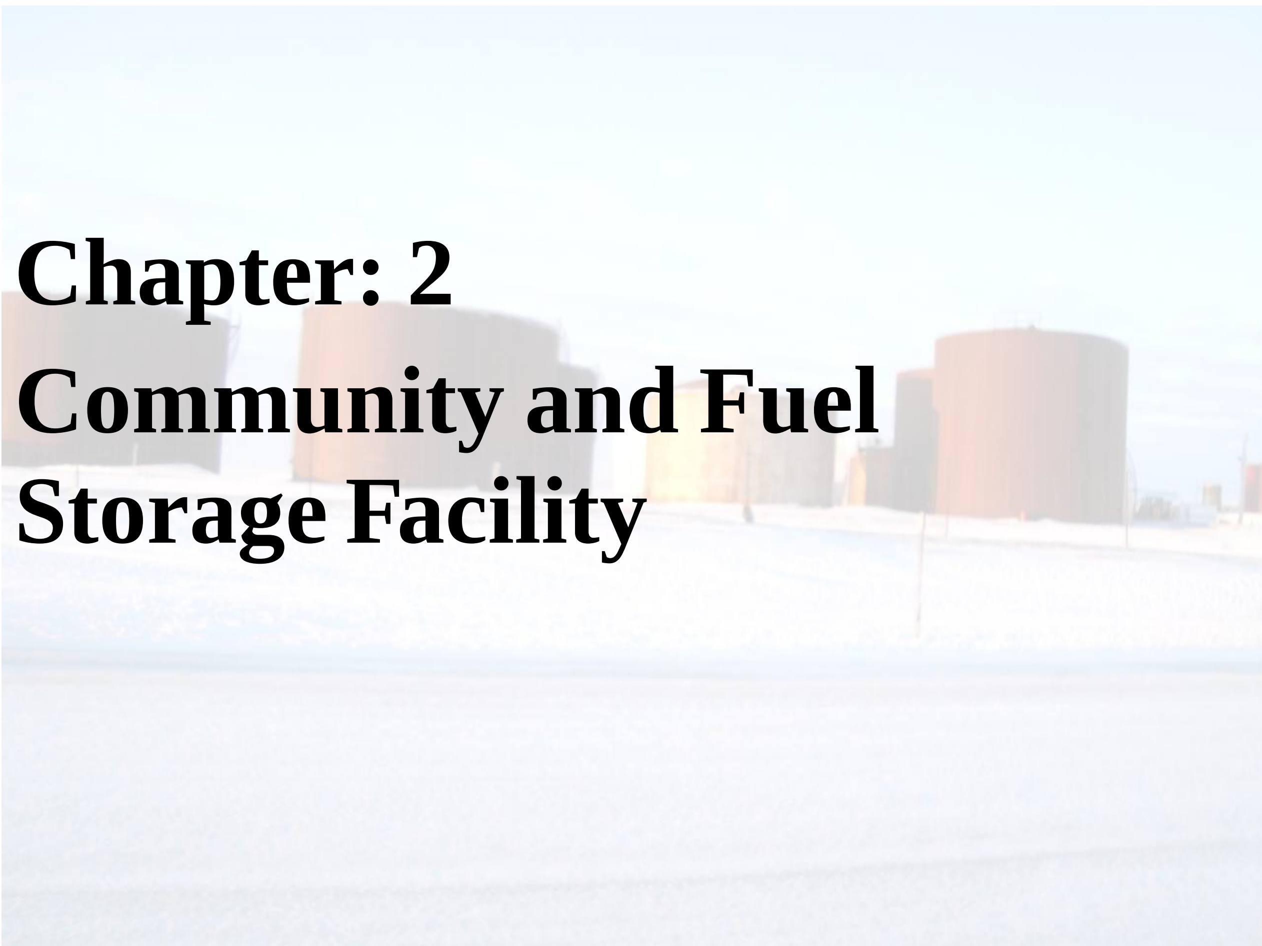
- ensure the safety of staff and general public ,protect the public and private property
- protect environment; air, water and land
- lead to the resumption of normal operations as soon as possible
- reduce the risk of oversights while operating under the stress of an emergency and the publicity it generates
- facilitate action through a system-wide awareness of procedures and policies
- clearly identify responsibilities and roles of staff members
- minimize the negative impact of the emergency situation or emergency

- facilitate communications with all partners and thereby managing the emergency or emergency situation; and

In cases of fire, the protocols set out in the fire safety plan shall apply. Circumstances may arise, however, where a fire affects critical PPD's operation and as a result, activation of the ERP may be necessary. This plan is also intended to apply to emergencies that are isolated and readily contained. For example, a situation or individual may create an emergency in a particular Hamlet however; these types of emergencies may not give rise to the activation of the ERP. "Emergency management program" means a program, plan, arrangement or other measure for the following:

- mitigation of hazards that may cause emergencies,
- prevention of emergencies,
- preparedness for emergencies,
- response to emergencies,
- mitigation of the effects of emergencies,
- recovery from emergencies.





Chapter: 2

2 Community and Fuel Storage Facility

Community and Fuel Storage Facility

2.1 Resolute Bay:

Resolute Bay is an Arctic waterway in Qikiqtaaluk Region, Nunavut, Canada; Resolute Bay is the second northernmost community in Canada. The Hamlet of Resolute Bay is located in the High Arctic on the south coast of Cornwallis Island with coordinates 74 41 N 094 52 W. Being a gateway to High Arctic, Resolute Bay is the major stopover for expeditions to the North Pole and to Quttinirpaaq National Park, Ellesmere Island and base for scientific research. There is a weather station as well as the Polar Continental Shelf project research camp located within the community. Resolute Bay is well connected with neighbouring communities by Northern airlines. The population of hamlet is about 250.Resolute history has the most European influence of all the Nunavut communities. The site was a critical junction along the Northwest Passage. The community is named after the HMS Resolute, a British ship that was in search of the lost Franklin expedition.

2.2 Tank Farm, Hamlet and Airport:

In Resolute Bay community, fuel storage facility and airport are well apart geographically. If we take tank farm as reference point, community is at 3 km northeast and airport is 5 km northwest. Tank farm is connected to community and airport through gravel roads. Initially most of the fuel was transferred from the main tank farm to Airport and Community direct by pipe line, but in 2004 the whole piping network was decommissioned, since then fuel has been transferred by trucks. Rough roads and extreme water conditions sternly affects the fuel distribution operation.

Any emergency situation at the tank farm is unlikely to affect the normal life in the community and regular activities at the airport directly. Of course an accident at the tank farm can halt the fuel dispensing and fuel distribution operation which in turn can influence regular life activities in the community. Moreover release of any petroleum product can potentially contaminate the water of nearby Bay and evaporated fuel can pollute the atmosphere so people of Resolute Bay will have to pay the price of that contamination in terms of facing the adverse effects of polluted environment.

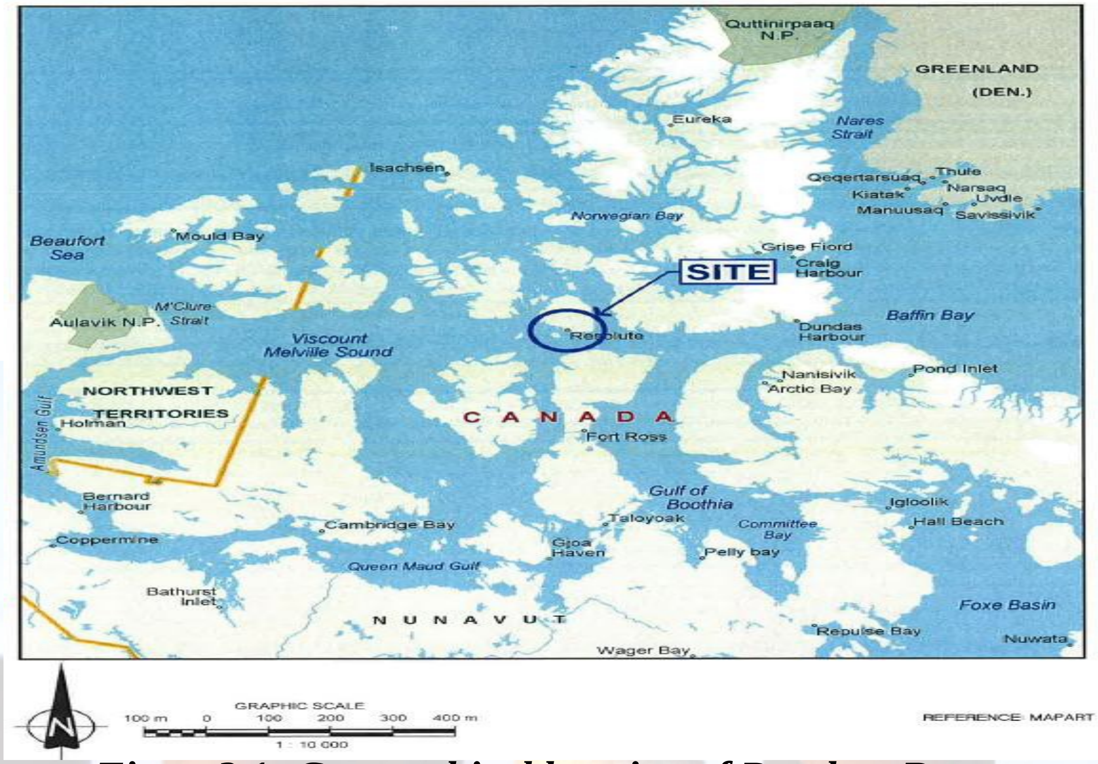


Figure2.1: Geographical location of Resolute Bay

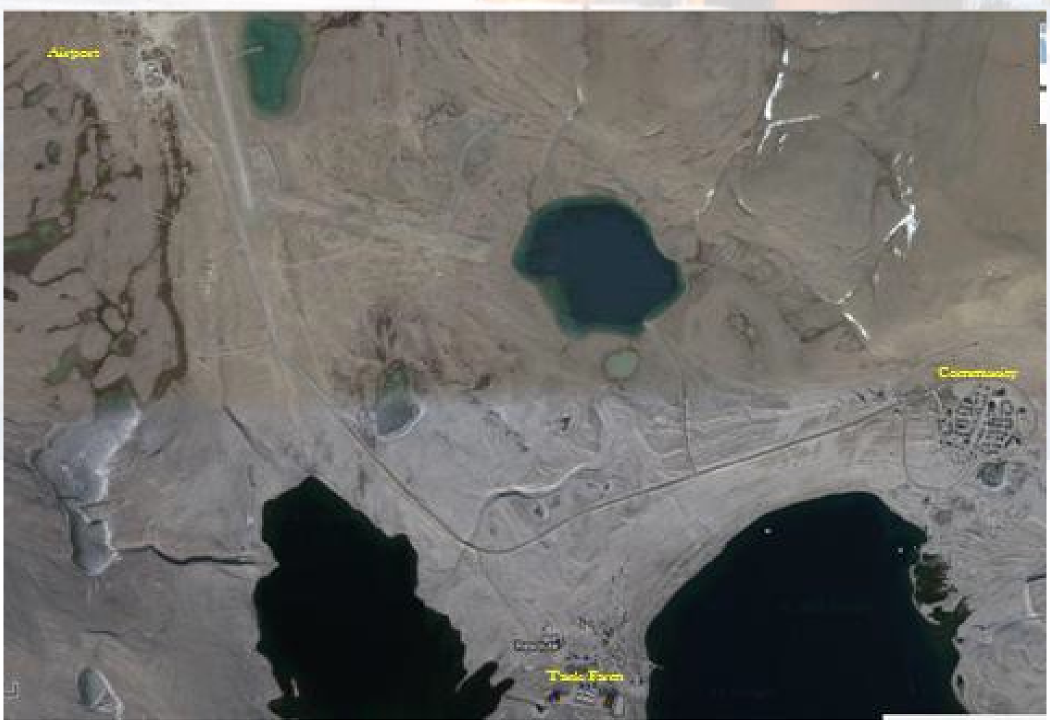


Figure2.2: Relative locations of Tank farm, community and airport

Figure2.3: Tank farm within its neighbourhood

2.3 Tank farm:

The Tank Farm serves as the primary storage and distribution point for petroleum products in the community. All of petroleum products arrive at the Tank Farm by resupply pipe line once or twice a year during summer months. A piping system comprising of three pipes, one for each product and shore manifold has been provided for the refilling of the tanks with petroleum products. The pipeline system delivers products to the Tank Farm at a high flow rate so an operator stays on duty as long as filling continues. In the event of any major spill, including tank overfilling or rupture of a pipe, orders must be given to shut down the resupply by the operator on duty. It takes several minutes to fully stop the incoming flow. Large quantities of these products, primarily flammable and combustible liquids, are stored at this location and distributed to the users by delivery vehicles. A complex system of piping interconnects the tanks with same products on the facility allowing products to be delivered or transferred without contaminating each other.

2.3.1 Facility description:

At the existing site of tank farm, a huge fuel storage facility was constructed in early 1970 s. With the enforcement of new Environmental legislation, a need was felt to renovate the facility to comply with new codes and regulations.

An upgrade project was initiated in 2002 and completed in 2013. Fuel storage facility at Resolute Bay could be divided into two; one newly constructed tank farm to the west and the old tank farm to the east. The new tank farm consists of approximately 120 m × 120 m lined and fenced facility surrounded by a berm. The facility houses eight aboveground vertical tanks built on API-650 standards. These tanks have assorted storage capacity for diesel, gasoline and jet A-1fuel.

Resolute Bay Tank Farm					
Product	**EC Identification #**	**Tank #**	**Tank Type**	**Capacity (L)**	**Location**
Diesel	EC 00021865	Tank # 103	Horizontal	51,032.00	Main tank farm
		Tank # 214	Vertical	3,197,979.00	Main tank farm
		Tank # 217	Vertical	4,771,640.00	Main tank farm
		Tank # 221	Vertical	4,768,330.00	Main tank farm
		Total Diesel		**12,788,981.00**	
Gasoline	EC 00021866	Tank # 01	Vertical	58,266.00	Town gas bar
		Tank # 104	Horizontal	51,092.00	Main tank farm
		Tank # 210	Vertical	3,200,164.00	Main tank farm
		Tank # 226	Vertical	798,451.00	Main tank farm
		Total Gasoline		**4,107,973.00**	
Jet A-1	EC 00021868	Tank # C	Horizontal	112,735.00	Airport
		Tank # 101	Horizontal	101,961.00	Airport
		Tank # 102	Horizontal	101,677.00	Airport
		Tank # 203	Vertical	925,612.00	Airport
		Tank # 211	Vertical	3,199,882.00	Main tank farm
		Tank # 218	Vertical	4,763,957.00	Main tank farm
		Tank # 222	Vertical	4,781,810.00	Main tank farm
		Total Jet A-1		**13,987,634.00**	

Table 2.1: Product-wise storage capacity

The old tank farm is an area of 100 m × 100 m with 13 vertical tanks. That tank farm is also lined and features a spill catchment basin on its eastern perimeter.
The old tank farm slopes towards the east; therefore any surface drainage would flow into the spill catchment basin.

The old tank farm facility is no longer in use. Two horizontal tanks with 45,000 L capacity each containing diesel and gasoline are located within lined and fenced containment area north of old tank farm. Tank 104 is resupplied via aboveground pipeline connected to an 800,000 L capacity tank located within the new tank farm facility. Similarly tank 103 is connected via an aboveground pipeline to one of the diesel tank within new tank farm.

Figure 2.4: Systems identification with Environment Canada

Regarding the tanks standing at old tank farm, decision has not been made yet whether or not to decommission them permanently. Tanks on the new tank farm have been recently registered with Environment Canada under three identification numbers; one for each product. On the north side of the tank farm two dispenser buildings were provided; one for jet truck fill and other for diesel and gas.

A new lock and key system was installed in Jan 2011 beside the gas and diesel dispenser. The small building housing the keys panel also serves as operator shelter.

Over fill High level alarms as required in CCME was installed in the year 2013.

On the west site of new tank farm there is open tundra, on the south side there is a solid waste facility at some distance, on the north side there are some houses and private storage containers, the owners of the installations must be informed in case spill running out of the tank farm. Most sensitive area is on the east where there is an expansion of sea water which is active marine habitat and source of fresh water.

2.4 Historical fuel sales:

So far population is concerned Resolute Bay is 2^{nd} smallest community of Nunavut but fuel consumption is much higher than that of some other communities with relatively larger population. Actually community of Resolute Bay serves a base point for most expedition to North Pole of the Earth.

During the last ten years fuel demand has doubled especially the jet fuel sales became almost four times. Product wise annual sales for the last ten years are provided to demonstrate the trend in ever growing fuel demand in this community. Sometimes fuel stored at that facility serves as reserve to meet DND's demand. Many times fuel has been transferred from here to Eureka and Alert military base.

Historical fuel sales, Resolute Bay			
Year	**Volume in litres**		
	Diesel Fuel	**Gasoline**	**Jet A-1**
2010/11	3,867,485	266,268	2,997,808
2009/10	3,268,442	257,533	1,770,059
2008/09	2,957,072	246,525	1,934,661
2007/08	3,031,479	289,954	2,074,543
2006/07	2,536,544	244,676	2,192,523
2005/06	2,566,512	251,120	2,130,195
2004/05	2,671,315	239,216	1,763,715
2003/04	2,409,642	210,191	1,648,580
2002/03	2,492,269	250,301	1,769,250
2001/02	1,934,245	200,746	818,252

Table 2.2: Historical fuel sales at Resolute Bay

2.5 Hamlet:

Resolute Bay is second most northern community with just 250 people living there. Most of the modern life amenities are available in the community like school, health centre, RCMP detachment, drinking water supply, power supply, sewage system, high speed internet, cable TV etc. Electricity is generated by diesel and all houses and building are heated by diesel fuel as well. For all of its fuel needs the community depends upon petroleum products supplied by PPD fuel delivery contractor.

Any run short of fuel especially during winter months can jeopardize the community. Any fuel spill or fire at the fuel storage facility is unlikely to hurt the community directly but substantial loss of fuel or paralyzed fuel distribution operation can take a serious toll on routine life in the community.

2.6 Airport:

Although not as busy as it once was, Resolute Bay Airport is still the core of the town, serving as an aviation hub for exploration in the region and connected by direct service to Iqaluit. Resolute Bay is well connected with other communities of Nunavut by local airlines service. First Air operates flights from Iqaluit to Resolute Bay on Wednesday and Saturday, also from Edmonton via Yellowknife on Saturday. During the busier summer months, a second flight from Edmonton via Yellowknife is available on Thursdays.

2.7 Climate

The knowledge and understanding of the local climate and weather pattern are instrumental to develop and execute at emergency plan so a short description about them has been made a part of that document. Resolute Bay has a polar arctic climate with long cold winters and short cool summers. Resolute's average high for the year is −13.3 °C (8.1 °F) while the average low for the year is −19.5 °C (−3.1 °F). Resolute Bay has a very dry climate with an average precipitation of 150 mm (5.91 in) a year, most of it falling as snow from August to September. The record high for Resolute is 18.4 °C (65.1 °F) on July 9, 2011. The record low for Resolute is −52.2 °C (−62.0 °F) on January 7, 1966. Persistent snow cover in excess of 2 centimeters across this section ranges from about 260 to 280 days per year bridging fall, winter, and spring. At Resolute Bay, only the months of June, July and August have mean daily maximum temperatures above zero and of these months, only July also has an above zero mean daily minimum. Ice melt begins in June with the maximum amount of open water occurring in mid-September. Summer is the time of 24 hours of daylight while winter is the time of 24 hour darkness.

2.7.1 Frozen season

The frozen season begins in September as new ice forms in coastal areas and skims over the surface of open water areas. The frozen season ends in June. Once the open water areas are ice covered, the abundant source of moisture for low cloud and fog is cut off. Before this happens, a combination of weather systems and open water contribute to make September followed by October the snowiest months. The snow routinely gives obscured ceilings by snow and restricted visibility. The frozen season is also the blowing snow and blizzard season. The entire area of Resolute Bay is vulnerable to strong northwest winds and blowing snow and is part of the blizzard alley that extends southeast from the Arctic Basin.

Resolute Bay experiences on average 12.6 blizzard events during the frozen season. Just as September is the month showing the most snow, September is also the most likely month for freezing drizzle or freezing rain. Moisture associated with heating systems and aircraft exhaust can at times trigger ice fog below the inversion. An approaching upper trough can trigger a layer of ice crystals that extends up to 18,000 feet or more. Under such conditions light snow can fall from skies that have no discernible cloud. This "fluffy" snow readily becomes blowing snow. This ice crystal haze clears with the passage of the upper trough. The spring months of March, April and May reside in the frozen season. Statistically, they are the months of most favourable flying weather. These months are also the months that the area of 24-hour daylight pushes south and bring about a thinning snow cover. Warmer and moister air masses that have, except for rare occasions, lingered well south, now move into the area. At Resolute Bay for example, average snowfall values go from about 4 centimeters in January and February to values near 6 centimeters in March to near 10 centimeters in May.

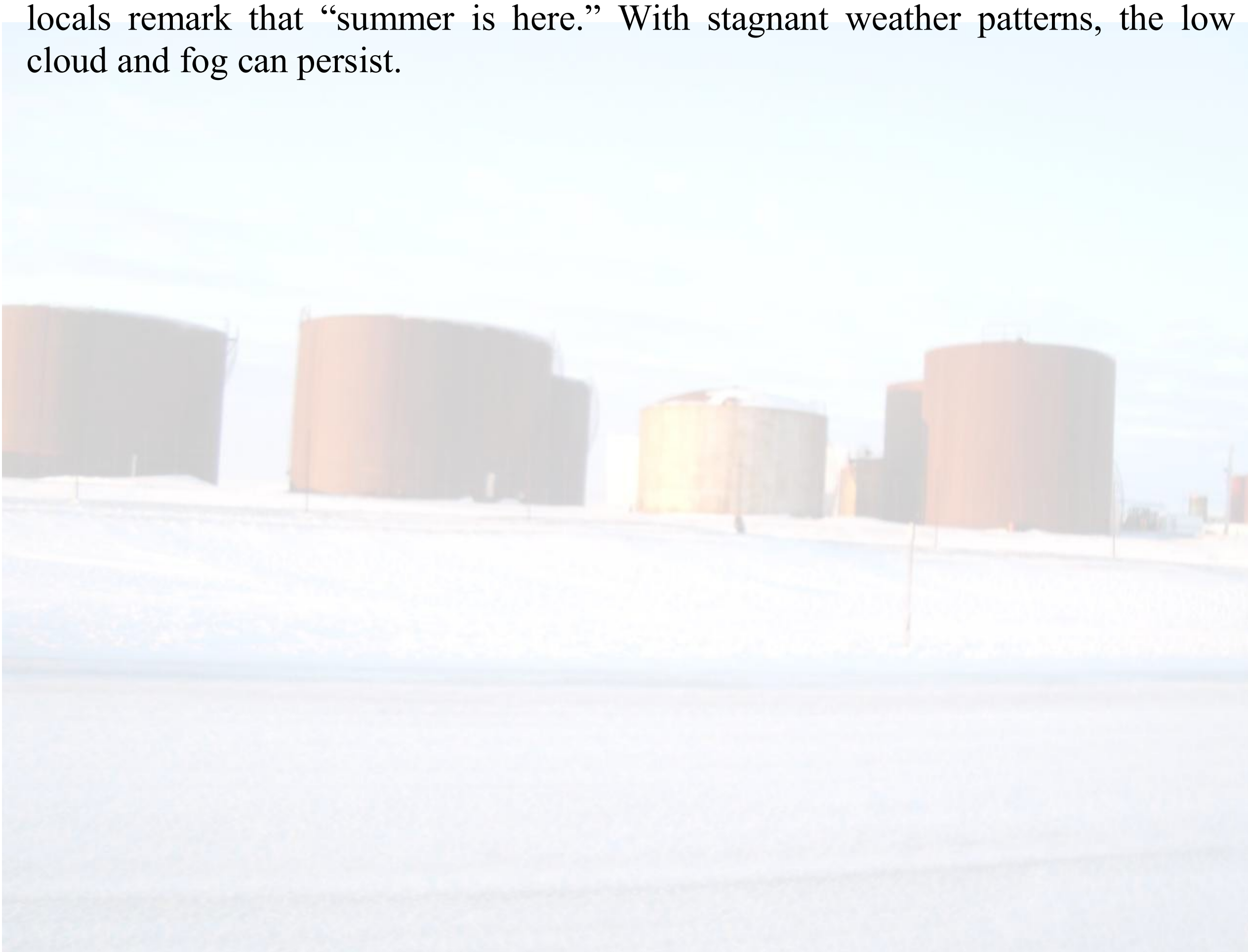
2.7.2 Unfrozen season

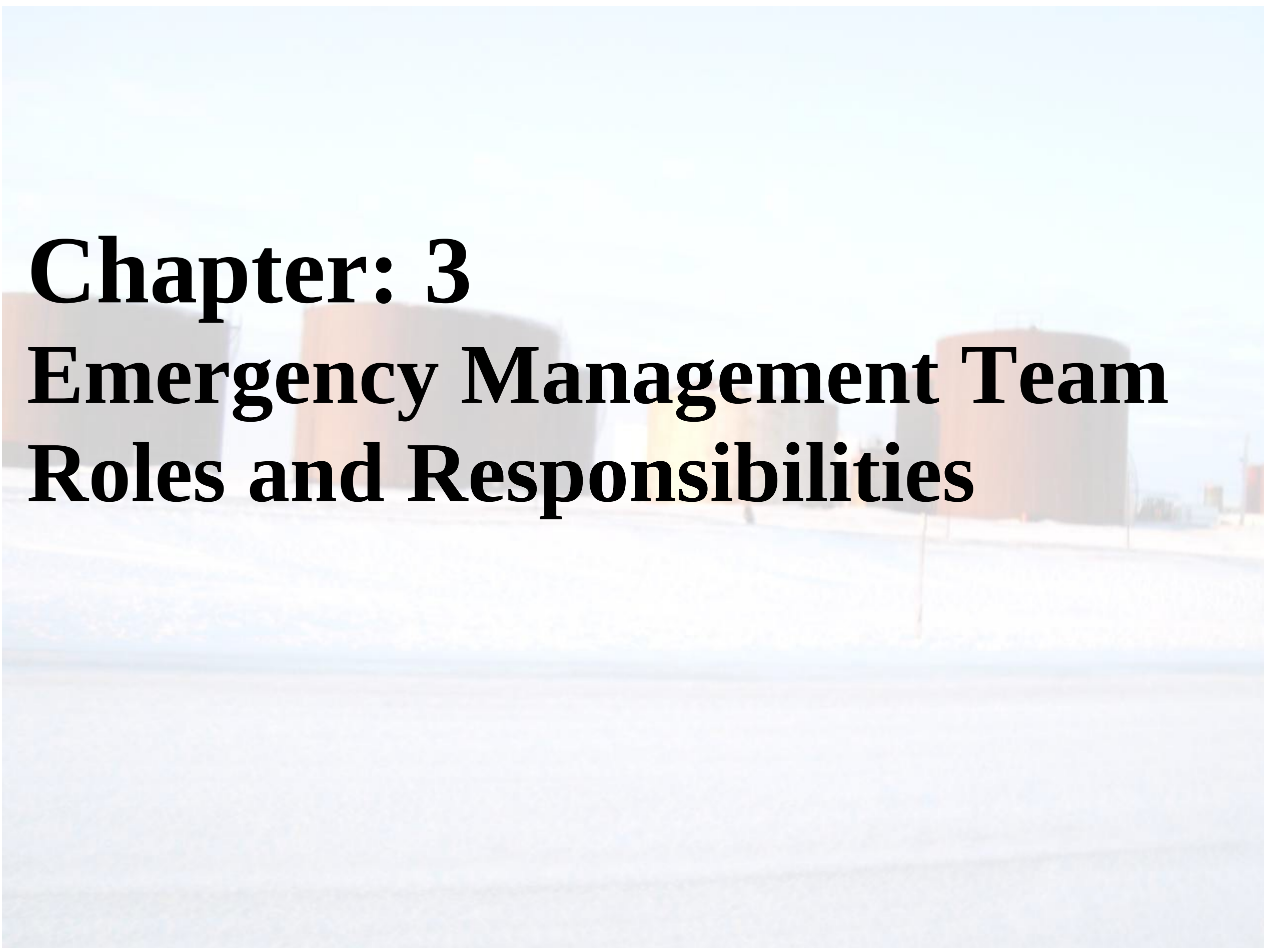
At Resolute, the months of June, July and August have mean daily maximum temperatures above zero degrees Celsius of these months only July has an above zero mean daily minimum. During the unfrozen season, low cloud and fog are the routine across ice-covered waterways and open water areas. Onshore flows readily bring these conditions inland. During summer, Resolute Bay is vulnerable to onshore flow that moves the cloud easily across low terrain. Summer frequency of ceilings is below 1000 feet and/or visibility below 3 miles.

2.7.3 Local effects:

In Resolute Bay and its vicinity - winter has more stable weather than any other season as cold arctic air pervades over the area. There are small polynyas to the north of Cornwallis Island and with a northerly flow fog and low cloud can make it across the island to Resolute. With a strong northwesterly flow, there can be blowing snow and depending on the amount of snow upstream and the strength of the winds, the blowing snow can constitute a blizzard. Spring brings warmer temperatures and the start of the melting season. As open water develops, fog and stratus can be a problem as it moves into Resolute from the west and southeast particularly.

Northwest winds transport low cloud into Resolute, as do the winds from the west and southwest. When the fog and stratus starts to roll in during the late spring, the locals remark that "summer is here." With stagnant weather patterns, the low cloud and fog can persist.





Chapter: 3

Emergency Management Team Roles and Responsibilities

Emergency Management Team
Roles and Responsibilities

3.1 Emergency Management Team:

As an owner of the fuel storage facility at Resolute Bay, PPD is accountable to GN as well as to Federal regulatory agencies for its inability to handle fuel related emergencies and environment protection. Developing Environmental Emergency Plans and keeping them up to date is sole responsibility of PPD. PPD doesn't physically exists in most of the communities but whole territory comes under its jurisdiction so far managing the emergencies related to fuel storing, transferring and distribution are concerned. It is a great undertaking so PPD has to ensure that things are managed properly at community level. In case of mismanaging the emergency PPD would be liable to penalty.

PPD's fuel delivery contractors serve its eyes and ears in all communities. PPD has established an internal team, Emergency Management Team, to work with fuel delivery contractors' emergency teams, Emergency Response Team, to effectively respond to environmental emergencies. PPD's emergency management & emergency response teams are professional emergency response force with a full complement spill response supplies, a complete inventory of firefighting and related equipment, and a sufficient staff trained for emergency response.

These teams are equipped, positioned, and trained to respond in a timely and effective manner to unpleasant occurrences. PPD is intended to enhance the capabilities of emergency teams through regular instruction and onsite drills, the ongoing development of the Baseline Needs Assessment and periodic evaluations to the requirements of NFCC and other applicable standards related to emergency response. Based on the above fire protection program and related engineering and administrative safeguards, the identified spill/fire hazards and associated risk are acceptable. Four most important PPD's staff members constitute the Emergency Management Team, with a unique set of duties for each member of the team. The names and positions along with their contact information and main duties have been summarized in the following table.

Emergency Management Team				
Name/Position	Address	Phone #	Email	Duties
Anil Gupta Manager Tech & Envir. Services	PPD HQ Rankin Inlet	867-645-8421	AGupta@gov.nu.ca	1. Receive information from fuel delivery contractor and report to environmental regulatory agencies 2.Arrange Environmental Site Assessment, ESA, of the affected area 3.Develop a long term remediation action plan 4. Attend the site if necessary
Richard Kellett Manager Nunavut Field Operations	PPD HQ Rankin Inlet	867-645-8443	RKellett@gov.nu.ca	1.Guide the fuel delivery contractor for containing and cleaning the leaked/spilled product 2. If fuel delivery contractor is not able to handle the cleaning process, arrange another contractor to help him 3. Work with contractor and inventory control specialist to estimate the lost product 4. Attend the site if necessary
Bram Sikma PPD Regional Head Kitikmeot	PPD Regional Office, Cambridge Bay	867-893-4135	BSikma@gov.nu.ca	1.Under the supervision of Nunavut field operations, investigate the reason of incident 2. Send spill response supplies to fuel delivery contractor 3. Liaise between fuel delivery contractor and PPD HQ 4. Attend the site
Derek Williams Envir. Services Specialist	PPD HQ Rankin Inlet	867-645-8441	DWilliams@gov.nu.ca	1.Maintain records of emergency incidents 2. Assist Manager Tech. & Envir. Services to revise Environmental Emergency Plan 3.Edit the information on fuel storage system with Environment Canada, if necessary after recovery from emergency situation

Table3.1: Emergency Management Team

Emergency Management Team exists to aid in the Emergency Response Plan implementation and to ensure on-going emergency preparedness at PPD. These individuals have a key role to play in providing either emergency guidance or support. They have also been a primary source of information by which the Plan was developed. Most staff from PPD's operation would likely comprise the Emergency Management Team should the plan be activated.

3.2 Emergency Response Team:

In case of an emergency on the fuel storage facility PPD's fuel delivery contractor would be the first one to respond to the incident. Fuel contractor must establish an Emergency Response Team. As we have already discussed emergency could range from a small leak to a complete catastrophe.

If it is a small leak, fuel delivery contractor with his team will try to identify the source of leak and disable it. At the same time he will inform the PPD regional office and PPD HQ and get advice if he feels the situation is out of his control. He will fulfill all reporting requirements. If necessary and agreed with PPD HQ he will stop the fuel distribution operation until next order. Contaminated area will be closed for general public. In the event of an emergency, PPD's fuel delivery contractor will establish an incident command centre close to the storage facility to coordinate the response to the incident.

PPD's staff will help and guide fuel delivery contractor but he himself will have to take the lead on the ground. In the event of an on-site evacuation, all locations will establish an escape route and 1-2 evacuation sites. The evacuation sites will be identified on the facility. In the event that an evacuation off-site is required, all locations will be evacuated. Fuel delivery contractor has been advised to furnish a memorandum of understanding with other community stakeholders to ask for their help in case of emergency. Local heavy equipment operators and local labourers will be hired for the clean-up operations, if needed. The need would be identified by fuel delivery contractor but PPD HQ's approval would be mandatory, if PPD is to pay the services.

Emergency Response Team				
Name/Position	Address	Phone #	Email	Duties
Bob Mitchell Team Leader	South Camp Resolute Bay	867-252-3925	Bob.Mitchell@atcosl.biz	1.Disable the spill/leak source and assess the product loss 2.Make the initial call to NWT spill line 3. If it is spill or leak, prepare standard spill report and fax it to 24 hour spill line 4. Assign duties to team members 5.Execute all facets of Environmental Emergency plan
Rick Gaulton Site Superintendent	South Camp Resolute Bay	867-645-3925		Respond as directed by the team leader
Guy Dorion Heavy Equipment Operator	South Camp Resolute Bay	867-252-3925		Respond as directed by the team leader
Mark Lane Helper	South Camp Resolute Bay	867-252-3925		Respond as directed by the team leader
Jean-Louise Dorion Helper	South Camp Resolute Bay	867-252-3925		Respond as directed by the team leader

Table 3.2: Emergency response team

3.2.1 Initial team response:

Emergency response team will assess the area for hazardous conditions such as fire, health and safety issues. Stop the source of the spill. Contractor could continue the normal operation only if the area is safe from hazardous conditions. Response Team will check the area for any people and if they are injured, First Aid and CPR will be provided. Warn people in and around the Tank Farm Facility or the shore manifold of the danger and evacuate them. Move vehicles, only in case of fire and only if the conditions are safe. We can summarize the steps to be taken by Emergency Response Team while responding to a spill.

- Remove non-essential personnel from the scene

- Restrict public access to the area
- Put on PPE
- Approach spill from upwind
- Shut off all the valves causing fuel transfer
- Absorbing pads and rolls are to be placed on the visible spill
- Susceptible area will be flag barricaded in such a way that is visible to anyone entering the neighborhood
- Intrinsically safe equipment will be used to do the cleanup
- Eliminate all ignition sources
- Fuel soaked pads and rolls will be placed in a drum
- Contained liquid fuel will be dumped into a slop tank
- If fuel contact with the skin occurs, remove contaminated cloths, dry wipe exposed skin and cleanse with waterless hand cleaner and follow by washing thoroughly with soap and water
- If product is found under the skin, regardless of the wound size, immediately contact your doctor

Once the immediate threat to public health and the environment has been mitigated, the incident is further stabilized and cleaned up under the supervision of PPD's managers. Fuel delivery contractor will dispose recovered material which is classified as a "special waste" or "non-recoverable according to approved procedure.

Figure 3.3: Fuel absorbing pads

3.3 Roles and responsibility

Local fuel delivery contractor will ensure the timely and appropriate implementation of the Environmental Emergency Plan. He will make the resources including personnel available to combat emergency. Overall supervision is the responsibility of the fuel delivery contractor.

He has a joint responsibility with PPD to ensure all employees receive training on their roles and responsibilities during an emergency. He will ensure that all members of emergency response team participate in emergency exercises and reviews. He will ensure that his employees have clear understanding of their roles and responsibilities during an emergency.

The PPD Emergency Response Plan will operate on the pre-determined procedures for command, control and coordination set out within this plan. A community wide emergency support centre has been developed with the help of Emergency Preparedness Iqaluit at the Hamlet Office of Resolute Bay. This Emergency Operations Centre (EOC) exists as a resource to Emergency Response Team who may choose to activate this resource. It serves as the means through which PPD and multi- department/agency response efforts are coordinated. This centre would serve as the command centre from which decisions are made and implemented.

Within it there will exist an immediate means of sharing information and advice between the Emergency Response Team, PPD and other response group leaders. This Centre would also be shared with external emergency response agency leaders as required.

3.4 Resource Mobilization:

Most of the environmental emergencies require equipment and operators. It is not possible to dedicate a complete set of personnel and machinery to deal with emergency situation and put them in a reserve for ever. Mostly the same resources are engaged on routine work when the operation is running smoothly. Emergency events don't follow a schedule so the resource needs pop up abruptly. Since an emergency is an unexpected event so the intended resources may not be available right away. PPD's fuel delivery contractor might have already deployed them on regular work at that time. Initial assessment determines how much manpower and equipment would be enough to effectively respond to a particular emergency situation.

Figure 3.4: Spill Kits

Here resources mobilization refers to the process for activating Emergency Response Team fully equipped with required machinery as defined in action plan. This could only be achieved by re-deployment of the resources. Situation Reports are gathered to further define the event and briefings with Response Teams determine how best to deploy the available resources. For a successful resource mobilization some questions need to be answered such as:

- Have all members of Emergency Response Team been contacted?
- Has the Emergency Response Team been briefed for a coordinated response?
- Has an agenda and time frame for response activities been established?
- Have monitoring procedures been initiated to report on problems and progress?
- Are communication channels and equipment being provided adequate?
- Have response priorities been clarified and communicated to each team member?
- Is it necessary to activate the Emergency Operations Centre?
- Have External Emergency Response Agencies been notified on how to reach the Emergency Operations Centre?
- Have any time critical activities been identified and responded to?
- Have essential services been relocated from affected areas?
- Have roles and responsibilities been assigned for critical missing functions?

Fuel contractor, as a team lead for the response, has to re-deploy the resources to handle the emergency situation. Initially after assessing the scale of emergency, he can make a request to PPD for additional resources. Moreover community stakeholders should also be asked for the help.

3.5 Resource Coordination:

PPD HQ and regional office would extend their cooperation but it is sole responsibility of the contractor to coordinate resources on the ground. Here resource coordination means to the deploying of resources to actually address the needs of the event.

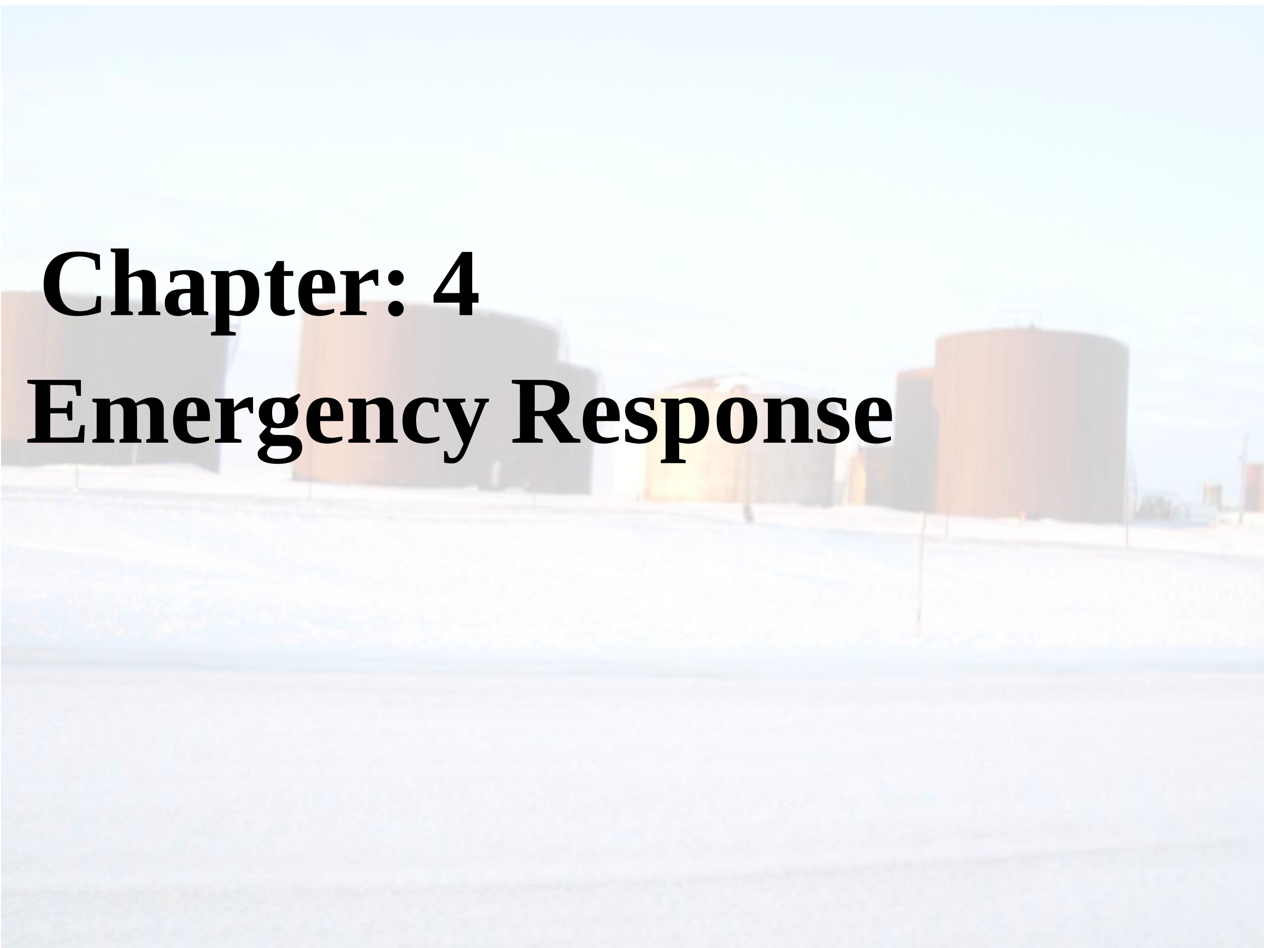
It includes coordinating teams and communication networks for reporting on and modifying Response Team activities as required. Coordination begins once the necessary Emergency Management and Response Roles are filled and coordinating centers have been established.

While dealing with the emergency the following questions regarding the resource coordination need to be answered:

- Is traffic or crowd control necessary?
- Have missing resources, equipment and supplies been identified?
- Is it necessary to salvage or protect critical PPD property or assets?
- Is a perimeter established around the event site?
- Is a casualty collection area and temporary morgue required?
- Is a staging area required to support the event site?
- Do the Response Teams have the necessary materials, staff and support?
- Have the necessary Response Team representatives been sent to the Site?
- Are emergency purchases required and the arrangements in place?
- Is an advisory system in place to update PPD staff, other contractors, and local Government?
- Has the public been informed of the event and its consequences?
- Is a media center or public inquiry service necessary?
- Are updated situation reports available to the Response Team?
- Have the necessary victim support services been summoned?
- Are victims of the event being fully responded to?
- Is a reception Centre necessary for those affected?
- Do Emergency Responders have the information they need?

Chapter: 4

Emergency Response



Emergency Response

4.1 Emergency Response

Response to an environmental emergency includes many facets, such as maintaining communication systems between stakeholders, alerting and warning regulatees, evacuating the facility and accounting for personnel and public. The variety of response can vary greatly in scope depending upon nature and magnitude of the emergency. To exercise a quick and effective emergency response PPD does sound planning and pre-established partnership with other community groups. In fact effective response calls for cooperation between shipping companies, environmental regulatory agencies, communities, local organizations and government through affiliation formed before emergencies occur. PPD believes in strengthening these partnerships by regular and combined exercise of the environmental emergency plan with all of those involved. Communication from the facility to off-site agencies and between responder is important and necessary for coordinated and successful response effort. Effective emergency response include quick activation of the emergency plan, proper notification of the emergency to first responders and affected parties, rapid assessment of the probable path of impacts of an emergency, adequate resource mobilization and reporting activities. PPD’s response is intended to include all aspects of managing and emergency situation until the emergency phase of the event is considered over.

As a part of emergency preparedness PPD developed a list of emergency response equipment along with equipment locations and the identified measures to be taken to notify members of public who may be adversely affected by an environmental emergency. Under the directive of Environment Canada PPD is intended to document a facility’s five year accident history including all accidental fuel releases that have resulted in personnel injuries, facility evacuations, sheltering in place, property damage and environment damage. By developing a site specific emergency plan PPD expresses its senior level commitment to environmental emergency planning measures that is critical both at territorial level and the fuel storage facility at Resolute Bay.

Under the recommendation of Environment Canada PPD did consultations with community, other interest groups as well as local and territorial authorities in the development and preparation of that plan and also shared the implemented plan with these persons. Communication of risks to surrounding communities is an essential component of both prevention and preparedness activities. PPD’s fuel delivery contractor got the responsibility to communicate the information on what the public should do in the event of an emergency and their ability to react appropriately is an essential component of preparedness. This kind of communication can help dispel undue fears over risk that may not be present and can also assure the community that risks that are present are under proper control.

However PPD may hold on some information whose wide spread can cause disarray and chaos among the masses and may lead to security issues. PPD is intended to arrange the drills and table top exercises to assess the applicability of emergency plan. These tests and exercises are a simulation of a possible emergency. Testing of the environmental emergency plan shows if the team can adequately deal with the scenario that is presented in the exercise. As a first step of exercise PPD informs those affected that a test being planned. This will enable responders and participants to react in the proper manner through adequate pre- planning. Once the skills and knowledge have been demonstrated, the scenario can be tested with only the exercise design team knowledgeable in advance.

PPD ensures that the testing reflects a credible type of event for fuel storage facility. PPD will design the exercise in such a way that it ensures the reinforcement of any previous training. PPD will do a post exercise evaluation, document the lesson learned and identify the areas where further improvement is possible. The type of exercise chosen depends on its purpose, availability of resources and the limitations of conducting exercises that apply to location of operations. Exercises can be either administrative or operational. Administrative exercises are usually held in a conference room environment and can be table top or synthetic. Synthetic exercises are pre-programmed exercises in which all participants use computers. Operation exercises include those where communication are tested and major or full blown exercises. A major exercise is similar in content to a table top exercise except that it is intended to provide a realistic simulation of an emergency response and all the required sources are actually deployed.

The exercise design process is composed of following main steps:

- Devising a multi-year program; a full blown exercise may not be necessary every year but should be conducted at least once as part of multi-year cycle
- planning the annual exercise
- Holding the exercise
- Evaluating the outcome
- Reporting on the outcomes

PPD stores three petroleum products at Resolute Bay storage facility but the emergency situations associated with all products are similar so PPD is intended to undertake only one exercise. The insights gain through these exercises are invaluable for PPD and its fuel contractor should a real emergency ever occur. Responding to an actual incident is not usually a valid or appropriate test of the emergency plan. An actual incident may be considered a test of environmental emergency plan only if certain conditions are met.

For an actual incident to be recognized as a test, it must include the appropriate agencies, proper debriefing and evaluation, corrective actions and documentation as in a typical exercise. It would be detrimental to apply untested plan as it may not be adequate to handle emergency at hand. Testing or exercising enables critical aspects of the plan to be examined in a structural way, simulating conditions to reveal major mistakes and omission so that they can be subsequently corrected without disastrous consequences. PPD's environmental emergency plan would be tested annually and record would be maintained on what went well and what didn't work.

4.2 Risk assessment:

A wide range of emergency situations are possible on fuel tank farm. In the event of an emergency first step is to assess the damage and devise a risk management strategy to limit the damaging effects. If incident results in fatalities or personnel injury then emergency responder will have their top priority to take the injured persons to health centre and close the area for public. Fuel delivery contractor may have to get involve local RCMP. Once all the affected people have been attended then Emergency Response Team will turn to protect the environment. Realizing the proximity of bay to the tank farm fuel would not let to migrate to shore line.

4.3 Emergency reporting protocol:

PPD as owner and fuel delivery contractor as operator of the fuel storage facility are jointly responsible to inform the environmental regulatory agencies and affected parties of the emergency situation.

4.3.1 Reporting to Environment Canada:

Section 201 of Canadian Environmental Protection Act, CEPA, 1999 requires that when an environmental emergency occurs for any of the substances on the list established on Schedule 1 under the *Environmental Emergency Regulations*, any person who owns or has the charge, management or control of the substance, immediately reports the emergency to EC enforcement officer. Within thirty (30) days of the emergency, a report is also to be submitted to EC. PPD's fuel delivery contractor as facility operator has the obligations to notify emergency to the Environment Canada within the same time frame. Environment Canada has different offices to be notified of the emergency.

Any environmental emergency within Nunavut would be reported to:

Director of Environmental
Protection Prairie and Northern region
Environment Canada
Twin Atria No. 2
210-4999 98th Ave
Edmonton AB
T6B 2X3

PPD HQ will prepare a written report on the emergency situation and the efforts made to respond the emergency and will send it to Environment Canada within 30 days of the incident. Here are the main content of that report:

- The names of owner (PPD) and operator (Fuel contractor) of the storage tank system
- EC identification number of storage tank system
- The date on which the spill occurred, if known
- The type of petroleum product that is subject of the report
- Quantity of the spilled product, if not known give estimate
- Description of circumstances of spill/leak
- Description of measures taken to contain, cleanup of the spill and to prevent subsequent occurrences

4.3.2 Reporting to 24 hour spill line:

PPD is not present in most of the communities so fuel delivery contractors represent the PPD at community level and these are the people who get to know about the emergencies first of all. Fuel delivery contractor prepare a standard spill report and fax it to 24 hour spill line.

24 hour spill line phone..867-920-8130
24 hour spill line fax...867-873-5763

Northwest Territories · Nunavut · Canada

NT-NU SPILL REPORT

OIL, GASOLINE, CHEMICALS AND OTHER HAZARDOUS MATERIALS

NT-NU 24-HOUR SPILL REPORT LINE
TEL: (867) 920-8130
FAX: (867) 873-6924
EMAIL: spills@gov.nt.ca

REPORT LINE USE ONLY

A	REPORT DATE: MONTH – DAY – YEAR	REPORT TIME	☐ ORIGINAL SPILL REPORT, OR	REPORT NUMBER
B	OCCURRENCE DATE: MONTH – DAY – YEAR	OCCURRENCE TIME	☐ UPDATE # ______ TO THE ORIGINAL SPILL REPORT	____-__________
C	LAND USE PERMIT NUMBER (IF APPLICABLE)	WATER LICENCE NUMBER (IF APPLICABLE)		
D	GEOGRAPHIC PLACE NAME OR DISTANCE AND DIRECTION FROM NAMED LOCATION	REGION ☐ NWT ☐ NUNAVUT ☐ ADJACENT JURISDICTION OR OCEAN		
E	LATITUDE DEGREES MINUTES SECONDS	LONGITUDE DEGREES MINUTES SECONDS		
F	RESPONSIBLE PARTY OR VESSEL NAME	RESPONSIBLE PARTY ADDRESS OR OFFICE LOCATION		
G	ANY CONTRACTOR INVOLVED	CONTRACTOR ADDRESS OR OFFICE LOCATION		
H	PRODUCT SPILLED	QUANTITY IN LITRES, KILOGRAMS OR CUBIC METRES	U.N. NUMBER	
	SECOND PRODUCT SPILLED (IF APPLICABLE)	QUANTITY IN LITRES, KILOGRAMS OR CUBIC METRES	U.N. NUMBER	
I	SPILL SOURCE	SPILL CAUSE	AREA OF CONTAMINATION IN SQUARE METRES	
J	FACTORS AFFECTING SPILL OR RECOVERY	DESCRIBE ANY ASSISTANCE REQUIRED	HAZARDS TO PERSONS, PROPERTY OR ENVIRONMENT	
K	ADDITIONAL INFORMATION, COMMENTS, ACTIONS PROPOSED OR TAKEN TO CONTAIN, RECOVER OR DISPOSE OF SPILLED PRODUCT AND CONTAMINATED MATERIALS			

L	REPORTED TO SPILL LINE BY	POSITION	EMPLOYER	LOCATION CALLING FROM	TELEPHONE
M	ANY ALTERNATE CONTACT	POSITION	EMPLOYER	ALTERNATE CONTACT LOCATION	ALTERNATE TELEPHONE

REPORT LINE USE ONLY

N	RECEIVED AT SPILL LINE BY	POSITION STATION OPERATOR	EMPLOYER	LOCATION CALLED YELLOWKNIFE, NT	REPORT LINE NUMBER (867) 920-8130

LEAD AGENCY ☐ EC ☐ CCG ☐ GNWT ☐ GN ☐ ILA ☐ INAC ☐ NEB ☐ TC | SIGNIFICANCE ☐ MINOR ☐ MAJOR ☐ UNKNOWN | FILE STATUS ☐ OPEN ☐ CLOSED

AGENCY	CONTACT NAME	CONTACT TIME	REMARKS
LEAD AGENCY			
FIRST SUPPORT AGENCY			
SECOND SUPPORT AGENCY			
THIRD SUPPORT AGENCY			

Figure 4.1: spill report

4.3.3 Reporting to Transport Canada:

If fuel spill occurs during offloading it from a vessel and some fuel is likely to enter the sea water, the owner or/and operator of the facility is also obligated to report the spill to Transport Canada and prepare a report to be sent as soon as possible. Carrier Company is also under obligation to do the same reporting from their end.

Either PPD or PPD's fuel delivery contractor shall provide the following information to TC in the initial report:

- Specific location - name of shipper involved
- Type of incident - leak, spill, fire or no fire
- Extent of spill, leak or fire

4.3.4 Reporting to Environment Protection Nunavut:

The office of director of Environment Protection, DOE, and Nunavut is a territorial regulatory body to ensure the environmental protection. PPD always informs DOE in case a spill occurs. PPD also shares Environmental Site Assessment Reports on fuel storage facilities with Department of Environment Nunavut. Site specific Remediation Plans are also developed in collaboration with DOE office.

4.3.5 Notification to Community Stakeholders:

PPD's Environmental Emergency Plan includes the measures to be taken to notify members of the adversely affected public in the case of an emergency. This could involve the use of emergency announcements on local radio and television, door- to-door notification and/or the use of emergency e-mail and text messages.

Depending upon the severity of the emergency situation PPD's fuel delivery contractor will call for assistance from the other community stakeholders such as local Fire Department, the Nursing Station, the RCMP, and Public Works or Hamlet Maintenance staff.

Here is the list of important community stakeholders to be notified as soon as possible:

Fire Department..867-252-3333
RCMP..867-252-0123
Nursing Station..867-252-3844
Public Works..867-252-9953
Hamlet Office..867-252-3616

Wildlife/Environmental officer	867-439-9945
Airport	867-252-3981
Nunavut Power corporation	867-252-3626
Radio station	867-252-3664

4.3.6 Reporting to PPD:

Regional Head PPD Field Operation Kitikmeot	867-983-3145
Manager, Nunavut Field Operations	867-645-8443
PPD Maintenance Coordinator	867-645-8442

PPD fuel delivery contractor shall call the Regional PPD Head (formerly known as the Regional PPD Officer) with an account of the cause of the incident and what action was initiated to control situation. The Regional PPD Head shall call the Manager of Nunavut Field Operations with an account of the emergency situation. The Manager of Field Operations shall share the information with the Director of Petroleum Products Division Headquarters Rankin Inlet. Once PPD's Director is fully aware of the situation he will involve the other staff from PPD's operation to fully control the situation.

4.3.7 Reporting to Canadian Coast Guard

Excerpts from the CCG Letter of Promulgation:

"Through legislation such as the *Canada Shipping Act*, the *Arctic Waters Pollution Prevention Act*, the *Oceans Act*, and subject to various inter-agency agreements, the Canadian Coast Guard of the Department of Fisheries and Oceans has lead agency responsibility for ensuring responses to ship-source spills, mystery spills, and ship-source pollution incidents that occur as a result of loading or unloading to or from ships at oil handling facilities in waters of Canadian interest".

The Canadian Coast Guard *Marine Spills Contingency Plan* defines the scope and framework within which the Canadian Coast Guard will operate to ensure a response to marine pollution incidents. The polluter is expected to respond to incidents, while the Canadian Coast Guard will monitor and, whenever necessary, augment or assume management of the response when it is in the interest of the public. The Canadian Coast Guard also provides assistance to other federal, provincial, territorial or local agencies.

The Canadian Coast Guard *Marine Spills Contingency Plan* is divided into the following three chapters:

- National Contingency Chapter, which establishes the Canadian Coast Guard policy for the conduct and procedure for monitoring a polluter-led response or responding to a marine pollution incident for which it is the lead agency or where it supports another agency leading the response;
- Regional Contingency Chapter, that corresponds to the Canadian Coast Guard regional geographic areas of responsibility and which translates policy direction into operational measures appropriate to the geographic area;
- Area Contingency Chapter, which is local level, plans pursuant to the Regional Contingency Chapter.

The custodian for the overall coordination of the Canadian Coast Guard *Marine Spills Contingency Plan* is the Director General, Rescue, Safety and Environmental Response, Canadian Coast Guard Headquarters, Ottawa.

David B. Watters
Commissioner

4.4 Response strategy:

On the discovery of a leak/spill or fire a response strategy is to be developed by Emergency Response Team and PPD's fuel delivery contractor got the responsibility to set the priorities to safeguard health and safety of his personnel and general public. Initial actions should be directed toward the tactical priorities listed below:

- Action should proceed cautiously
- High level of safety
- Avoid committing personnel to dangerous situations

Most incidents at the Tank Farm complex will involve either a constant leak or a massive spill of a petroleum product. The situation may or may not involve a fire.

4.4.1 Tactical priorities:

- Ensure that GN and contract employees are not within a hazardous atmosphere or have the potential to be exposed.
- Cover the spill with absorbing pads or foam blanket to control fire and/or prevent ignition.
- Control potential sources of ignition.
- Have a trained personnel monitor the foam blanket to determine its effectiveness.
- Contain the spill or run-off.
- Identify and control the source of the spill or leak.

- Maintain foam blanket until product can be picked up. Keep all personnel and vehicles out of the spill area.
- Maintain an adequate volume of foam solution on scene for the duration of the incident.

4.4.2 Assessment & notification:

This is the process by which the event is assessed for its response requirements and the necessary personnel and resources summoned along with meeting the notification requirements.

- Have the necessary agencies been notified?
- Have people been notified and moved to safety?
- Are rescue or evacuation efforts required?
- Are medical services on their way?
- Are escalating factors identified and controlled?
- Do threats exist to nearby populations contained?
- Has the nature and effects of the event been fully assessed?
- Have damaged utilities been shut off?
- Are there any critical services, which need restoring immediately?
- Are any hazardous materials located at the site?

4.4.3 Remedial measures to fuel leak:

At Resolute Bay tank farm all tanks and piping are aboveground installation so regular visual inspections are performed on them for leak detection. On the discovery of any stains of fuel near the tanks, PPD's contractor will immediately inspect the walls and floor of the tank thoroughly.

On the confirmation of leak, the leaking component will be isolated from the rest of system and will not put in service until fully repaired but the remaining system could be stay in operation. If the isolation of leaking component is not possible, then the whole system will be withdrawn from service until the leak is repaired.

Sometimes it may not be possible to withdraw the leaking component from service, in this case PPD's contractor will do:

- immediate measures will be taken to reduce the amount of fuel entering into the environment to minimize any short-term or long-term harm to the environment and/or danger to human life or health

- Environment Canada will be notified in writing of circumstances that had made the withdrawal of leaking component impossible and the measures taken to comply with the EC requirements.

4.4.4 Spill containment efforts:

Whole fuel storage facility has been provided with secondary containment in the form of lined, bermed and fenced area. Additionally a big spill catchment basin is available to contain a large spill on the facility. It is highly unlikely for a spill to migrate beyond the lined area but it is still imaginable so a strategy must be devised to deal with a spill that has a potential to affect sensitive marine environment of the east side of the facility.

The scale of efforts to be initiated to contain the spill depends upon the magnitude and location of spill.

- If it is a small spill (under 100 L) within the lined area, fuel contractor's response team will disable the source of spill and use absorbing pads and rolls to clean up the visible fuel and dump the used spill kit supplies to a drum.
- If there is a spill greater than 100 L but within lined area, spill will be cleaned as described above and contaminated soil/snow will be hauled to spill catchment basin.
- If spill goes beyond the tank farm lined area, it will be cleaned by absorbing pads; efforts will also be made to transfer the spilled products into drums which later would be emptied in a slop tank. If fuel is absorbed in snow, contaminated snow will be hauled to catchment basin. If it is a summer time and fuel is absorbed in the soil, a formal ESA study will be conducted on the contaminated area and soil remediation will be done, if deemed necessary.
- Measures will be taken not to let the contamination spread beyond the catchment basin especially during spring freshet. A detailed snow management and removal plan will be developed and implemented on catchment basin.
- In case of a massive spill out of the lined area, besides executing the regular spill response, help will be asked from other community stakeholders as well as from PPD. If there is a suspicion of fuel migration to sensitive marine environment, a barrier wall or trench will be made to hinder the possible movement of fuel towards the shoreline.

4.4.5 Strategic Partners for Cleanup Operation:

In case of small leak or spill, PPD's fuel delivery contractor should be capable of cleaning operation but when there is a massive spill; situation may be out of his control.

The clean-up strategy will be discussed with the following personnel:

- Manager, Nunavut Field Operations, PPD
- Manager, Local Heavy Equipment Company
- Head, PPD Kitikmeot Field Operations
- PPD Maintenance Coordinator
- Local Wildlife/Environmental Officer
- Local Senior Administrative Officer (SAO) Local Fire Chief

The clean-up strategy will determine the following information:

- An estimated cost for materials and labour
- An estimated time-frame from start to finish of the clean-up
- A contaminated storage site with the assistance of the SAO, the Fire Chief, the Wildlife/Environmental Officer and Head, PPD Baffin Field Operations
- The Fire Chief and the Wildlife/Environmental Officer will determine if the spilled product can be incinerated.
- If storage containers are to be used, the PPD Manager of Field Operations will be consulted.
- The Wildlife/Environmental Officer will be notified of the contaminated storage location.

If a Clean-up Strategy meeting cannot be arranged the following steps will be taken to ensure immediate clean-up procedures.

- Use sorbent material to soak up the spilled product.
- Place the soaked material into empty 45 gallon drums.
- If drums are not available, find a non-flammable container to place the material, until it can be removed from the site.
- Contact the local Wildlife Office to determine a suitable site to store or dispose of the contaminated gravel or sorbent material.
- Contact the Hamlet Office and advise them of the contaminated storage site approved by the Wildlife Office and confirm their written approval.
- When the clean-up is completed have a Hamlet and DOE representative inspect the site. If the contaminated product is to be kept in storage and will be moved at a later date, the GN Department of the Environment will be sent a written notice.
- The Wildlife/Environmental Officer will close the file when he is satisfied with the completion of the clean-up operations.
- A copy of the Spill Closure will be sent to the Manager, PPD Field Operations

A level one response usually involves a response using only on-site resources with the expectation of escalation being limited or unlikely. An example of this level of response would be a minor spill. The Emergency Management Team shall be notified but not assembled for the purpose of a level one response.

A level two response requires support from outside authorities. These types of incidents may result in the evacuation of PPD facilities. The Emergency Management Team shall be notified and shall respond to ensure the safety of all staff and general public. The Emergency Management Team may be called upon to activate the Emergency Operations Centre or attend. Any communications to media or stakeholders shall be done only with the approval PPD Director or designate.

A level three response is an unusual and serious event that requires extensive support from outside authorities or agencies. This type of response may result in the evacuation of PPD facilities. An example of this level of response would be a large fuel spill or fire.

- The Emergency Management Team may be called upon to activate the Emergency Operations Centre.
- Any communications to media or stakeholder shall be done only with the approval of PPD Director or designate.

NOTE: A large spill can create an extremely large vapor problem and may flash back from ignition sources at significant distances. While covering the spill to suppress vapors, the direction and extent of vapor travel must be determined.

4.4.6 Controlling a fire at tank farm:

When attempting to control a large flammable liquid fire, the strategy should be to wait until enough foam concentrate to control the fire is on the scene before beginning the attack. If the attack runs out of foam before the fire is controlled, all of the foam will have been wasted. The minimum foam solution supply and the total amount of foam water solution required for each storage tank has been calculated and is available in the Storage Tank Tactical Guidelines.
Foam 34 carries approximately 400 gallons of Class A Foam and 200 gallons of Class B Foam. Foam Tanker 34 carries approximately 1,000 gallons of 3% AFFF-6% ATC concentrate. Foam 44 carries approximately 400 gallons of Class A Foam and 200 gallons of Class B Foam.

Fires which are controllable with the foam supply on hand should be attacked without delay. This applies to most spill fires and tank vehicle incidents. If the fire is too large to be controlled by the initial attack capability, PPD's contractor will ask the help from local fire department and other community stakeholders. At the same time contractor should consider a holding action to protect exposures and prevent spread until additional foam supplies can be assembled and prepared for use.

4.4.7 Substantial loss of fuel:

If there is a total loss of fuel but no devastating fire resulted, even then there will be an emergency situation because fuel is life line for every community including Resolute Bay. All the buildings and houses are heated by diesel, electricity is generated by diesel and air travel depends on PPD fuel supply. Once the fuel is short all of the services will get suspended and life would be a nightmare in the community. To deal with this sort of emergency we need to fetch fuel by airlift from neighboring communities to sustain life activities for few days. It is not possible to get fuel from refineries in few days. It will take at least three weeks to bring the fuel from refineries located in Southern Canada but most likely it will take more because refineries may not have the fuel handy which could meet our specs, especially in winter when sealift is impossible due to frozen water.

If such emergency situation arises in Resolute Bay, fuel would be airlifted from Grise Fiord, Arctic Bay, Pond Inlet, or Iqaluit to meet the community needs for maximum couple of weeks because each community has a limited supply of fuel for its own needs. To survive throughout the year, an immediate order would be placed to the appropriate refineries to produce the fuel that we need on urgent basis. PPD would make all of these arrangements with the assistance of other departments of GN.

4.5 Tank Farms Fire Hazards Analysis (FHA)

The revised Tank Farms Fire Hazards Analysis (FHA) evaluates the spectrum of fire and related hazards for the bulk fuel storage facilities in relation to existing safeguards and fire protection program features. The conclusions of the analysis dictate that the fire risk associated with the Tank Farms is within acceptable limits, an adequate margin of fire safety exists, and fire protection defense in depth (DID) has been provided in accordance with applicable fire safety criteria.

The conditions in place are deemed not to be safety significant and that a comparable level of safety has been achieved through the implementation of a multifaceted fire safety program. Fire and related hazards associated with the Tank Farm facilities are both delineated in the FHA and described elsewhere in corresponding documents and related studies. They include a spectrum of common hazards, such as conventional ignition of ordinary combustible materials, through various scenarios associated with the ignition of off gases related to stored waste, among other accidents. For each of the hazards, PPD has evaluated the risk associated with credible (and beyond credible) events.

Similar analyses have already been conducted by a diverse group of qualified and experienced fire protection engineers, accident analysts, and supporting experts. Resulting from these analyses and consistent with Integrated Safety Management principles, appropriate safeguards could be implemented with the intention of minimizing the occurrence of an ignition or limiting the consequences of a fire or related event if one should occur. In addition to a range of specific fire prevention and protection features, fire safety could be achieved through design and operational safeguards, such as tank ventilation systems and equipment inspection, testing and maintenance programs. No single safeguard is relied upon to assure an adequate margin of safety. The fire protection program that has been recommended by different regulatory agencies for the Fuel Tank Farms is multifaceted. It includes, among other attributes, a range of fire prevention measures, such as combustible material and ignition source controls.

It also manifests both passive fire safety features (such as fire barriers within buildings and combustible free zones around facilities) and active fire protection systems for facilities (principally fire suppression and detection systems). As a risk management outcome, PPD has established a clear understanding on how to control and emergency on tank farms. The overall program encompasses the training of employees in hazard recognition, fire prevention, and emergency response. It includes a number of fire protection engineering related activities such as routine fire safety assessments of all facilities, the review of planned modifications to assure conformance to fire applicable standards, and the development of hazards analyses for work activities. All are intended to minimize the risk from fire and related events.

The capacity of these systems is sufficient to suppress any credible fire as confirmed by water flow tests and is suitably redundant to avoid interruption as a result of a single component failure. The fire protection systems are provided to correspond with and mitigate distinct fire hazards associated with these facilities. PPD has provided portable fire extinguishers of appropriate type to fuel delivery contractor. PPD’s contractor got the responsibility to get them certified annually by the office of Fire Marshal and make them readily accessible to those trained in their use. Ignition sources, such as energized electrical equipment, smoking materials, cutting torches, etc. are also controlled in such a manner as to minimize the potential for ignition and the development of uncontrolled fires. To assure that the contractor’s staff and general public are capable of evacuating any gas station in the event of a fire, proper notification system is in place

Chapter: 5
Health and Safety

Health and Safety

5.1 SITE CONTROL

In the event of an Oil Pollution Incident (OPI), an immediate assessment will be made to ensure that the site is secure. Oil Pollution Incidents (OPIs) can attract curious onlookers, and the site must be controlled in such a way as to ensure that they are kept well outside any hazardous-area zone. Only those directly involved in the containment, control or cleanup of the Oil Pollution Incident (OPI) should be allowed in the general vicinity of the spilled product.

This rule is very important as there are many issues surrounding the possible injury of non-authorized and unqualified individuals. Insurance, liability, capability and general health and safety of the public are a few. If the Oil Pollution Incident (OPI) escalates to involve the services of the Canadian Coast Guard (CCG), the Canadian Coast Guard (CCG) will have an established Health and Safety protocol.

a) Fires:

There will be two fully charged 20 lb. Class ABC fire extinguishers and a hand-held horn to alert personnel. This is an integral part of the response equipment.

b) Slippery rocks, decks or other wet surfaces:

All Persons working on an Oil Pollution Incident (OPI) must wear oil-resistant rubber steel-toed safety boots with textured bottoms while working on a cleanup site.

c) Work on or near water:

All persons working on docks, piers, jetties or in close proximity to the water must wear the appropriate Personal Flotation Devices (PFDs). Persons working on shore near water do not have to wear PFDs unless they are actually working over the water.

d) High noise exposure:

All personnel must wear hearing protection when operating equipment or machinery or when in areas where noise levels require personnel to raise their voices to be heard.

e) Buddy System:

A buddy system must be observed at all times when workers are in the work area.

Persons must work within sight of their assigned partner (buddy) at all times.

f) Personal Protective Equipment (PPE) requirements:

Selection of outer PPE will be based on the potential for whole body contact with the product. A potential for repeated contact will require rain gear (top/bottoms). Clothing will be kept fully zippered when handling those materials. Supervising personnel may authorize the removal of suit tops if there is not potential for upper body contact. Personnel with high body-contact potential will tape gloves and boots. Personnel with limited skin contact potential may wear disposable clean guard garments or equivalent.

Personnel with no exposure potential (inspectors, monitors etc.) need not wear protective clothing. All personnel on shore cleaning operations will wear safety glasses (regular glasses will be satisfactory). Personnel handling contaminated materials will wear outer chemical resistant gloves. Sleeves will be taped whenever handling heavily contaminated wet materials. This will happen during removal of oil-soaked sorbents or shoveling oil-soaked snow and dirt.

g) Hypothermia:

Hypothermia is a condition of having the body temperature fall below 36°C (96.8°F), at which point the individual will likely suffer reduced mental alertness, reduction in rational decision-making and loss of consciousness with the threat of fatal consequences.

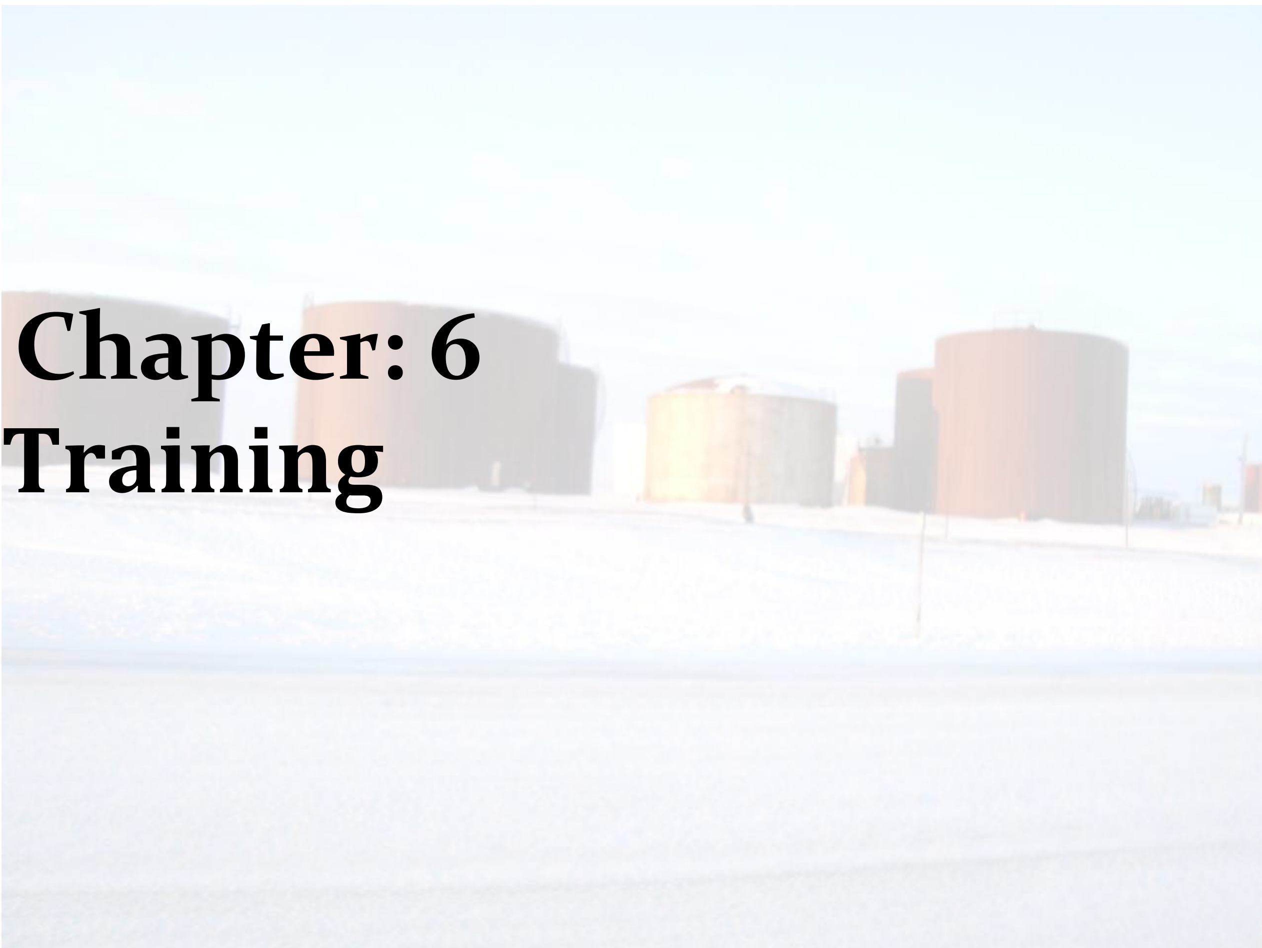
5.2 Protection to the Community:

Any significant spillage of product such as diesel may cause a significant threat to the community if the vapour plume approaches a populated area. Based on the wind direction a determination of the potential area of impact will be made and the community notified of any potential hazard. If the spill approaches or enters a watercourse, lake or ocean the community will be notified of any potential hazard to drinking or recreational activities.

5.3 Decontamination:

Adjacent to, or near the Oil Pollution Incident (OPI) zone, decontamination stations will be established. The decontamination stations will be laid out so that personnel will pass through the station prior to leaving the contaminated area. The decontamination stations may be bermed and lined with plastic sheeting. Washing solutions may be placed near the "Oil Pollution Incident Zone". All solutions in tubs will be clearly marked.

Note: Notwithstanding the preceding, all applicable health and safety rules, regulations, and legislation will be adhered to. The health and safety specialist will be consulted as well as any other staff that may possess expertise regarding the health and safety of all involved.



Chapter: 6
Training

Training

6.1 Regular training:

A significant number of the spills that occur at aboveground storage tank facilities result from improper procedures during routine activities. These accidents can be reduced or eliminated if operating personnel are properly trained about correct safety procedures and the importance of following them to prevent injury and environmental incidents. Training must be periodically followed up to ensure that proper procedures are being followed. All employees will be trained in their roles and responsibilities under the emergency response program and will participate in emergency exercises annually. Following trainings are to be received by all members of Emergency Response Team:

- WHMIS
- First Aid
- CPR Level C

Employees who are involved in transporting the fuel especially fuel truck drivers need additional training programs:

- TDG, Transport of Dangerous Goods
- SOTO, Supervisor for Oil Transfer Operation
- Aviation Fuel Handling Training

New or transferred employees shall receive orientation on the emergency response procedures as part of their general workplace safety orientation. They should receive Emergency Response Plan, participate in Emergency Exercises and receive Safety Briefing.

In the next chapter PPD has listed the people designated to carry out environmental emergency plan along with their roles and responsibilities in an emergency. PPD is intended to conduct an emergency exercise at least annually to ensure the emergency response plan is current, comprehensive and effective.

6.2 Responder Training:

The success of any Oil Pollution Incident (OPI) response depends on a clear mandate as to expectations and adequately trained personnel. The level of training has to be tailored to the functions to be performed and the skills of the individual. In this case of the Facility, it provides specific training to the Facility employees. For all ship to shore fuel transfers, all employees are trained in the Supervisor of Oil Transfer

Operations (SOTO) course. It is assumed that if the Canadian Coast Guard (CCG) is called in, its employees and contractors are adequately trained.

6.3 Training For Casual Employees:

PPD hires casual employees from time to time to help the regular staff during resupplies and other O&M works. Casual employees will be trained based on the program PPD has in place to comply with applicable health and safety requirements. Upon hire, every employee and contractor will receive a safety orientation and copy of the PPD Safety Rule Book. PPD has a strict non- smoking policy during fuel handling and in the fuel storage facilities.

6.3.1 Short-Notice Employees/Volunteers:

Incase PPD should hire short-notice employees or use volunteers; they will be used in specific jobs working under the direction of a qualified person. PPD will ensure that these persons receive the Basic Health and Safety Training Course.

6.4 Response Training For Short-Notice Employees/Volunteers:

During oil spill incident, contractors, short-notice employees and volunteers may be called upon to assist in the control, recovery or disposal of the spilled fuel. Before anyone is allowed in what is considered the “HAZARDOUS AREA”, appropriate training /orientation will be given by a trained official.

6.5 Training Exercise:

PPD will ensure fuel handling staff should be trained for Environmental Emergency Plan. Training may consists of Mock exercises in the form of tabletop or an operational exercise. The training exercises serve the purposes of training personnel, evaluating the ability of the staff to respond to a spill, and demonstrating the ability to respond to a spill. The result of a training exercise should be to identify areas for improvements for the existing contingency plan and the application of the contingency plan.

6.6 Tabletop Exercise/In Class Exercise:

A tabletop exercise is mainly theory. Tabletop exercise can be organized during a meeting of the operational staff in the regional offices.

Prior to proceeding for tabletop exercise, Environmental emergency plan should be reviewed and discussed to make sure everyone understands the information. A tabletop exercise consists of writing a spill scenario and goes through the steps in dealing with the spill using environmental emergency plan. A thorough discussion should be held and improvement if required be made to the environmental emergency plan.

6.7 Operational Exercise :

Operational exercise training involves the deployment of resources required to test the emergency plan. Equipment required for emergency plan is deployed and will indicate the knowledge and readiness of the responder but of the equipment used for containment and clean-up. Operational exercise is designed in the stages of programming, planning, conducting and reporting of a spill scenario.

Operational exercises will be organized in the regional offices to make sure responders can make best use of time and resources.

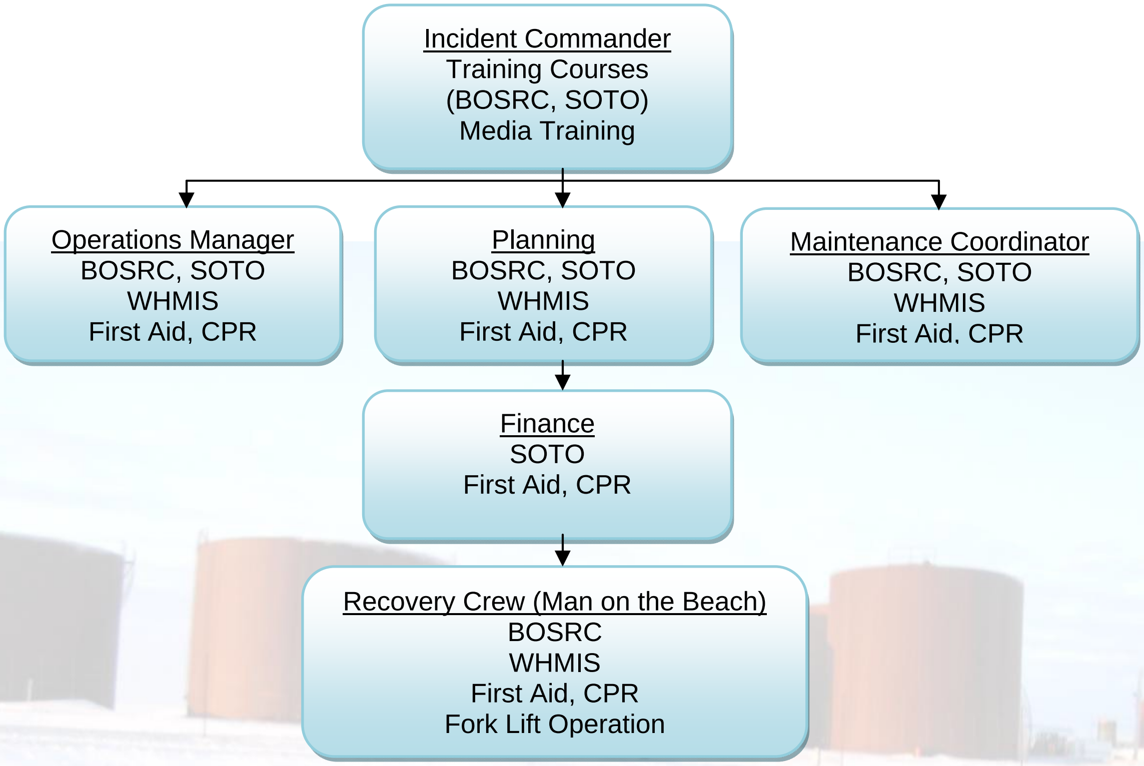
6.8 Basic Health And Safety Training Course:

This course will help understand response personnel with the information and knowledge to understand the health and safety issues associated with the provision of spill response services.

This course is designed and outlines the responsibilities of both the employer and the employee concerning health and safety at the work site, explains the hazardous associated with petroleum products and safety procedures associated therein.

Training - Basic Standard Organizational Chart

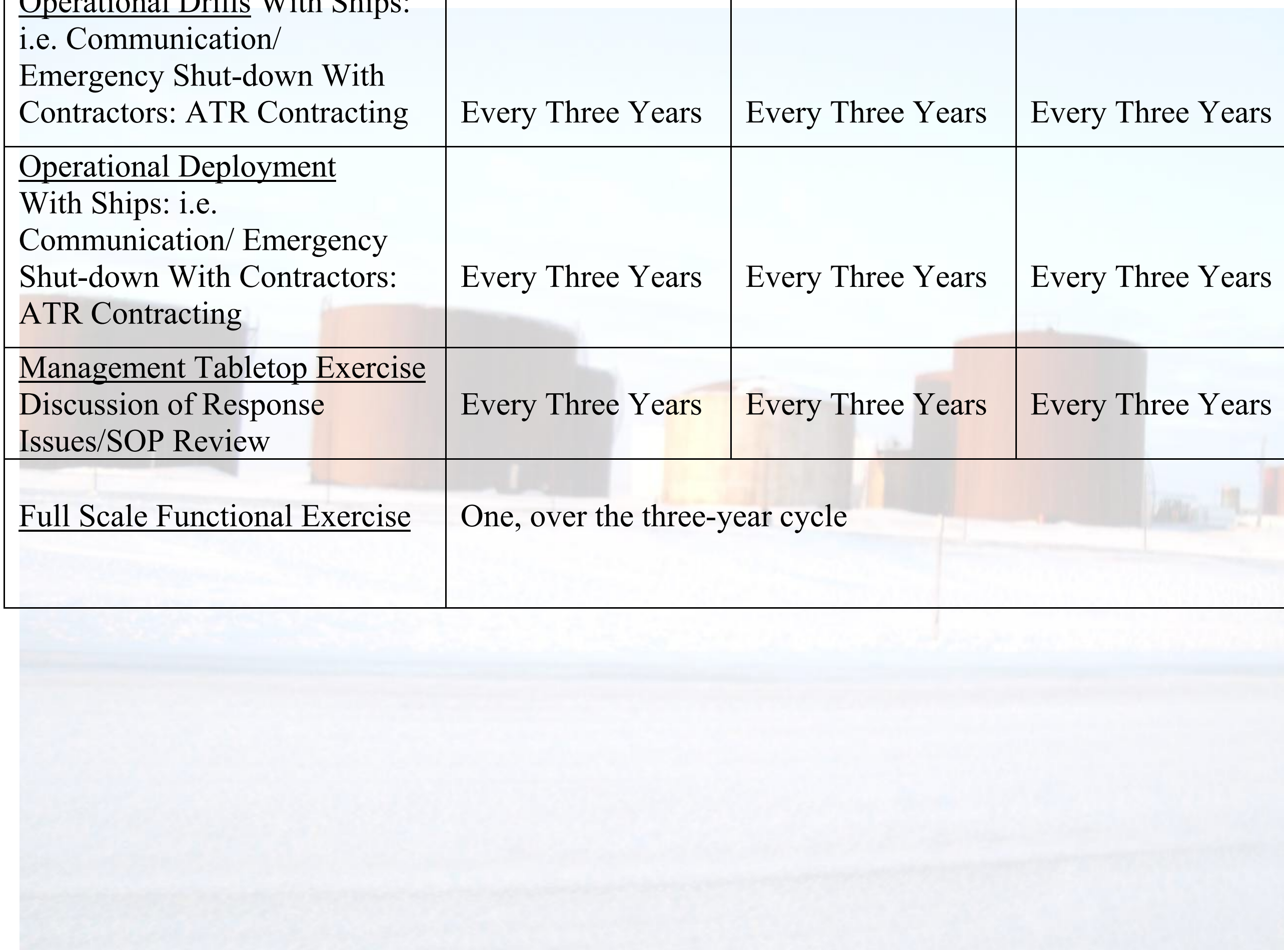
Note: courses identified
Refresher course every three years



BOSRC*- Basics of Oil Spill Response Course*
SOTO*- Supervisor of Oil Transfer Operations Course*
WHMIS*- Workplace Hazardous Materials Information System*
CPR*- Cardiopulmonary Resuscitation*

Training /Exercise Programme

ACTIVITY DESCRIPTION	YEAR 1	YEAR 2	YEAR 3
Internal Notification Exercise External Notification Exercise	Every Two Years Every Two Years	Every Two Years Every Two Years	Every Two Years Every Two Years
Operational Drills With Ships: i.e. Communication/ Emergency Shut-down With Contractors: ATR Contracting	Every Three Years	Every Three Years	Every Three Years
Operational Deployment With Ships: i.e. Communication/ Emergency Shut-down With Contractors: ATR Contracting	Every Three Years	Every Three Years	Every Three Years
Management Tabletop Exercise Discussion of Response Issues/SOP Review	Every Three Years	Every Three Years	Every Three Years
Full Scale Functional Exercise	One, over the three-year cycle		



PPD Personnel Training Record

Name & Position	Course & Training	Expires DD/MM/YY	Community	Comments

Chapter: 7 Communication

Communication

7.1 Communication during emergency:

There is nothing more important during an emergency than effective communication. All crises will eventually end either in a positive or somewhat negative way. Effective communication can often help hasten the end of an emergency and minimize any negative after-effects. Communication is a critical part of emergency management. GN officials, PPD Staff, contractors and the media expect to be informed promptly about any emergency situation, with up-to- date and accurate information. Immediately upon becoming aware of any emergency the senior management of PPD and/or the Emergency Management Team shall be notified, as laid out in notification section. If needed, Emergency Management Team shall be assembled in the Emergency Operations Centre, this centre could be a virtual conference, to decide a course of action for the event that is ongoing, has taken place or is about to take place. PPD director or some higher official within GN & CGS department will appoint someone as a Public Information Officer. This Public Information Officer, or designate should take the time to prepare a written statement for release. It is very important to stay away from verbal *off the cuff* communications during an emergency. A report should be a clear, concise statement of the basic facts, including: who was involved, where it happened, when, why (if known), and what is being done in response to the situation. If the occurrence is ongoing, the Public Information Officer or designate should indicate how frequently he/she will provide updates and when the next one will come.

7.1.1 Communicating with PPD's Staff:

When an unpleasant incident, emergency, or disaster occurs the staff should be informed by the Emergency Management Team or designate as quickly as possible regarding the emergency, the response and how it will affect the PPD operations. Staff members should also be informed of any role they may be asked to play either during or after the emergency. Staff members shall be updated as the situation develops.

All inquiries made to staff members during an emergency shall be referred to the Public Information Officer or designated spokesperson. Staff members should explain to the person or media member asking the question(s) that the spokesperson will handle all the dissemination of information and is more up to date with the situation and therefore better qualified to answer any questions. If more than one spokesperson addresses the media, make sure that all are using the most current facts and that messages are consistent in consultation with the Public Information Officer or designate. The staff shall receive all messages being distributed; staff should read them and become familiar with them.

7.1.2 Communicating with other contractors:

When an unpleasant incident, emergency, or disaster occurs the PPD's fuel delivery contractors should be informed by the Public Information Officer or designate as quickly as possible regarding the emergency, the response and how it will affect the PPD operations. Fuel related emergencies in one community can have a potential to affect the PPD's operation in other communities. Fuel delivery contractors share the problems and responses to emergency situation. If as a result of an incident fuel is lost in one community then PPD may have to look for another community to fetch the fuel from to meet the needs of affected one. Emergency response supplies and even trained personnel could be shared to effectively manage the emergency situation.

7.1.3 Emergency Communication and the Media:

An emergency generates rumors, speculation, and misinformation. It is how the PPD officials handle the emergency and how they are portrayed as handling it in the news media that will directly affect their credibility and reputation. It is up to the Public Information Officer or designates to provide the media with accurate information about the emergency and what PPD is going to do about the emergency.

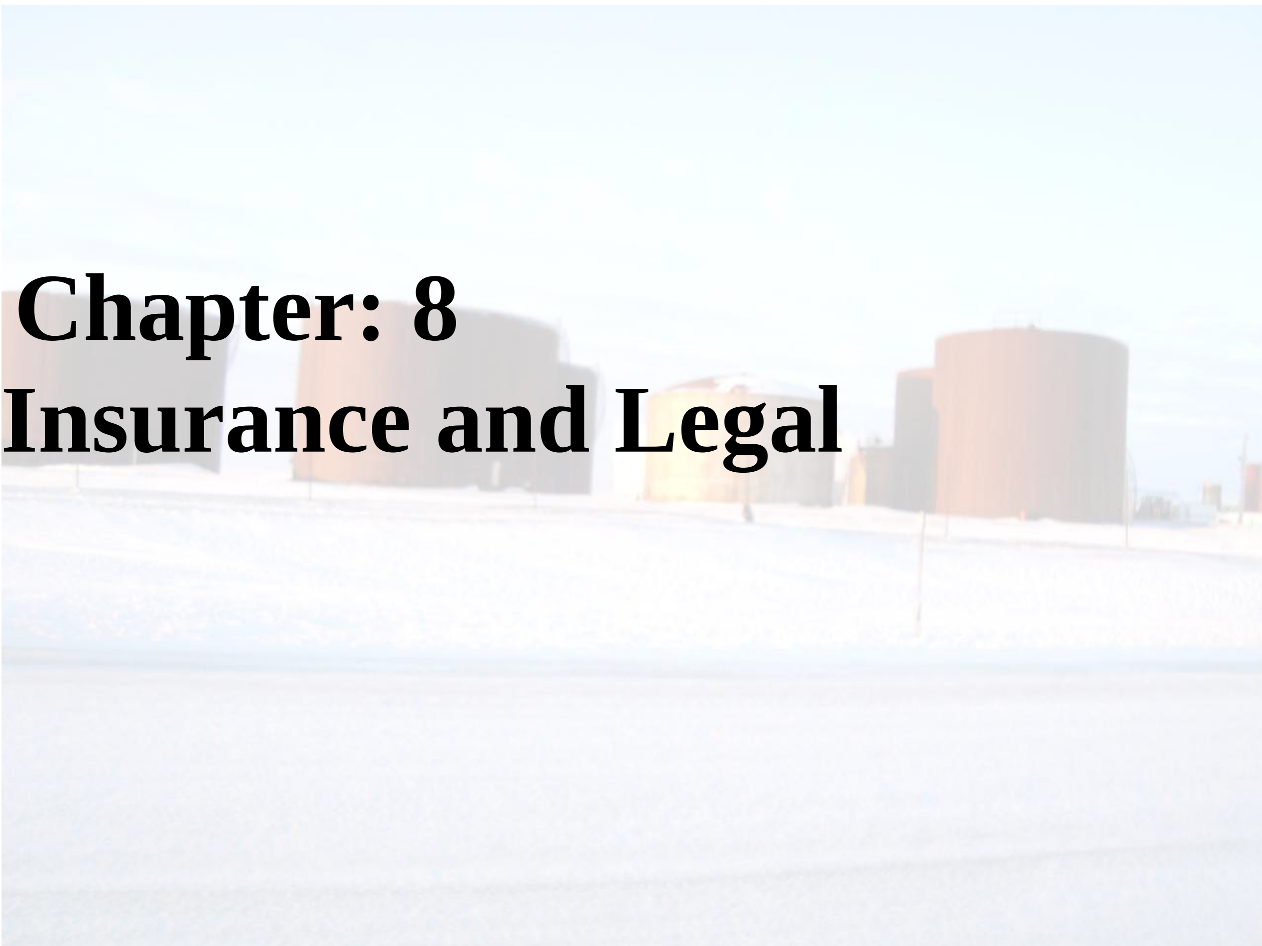
The primary communications goal is to keep the public informed about the emergency while protecting the reputation of PPD and its officials as competent, sensible, responsible, and caring. Special care must be taken during the emergency communication to maintain staff privacy and avoid disruption to normal PPD operations. Any communication with the media during an emergency should be done in consultation with the Public Information Officer, or designate of PPD.

7.1.4 The Role of the Spokesperson:

The Public Information Officer, or designate should be prepared to come under news media scrutiny. As GN officials, they must be prepared for media coverage, not all of which will be flattering about the GN or its policies. One person should be designated as the media spokesperson and contact. Sometimes during the event the PPD Director or designate will be required to speak with the media. If or when this situation occurs the PPD Director or designate, shall consult with the Public Information Officer and review all media reports that have been issued.

The Public Information Officer should:

- be familiar with the media and the media's relationship with the PPD;
- be relaxed, calm, confident, and credible;
- be accessible, open, transparent, trustworthy, and truthful;
- know what is being done to help cope with the situation and show empathy and be supportive;
- anticipate questions and prepare possible responses, including the description of the event itself and engage stakeholders;
- consult with subject matter experts for information and support; should be reflective of PPD's organizations culture and reputation



Chapter: 8
Insurance and Legal

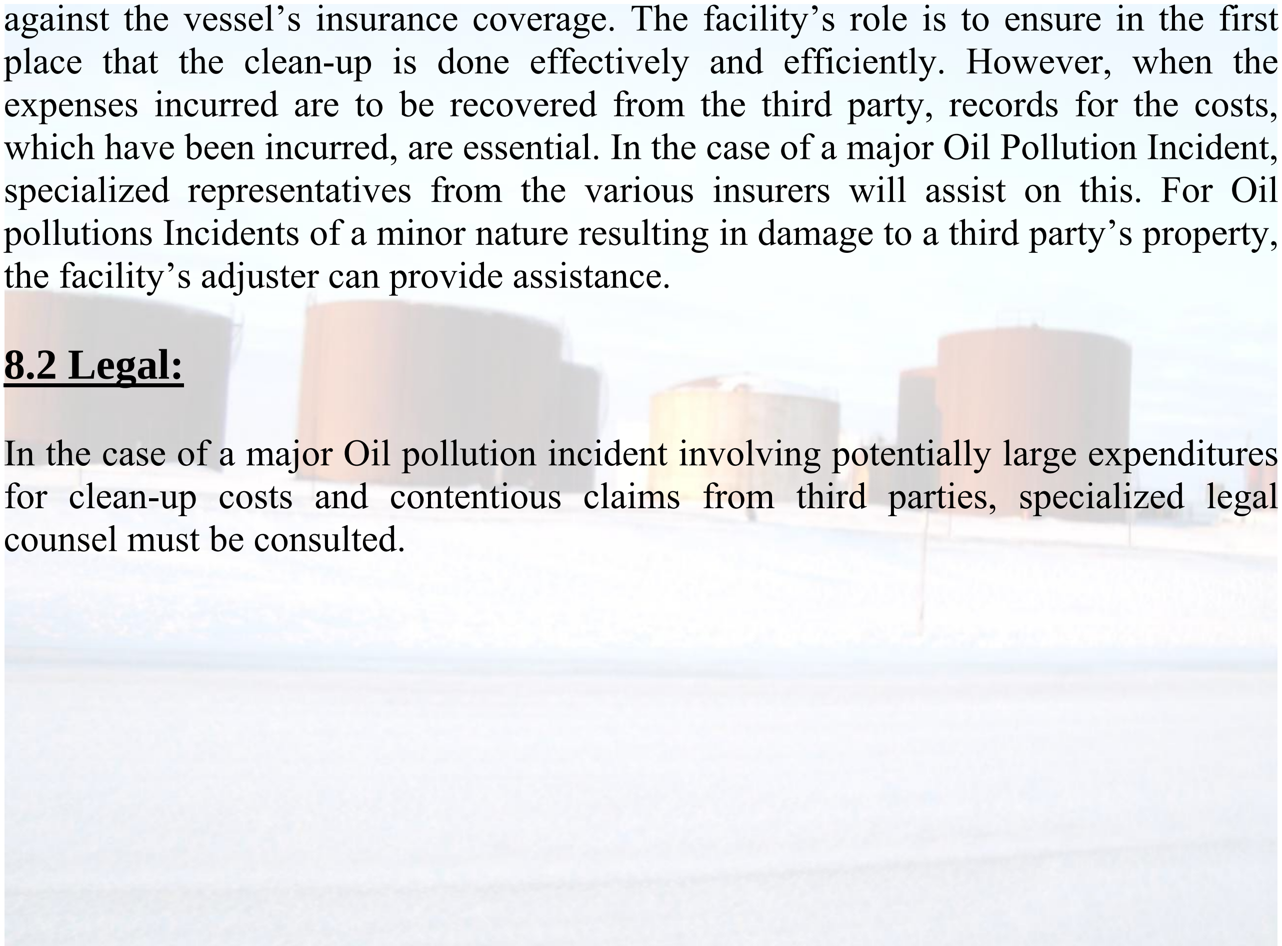
Insurance & Legal

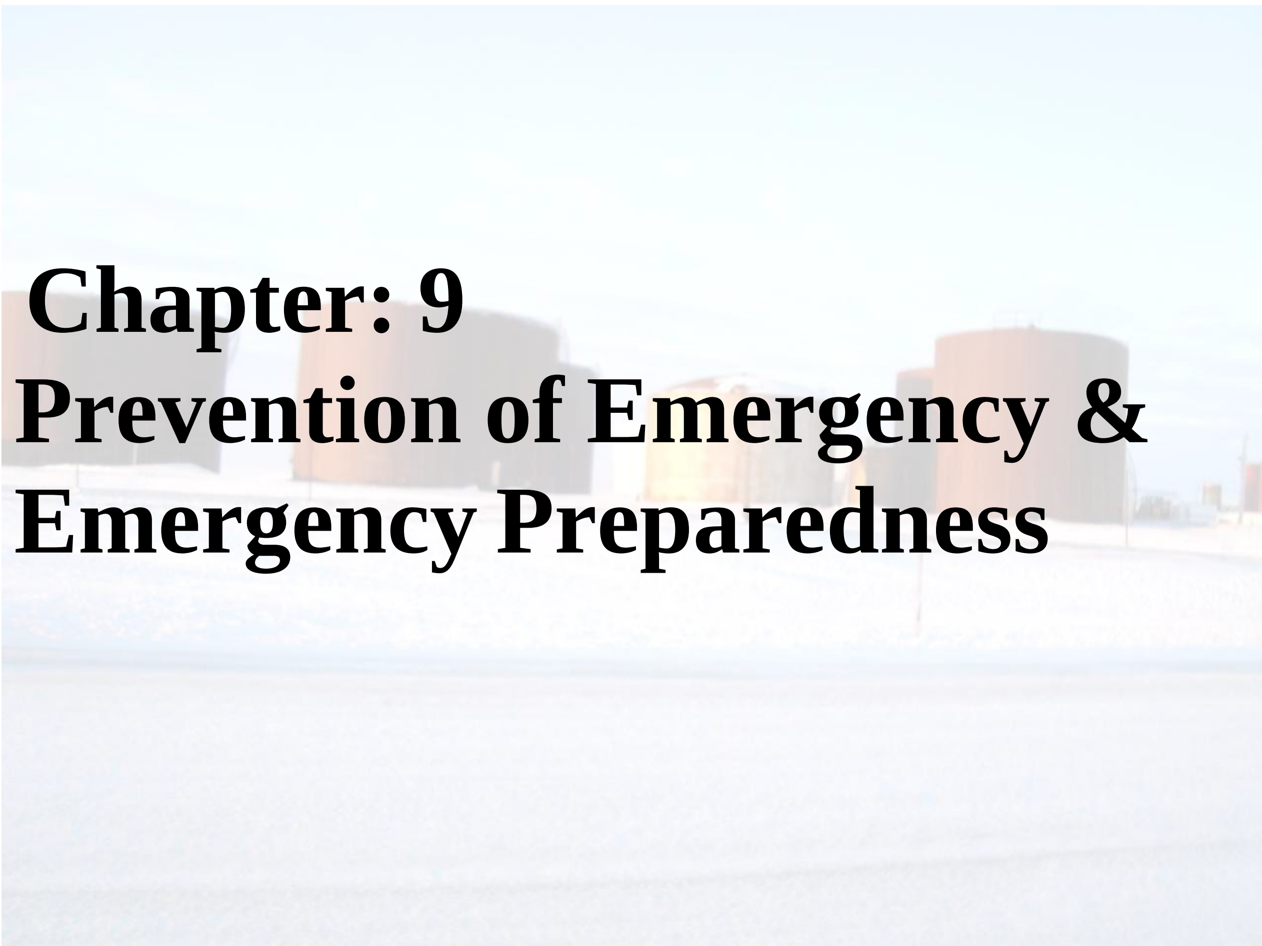
8.1 Insurance:

Where the Vessel is owned or operated by a third party is involved in and deemed responsible for and Oil Pollution Incident, prompt notice must be given to the third party advising them that PPD will be holding them responsible for the clean-up costs and damages resulting from the Oil Pollution Incident. The facility employees must recognize that vessel/companies involved in delivering products to the facility are required to carry insurance to cover their operations. Claims will therefore be made against the vessel's insurance coverage. The facility's role is to ensure in the first place that the clean-up is done effectively and efficiently. However, when the expenses incurred are to be recovered from the third party, records for the costs, which have been incurred, are essential. In the case of a major Oil Pollution Incident, specialized representatives from the various insurers will assist on this. For Oil pollutions Incidents of a minor nature resulting in damage to a third party's property, the facility's adjuster can provide assistance.

8.2 Legal:

In the case of a major Oil pollution incident involving potentially large expenditures for clean-up costs and contentious claims from third parties, specialized legal counsel must be consulted.





Chapter: 9
Prevention of Emergency & Emergency Preparedness

Prevention of Emergency & Emergency Preparedness

9.1 Brief:

The chances of environmental emergency events can be reduced by identifying in advance the frequency, potential consequences and impact of such events. The prevention of such emergencies includes several components, the most important being the knowledge gained from evaluating the risks associated with the substance of concern. As most incidents leading to an emergency are caused by deviations from normal conditions within a facility, the evaluation of past emergency events occurring at the site and at other similar places in Canada and the range of potential scenarios, including worst probable case, is critical to understand a facility's capabilities and resources in the event of a crisis. We can't plan for every imaginable worst probable case, as it is not practical; however PPD's environmental emergency plan addresses those worst probable cases and other scenarios that may be credible. As it has well said prevention is better than cure, the key to reducing the frequency and severity of the environmental emergency events is preventing them from happening in the first place.

We have combined the prevention activities with appropriate preparedness and response to make it most effective risk management strategy. Different case histories have shown that it is much more cost effective to implement an appropriate risk management program in advance than to repair any resulting damage done to the people, place and environment after the fact. PPD believes that with preventive action, problems can be anticipated, corrective action can be taken and risk can be managed to avoid environmental damage. The incident preventive strategy laid out in this plan refers not only mitigation measures such as maintenance and spill containment, but also to the management systems for design and operation and to ensuring that the facility operates as intended. For the smooth running of PPD's operation, an operation safety management exercise will be carried out yearly by applying the management principles and systems to the identification, understanding and control process hazards to prevent operation related injuries and accidents.

Following are the salient features of our safety management:

- Risk assessment
- Facility design and construction to specific standards
- Preventative maintenance checks and programs
- Maintaining effective operating procedures and safety documentation
- Operator competence assurance
- Procedure to ensure that changes in design or service or staff are effectively managed and to minimize effect on operations

- Incident investigation and analysis to minimize recurrence
- Assessment of compliance to standards
- Document the lesson learnt from past incidents

Normally, issues such as operation risk management, management of change and management of human factors are documented and complemented with traditional health and safety programs and applicable federal/territorial legislation. Learning from the past history is definitely important for the future safe operation of storage tanks. After the review of relevant literature we can say that at fuel tank farm generally lightning is the most frequent cause of accident and the maintenance error is the second most frequent cause. The rest were operational error, equipment failure, sabotage, crack and rupture, leak and line rupture, static electricity, open flames etc.

A fishbone diagram (The cause and effect diagram) is used to summarize the effects and the causes that create or contribute to those effects and 2nd diagram summaries how we can prevent these accidents.

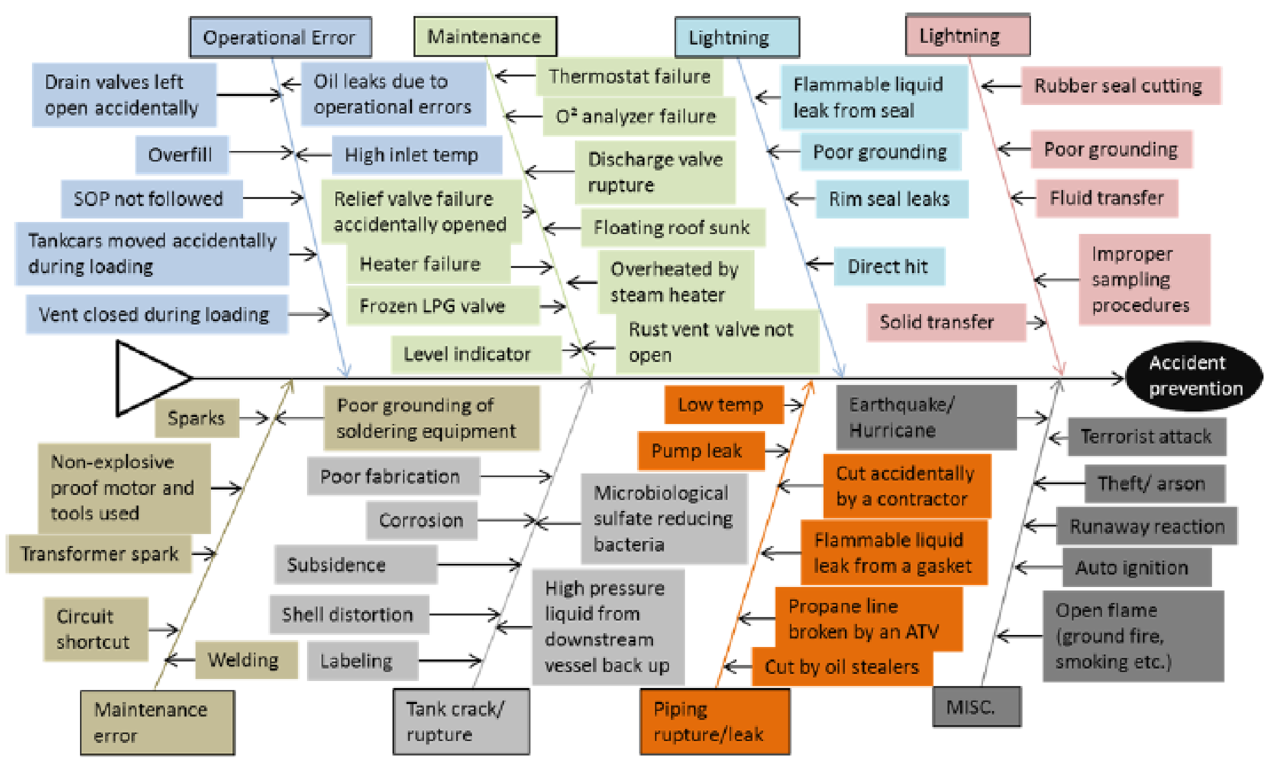


Figure 9.1: Fishbone diagram of accident cause

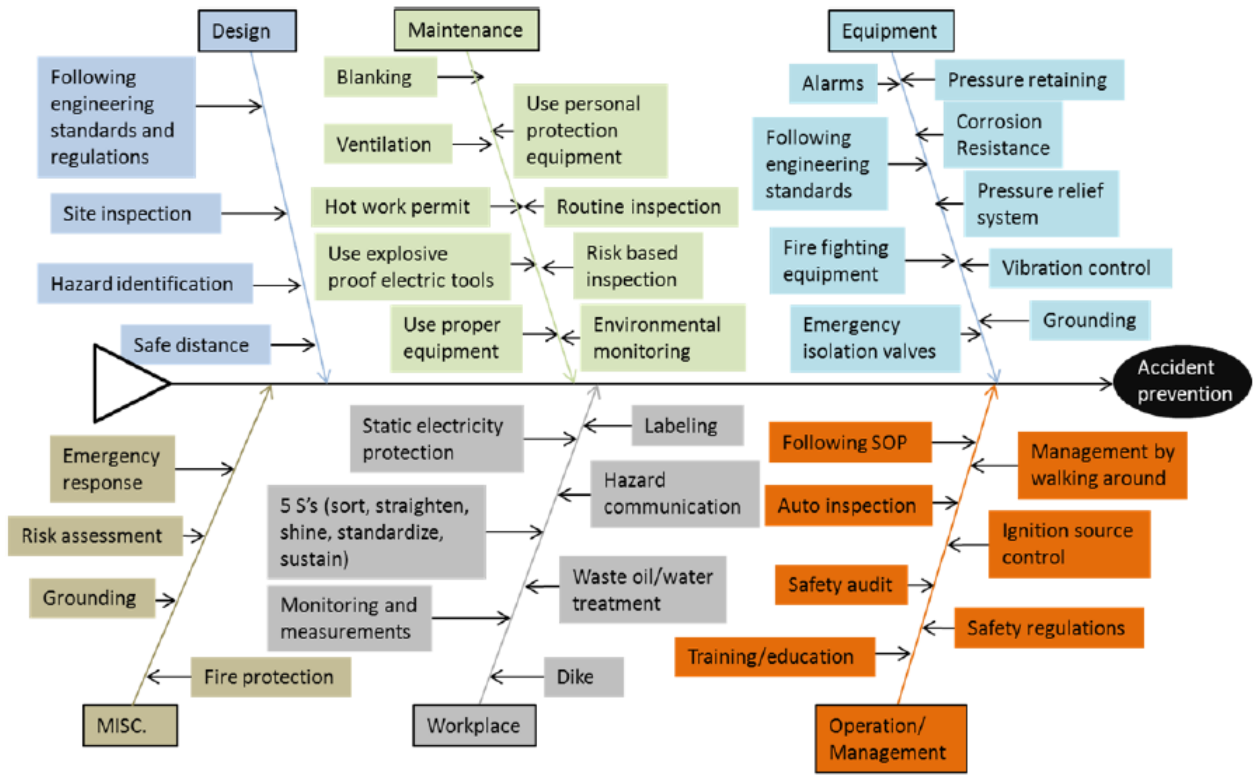


Figure 9.2: Fishbone diagram for accident prevention

9.2 Incident prevention strategy:

Fire/explosion, leak and spill incidents on the tank farm could be avoided if we use standard safe practices for routine work on the facility.

9.2.1 Tank cleaning and fire incidents:

By adopting the well-established safe practices for tank cleaning we can prevent some of the fire and spill incidents on tank farm. Most of the tanks at Resolute Bay tank farm are of API-650 standard and cleaning process on these tanks has a specific protocol. The standard procedure for cleaning such tanks is well explained in Publication API 2015. That journal describes procedures for gas freeing, entry into, cleaning inside and exiting from the petroleum storage tank.

It is recognized that circumstances determine the specific applications of the procedure described. If the work is done by a contractor, a designated owner's representative should ensure that the contractor is made aware of the correct procedure to be followed. Personal injury and property damage are less likely to occur when employees have thorough knowledge of the operation, proper use of approved equipment and the hazards involved before the job begins.

Mixtures of hydrocarbons can be ignited only if the fuel-air ratio is within lower and upper limits (1-10% hydrocarbons vapours by volume in air). Tank cleaning involves the following major steps:

- Preliminary preparations, external inspection of the tank and surveying the immediate area, training and indoctrination of the crew and inspection of equipment.
- Determining the dike area is free of flammable or toxic materials before personnel are permitted to work around.
- Controlling sources of ignition in, around and on the tank.
- Emptying the tank by pumping and floating with water. Before the tank is opened all residual product should be pumped or drained off to the lowest possible level through the water draw.
- Blinding of the tank and de-energizing electrical circuits.
- Vapour freeing the tank.
- Testing the tank for oxygen, hydrocarbons vapours and toxic gases.
- Opening the tank for entry for removal and disposal of sludge.
- A qualified person, authorized to do so, should sign and issue an entry permit before a worker enter a petroleum storage tank.
- While workmen are inside the tank completing the cleaning process, a workman should be available outside the tank to assist those within the tank in the event of an emergency.

9.2.2 Precautions while tank cleaning:

- When being vapour freed by ventilation, tanks containing rich vapour space will be in the flammable range sometime during the ventilation process. Don't consider the tank risk free during ventilation.
- During the tank vapour freeing operation, all sources of ignition in the tank and in the vicinity of the tank should be eliminated.
- Even after tank has been freed of vapour, flammable mixtures may still be formed from residual products or sludge, keep monitoring the vapour concentration.
- Vapour and liquid may enter through un-blinded lines to gas freed tank.
- Tank vapours should be checked frequently even if initial measurements indicate airborne quantities are within acceptable limits.
- Flammable mixtures may be ignited by a variety of ignition sources that may include electrical lamps, power tools, explosion proof appliances and static electricity, be aware of all of them.
- Unexpected sources of ignition often occur so it is not sufficient just to eliminate conditions known to be a possible source of ignition; every effort

must be made to avoid the release of vapours near ground level during ventilating and cleaning operations.

9.3 Provision of tank over-fill protection:

Overfills of aboveground fuel storage tanks are and should be a concern to anyone interested in safety and the environment; Tank overfills have the potential to negatively impact both. More important, overfills can cause injury or death to people. We will review current industry practices and rely heavily on the most comprehensive approach to overfill prevention that is currently in the public domain- API 2350. Overfills typically occur because a transfer of petroleum liquid exceeds the capacity of the tank. Tanks generally receive transfers in 3 basic ways:

- From pipeline
- From marine (barge or ship)
- Transfers from other tanks at the same facility or from a process which is manufacturing the stored product

Thus, there are at least three ways that overfills can occur.

However, overfills can occur from unexpected scenarios. For example, if there is a tall tank and a short tank, that are connected by piping, gravity can cause the taller tank to flow through open or failed valves to the shorter tank causing and overflow. The same applies to tanks that are at different elevations. This is commonly called "gravitating", a movement that occurs without operator intervention. Unsecured check valve has been the cause of this scenario more often. In fact, overfills in tanks can occur in so many ways, that there is no single method that will prevent overfills.

A comprehensive approach including at least the following must be taken and this includes at least the following factors:

- Operating practices
- Written procedures
- Training
- Equipment systems, selection, testing, inspection and maintenance
- Management of change

While it should be understood that the impact of an overfill can vary, from minimal to serious, there are two impacts of concern to the industry. The other consequence of concern is frequent overfills that result in environmental damage. These collectively lead to the conclusion by the regulatory community that the industry is not sufficiently concerned with protecting the people and the environment.

There is some truth to this as more can be done. Most of the occurrences of overfilling are attributed to human negligence and system failure. These incidents in recent years have resulted in loss of life and billions of dollars in damages to petroleum facilities word-wide.

The incidents of overfilling have also occurred on PPD's storage facilities repeatedly. In the wake overfilling occurrences the American Petroleum Institute (API) recommended practice (RP) 2350 and same was adopted by Environment Canada to protect the environment here so the most widely accepted guideline for overfill prevention of petroleum storage tanks has been revised. Vital to these new requirements is the application of level instrumentation as one part of a comprehensive Overfill Prevention System (OPS).

All of the tanks on PPD's facilities are subject to that requirement because they have capacity more than 5,000 L of combustible liquid and they receive liquid from marine vessels with the exception of those built before Jun 12, 2008. An OPS typically includes an alarm signal system and allied support systems- shutdown or diversion valves, communications, sensors, and logic solvers. OPS should be on an uninterrupted power supply. API 2350 categorizes storage tanks by the extent to which personnel are in attendance during receiving operations. The overfill prevention methodology is based upon the tank category.

Category I: Personnel must always be on site during the receipt of product, must monitor the receipt continuously during the first and last hours and must verify receipt each hour. Level instrumentation is not required but may be used. Output will be local only. Alarm may be point or continuous level devices. Termination of receipt is done manually by site personnel or by the transporter as instructed by site personnel.

Category II: Personnel must be present during the initial and final 30 minutes of the receipt. The transporter must assist in monitoring the high-high alarm. Tanks must be equipped with an Automatic Tank Gauge System (ATGS) that includes a high-high alarm and has a transmittable output signal. The level sensor would be continuous or point and a single sensor may be used for both level and high-high alarm. If a separate sensor is used for high-high level it may be point or continuous.

Category III: Personnel are not required to be present during receiving operations but are remotely located at a control centre. The transporter must monitor the level and high-high alarm. Tank must be equipped with an ATGS consisting of a level sensor and independent high-high sensor. The outputs of both of instruments must be transmitted to a control centre in real time. The level sensor will be continuous. The high-high level sensor may be continuous or point. The control centre has the ability to terminate receipt. In addition the HH sensor must automatically terminate flow to the tank or alert the transporter to terminate receipt. Failure of the ATGS must also automatically terminate flow. In Resolute Bay overfill protection system has been on all the tanks those were built after Jun12, 2008.

9.4 Secondary containment:

Secondary containment means containment that prevents leaks and spills from the primary storage tank system from reaching outside the containment area. It includes double–wall aboveground storage tanks and piping, and impermeable barriers. Single-walled storage tanks must be installed in an impervious secondary containment with a minimum holding capacity of 110%. If one tank is on the lined area, volume of secondary containment $\geq$ 110% of the tank capacity. If two or more tanks are installed on the lined area, volume of secondary containment $\geq$ 100% of largest tank plus 10% of greatest volume of either largest tank or aggregate of the other.

- The containment area may also be roofed or have rain shields.
- Containment floor surfaces should extend 30 cm beyond the edge of the tanks in order to collect any dripping and enable visibility of all parts of the tanks for a visual leak inspection.

Figure 9.3: Spill

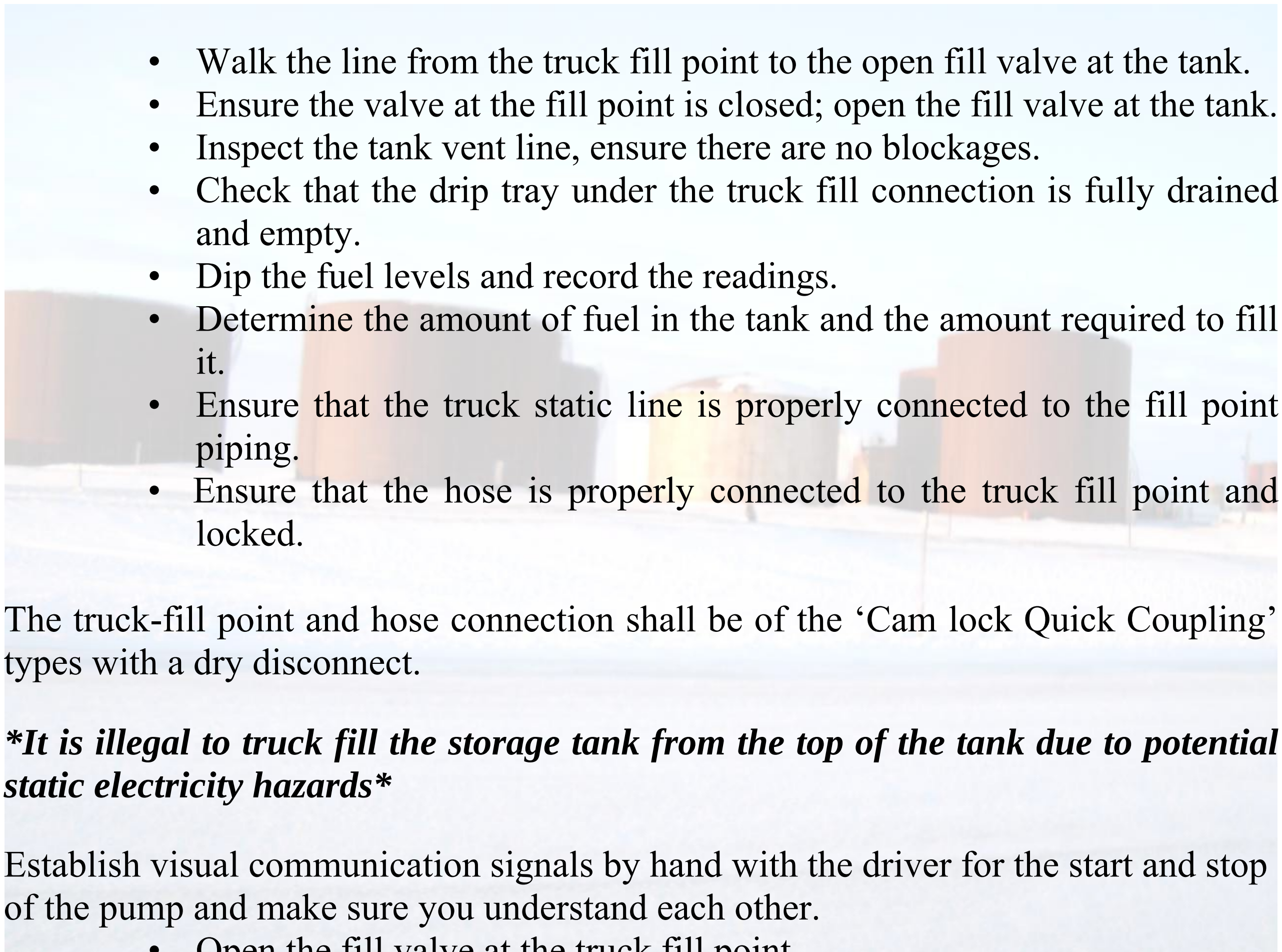
Secondary containments are generally not considered necessary for double-walled tanks. However, secondary containments can provide an extra level of protection, particularly when the tanks are located in a sensitive area. These containments are meant to confine leaks and overflow of fuel. Double walled tanks and double walled piping can serve as secondary containment. For the berm area polythene liner are used to contain the spill and leak.

9.4.1 Buried fuel delivery pipes:

Section 5 of CCME guidelines requires, underground buried piping and piping through berm should contain secondary containment in the form of double walled pipe or have leak detection system/Cathodic protection.

9.5 Truck to Tank Fuel Transfer Procedures:

Whenever fuel is transferred from a truck to a live storage tank (90,000L or less) the following procedures must be followed:



- Walk the line from the truck fill point to the open fill valve at the tank.
- Ensure the valve at the fill point is closed; open the fill valve at the tank.
- Inspect the tank vent line, ensure there are no blockages.
- Check that the drip tray under the truck fill connection is fully drained and empty.
- Dip the fuel levels and record the readings.
- Determine the amount of fuel in the tank and the amount required to fill it.
- Ensure that the truck static line is properly connected to the fill point piping.
- Ensure that the hose is properly connected to the truck fill point and locked.

The truck-fill point and hose connection shall be of the ‘Cam lock Quick Coupling’ types with a dry disconnect.

It is illegal to truck fill the storage tank from the top of the tank due to potential static electricity hazards*

Establish visual communication signals by hand with the driver for the start and stop of the pump and make sure you understand each other.

- Open the fill valve at the truck fill point.
- Authorize the truck driver to start pumping**.**
- During the pumping stage, walk the line to determine if there are any leaks in the filling system under pressure.
- Be in constant communication with the truck driver either visually or by radio at all times.
- Ensure that the tank is filled not more than 18” from the tank top to allow for volume expansion, or until the high level alarm is sounded if the tank is so equipped.
- Signal the truck driver to stop pumping.
- Shut off the truck fill point valve and the tank fill valve.

- Ensure that the EC-00000xxx number of your fuel system is recorded on the fuel delivery slip.
- Sign the fuel delivery slip for the fuel received and obtain a copy.
- Remove the static line.
- Empty the drip tray and clean it out.
- Dip the fuel and record (closing).
- Close the gauging hatch.
- Carry out the final inspection of the tank and the fuel pipe line. Ensure the proper valves are open and closed.

9.6 Proper inventory reconciliation:

New EC regulations for Petroleum Products and Allied Petroleum Products Storage Systems dictates that the owner of an aboveground storage tank system or the owner's designated representative shall ensure that the product level in an aboveground storage tank containing fuels is measured and reconciled at least weekly in conformance with Sentence 5.2.2(1). The storage tank inventory control measurements shall be reconciled by comparing product measurements with dispenser meter readings, shipments, deliveries, and internal transfers. The computation of any gain or loss of product shall be recorded and included with a monthly summary of cumulative losses or gains of product.

The authority having jurisdiction shall be notified immediately in conformance with Section 5.9 when a leak or discharge is indicated by any one of the following:

- any unexplained loss of 1.0% or more of throughput in one month from an aboveground storage tank as indicated by the recording and reconciliation of inventory records done in conformance with Sentence 5.2.2(1)
- inventory reconciliations showing 4 or more consecutive weeks of unexplained product losses; and
- inventory reconciliation showing an unexplained loss in one calendar month.

Besides the compliance with EC regulations PPD has internal requirements to reconcile the fuel inventory on regular basis so a formal inventory reconciliation program is in place. Every single tank is physically dipped at the end of each month by PPD’s contractors and Tank Gauge Reports, TGR, are sent to PPD HQ every month. PPD staff reconciles the sales and verify them from TGRs. If substantial variance is found tanks are re-dipped. A significant product loss points towards an undiscovered leak or spill. On the basis of inventory reconciliation, investigations are launched to identify the source of product loss.

9.7 Record keeping:

Under the new Environment Canada regulations PPD is required to keep records of the design and installation of tank system for the life of the system. These must include a record establishing that the system was installed by an approved installer or installation was supervised by a professional engineer as well as a set of 'as- built drawings bearing the stamp and signature of professional engineer. Records of tank inspections (API-653, leak detection), operation and maintenance and record of permanent removal of the system from service are also to be kept for at least five years. PPD complies with this EC requirement and maintains these records at the tank farm as well as at PPD HQ.

9.7.1 Preventative maintenance:

Preventative maintenance goes a long way in avoiding the accidents at the fuel storage facility so PPD has established a preventative maintenance program to keep the fuel tanks and other accessories in good working condition. PPD's fuel delivery contractors are obligated to perform monthly visual inspection on the tank farm and submit a monthly check list. Fuel transfer pumps, overfill protection systems, corrosion prevention systems, fuel cabinets and electrical installations are all inspected regularly to identify the potential maintenance issues so that they could be tackled proactively. PPD also keeps the record of all the maintenance work done on the tank farm.

9.7.2 Ongoing leak detection and monitoring:

In field–erected aboveground storage tanks and horizontal shop–fabricated storage tanks, the floor rests on the ground. Regardless of whether an impermeable barrier lies beneath the floor of the tank, the term "leak detection" is used to describe a system of pipes (usually perforated) located under the floor of the storage tank. These perforated pipes transmit any leakage to the tank perimeter where the product can be observed or detected. API-650 Standard provides a number of excellent details and specifications for this type of leak detection.

Leak detection terms are complicated for underground piping. To be consistent with the CCME– EPC–61E "Environmental Code of Practice for Underground Storage Tank Systems containing Petroleum Products and Allied Petroleum Products" and to specify the required performance level or type of leak detection, the terms level 1, level 2, level 3 or level 4 are attached to the term leak detection. A precision leak test should also be discussed. Since leaks from aboveground piping can be easily observed so sophisticated leak detection systems are not required.

Level 1 leak detection: is leak detection capable of detecting leaks of less than 0.38 L/h with a probability of detection of 0.95 and a probability of false alarm of 0.05. Pressure testing of piping will often meet level 1 performance. An alternate method of level 1 leak detection is to add tracer compounds periodically to the petroleum product and then sense for the tracer. Precision leak detection is considered level1 response as well. Although statistical inventory analysis might qualify as level 1 leak detection, it would not qualify as a precision leak test because the data is typically acquired over a period of 30 days.

Level 2 leak detection: Level 2 leak detection means a device or method that is capable of detecting a leak of 0.76 L/h with a probability of detection of 0.95 and a probability of false alarm of 0.05. If the pipe is larger than 75 mm in diameter, secondary containment is not required (although it is recommended). In some cases a line–leak detector may work. However, in large–diameter pipe and/or with long pipe runs (for example, an airport hydrant system), line–leak detectors are not suitable. In these situations, level 2 leak detection is required. There are several types of level 2 leak detection. Some are only suitable for underground storage tank systems with underground piping and an accurate product flow meter or dispenser (typically retail service stations).

Statistical inventory reconciliation is a level 1 or level 2 leak detection methods those are suitable for underground storage tanks and piping, but it is not suitable for use with underground piping connected to an aboveground storage tank. Groundwater monitoring or vapour monitoring are types of level 2 leak detection that may be suitable for larger diameter piping. Product vapour pressure and subsurface conditions (soil type, depth to groundwater) are significant factors in determining whether one of these types of leak detection is suitable for a particular site. Leak detection methods that provide level 1 performance would of course be considered satisfactory level 2 leak detection.

Level 3 leak detection: The Level 3 leak detection means a device or method used in pressure piping that operates whenever the submersible pump starts up, and that is capable of detecting a leak of 12 L/h with a probability of detection of 0.95 and a probability of false alarm of 0.05. Here provided by line–leak detectors that are located on the primary pipe. Product passes through the line–leak detector.

These devices sense a change in petroleum product pressure when a submersible pump starts up. Line–leak detectors are normally used at retail service stations and card locks that have submersible pumps and constantly pressurized piping. These devices are capable of quickly detecting large leaks (approximately 12 L/h). Some line–leak detectors are also capable of detecting small leaks as in level 1 or level 2 leak detection. Line– leak detectors are not available for pipe greater than 100 mm in diameter.

Level 4 leak detection: Level 4 leak detection means a device or method that is capable of detecting a leak with a probability of detection of 0.95 and a probability of false alarm of 0.05:

- before the monitoring sump or interstitial space fills to 50% of its capacity by volume, or
- before 600 L has leaked, whichever comes first.

Underground piping of 75 mm in diameter or less must have secondary containment, typically in the form of double–wall piping. With double–wall piping, the secondary or outer pipe typically drains to a sump where a level 4 leak detection device (a product or water sensor) detects the petroleum product or water. Probes may also be located in the interstitial space between the primary and secondary piping. When the leak–detection device is not an electrical device (such as a monitoring well or statistical inventory reconciliation), electrical interlocks may not be possible.

Even with the present mechanical type of line–leak detectors, a line leak within a submersible pump system can result in large volumes of product being pumped into the ground. Leaks from submersible pump systems have been the cause of some of the largest environmental and safety incidents. Where line–leak detectors are used, they shall not be bypassed when problems are encountered when dispensing the product. Line–leak detector means a device used in pressure piping systems to detect a leak in the piping.

Prior to implementation of new EC regulations on the Tank Systems for Petroleum Products and Allied Petroleum Products in Jun 2008, there was no leak monitoring or leak detection mandatory requirement. Under these new regulations PPD’s tank systems have specific requirements for leak detection and monitoring which must be in place by June 12, 2010. At Resolute Bay all tanks are either double walled or have secondary containment but PPD do have some tank systems that don’t have double walls and secondary containment so leak detection and monitoring requirements apply to them. Resupply line is aboveground single walled piping but without secondary containment so PPD’s fuel delivery contractor does monthly visual inspection for leak detection.

9.7.3 Tank farm design and Spill containment:

In Resolute Bay the new tank farm is fully lined and bermed and is capable to contain largest possible spill within the lined areas. All the tanks that are now on old tank farm and new tank farm were once on old tank farm lined area. Before gasoline and diesel are dispensed they are temporarily transferred and stored in tank 104 and tank

103 respectively. The ground where tank 103 and 104 are sitting now has long been a part of old tank farm too.

The old tank farm was built according the design that was in compliance with the codes and regulations enforced at that time. A large enough spill catchment basin was also constructed as an integral part of the tank farm to contain largest possible spill on the facility. The liner that is underneath the old tank farm extends to spill basin and under the tank 104 and tank 103.

The design of tank farm provides natural slope towards the spill basin and directs the flow of fuel and water towards the basin. During spring thaw, basin presents the scene of a big pool full of water. Water has to be pumped out of the basin every year. 40 years must have affected the strength of liner but there is no evidence of substantial damage to liner integrity otherwise water would have not been standing there. There might have been a number of spills on the facility since the time of its construction and the subsoil has been facilitating the migration of fuel to the spill basin so it is expected to have high water/fuel conduciveness and porosity. Any spill within the lined area is expected to migrate to the catchment basin due to tank farm design.

9.8 Preparedness to combat emergency:

Under the obligations of the *Environmental Emergency Regulations,* Petroleum Products Division of Government of Nunavut is demonstrating its preparedness to deal with potential incidents by:

- Identifying potential risk
- Documenting alternative scenarios and potential consequences
- Developing environmental emergency plans to mitigate the risks
- Training personnel to apply the environmental emergency plans
- Reviewing and practicing the incident preventative strategies regularly

While developing the environmental emergency plan PPD involved the key stakeholders to enhance the level of preparedness. Local fuel delivery contractor is the first responder to any emergency on the tank farm so their inputs were incorporated in this plan. PPD as a regulatee has identified and ensured adequate capabilities and resources do exist to enable staff of local fuel delivery to safely respond to full range of potential emergencies. During the preparedness planning PPD did recognize that depending on the significance and possible escalating of particular events, the facility's capability and resources to effectively respond may be inadequate. In such instances PPD has directed the fuel contractor to obtain the required sources and equipment through arrangements and mutual aid agreements with other community stakeholders.

PPD prepares itself to identify the gaps and tries to fill them by upgrading the equipment, expanding the emergency response staff and by increasing the communications between community stakeholders and public safety agencies. PPD's preparedness measures to identify all activities essential to ensuring high degree of readiness for a prompt and effective response to an environmental emergency. GN/PPD arranges drills a and exercises as well as effective training for key personnel in and around the fuel tank farm to provide the means of testing the facility's resources and equipment and also raise awareness.

PPD's fuel delivery contractor keeps heavy equipment and has been advised to make them readily available and regularly maintain and test them. An inventory of equipment currently available on and off the site along with quantity, location, description, intended use and capabilities are ensured retained and accessible to responders. PPD is intended to review this emergency plan regularly to ensure that changes within the facility are integrated into the plan. By implementing effective prevention measures, preparing personnel and implementing an environmental emergency plan can determine the necessary level of preparedness for each situation.

9.8.1 Spill response supplies:

Environment Canada requires us to list the type and location of equipment that would be used in emergency scenarios such as shovels, spill kits and fire extinguishers. If only a small amount of equipment is needed then a simple text description of the locations may be sufficient but if our emergency plan requires a large quantity of onsite equipment it may be easier to provide locations using a diagram or map of the site/area. In Resolute Bay shelter besides new lock and key gas station where spill kits are kept. Additional kits are available in contractor's store room. Fuel delivery contractor will provide hand tools, light vehicle and back hoe to the emergency response team if need arises.

Figure 9.3: Absorbing pads being applied on spilled products

9.8.2 Heavy equipment:

In Resolute Bay, PPD's fuel delivery contractor is also a local construction contractor so he keeps all kinds of heavy equipment e.g. loader, bulldozer, dump truck, back hoe, excavator etc. Hamlet has its own machinery which could be borrowed if fuel contractor's equipment proved deficient. Nunavut Construction Ltd is another company who also keeps heavy equipment in the community and has been working on tank farm upgrade project so their services could also be hired for the cleanup operation.

9.8.3 Spill response team readiness:

PPD has advised all the fuel delivery contractors to form their Emergency Response Teams comprising of the people living within the community and could be available when a need arises. It is fuel delivery contractor's duty to keep Personnel Protection Equipment ready all the times e.g.

- Nomex coveralls
- Gloves
- Steel toe boots
- Goggles
- Hard hat

9.8.4 Fire extinguishers:

Four fire extinguishers are made available at different places within the tank farm fenced area whereas one is in the operator shelter. As a part of equipment inspection and testing program PPD ensures that all the fire extinguishers are kept in good working conditions. The inspection and testing date and time are documented and maintained at the location of the equipment as well as at PPD HQ. From time to time representatives of Fire Marshal visit the fuel storage facilities. They do inspections on these fire extinguishers and inform PPD if they are not properly maintained.

9.8.5 Provision of corrosion prevention mechanisms:

To maintain the integrity of metallic structures is helpful in preventing the emergency situations. Depending upon the structure to be protected different corrosion protection techniques are employed e.g.

1. Cathodic protection

Cathodic protection or cathodically protected means a method of preventing or reducing corrosion of a metal surface by making the metal a cathode by using either an impressed direct current or attaching sacrificial anodes.

- Sacrificial anode systems
- Impressed current systems

2. Corrosion resistant coating

All the tanks and aboveground piping are coated with weather resistant paints. In some communities jet tanks are epoxy lined internally to prevent corrosion. Under the latest EC regulations, maintenance checks on the operation of cathodic protection systems shall be conducted in conformance with: API RP 651, "Cathodic Protection of Aboveground Petroleum Storage Tanks".

Cathodic protection measurements conducted in conformance with Article 5.5.1 shall be considered satisfactory if:

- the measured surface potential for underground piping is equal to or greater than 850 mV negative using a copper/copper sulphate reference electrode; and
- the measured surface potential for the aboveground storage tank meets the criteria of a corrosion expert.

If corrosion protection monitoring conducted in conformance with EC requirements indicates inadequate protection, corrective measures shall be taken within 180 days to ensure that the measured surface potential conforms to the requirements.

9.8.6 Warning and safety signage:

Petroleum storage tanks should be labeled on at least one side (preferably both) with the name of the product stored in the tank (gas, diesel, jet, or slop etc.). The words “Flammable - Keep Fire and Flame away”, and “No Smoking - Ignition Off” should also appear on the tank and near the dispensing area. These warning signs should be visible when refueling.
All the tanks at Resolute Bay tank farm have been identified with Environment Canada under three identification numbers and these numbers are being displayed on respective tanks. Each tank has been labeled with tank number and product type. Tank farm is a secured and locked facility. For the safety of contractor staff and general public signs such as No tress passing, watch you steps, slippery when wet are also placed at appropriate places.

9.8.7 Securing the valves and joints:

Valves and joints are potential sources of fuel leak so they should be inspected regularly. PPD’s fuel delivery contractor at Resolute Bay has been provided with locks and chains to keep all the valves locked when they are not opened. Flex connectors are also checked and replaced when needed. Resupply connections at the shore manifold are also kept locked and secured.

9.8.8 Arrangements for marine resupply:

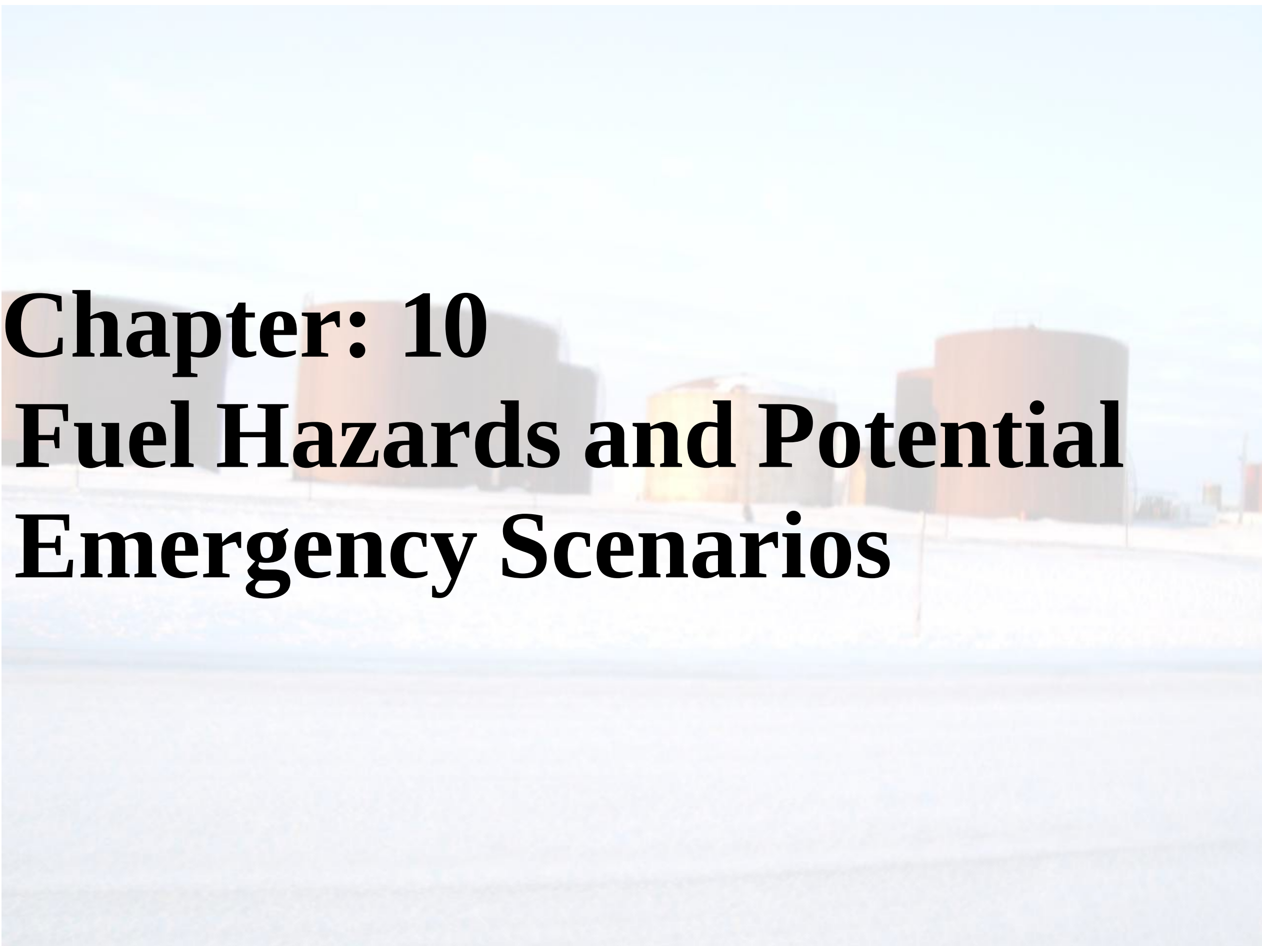
Annual fuel resupply is the biggest routine event of PPD’s operation. To manage and safely offloading the fuel require lot of experience and attention. In Resolute Bay, once the tanker is ashore resupply takes 3-4 days. Before starting resupply all the spill response supplies are kept handy and necessary equipment are tested to ensure their operability. Mooring and vessel anchorage is properly done before off-loading the fuel.

9.8.9 Product transfer area:

Under new EC regulations all fuel storage tanks are to be upgraded to have product transfer area designed to contain spill by Jun12, 2008. Product transfer area is the place where product is transferred from one system to another e.g. sea vessel to resupply line, shore manifold, truck fill area close to fuel dispenser and around the gas bars. PPD has provided lined and bermed transfer areas to contain the possible spill while transferring the product.
At the tank farm, transfer areas are properly constructed close to the jet, diesel and gasoline dispensers. These areas have been extended to at least three meters- the distance between the fueling vehicle and fuel tank. Hoses and nozzles are main equipment used in these areas. Transfer areas are likely to have a leak or spill due to equipment failure, human error and corrosion. We have mitigated the dangerous effects of spill by running a preventative maintenance program and keeping enough inventories of spill response supplies on the hand. A lined and cemented transfer area has also been provided at the shore manifold. The capacity of area has been ensured to hold enough fuel before measures to stop the release can be taken.

Figure 9.4: Shore manifold, two bollards for ship anchorage are ready to be installed (on the right)

Chapter: 10
Fuel Hazards and Potential Emergency Scenarios



Fuel Hazards and Potential Emergency Scenarios

10.1 Natural hazards:

Like all businesses and infrastructures, PPD's operation and fuel storage facility is susceptible to be affected by natural hazards. The time table for these phenomena is mostly unpredictable. Despite tremendous scientific developments and technological advancements the onset pattern and to how reduce the severity of natural events is still beyond the control of mankind. On the other hand now we are well equipped with knowledge and machinery to contest these unforeseeable and controllable incidents. With proper planning and lesson learnt from our past experiences we can develop a better risk mitigation strategy to safeguard our beings and our belongings from the detrimental effects of these disasters. Being on the open tundra tank farm is vulnerable to severe weather condition like heavy snow fall, blizzards and tornado. High winds have potential to distort tank structure especially when they are under construction.

Drought, fog and earthquake have their own consequences. To transfer the risk associated with these natural events. All GN owned tank farms including the one at Resolute Bay are insured for their replacement in case some or all storage capacity is gone due to damage caused by natural catastrophe. GN/PPD renews the insurance policy every year but resulting environmental damage is not insured. GN/PPD as a responsible party does due diligence to repair such damage when need arises. PPD, local fuel delivery contractor, GN Emergency Preparedness Services and community stakeholders develop a collective combat approach and stand by each other in the need of hour to mitigate the damages. Some of the common hazards have been thought of and their probability and impact along with risk management strategy has been tabulated in attached risk matrix.

Natural Hazards				
Hazard	**Probability**	**Impact**	**Risk Score**	**Risk Management Strategy**
Drought	2	1	2	Weather watch/Warinings
Land Fire	1	10	10	Execute Muncipal Energy Management Plans
Fog	6	1	6	1-Weather watch/ Warnings 2-Use communication systems 3-Driver Training
Blizzards	5	2	10	1-Weather watch/ Warnings 2-Use communication systems 3-Driver Training
Heavy Snow	3	1	3	1-Weather watch/ Warnings 2-Use communication systems 3-Driver Training
Thunder Storms	1	2	2	1-Weather watch/ Warnings 2-Use communication systems 3-Driver Training
Hail Storms	1	2	2	1-Weather watch/ Warnings 2-Use communication systems 3-Driver Training 4-Buy Insurance
Lighting Stomrs	1.5	1	1.5	1-Weather watch/ Warnings 2-Use communication systems 3-Driver Training 4-Buy Insurance
Tornadoes	1	10	10	1-Weather watch/ Warnings 2-Use communication systems 3-Driver Training 4-Buy Insurance
Extreme Heat	1	8	8	1-Weather watch/ Warnings 2-Use communication systems 3-Driver Training 4-Buy Insurance 5-Stress safe work places
Extreme Cold	8	1	8	1-Weather watch/ Warnings 2-Use communication systems 3-Driver Training 4-Buy Insurance 5-Stress safe work places
Earthquakes	0.5	10	5	Passive risk acceptance
Landslides/ Mudslides	0.5	8	4	Passive risk acceptance
Floods	2	5	10	1-Weather watch/ Warnings 2-Use communication systems 3-Driver Training 4-Buy Insurance

Table 10.1: Risk matrix for natural hazards

All fuel related emergency situations are linked one way or the other to unwanted and uncontrolled release of fuel to its environment. These incidents have potential to cause danger to human life or health and harm the physical environment. This plan has been developed to deal with the emergency related to all the three petroleum products PPD stores and sells in the community of Resolute Bay i.e. diesel, gasoline and jet A-1. Since the petroleum products share their physical and chemical properties and hence the injurious effects on the human beings and their physical environment so this single Environmental Emergency Plan can work for them.

10.2 Toxic nature of fuel:

All Hydrocarbon Gases Category members contain primarily hydrocarbons (i.e., alkanes and alkenes). When inorganic components are present they consist of asphyxiate gases such as hydrogen. Unlike other petroleum product categories (e.g. gasoline, diesel fuel, lubricating oils, etc.), the constituents of hydrocarbon gases can be evaluated for hazard individually, and the results of the constituent evaluation can then be used to predict the screening level hazards of the Category members. The constituents used to evaluate the hazards of Hydrocarbon
Gases Category members are:

- Hydrocarbon Gases Benzene
- 1,3-Butadiene
- C1 – C4 Hydrocarbons
- C5 – C6 Hydrocarbons o Asphyxiate Gases
- Carbon dioxide
- Hydrogen gas
- Nitrogen gas

The screening level mammalian health hazards associated with Petroleum Hydrocarbon Gases have been characterized by the constituents of each petroleum hydrocarbon gas. Each specific gas constituent could be adjusted in the respective petroleum hydrocarbon gas. This adjustment for the dilution of each component in a petroleum hydrocarbon gas represents the calculated concentration of the petroleum hydrocarbon gas required to reach the toxicity value. In many cases, there is more than one potentially toxic constituent in a petroleum hydrocarbon gas. In those cases, the constituent that is most toxic for a particular endpoint in an individual petroleum hydrocarbon stream is used to characterize the endpoint hazard for that stream.

The hazard potential for each mammalian endpoint for each petroleum hydrocarbon gases is dependent upon each petroleum hydrocarbon gas constituent endpoint toxicity values and the relative concentration of the constituent present in that gas. It should also be noted that for an individual petroleum hydrocarbon gas, the constituent characterizing toxicity may be different for different mammalian endpoints, again, being dependent upon the concentration of the different constituents in each, distinct petroleum hydrocarbon.

Hydrocarbon based fuel affect nervous system ranging from headache to death. Kidney and liver could also be damaged by fuel vapours. Aspiration into lungs can cause severe lungs damage leading to pulmonary edema and bronchial pneumonia. Exposure to petroleum hydrocarbons by skin contact may aggravate dermatitis. Also prolonged or repeated inhalation exposure to high concentration could cause liver tumors. Benzene, an essential component of hydrocarbon fuels, is known for its carcinogenic nature. High vapour content or liquid concentration can irritate eyes. If swallowed may cause nausea, irritation, vomiting, diarrhea and depression.

10.3 Fuel related emergencies:

There could be many different ways constituting unintentional release of fuel into the environment. In Resolute Bay all three products are transferred from tank farm to customers by fuel delivery trucks; everyday aircrafts are refueled by truck, diesel is transferred to NPC facility on regular basis by truck. Almost daily few truckloads of home heating diesel are supplied to customers by truck. Moreover transfer of gasoline to the town gas bar is also done by trucking. Considering the scale of truck filling requirements from the tank farm it is highly likely that fuel overflows while truck filling.

Overfill protection is being provided on each truck but failure of the system and human error can cause a overflow so the best strategy is to put all the overflow preventative measures in place and stay prepared to deal with the overflow. Adequate inventory of spill response supplies are maintained at the tank farm. An EC approved fuel transfer area can also limit the damage to environment in case of spill. Right now none of the eight vertical tanks on the new tank farm have overfill protection so an extra care needs to be taken while refilling these tanks through marine resupply.

A variety of incidents can initiate a fire on the tank farm. PPD recommends safe and approved practices for tank cleaning, fuel transferring, tank dipping and regular maintenance to avoid such incidents. Necessary training is also arranged to mitigate the chances of any mishaps. Staff from PPD HQ and from PPD regional offices visits each community twice a year to ensure the integrity and worthiness of the overall infrastructure. The probability and impact of some fuel related emergencies are tabulated below along with their risk management strategy.

Fuel Related Emergencies				
Hazard	**Probability**	**Impact**	**Risk Score**	**Risk Management Strategy**
Fuel Truck Overfill	5	5	25	1-Overfill system 2-Trained truck driver 3-EC approved fuel transfer area 4-Readiness to implement Environmental Emergency Response Plan
Continuous Leak	2	4	8	1-Developing preventative maintenace program 2-Ensuring secondary containment 3-Exercising routine visual inspection 4-Readiness to implement Environmental Emergency Response Plan
Tank Overill	5	7	35	1-Overfill alarm sysems 2-Trained operator 3-EC approved fuel transfer area 4-Readiness to implement Environmental Emergency Response Plan
Fire	5	8	40	1-Readiness to implement facility and gas station evacuation plan 2-Trained personne 3-Ongoing coordination with local fire department 4-Readiness to implement Environmental Emergency Response Plan
Fuel Spill	4	6	24	1-Availability of spill response supplies 2-Trained personnel 3-Ongoing coordination with community stakeholders 4-Readiness to implement Environmental Emergency Plan

Table 10.2: Common fuel related incidents causing emergency

10.3.1 Persistent fuel leak:

Entry of fuel to air, soil and water has long lasting effects. If the storage and transportation of fuel is not properly monitored a leak can go unnoticed for extended period of time. A small leak may not go beyond the lined area but it could be a source of fuel loss and polluting the local atmosphere. Air with high concentration of hydrocarbon vapours is not fit for breathing. Further a continuous small fuel leak can create an ignitable air mixture in the vicinity of the source which in turn can result into fire or explosion on availability of ignition source. Under the new EC regulations leaking storage tank systems must be withdrawn from service immediately. Environment Canada has also made leak detection mandatory. Initial test has been described on all single walled underground piping and above ground piping without secondary containment. A permanent leak detection and monitoring program has been recommended. As an ongoing tank farm inspection program, local fuel delivery contractor makes a thorough visual inspection on tanks, valves and piping and submits a furnished inspection checklist to PPD on monthly basis.

Figure 10.1: Pipe Leak

10.3.2 Fire or explosion on the Tank Farm:

Fire or explosion is an incident that could occur at the tank farm with most devastating effects; it will not only damage the environment but also destroy the property. There could be more than one reason for the fire to start. Most likely the facility is built on permafrost. Under the influence of global warming subsoil can get unstable resulting into the collapse of facility causing the spill and hence the fire. Changes in the earth crust have potential to destabilize the tank foundation but geographically Resolute Bay is not known to be close to any earth crust fault which otherwise could give rise to earth quake or so. Unsafe tank cleaning practices and maintenance by untrained personnel using unapproved tools and equipment may initiate a fire or cause explosion. An ignited fuel vapours may result in a major fire in the dike area around the tank as well as a fire at the surface level of the tank.

Figure 10.2: Fire

The best rule to avoid the fire is not to let Fire Triangle complete, fuel vapours, air and ignition source. Fuel vapour concentration should be monitored and controlled within safe limits on the facility.

We cannot control the air. Many things can act as an ignition source such as smoking, using equipment those are not intrinsically explosion proof and instant static charge etc. In case of fire, emergency could be three dimensional:

- To control the fire
- To mobilize the medical efforts to deal with the medical emergency
- To address the shortage of fuel

In case of large fire incident, emergency would be dealt with by the collective efforts of PPD, Community Fire Fighting Services, Hamlet and Medical support staff. PPD hold the responsibility to provide technical support on how fuel initiated fire could be controlled and what safety precautions need to be taken to avoid fire/fuel related causalities but other community stakeholders will have to contribute to emergency efforts. For the development of an effective and practicable Emergency Response Plan to deal with catastrophic failure of tank farm, detailed response is provided in chapter 4.

10.3.3 Fuel Spill:

The greatest concern with a tank is the possibility of an overflow spill. There is a potential for large spills and if a tank keeps overflowing unnoticed or if a line ruptures or becomes disconnected.

10.3.4 Effect on aquatic life:

All the three petroleum products have many toxic effects on aquatic life. Entry of PHCs could result in potential acute toxicity to some form of aquatic life. Oil coating of birds, sea otters or other aquatic life which come in direct contact with the spilled oil is another potential short term hazard. In the short term spilled oil tends to float on the surface; water uses threatened by spills include: recreation; fisheries; industrial; and irrigation. The spill product could combine with black oil and can cause mortality of marine fish.

10.3.5 Ground water contamination:

Any addition of undesirable substances to groundwater caused by human activities is considered to be contamination. It has often been assumed that contaminants left on or under the ground will stay there. Groundwater often spreads the effects of spills far beyond the site of the original contamination. Groundwater contamination is extremely difficult, and sometimes impossible, to clean up.

Nationwide leaks of petroleum products have been increasing over the last two decades because underground steel tanks installed in large numbers in the 1950s and 1960s have become corroded and leaking now. Although PPD does not have any underground fuel storage but common leaks and spills can pollute the groundwater if not contained properly.

Groundwater dissolves many different compounds, and most of these substances have the potential to contaminate large quantities of water. Long term potential hazards of the some of the lighter, more volatile and water soluble aromatic compounds in petroleum products include contamination of groundwater. For example, one liter of gasoline can contaminate 1, 000, 000 liters of groundwater. This problem is particularly severe in the Atlantic and Arctic regions where there is a high usage of groundwater. In many cases, the problem is noticed long after the aquifer is contaminated, for example, when consumers start tasting or smelling gasoline. Most chronic effects are associated with the exposure of aromatic (Benzene, Toluene, Ethyl benzene, Xylenes) compounds of petroleum hydrocarbons.

10.3.6 Soil contamination:

Entry of petroleum products into the soil impairs its usefulness that is why a Canada Wide standard has been developed to categorize the soil contamination. Soil contamination commonly occurs when petroleum storage and handling systems leak and fuel spills contaminate surrounding soils, or when repeated overfills, surface spillage and housekeeping losses result in a contaminated area. When this occurs, the soil acts as an on-going source of contamination which may need to be remediated to prevent it from continuing to be a source of pollution.

PPD deals with only refined petroleum products so contamination caused by them is under discussion here. For the purposes of this emergency plan, refined petroleum hydrocarbons includes any mixture of hydrocarbons that is or could be used as a combustible fuel and includes gasoline, diesel fuel and jet fuel. One of the most practical ways for treating petroleum contaminated soils is by some form of land surface treatment whereby petroleum contaminated soils are applied onto the soil surface and periodically turned over or tilled to aerate the contaminated soils to enhance the volatilization and biodegradation processes. To facilitate prompt remediation of the soils they must be spread thinly and ploughed regularly.

Tilling the soils promotes volatilization (evaporation) of the lighter portions while the remaining compounds are immobilized within the soil mass and breakdown biologically. Naturally occurring soil micro-organisms such as bacteria and fungi combine with sunlight, oxygen and moisture to biodegrade (breakdown biologically) the petroleum products. Soils which have been successfully remediated are acceptable for reuse, either as intermediate or final cover at municipal waste disposal sites.

10.4 Sabotage and vandalism:

All the PPD's fuel storage facilities are fully fenced and locked. Local fuel delivery contractor keeps the keys. Only allowed persons have access to interior of the facilities but unauthorized trespassing is always possible especially when the facility could not be guarded round the clock. Like natural events sabotage and vandalism is also unpredictable but our vigilant and watchful behavior can reduce the chances of such incidents. Sooner the damage caused by these incidents is noticed/discovered better the remedy and recovery possible. This again stresses on regular facility inspection.

Figure10.3: Sabotage

10.5 Fuel truck flipping:

Our fuel trucks are always on the road making deliveries. Most of the roads in Resolute Bay are not well paved; snow and weather make them more rough and treacherous so fuel truck flipping is an imaginable incident. How to deal with a fuel spill resulting from a turning over a truck, should also be part of PPD's emergency plan. Some fuel absorbing pads and rolls are recommended to be carried on all the trucks. Fuel truck driver should be trained to adequately respond to the situation.

10.6 Fuel quality related emergencies:

PPD understands that fuel quality related issues have little to do with environmental emergencies but they have potential to disrupt PPD's operation. The fuel supplied by marine resupply could go off specs necessitating its temporary storage or transfer to slop tanks. Quality related issues render the fuel unusable causing fuel shortage within the community so fuel will have to be air lifted in on emergency basis. All the situations could constitute an emergency scenario that requires pre planning.

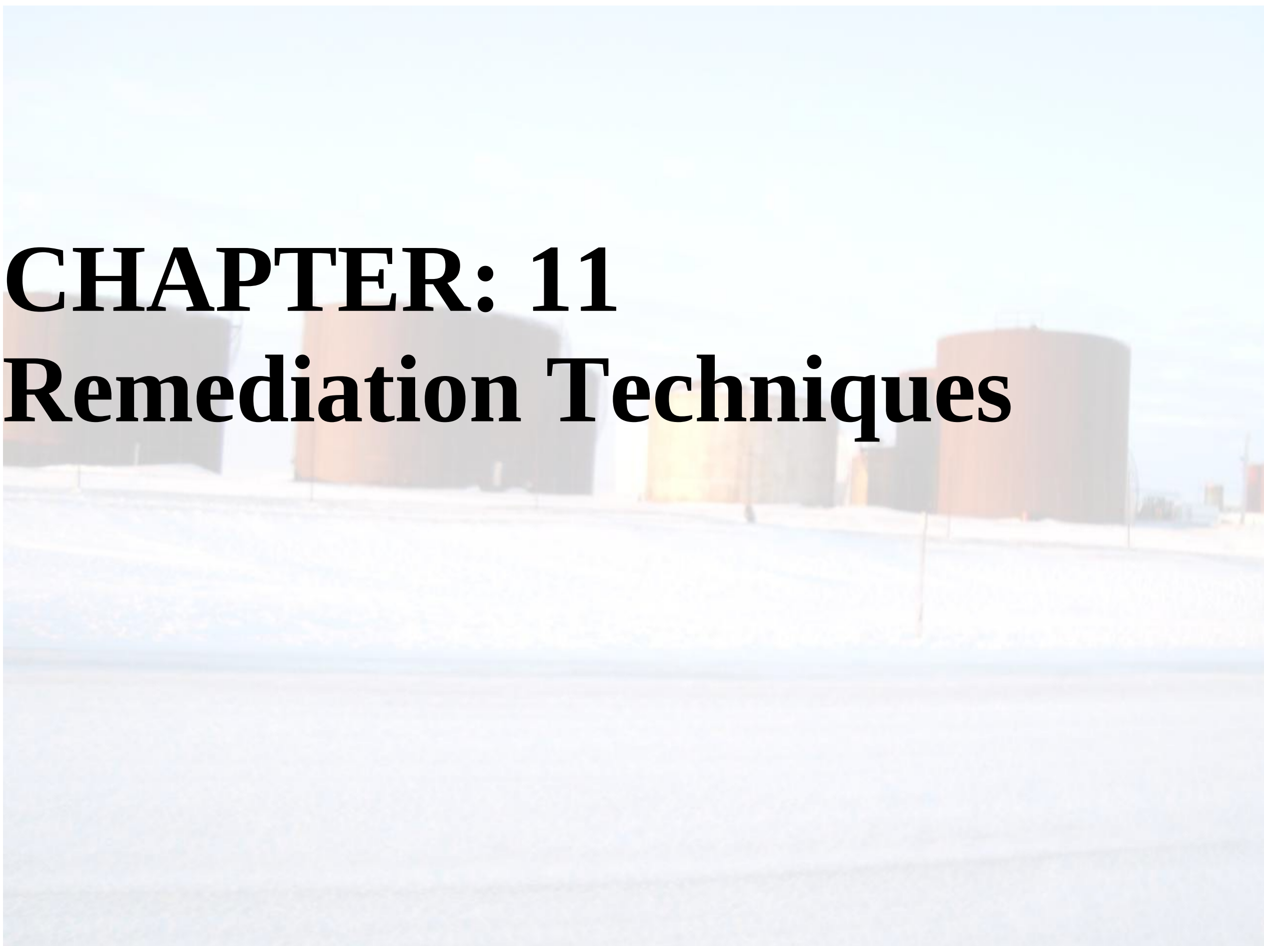
10.7 Marine fuel resupply goes wrong:

Resolute Bay fuel storage facility is replenished at least once a year by sea borne fuel tanker. The vessels are pretty large with multimillion liters capacity of fuel so they need to be properly secured before fuel offloading could be started. In Resolute Bay proper mooring and shore bollards are available for tanker anchorage. Blizzards are frequent in Resolute Bay so they can interrupt the oil transfer operations with potential risk of fuel spill into the water. In the event of spill, Transport Canada and Canadian Coast Guards are to be informed but the spill cleanup is the joint responsibility of PPD with marine carrier and local fuel delivery contractor. PPD will ask for assistance from the Canadian Coast Guard, if the incident involves a fuel discharge of more than 100 liters at the PPD shore manifold.

Figure10.4: Shore manifold

Figure 10.5: Resupply underway

CHAPTER: 11
Remediation Techniques



Remediation Techniques

11.1 Remediation techniques:

In cold regions like Nunavut territory, oil and fuel spills are among the most extensive and environmentally damaging pollution problems constituting potential threats to human health and ecosystems. There is evidence that spills are more harmful in cold regions, and that ecosystem recovery is slower than in warmer climates. In this environment the rate of natural attenuation is very slow, and the rate of off-site migration is often relatively fast. Remediation of petroleum contaminated soils is much more expensive in polar and sub polar regions than in developed temperate regions.

Dig-and-haul and offsite treatment is particularly expensive, such treatment is also environmentally damaging because the soil that is removed is essentially destroyed, and the underlying permafrost can be degraded. Low-cost, on-site remediation alternatives have not been widely adopted in these regions, largely because problems such as remote access, high energy costs and environmental factors must be managed to achieve accelerated clean-up. Environmental factors include low temperatures, spatially- and temporally-variable water distributions, low nutrients and soil heterogeneity.

Soils with high water contents typically have low oxygen diffusivities and associated low oxygen levels which, when coupled with other limitations such as low temperatures and low nutrient availability, can reduce natural biodegradation to nearly negligible rates.

Few studies have evaluated the effects of increased aeration on hydrocarbon contaminant degradation in Arctic soils. Although their studies did not directly evaluate soil aeration, Reynolds et al. (1998) observed that longer hydrocarbon half-lives were associated with areas of a Fairbanks (Alaska, USA) land farm that tended to remain saturated for longer periods after rain, indicating that poor aeration may have limited bioremediation. Similarly Yeung et al. (1997) found that the half-life of crude oil in contaminated soil was reduced from 248 to 182 days by providing aeration to a bio-treatment cell in Alberta, Canada. Research quantifying the relationship between soil oxygen levels and hydrocarbon biodegradation in cold region soils is lacking, however several studies (such as those cited above) indicate that rates of degradation may be increased by aerating oxygen limited soils. Research on biodegradation of naturally occurring organic material (NOM) in northern soils also demonstrates that degradation of these materials in wet environments is limited by lack of oxygen and can be accelerated by providing aeration.

Figure 11.1: Recovery Cycle

11.2 Land Containment:

11.2.1 Trenches:

Earth trenches are practical only under *summer* conditions. The trench must be dug to bedrock or impermeable ground. If water is present in the excavated trenches, it should be assumed that contamination could result and eventually be discharged into surface waters. A waterproof liner may be placed on the bottom and sides of the trench to prevent seepage. Shallow trenches placed down slope of the spill will be effective in trapping fuel from surface run-off and if care is taken from slightly below the surface. Trenches can be dug to divert the oil away from environmentally sensitive areas and streams. The material and equipment needed for trench construction are a backhoe, loader, dozer, shovels, picks and waterproof liners.

Figure 11.2 Trenching in sand, snow and ice

Sand and rocky ground conditions are common as well as snow and ice. In some ways these conditions are good because the spill will not penetrate rock or ice as readily. It is then a matter of steering the flow into a suitable position for easy recovery down slope. A natural depression down slope can be used for temporary containment along with a plastic liner.

Snow actually makes a very good sorbent particularly when it is light and dry much like the snow that is prevalent above the tree line. The contained snow then can be later disposed of with an approved and suitable oil- water separator. In some ways these conditions may hinder spill containment. Sand will allow fuel to filter through until it hits permafrost. The oil will then flow with the slope beneath the surface layers and make guiding the spill difficult. It is important not to let this happen if at all possible.

Oil can also lower the freezing point of ice and snow. The slushy mix that results will flow as steady as syrup. The oil flow can also create its own trench and form tunnels that cannot be seen from the surface. It is important to know how much is flowing and the direction of flow to effectively steer and contain the spill. See the figure Plywood Barriers later in this chapter as they can be used for diverting a land spill below the snow surface.

<u>11.2.2 Berms:</u>

A containment berm can be constructed of available materials such as earth, gravel, or snow. Use earth-moving equipment or manual labor to construct the berm. Form the materials into a horseshoe shape ahead of the flow of oil. Use plastic sheeting to line the walls of a soil berm to prevent oil penetration. Sandbags filled with sand or other heavy material also make excellent containment barriers.

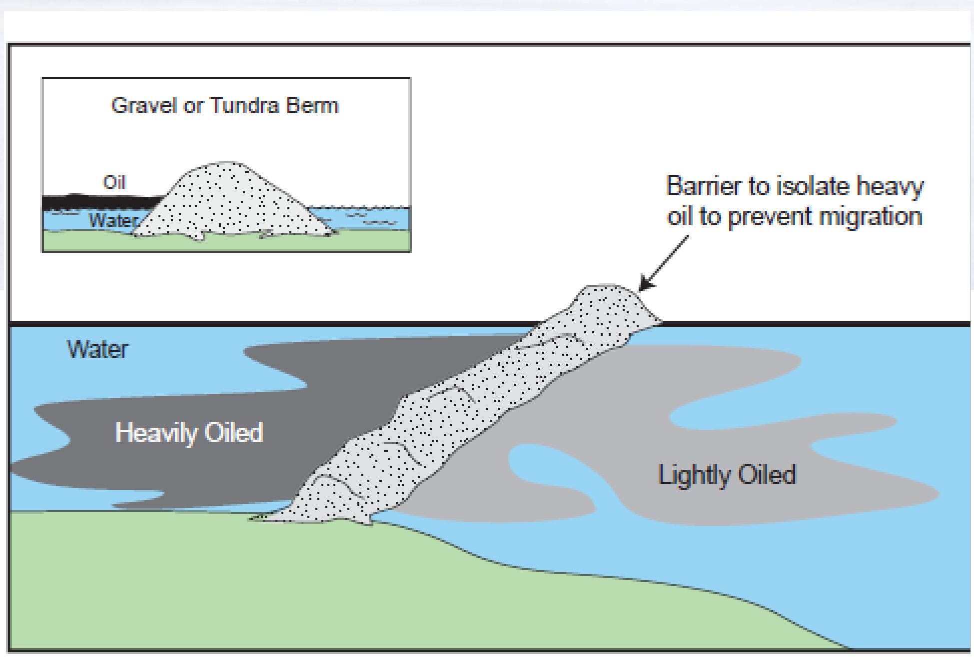


Figure 11.3: Containment Berms

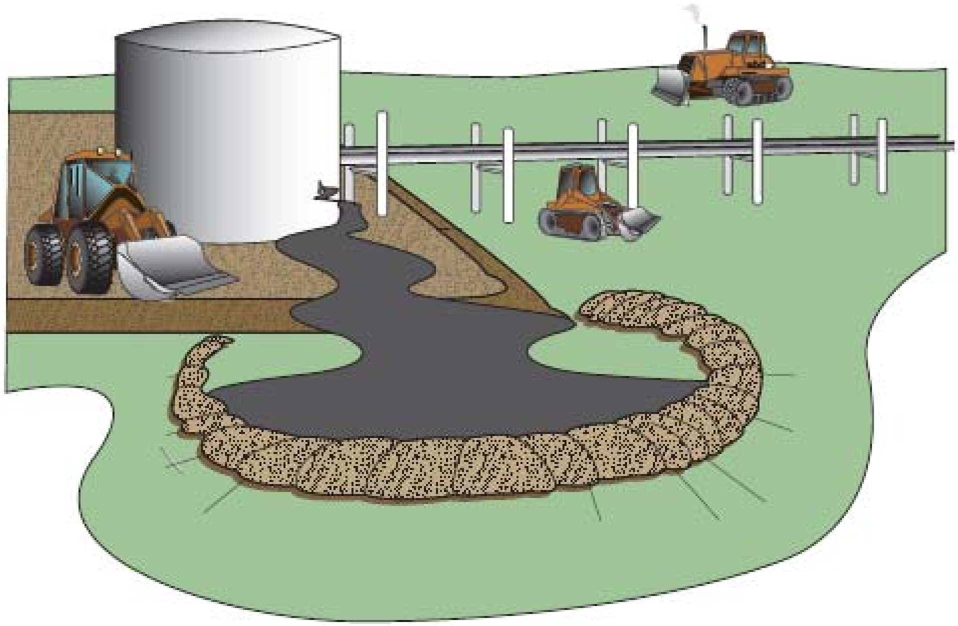


Figure 11.4: Containment Berms

11.2.3 Marsh and Tundra:

Marsh and tundra are wetlands that are sensitive habitats, where extra care must be taken to minimize damage when constructing and operating barriers. Excavation and other ground disturbances in these environments can cause more damage than a spill. Any activity that has the potential to push the contamination into the soft soils should be avoided. In some cases, it may be best to wait for cold weather to freeze the substrate before working on tundra or marsh. In other cases, the Environmental Unit may recommend no clean-up activity at all, leaving the marsh/tundra to recovery naturally.

Travel across marsh and tundra with tracked vehicles, heavy equipment, and even foot traffic can seriously damage these sensitive habitats. Disturbance is greatly reduced by using sheets of plywood, outdoor carpet, or other similar material as a traveling surface and minimizing trips with equipment. Before excavating in marsh or tundra, check for the presence of groundwater or permafrost. Do not excavate into frost-laden (cemented) soils, since disruption of the permafrost could accelerate thermal erosion. The depth of the excavation is limited by the depth of the permafrost or the water table.

11.2.4 Dams:

Earth or snow dams constructed across ditches may be used to contain a spill and stop its flow. A dam may be built with earth, wood, sandbags, and snow. The dam should be lined with plastic sheeting to make it impermeable to the spilled product.

In the ***winter***, water may be sprayed on snow dams forming ice to make it impermeable. Care should be taken to ensure that the dam is large enough to contain the entire spill; insufficient capacity may result in overtopping failure. For ditches with flowing water or for small streams, it may be necessary to allow water flow to continue and to retain the lighter-than-water liquids. Water bypass dams may be constructed on small, slow flowing ditches or streams. An earth dam is built stopping the flow of water and oil in the ditch. Water is then allowed to continue down the ditch by piping water from below the level of the fuel.

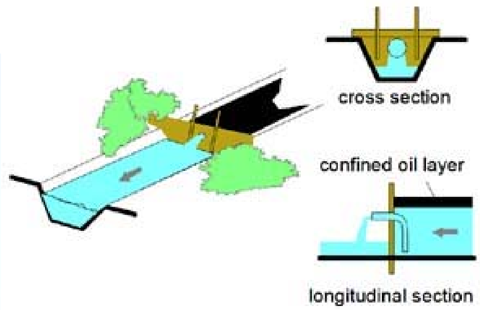


Figure 11.5: Containment Dams

11.2.5 Weirs:

Weirs may be also used in ditches and at culverts. Materials commonly used such as plywood, lumber and sheet metal may be placed to completely or partially block culvert entrances. These barriers are effective on slow moving streams.

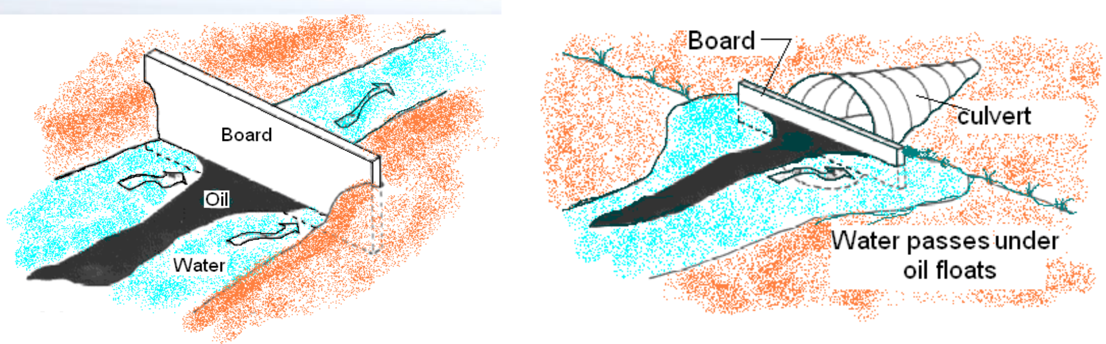


Figure 11.6: Containment Weirs

11.2.6 Water Containment:

Water containment measures generally include the use of barriers or booms. Unless the entire flow of contaminated water can be stopped by damming, these methods are limited to the containment and recovery of materials that can be separated and float on water. Certain materials such as gasoline or other volatile or flammable petroleum products have a high risk of fire or explosion. For these materials, containment and evaporation (without recovery) or burning may be a preferred approach.

11.2.7 Barriers – Snow Fence and Sorbent Barrier:

Snow fence and sorbent barriers may be used in streams (less than 1 m deep) with soft beds into which stakes can be driven. This method is limited to *summer conditions*. A snow fence barrier is installed to span the width of the stream, anchored at both ends, and stakes are driven into the stream bottom at 1 to 2 m intervals. Straw bales or commercial sorbents are placed on the upstream side.

11.2.8 Barrier and Sorbent :

Sorbent will float against the upstream side of the barrier but must be replaced before they sink. The barrier should be angled against the current for shore side collection. Multiple snow fence barriers can provide backup against potential losses from upstream barriers. Net or chicken wire barriers can be constructed in the same way. For stronger currents, these are more practical since water can flow through more easily.

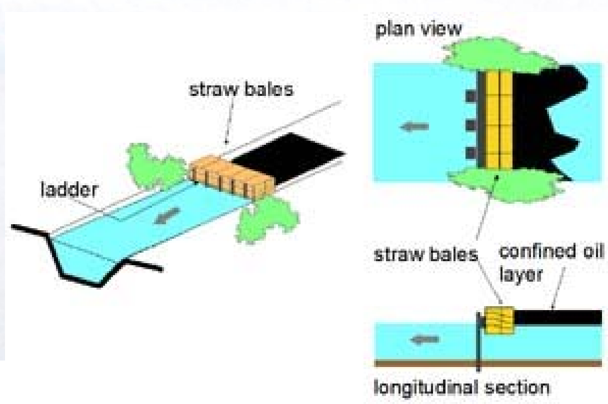


Figure 11.7: Containment Barriers

11.2.9 Booms:

The general principles in using a boom are to contain a spill of floating liquid or debris, to deflect or divert material to a defined area so that it may be recovered, and to protect sensitive areas from contamination.

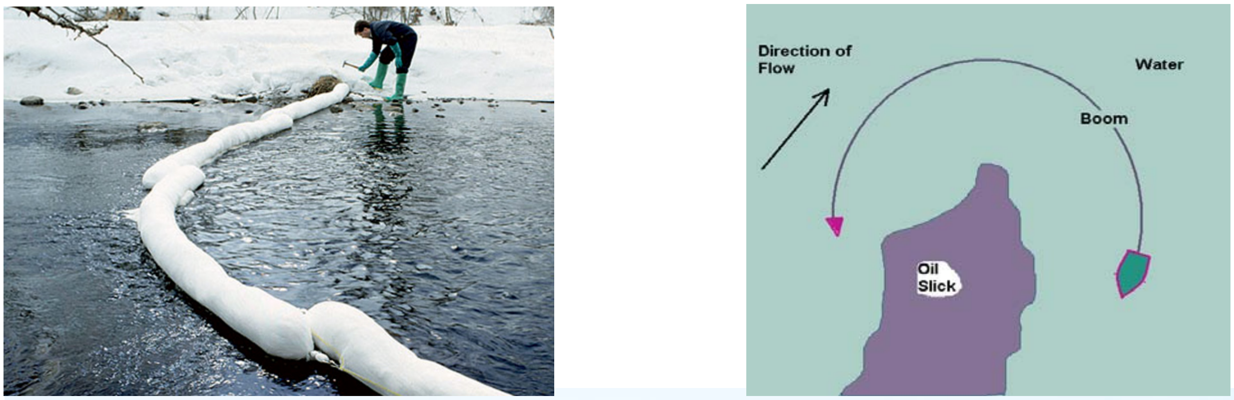


Figure 11.8 Boom Deployment

Boom deployment is important because the angle of the boom relative to how fast the water is moving affects how well the oil may be contained. The faster the stream, the more angled the boom. Several booms arranged in parallel may be necessary to contain all the fuel. These should be spaced to allow for fuel, which may escape the first boom, to float to the surface and be contained by the next boom. In addition, the use of several booms permits the removal of a boom for cleaning. Booms may be either commercially made or homemade.

Commercially made booms are designed to float and keep oil from escaping under the boom. Homemade booms may be constructed from logs, railroad ties, telephone or power poles, trees or lumber. These may be used to deflect floating material to shore or to keep floating material within a contained area. Individual sections are connected together by rope, chain or wire. A seal around the joints to prevent leakage can be made by wrapping with plastic sheets or burlap. Wooden or other floating booms can be used to contain the spilled fluid itself or the sorbent containing the fuel. They can also be used upstream of sorbent booms to improve the efficiency and longevity of the sorbent material. Inflated fire hose or Styrofoam can also be used as homemade booms.

11.2.10 Containment under Ice:

Vertical barriers in ice such as plywood may be used to deflect oil under ice in slow moving deep waters. The ice must be strong enough to support the necessary personnel and equipment. Vertical barriers are put in place by cutting trenches in ice at an angle to current flow, inserting the plywood barriers and allowing them to freeze in place. The location of the oil slick may be monitored by drilling observation holes with an ice auger.

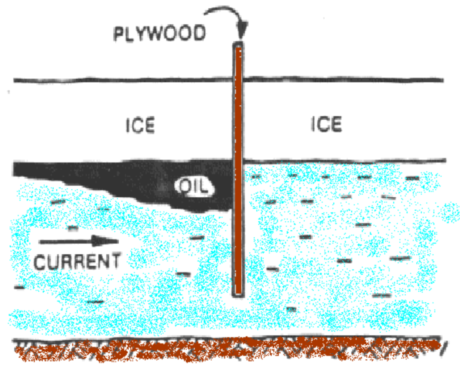


Figure 11.9: Containment Barriers

Ice slotting may be used in rivers or streams when current speeds are slow, less than0.5 m/second. A trench is cut into the ice using a chain saw or "ditchwitcher" machine at an angle to the current, to deflect and concentrate oil that passes through the area. Because of the thick ice encountered during the winter, cutting and removal of ice blocks is often difficult.

Loaders or backhoes may be needed to lift blocks out of the slot, or backhoes may be used to push blocks down. Oil, which accumulates in the ice slot, may be pumped out, absorbed or burned in place.

11.2.11 Angled Ice Slot:

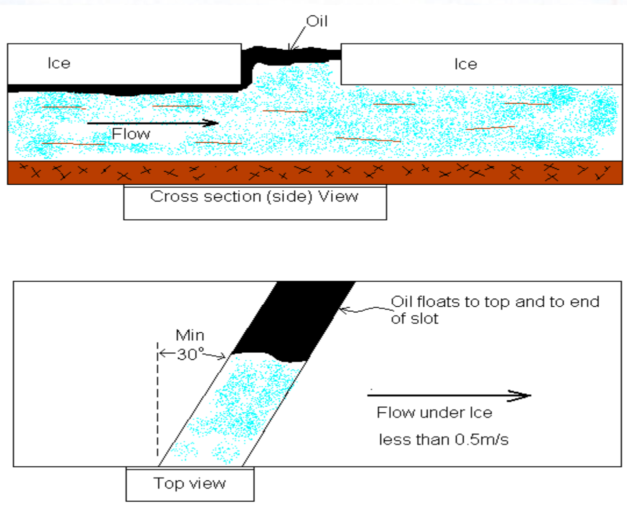


Figure 11.10: Oil on Ice

Sometimes it is best to do little, in three situations:

1. When oil is spilled in a sensitive environment, it is sometimes best to leave the clean-up to nature, as the activity itself may cause more damage.

2. Sometimes natural removal processes are faster or more effective than human efforts. For example, some storms can make shoreline conditions unsafe, but may also remove the oil quite effectively.
3. Areas such as the fiords and rocky coasts along the Canadian Arctic Archipelago are also best left, because the action of high-energy waves will break up the oil.

11.2.12 Weather Affects Response Activities:

The response team depends on weather reports to provide information that is essential for tracking, containing and cleaning up a spill. The location of the accident, the season, the time of day, and the type of response actions planned will influence what information is useful.

Decisions on which clean-up and containment methods to use depend on present and forecast weather conditions at the spill site. Meteorologists provide:

- forecasts of wind shifts and strengths;
- warnings of severe weather, such as high winds, blizzards and ice storms;
- information on wave heights, air and sea temperature, and air mass stability;
- forecasts of the icing potential, wind chill, fog, and visibility; and
- information on the presence and movement of ice flows.

11.2.13 Larger scale water containment:

In open water situations such as a bay or lake a slick may need to be isolated so as not to reach shore or to prevent spreading. A boat deployment of a boom may be necessary. The contained slick may be removed with a skimmer or with sorbents.

11.2.14 Barrel Containment:

If liquid is leaking from a barrel, the leak may be stopped by plugging the leak or by rolling the barrel over so the hole is on top. A leak may be plugged with wooden wedges wrapped with a cloth, covered with heavy duty tape, or with an inner tube placed over the leak and tightened with a rod or stick. All of these methods are to be used as temporary seals only. The liquid needs to be transferred into a new barrel or storage tank to prevent further contamination.

11.3 Recovery:

Fuel recovery methods generally include direct suction, mechanical removal and the use of sorbent material. Uses of sorbent pads serve the most common spill recoveries. A water spray mist may also be used to herd the fuel to an area for collection.

11.3.1 Direct Suction Equipment and Techniques :

Direct suction methods include the use of vacuum trucks, portable pumps or shop vacuums. Vacuum or portable pumps can be used to directly recover materials from damaged containers or from thick slicks on water. Shop vacuums are suitable for small spills if a power source is available.

Commercial skimmers are available for attachment to vacuum hoses. These skimmers serve to “skim” floating product from the water surface while reducing the amount of water recovered. Suction screens may be required to prevent hose plugging by floating debris and to prevent pump damage. Care should also be taken to prevent the uptake of water in order to minimize the final volume of material which requires disposal and to prevent emulsification of oil and water. Once removed from the water body, however, water and oil can be separated using gravity separation.

Valves on vacuum trucks can be used for water/oil separation or a drum separator may be readily constructed using a 45 gallon drum and hardware. Oil soaked sand may be separated by adding water to contained sand. Much of the oil will float to the surface of the water and can be separated more easily.

CAUTION: All containers used for the recovery of fuel must be grounded because of the potential for static-electricity build-up and fire.

11.3.2 Manual and Mechanical Recovery :

Manual recovery by use of hand tools (cans, buckets, shovels, rakes) is an effective means of recovering fuel from small spills or from areas that are inaccessible to larger equipment. This is often the only method available, and in some cases preferred as it causes the least amount of damage to the area.

Mechanical recovery using heavy construction equipment can be used in some cases for recovery and loading of material for disposal. Caution must be used when operating such equipment around a spill site. In some instances, more damage could be produced from the operation of the equipment than from the spilled fuel. Escaping petroleum vapours may also be present and pose the danger of explosion and fire.

11.3.3 Bio-Sparging (scattering):

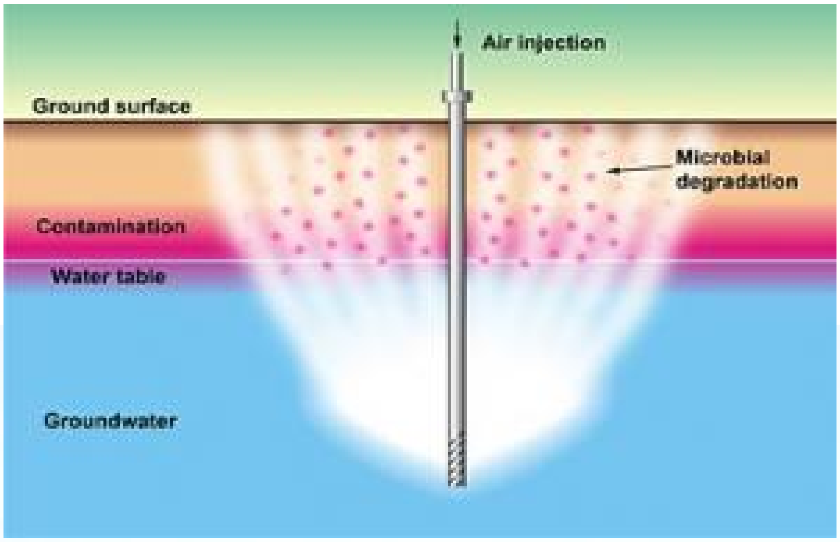


Figure 11.11: Bio-Sparging

Bio-sparging is an in situ remediation technology that uses indigenous microorganisms to biodegrade organic constituents in the saturated zone. In bio-sparging, air (or oxygen) and nutrients (if needed) are injected into the saturated zone to increase the biological activity of the indigenous microorganisms.

Bio-sparging can be used to reduce concentrations of petroleum constituents that are dissolved in groundwater, adsorbed to soil below the water table, and within the capillary fringe.

11.3.4 Bio-ventilation:

Bioventing is an in situ remediation technology that uses microorganisms to biodegrade organic constituents adsorbed in the groundwater. Bioventing enhances the activity of indigenous bacteria and simulates the natural in situ biodegradation of hydrocarbons by inducing air or oxygen flow into the unsaturated zone and, if necessary, by adding nutrients. During bioventing, oxygen may be supplied through direct air injection into residual contamination in soil.

Bioventing primarily assists in the degradation of adsorbed fuel residuals, but also assists in the degradation of volatile organic compounds (VOCs) as vapors move slowly through biologically active soil.

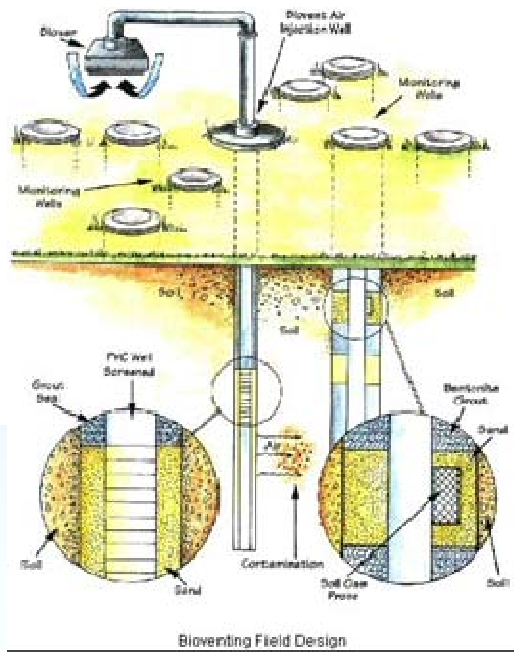


Figure 11.12: Bio-Ventilation

11.3.5 Sorbent Material :

Sorbents are insoluble materials or mixtures of materials used to recover liquids through the mechanism of *ab*sorption, or *ad*sorption, or both. *Ab*sorbents are materials that pick up and retain liquid distributed throughout its molecular structure causing the solid to swell (50 percent or more). The absorbent must be at least 70 percent insoluble in excess fluid. *Ad*sorbents are insoluble materials that are coated by a liquid on its surface, including pores and capillaries, without the solid swelling more than 50 percent in excess liquid. To be useful in combating oil spills, sorbents need to be both oleophilic (oil-attracting) and hydrophobic (water-repellent). Although they may be used as the sole cleanup method in small spills, sorbents are most often used to remove final traces of oil, or in areas that cannot be reached by skimmers.

Sorbent materials used to recover oil must be disposed of in accordance with approved local, state, and federal regulations. Any oil that is removed from sorbent materials must also be properly disposed of or recycled. Sorbents can be divided into three basic categories: natural organic, natural inorganic, and synthetic.

Natural inorganic sorbents consist of clay, perlite, vermiculite, glass wool, sand, or volcanic ash. They can adsorb from 4 to 20 times their weight in oil.

Inorganic sorbents, like organic sorbents, are inexpensive and readily available in large quantities. These types of sorbents are not used on the water's surface.

Synthetic sorbents include man-made materials that are similar to plastics, such as polyurethane, polyethylene, and polypropylene and are designed to adsorb liquids onto their surfaces. Other synthetic sorbents include cross-linked polymers and rubber materials, which absorb liquids into their solid structure, causing the sorbent material to swell. Most synthetic sorbents can absorb up 70 times their own weight in oil.

The characteristics of both sorbents and oil types must be considered when choosing sorbents for cleaning up oil spills:

- ***Rate of absorption*** -- The absorption of oil is faster with lighter oil products. Once absorbed the oil cannot be re-released. Effective with light hydrocarbons (e.g., gasoline, diesel fuel, benzene).
- ***Rate of adsorption*** -- The thicker oils adhere to the surface of the adsorbent more effectively.
- ***Oil retention*** -- The weight of recovered oil can cause a sorbent structure to sag and deform, and when it is lifted out of the water, it can release oil that is trapped in its pores. Lighter, less viscous oil is lost through the pores more easily than are heavier, more viscous oils during recovery of adsorbent materials causing secondary contamination.
- ***Ease of application*** -- Sorbents may be applied to spills manually or mechanically, using blowers or fans. Many natural organic sorbents that exist as loose materials, such as clay and vermiculite, are dusty, difficult to apply in windy conditions, and potentially hazardous if inhaled.

11.3.5.1 Sorbent Capacity:

Sorbent capacity can be listed by the amount of weight it will absorb in relation to itself ("Absorbs 12 times its weight.") or by its liquid capacity ("Absorbs 8 gallons."). For example, if a boom weighs one pound and absorbs 12 times its weight, it will absorb 12 pounds of fluid. However, since all liquids don't weigh the same per gallon, the weight capacity of the sorbent actually varies from liquid to liquid. So perhaps a more accurate way to assess sorbent capacity is by how many gallons it will absorb, or its liquid capacity. This amount will remain fairly static, regardless of the fluid weight. A boom that's four feet long and three inches in diameter will typically absorb 1 to 1¼ gallons of liquid. A pad that measures 16" x 20" and is 3/16" thick will absorb 28–32 fluid ounces. (Both of these examples are for polypropylene sorbents. Other materials may have different sorbent capacities.)

11.3.6 Underground Wells:

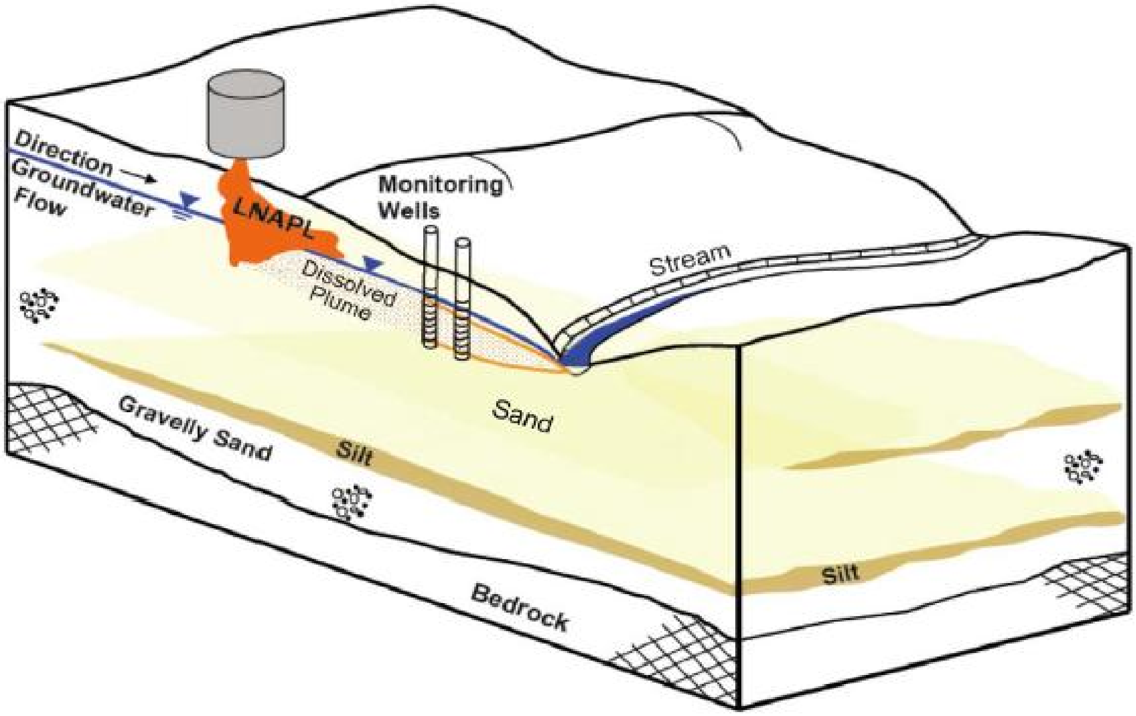


Figure 11.13 : Monitoring Wells

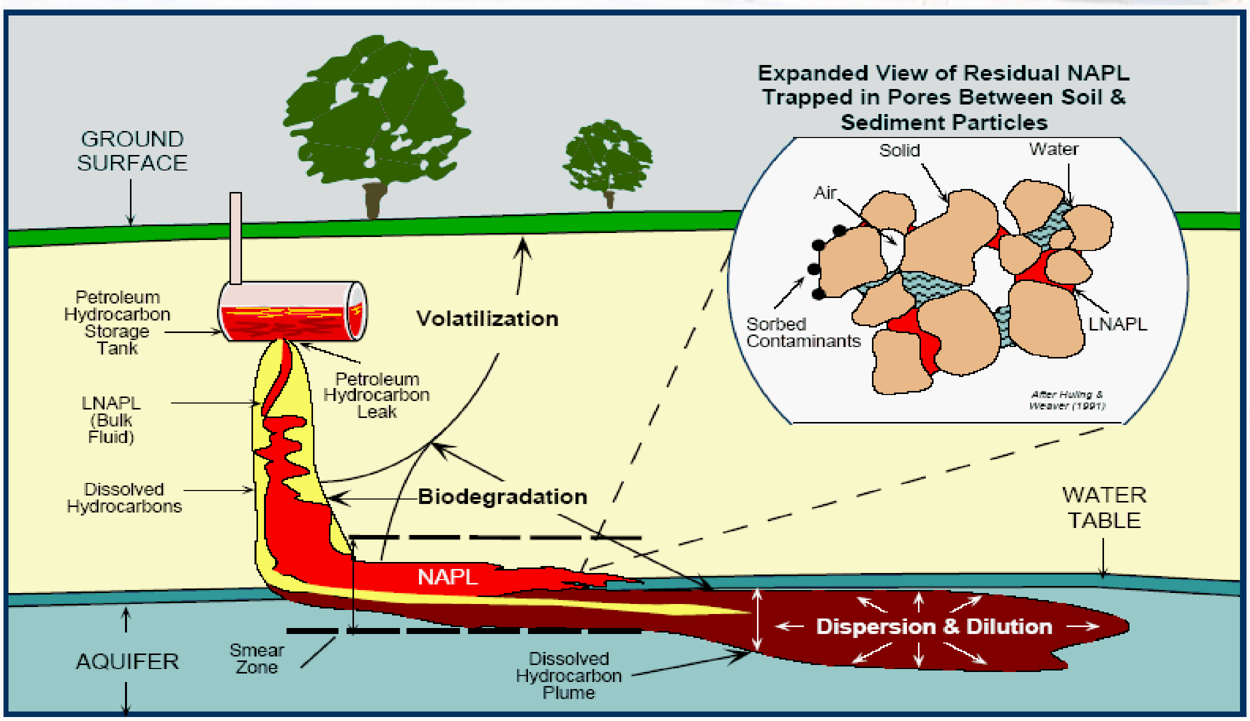


Figure 11.14: NAPL Migration

Light Non-Aqueous Phase Liquids LNAPL such as gasoline and diesel fuel etc.

Monitoring-wells are often drilled for the purpose of collecting ground water samples for analysis. These wells, which are usually six inches or fewer in diameter, can also be used to remove hydrocarbons from the contaminant plume within a groundwater aquifer by using a belt style oil skimmer. Belt oil skimmers, which are simple in design, are commonly used to remove oil and other floating hydrocarbon contaminants from industrial water systems.

A monitoring-well oil skimmer remediates various oils, ranging from light fuel oils such as petrol, light diesel or kerosene to heavy products such as No. 6 oil, creosote and coal tar. It consists of a continuously moving belt that runs on a pulley system driven by an electric motor. The belt material has a strong affinity for hydrocarbon liquids and for shedding water. The belt, which can have a vertical drop of 100+ feet, is lowered into the monitoring well past the LNAPL/water interface. As the belt moves through this interface it picks up liquid hydrocarbon contaminant, which is removed and collected at ground level as the belt passes through a wiper mechanism. To the extent that DNAPL hydrocarbons settle at the bottom of a monitoring well, and the lower pulley of the belt skimmer reaches them, these contaminants can also be removed by a monitoring-well oil skimmer.

Typically, belt skimmers remove very little water with the contaminant, so simple weir type separators can be used to collect any remaining hydrocarbon liquid, which often makes the water suitable for its return to the aquifer. Because the small electric motor uses little electricity, it can be powered from solar panels or a wind turbine, making the system self-sufficient and eliminating the cost of running electricity to a remote location

At sites where contaminated soil is in contact with ground water, or ground water contamination appears likely, a ground water contamination assessment is necessary. The objectives of the assessment are to determine whether ground water is, or likely to be, impacted with petroleum contamination and whether the impacted hydrogeologic unit is considered an aquifer.

Ground water samples from temporary monitoring wells are taken and analyzed for the appropriate parameters to determine the concentration of hydrocarbons. Based on the results of geophysical and soil vapour surveys, monitoring wells and piezometers are placed in strategic positions, and representative ground-water samples are collected and analyzed. The objective of a ground-water monitoring program is to identify, interpret and track the movement of a contaminant plume so that a comprehensive remediation program can be implemented if deemed necessary.

Note: In the text, the term "monitoring wells" refers to both "wells" and "piezometer stand-pipes".

11.3.6.1 Monitoring Well Location:

Monitoring well location is a function of the site's **flow conditions and the distribution of contaminant source(s)**. The best location for wells is determined by utilizing site screening methods which would identify and delineate the general extent and location of contamination.

Once contamination "hot spots" have been identified, wells may then be confidently placed to obtain representative results. The wells are then used to develop a 3-Dimensional geological and hydrological model of the site.

The number of wells required for a monitoring program is entirely site dependent, but a minimum of 3 is needed, and can range up to 200 or more wells for a 20 hectare site. **At least 1 well should be installed upstream of the contamination to provide baseline water quality information for the site.**

Linear alignment of wells should be avoided unless they are along an identified bedrock fracture.

Since comprehensive groundwater remediation is dependent on removal of contamination from the **vadose zone**(the water suspended in the soils above the water table), well location should enable monitoring of this zone to determine its level of contamination.

11.3.6.2 Sampling Quality Assurance And Quality Control:

Sample collection is often the greatest source of error in groundwater monitoring data. Therefore, a proper Quality Assurance/Quality Control (QA/QC) program should be established in order to ensure that data obtained are **accurate and representative** of actual groundwater conditions. **Quality Control** is the set of procedures used to measure and correct, when necessary, data quality. **Quality Assurance** is the set of procedures used to provide documentary assurance of the proper application of the methodologies used in the sampling program and the laboratory analysis before any field investigations commence.

Following should be considered before proceeding for sampling:

- Sampling locations (use a map).
- Sample collection methods.
- Equipment used, and methods for calibration, maintenance and decontamination procedures.
- Use of quality control samples.
- Type, number, and size of sample containers to be used.
- Sample volumes to be collected.
- The sampling order (least to most contaminated).

- Preservation instructions.
- Procedures for minimizing sample aeration and air contact (oxygen may affect the sample).
- Documentation requirements for well sampling records and sample log records.
- Procedures for maintaining chain of custody records.
- Plans for storage and transportation of samples.

11.4 Storage of Contamination Material :

Contamination material can cause health and safety concerns if not disposed of properly. Contaminated material should be stored in a safe place before being disposed to an appropriate location.

Storage of the contaminated material is required due to the following reasons:

- If a suitable location for disposal cannot be found
- If climatic conditions do not permit disposal at the time of cleanup
- If the selection of a disposal option requires further assessment or
- If transportation to a disposal/destruction facility is dependent on the availability of a suitable transportation vehicle.

Storage options generally consist of containers, barrels, drums, tanks or lined landfarms. The specific type of storage needed is dependent on the volume of recovered material, the degree of contamination with water and soil, the properties of the spill material, and the duration of storage required.

11.4.1 Vehicle Storage :

Vehicles suited for the storage of recovered fuel are tank trucks, vacuum trucks, dump trucks, flatbed trucks, trailer or sled-mounted tanks, and transport trailers.
Tank trucks may be used to separate oil and water by emptying the water from the bottom of the tank. Tank trucks typically have capacities ranging from 7.8 to 24.6 m3, while vacuum trucks typically hold 3.8 to 17.0 m3. Flatbed trucks and transport trailers are suitable for carrying 45-gallon drums and barrels.

11.4.2 Open-Topped Tanks:

Open-topped tanks such as plastic lined swimming pools may be quickly assembled on firm, level ground. The capacities range from 1 to 20 m3. They may be fed by several hoses at once and can store liquids and solid debris. These should be used only for short-term storage when storing fuel.

11.4.3 Drums and Barrels:

Tanks, drums and barrels, which are available in all communities, may be used for temporary storage of fuel.

11.5 Disposal of contaminated material:

Disposal or destruction of recovered fuel is needed to eliminate the risk of further contamination from the recovered fuel. No decision, except under emergency conditions, should be made until approval has been obtained from appropriate government agencies. The 24-hour Spill Report Line should be used to initiate such requests and a follow-up report should describe the disposal method used.

11.5.1 Salvage and Recycle :

Recovered diesel and lubricating oil may be reused directly as a low-grade heating fuel.

11.5.2 Fuel Burning:

In some areas, burning of contaminated fuel may be a practical and acceptable disposal technique. Burning of fuel requires prior approval and advice from appropriate regulatory agencies. Fuel must not be ignited unless all personnel and equipment are a safe distance from the area. Fuel on frozen water bodies can be burned using mass burning techniques. The residue and oil not burned can then be scooped up using scrapers, dozers, dump trucks, and finally with brooms and shovels and loaded into trucks.

Burning can also be considered when fuel penetration has been prevented because of frozen or compacted mineral soil or when the water table is at the surface. Residue can be removed the same way as on ice, but great care must be taken to protect area vegetation. The worst areas to consider burning is where islands of vegetation exist or where the surface has a moss cover into which the oil has penetrated to more than eight or ten centimeters.

11.6 Final Clean-Up and Restoration:

Natural Assimilation (Biodegradation) and Re-vegetation Oil can be degraded naturally by micro-organisms under proper conditions of temperature and nutrients. Tilling the affected soil to increase the exposure of the soil organisms and oil to oxygen can also be beneficial. The utilization of natural assimilation to treat, in whole or in part, soils affected by spilled oils requires approval of government agencies.

11.6.1 Replacement of Soil :

The grass on the upper layer of soil may have to be removed if these have been contaminated with oil or chemicals. When contaminated material is being removed, regulatory agencies should be contacted in regard to acceptable disposal sites.

In some instances, it will be necessary to replace contaminated soil with clean soil. Sensitive areas in the tundra should be left untouched. Equipment for the removal of contaminated soil includes front-end loaders and small dozers.

11.6.2 Land Based Response :

11.6.2.1 Scope and Purpose of Plan

This plan deals specifically with the preparation and response to a spill that could occur during the unloading of product from a fuel transport truck or holding tank while at the Facility. This Environmental Emergency Plan (EEP) is not intended to replace or supersede Emergency Response Plans currently in place, but to provide specific guidance on procedures, training and response for local land spills. This plan will demonstrate the Facility has an effective response capability. This plan is meant to be a working document for use by the Facility. The fundamental basis for planning will be established utilizing the development of a scenario for the class of product handled at the Facility.

11.6.2.2 Background :

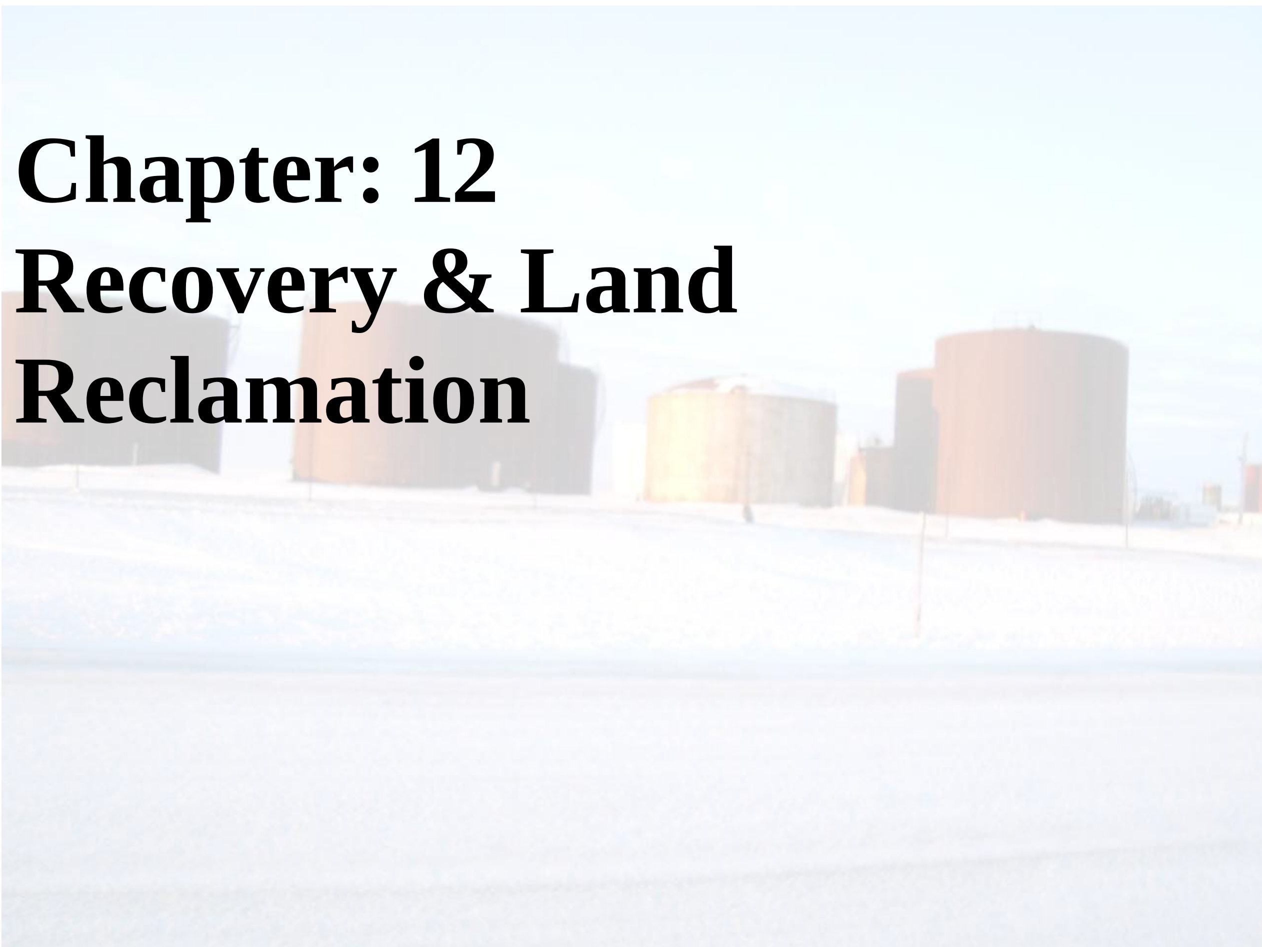
The Facility handles Distillate. The Facility personnel are familiar with the hazards associated with the products they are handling and have on hand, the appropriate material Data safety sheets.

11.6.2.3Preparation :

Prior to fuel transfer at the Facility, the staff will do the following:

- Make sure access to the storage tanks is readily accessible;
- Inventory the environmental emergency equipment; and
- Make ready environmental emergency equipment.

Chapter: 12
Recovery & Land Reclamation



<u>Recovery & Land Reclamation</u>

12.1-Introduction:

In this Environmental Emergency Plan, recovery refers to the reinstatement of any part of the environment damaged by or during the emergency. Recovery affects the both the operating entity itself and the surrounding community. The issue of recovery is best managed through discussion between all involved parties to assess the damage and agree on restoration plan. The level of environmental restoration is determined by many factors such as size, persistence and toxicity of a release, therefore recovery of an area to its natural state is not always possible. Thus restoration plans are situation specific and would need to be defined in terms of acceptability to affected stakeholders. Recovery from an environmental emergency involves activities and programs designed to return the place and its surrounding environment to a safe and acceptable condition.

The general objective of the recovery portion of and environmental emergency plan should be to provide sufficient direction to reduce impacts to the environment and to minimize the recovery time from a particular incident. The purpose of guidelines in this part of the plan is to prepare PPD, its fuel delivery contractor and public authorities to initiate recovery process as soon as possible, striving for a rapid recovery from environmental damage and a quick return to normal facility operations. Those leading the recovery process must be appropriately trained and well aware that rapid response without assessing the risks associated with the recovery efforts can lead to increased damage and longer recovery times for the environment. Depending upon the nature of incident business resumption process either can begin during response or can be initiated in stages until normal operations are restored.

Planning for the recovery phase during the prevention, preparedness and response process will improve recovery time and reduce impact to the environment. The actual recovery time depends upon many factors such as the extent of damage, availability and commitment of response personnel, resources and finances. PPD realizes the importance of establishing a pre-planned capability to recover and undertake swift damage assessments, because the longer it takes to recover, the higher the ultimate cost. PPD and its fuel delivery contractor will take the following steps to damage assessment in a recovery situation:

- Determine the extent of damage and appropriate communication to all relevant parties
- Develop a system to bring in the proper resources, including people, at the right time
- Work with outside resources to support recovery

- Organize community resources necessary for people recovering from an emergency situation

This includes the restoration of normal operations following a disruptive event, particularly where critical services are concerned. This also includes the long-term resumption of full operating capacity and evaluating the response process.

- Has a damage assessment been conducted?
- Have the legal issues been identified and addressed?
- Has a recovery team been assembled?
- Have priorities been sent for the restoration of services?

12.2 Post emergency response review:

The effectiveness of emergency response should be evaluated so that so that we can improve our response and learn from the past. After an emergency or an emergency exercise, a review and debriefing will be scheduled as soon as possible after the event (within 14 days). All parties that responded to or which were involved in the emergency shall be requested to attend. The review will be documented including any action items.

A separate debriefing will be held with PPD employees after the emergency or emergency exercise to communicate the findings of the emergency review. Lesson learnt would be documented to improve on emergency response.

12.3 Maintenance of damaged equipment:

Most of the accidents inflict damage to infrastructure rendering them not serviceable. In case of leak first structural integrity of piping, tank or truck tank is impaired then leak occurs. Damaged components affect the overall performance of the systems. Fire on the facility can result in distortion of the tank shape and twisting of the roof. Fuel delivery contractor and PPD may not have in house required expertise to do proper inspection and assessment on damaged structure so the services of a professional consultant may have to be procured.

Resolute Bay tank farm most of the tanks are of API-650 standards so in case of damage to the tanks as a result of accidents especially explosion or fire necessitates API-653 inspection be performed before tank is declared useable again. If a fuel pipe bursts, its replacement is essential; if valves and joints leak they should be repaired. Gas and diesel dispensing cabinets, dispenser building and operator shelter are some other structures that could be damaged as an accident at the tank farm. Repairing of all these components will have to be done before facility is reopened for the regular PPD's operation.

12.4 Environmental site assessment:

In Resolute Bay all the tank farm and dispensing areas are fully lined. Spill catchment basin is also lined so the release of spill within the facility would be considered contained but if it crosses the boundaries then PPD will have to get formal site assessment study done to delineate the contamination out of the berm. GN has standing agreement with some consulting companies who have been doing ESA studies on GN's facilities. Tank farm is close to the Bay so massive spill can contaminate the water there. To rule out the possibility of fuel reaching the water body in the proximity a formal site assessment study will be recommended. PPD will hire an environment consulting company to undertake ESA investigations aimed at the following objectives:

- To visually delineate the extent of observable liquid petroleum hydrocarbons (LPH) on the surface of snow / ice on and surrounding area
- To delineate the lateral and vertical extents of petroleum hydrocarbon impacts in the soil as a result of fuel release
- To delineate the extent of PHC impacts in groundwater / surface water (if possible) as a result of this spill incident
- To provide recommendations to minimize the environmental damage of the release

12.5 Soil remediation:

In Nunavut and across Canada, contaminated sites can pose a threat to human health, safety and the environment. Petroleum hydrocarbon contamination in soil is a concern for several reasons. To differing degrees, petroleum hydrocarbons are toxic to plants and animals, and are mobile and persistent in the environment. Petroleum hydrocarbons can also pose a fire or explosion hazard and can create aesthetic problems such as offensive odours and tastes. In some cases the concern may also be financial, because of the loss of property value and the cost of remediating the property.

The Department of Environment within Government of Nunavut has developed their own environmental guideline for contaminated site remediation. The intent of this Guideline is to help effectively manage contaminated sites. It helps to provide a consistent approach by describing the process used to manage (e.g. identify, assess, plan and remediate) contaminated or potentially contaminated sites on Commissioner's Land, including private land within municipalities, and by providing soil remediation criteria for petroleum hydrocarbons and other contaminants. The Environmental Protection Act (EPA) gives the Government of Nunavut authority to take measures to ensure the preservation, protection and enhancement of the environment, with the goal of long-term sustainability and stewardship.

Section 2.2 of the EPA provides the Minister of Environment with authority to develop, coordinate, and administer this guideline. The Department of Environment is the key territorial agency concerning the management of contaminated sites on Commissioner's Land. In Nunavut however, Indian and Northern Affairs Canada (INAC) retains responsibility for the management of inland waters, including surface water and groundwater. If contaminated water is encountered, INAC should immediately be consulted. Petroleum products are complex mixtures of hydrocarbons whose environmental fate depends primarily on the specific chemical and physical properties of their individual components. The relatively lighter, more volatile, mobile and water soluble compounds in fuels tend to fairly quickly evaporate into the atmosphere or migrate to ground water.

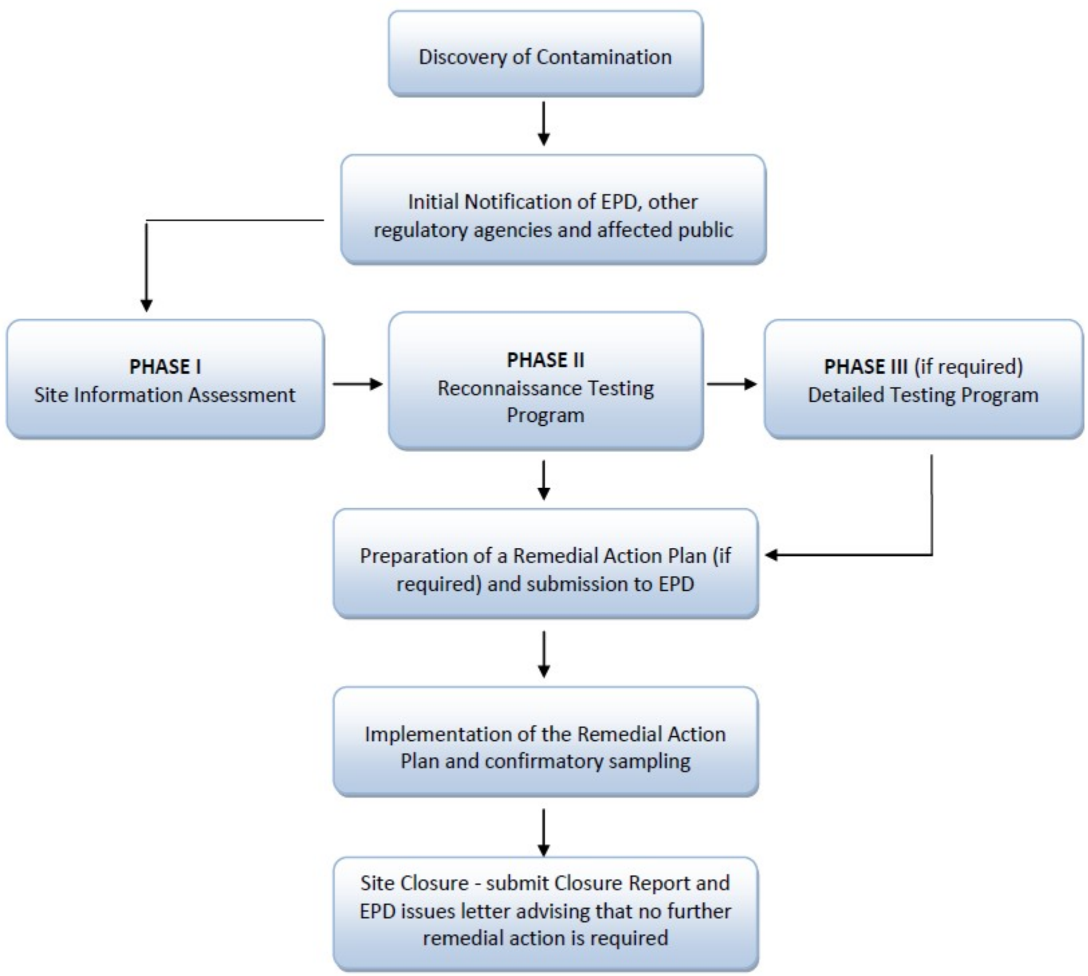


Figure 12.1: Contaminated Site management process

When exposed to oxygen and sunlight most of these lighter compounds tend to break down relatively quickly. However in groundwater, many of these compounds tend to be more persistent than in surface water. The compounds of petroleum products which tend to be somewhat more persistent and more bound to solid particles include the PAHs, alkyl PAHs and alkyl benzenes. Higher concentrations of heavier PAHs tend to be in adjacent contaminated soils than in ground water.

Cleaning up ground water without cleaning up soil contamination will usually result in a rebound of higher concentrations of these compounds portioning from contaminated soils into groundwater. Natural attenuation of these components by bioremediation lessens the degree of soil contamination with the time. The primary degradative fate process for petroleum hydrocarbons in soil is biodegradation. While volatization is expected to be dominant fate process for lighter components from soil surfaces, biodegradation becomes increasingly dominant as the soil depth increases. Some components of these fuels also migrate through the soil to groundwater.

12.5.1 Remediation criteria for petroleum hydrocarbons:

The term 'Petroleum Hydrocarbons' (PHC), describes a mixture of organic compounds found in and derived from oil, bitumen and coal. Petroleum products typically contain thousands of compounds in varying proportions, composed predominantly of carbon and hydrogen, with minor amounts of nitrogen, sulphur and oxygen.

The properties of PHC contamination in soils varies with the soil type, petroleum source and composition, degree of processing (crude, blended or refined) and the extent of weathering caused by exposure to the environment. Such factors complicate the assessment of the human health, safety and environmental risks associated with PHC contamination. This complicated assessment of risk makes it necessary to evaluate PHC as four fractions: F1, F2, F3, and F4. PHCs are subdivided according to specified ranges of equivalent carbon number (ECN). Each fraction is, in turn, made of sub fractions. These sub fractions are described according to their relevant physical and chemical properties and toxicological characteristics. These divisions between the fractions have been established in consideration of analytical factors, physical and chemical properties, the expected relevance to biological response in soils and the ability to utilize the definitions and associated properties.

Fraction 1 (F1)

The range of ECN is from C6 to C10. It includes gasoline and represents the volatile fraction of most hydrocarbon mixtures. The F1 fraction consists of aromatic sub fractions in the range C8 to C10, as well as aliphatic sub fractions in the ranges of C6 to C8 and >C8 to C10. The fraction is generally considered to be high in mobility, volatility and solubility

Fraction 2 (F2)

The range of ECN is from > C10 to C16. It includes kerosene, jet fuel and light fuel oils (No. 2 fuel oil, Arctic diesel) and represents the semi-volatile fraction of petroleum hydrocarbons. The F2 fraction is comprised of aromatics and aliphatic sub fractions in the ranges >C10 to C12 and >C12 to C16.

Fraction 3 (F3)

The range of ECN from >C16 to C34 and includes medium fuel oils (No. 4 fuel oil, Bunker B), heavy fuels oils (Bunker C) and lubricating and motor oils. It is comprised of both aromatics and aliphatics in the ranges >C16 to C21 and >C21 to C34.

Fraction 4 (F4)

The range of ECN is from > C34 to C50+. PHC within this range often make up a significant proportion of crude oils. The fraction is generally considered to be of low mobility, volatility and solubility.

Tier 1 and Tier 2 remediation criteria are prescribed for coarse-grained and fine-grained soils. As a result, sufficient textural information needs to be obtained through environmental site assessments to permit classification of the soils as either coarse or fine.

These classifications are defined as follows:

Fine-grained soil

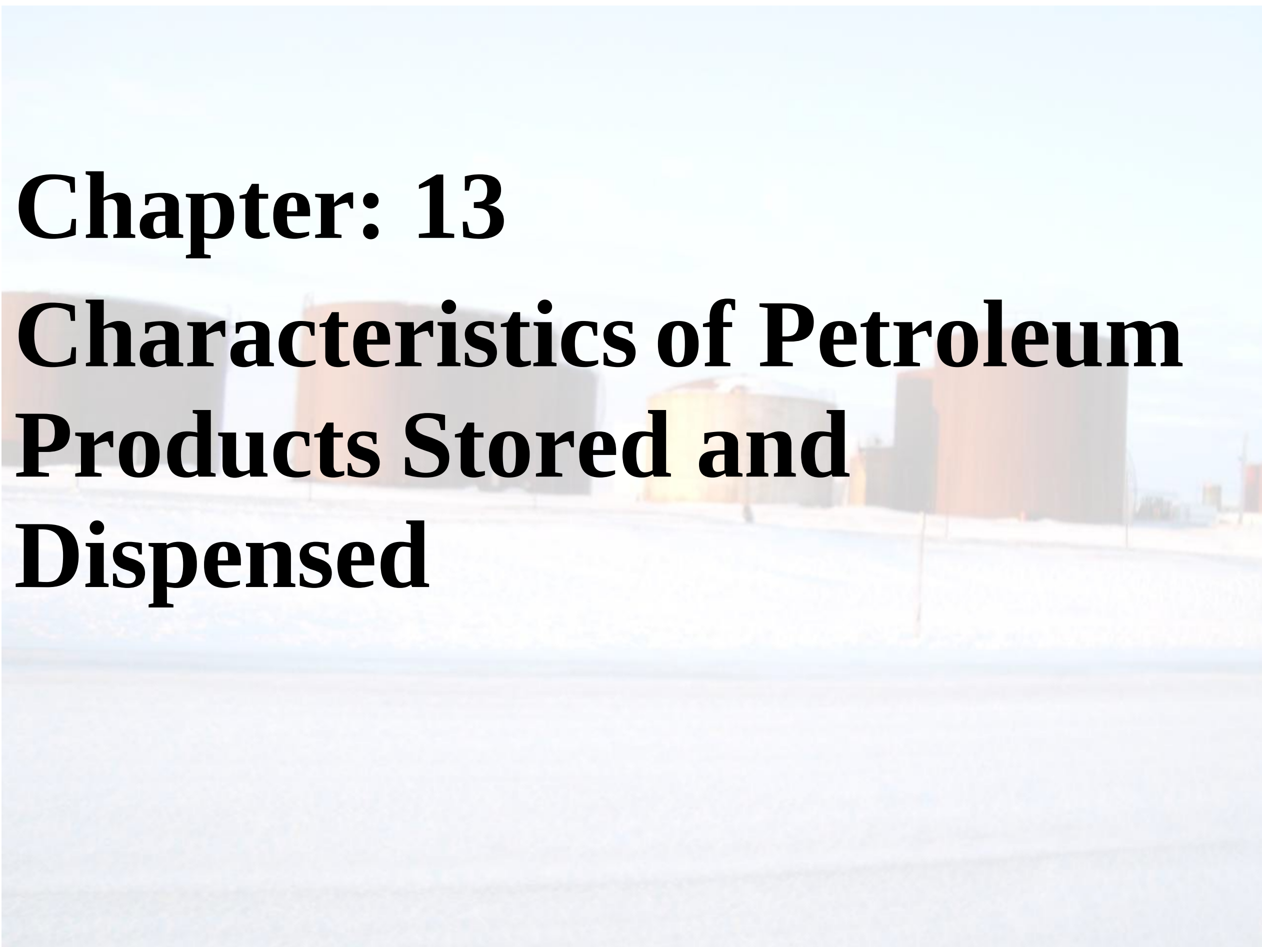
Soil having a medium grain size of <75 µm, as defined by the American Society for Testing and Materials, and includes silts and clays.

Course-grained soil

Soil having a median grain size of >75 µm as defined by the American Society for Testing and Materials, and includes sands and gravels.

Land Use	Exposure Pathway	Fine-Grained Soils				Coarse Grained Soils			
		F1	F2	F3	F4	F1	F2	F3	F4
Agricultural	Direct Contact w/Soil(DC)	12000	6800	15000	21000	12000	6800	15000	21000
	Vapour Inhalation-basement (VI)	710	3600	NA	NA	40	190	NA	NA
	Vapour Inhalation-slab-on-grade (VI)	610	3100	NA	NA	30	150	NA	NA
	Ecological Soil Contact (ESC)	210	150	1300	5600	210	150	300	2800
	Protection of Portable GW (GW-P)	170	230	NA	NA	240	320	NA	NA
	Protection of GW for Aquatic Life (GW-A)	RES	RES	NA	NA	970	380		
	Protection of GW for Livestock (GW-L)	4200	10000	NA	NA	5300	14000	NA	NA
	Management Level	800	1000	3500	10000	700	1000	2500	10000
	Governing Objective	**176**	**156**	**1366**	**5666**	**36**	**156**	**366**	**2866**
	Governing Pathway	**GW-P**	**ESC**	**ESC**	**ESC**	**VI**	**VI**	**ESC**	**ESC**
Residential	Direct Contact w/Soil(DC)	12000	6800	15000	21000	12000	6800	15000	21000
	Vapour Inhalation-basement (VI)	710	3600	NA	NA	40	190	NA	NA
	Vapour Inhalation-slab-on-grade (VI)	610	3100	NA	NA	30	150	NA	NA
	Ecological Soil Contact (ESC)	210	150	1300	5600	210	150	300	2800
	Protection of Portable GW (GW-P)	170	230	NA	NA	240	320	NA	NA
	Protection of GW for Aquatic Life (GW-A)	RES	RES	NA	NA	970	380	NA	NA
	Management Level	800	1000	3500	10000	700	1000	2500	10000
	Governing Objective	**176**	**156**	**1366**	**5666**	**36**	**156**	**366**	**2866**
	Governing Pathway	**GW-P**	**ESC**	**ESC**	**ESC**	**VI**	**VI**	**ESC**	**ESC**
Commercial	Direct Contact w/Soil(DC)	19000	10000	23000	RES	19000	10000	23000	RES
	Vapour Inhalation (VI)	4600	23000	NA	NA	320	1700	NA	NA
	Ecological Soil Contact (ESC)	320	260	2500	6600	320	260	1700	3300
	Protection of Portable GW (GW-P)	170	230	NA	NA	240	320	NA	NA
	Protection of GW for Aquatic Life (GW-A)	RES	RES	NA	NA	970	380	NA	NA
	Offsite Migration (OM)	NA	NA	19000	RES	NA	NA	4300	RES
	Management Level	800	1000	5000	10000	700	1000	3500	10000
	Governing Objective	**176**	**236**	**2566**	**6666**	**246**	**266**	**1766**	**3366**
	Governing Pathway	**GW-P**	**GW-P**	**ESC**	**ESC**	**GW-P**	**ESC**	**ESC**	**ESC**
Industrial	Direct Contact w/Soil(DC)	RES	RES	RES	RES	RES	RES	RES	RES
	Vapour Inhalation (VI)	4600	23000	NA	NA	320	1700	NA	NA
	Ecological Soil Contact (ESC)	320	260	2500	6600	320	260	1700	3300
	Protection of Portable GW (GW-P)	170	230	NA	NA	240	320	NA	NA
	Protection of GW for Aquatic Life (GW-A)	RES	RES	NA	NA	970	380	NA	NA
	Offsite Migration (OM)	NA	NA	19000	RES	NA	NA	4300	RES
	Management Level	800	1000	5000	10000	700	1000	3500	10000
	Governing Objective	**176**	**236**	**2566**	**6666**	**246**	**266**	**1766**	**3366**
	Governing Pathway	**GW-P**	**GW-P**	**ESC**	**ESC**	**GW-P**	**ESC**	**ESC**	**ESC**

Table 12.1: Remediation criteria



Chapter: 13

Characteristics of Petroleum Products Stored and Dispensed

Characteristics of Petroleum Products Stored and Dispensed

Developing a plan to deal with potential emergencies requires a comprehensive knowledge of the physical properties and characteristics of the petroleum products involved. A brief description is provided on the subject.

13.1 Diesel fuel:

Ultra-low sulfur diesel (ULSD) is a standard for defining diesel fuel with substantially lowered sulfur contents. PPD sells ULSD in all communities of Nunavut including Resolute Bay. Generally diesel is used in all kinds of diesel engines but in Nunavut the product is also used as home heating fuel, motor fuel, and fuel for power generation etc. Bulk fuel storage tanks are replenished usually once a year during the summer months. Diesel is mostly distributed to customers by trucking. In some communities modern RDR diesel dispensers are used for filling vehicles

Figure 13.1 : A modern RDR diesel dispenser

Figure13.2: USLD sample

13.1.1 Physical Properties of USLD:

The physical properties of diesel could be summarized as below.

Form:	Liquid
Appearance:	Clear, straw coloured
Odour:	Characteristic petroleum (kerosene) odour
Flash point-typical:	38°C minimum for diesel, 52°C minimum for #2 Diesel
Auto ignition temperature:	257°C (495°F)
Thermal decomposition:	No decomposition if stored and applied as directed
Lower explosive limit:	0.6 % (V) Upper: 4.7% (V)
pH:	Not applicable
Freezing point:	No data available
Boiling point:	154-372°C (310°-702°F)
Vapour pressure:	<2 mm Hg at 20°C
Density:	0.86g/cm³
Water solubility:	Negligible
Viscosity, dynamic:	1.7-40mPa.s at 37.8°C (100°F)

ULSD is produced from the fractional distillation of crude oil between 200 °C (392 °F) and 350 °C (662 °F) at atmospheric pressure, resulting in a mixture of carbon chains that typically contain between 8 and 21 carbon atoms per molecule. As of 2012, the density of petroleum diesel is about 0.832 kg/l, about 86.1% of the fuel mass is carbon, and when burned, it offers a net heating value of 43.1 MJ/kg as opposed to 43.2 MJ/kg for gasoline. However, due to the higher density, diesel offers a higher volumetric energy density at 35.86 MJ/L (128 700 BTU/US gal) vs. 32.18 MJ/L (115 500 BTU/US gal) for gasoline, some 11% higher, which should be considered when comparing the fuel efficiency by volume.

The CO_2 emissions from diesel are 73.25 g/MJ, just slightly lower than for gasoline at 73.38 g/MJ. Diesel is generally simpler to refine from petroleum than gasoline, and contains hydrocarbons having a boiling point in the range of 180-360°C (360-680°F). Because of recent changes in fuel quality regulations, additional refining is required to remove sulfur, which contributes to a sometimes higher cost.

13.1.2 Chemistry of ULSD:

Petroleum-derived diesel is composed of about 75% saturated hydrocarbons (primarily paraffin including straight chain, branch chain and cyclo paraffin),and 25% aromatic hydrocarbons (including naphthalenes and alkyl benzenes). The average chemical formula for common diesel fuel is $C_{12}H_{23}$, ranging approximately from $C_{10}H_{20}$ to $C_{15}H_{28}$. Actually ULSD is a mixture of following hydrocarbons fractions :

Figure13.3: Diesel is immiscible with water

Component	CAS-No.	Weight
Fuels, diesel,No.2 Gasoil- unspecified	68476-34-6	100%
Nonane	111-84-2	0-5%
Naphthalene	91-20-3	0-1%
1,2,4-Trimethylbenzene	95-63-6	0-2%
Xylene	1330-20-7	0-2%
Sulfur	7704-34-9	15ppm maximum

Table 13.1: Composition of ULSD

Microbes such as algae can cause some quality and environmental issues when let grow in a fuel tank. Algae need light to live and grow. As there is no sunlight in a closed fuel tank, no algae can survive, but some microbes can survive and feed on the diesel fuel. These microbes form a colony that lives at the interface of fuel and water. They grow quite fast in warmer temperatures. They can even grow in cold weather when fuel tank heaters are installed. Parts of the colony can break off and clog the fuel lines and fuel filters and may result into pipe burst contaminating the environment.

13.1.3 Diesel related environmental concerns:

Accidental release of diesel to the atmosphere is hazardous and could pose a threat to air quality and cause contamination of land and nearby water bodies. A disadvantage of diesel as a vehicle fuel in cold climates, compared to gasoline or other petroleum-derived fuels, is that its viscosity increases quickly as the fuel's temperature decreases, turning into a non-flowing gel at temperatures as high as - 19 °C (-2.2 °F) or -15 °C (5 °F), which cannot be pumped by regular fuel pumps. Special low-temperature diesel contains additives to keep it in a more liquid state at lower temperatures, but starting a diesel engine in very cold weather may still pose considerable difficulties. Diesel-powered vehicles generally have a better fuel economy than equivalent gasoline engines and produce less greenhouse gas emission. Their greater economy is due to the higher energy per-litre content of diesel fuel and the intrinsic efficiency of the diesel engine. While petro diesel's higher density results in higher greenhouse gas emissions per litre compared to gasoline, the 20–40% better fuel economy achieved by modern diesel-ignited automobiles offsets the higher per-litre emissions of greenhouse gases and a diesel-powered vehicle emits 10-20 percent less greenhouse gas than comparable gasoline vehicles.

In the past, diesel fuel contained higher quantities of sulfur. North American Emission Standards and preferential taxation have forced oil refineries to dramatically reduce the level of sulfur in diesel fuels. Canadian diesel fuel typically also has a lower octane number (a measure of ignition quality) than European diesel, resulting in worse cold weather performance and some increase in emissions.

Petro diesel spilled on a road will stay there until washed away by sufficiently heavy rain, whereas gasoline will quickly evaporate. After the light fractions have evaporated, a greasy slick is left on the road which can destabilize moving vehicles. Diesel spills severely reduce tire grip and traction, and have been implicated in many accidents. The loss of traction is similar to that encountered on black ice. High levels of sulfur in diesel are harmful for the environment because they prevent the use of catalytic diesel particulate filters to control diesel particulate emissions, as well as more advanced technologies, such as nitrogen oxide (NO_X) adsorbers (still under development), to reduce emissions. Moreover, sulfur in the fuel is oxidized during combustion, producing sulfur dioxide and sulfur trioxide, that in presence of water, rapidly convert to sulfuric acid, one of the chemical processes that result in acid rain. However, the process for lowering sulfur also reduces the lubricity of the fuel, meaning that additives must be put into the fuel to help lubricate engines.

13.2 Gasoline:

Gasoline is a toxic, translucent, petroleum-derived liquid that is primarily used as a fuel in internal combustion engines. It consists mostly of organic compounds obtained by the fractional distillation of petroleum, enhanced with a variety of additives. Gasoline is more volatile than diesel oil, Jet-A, or kerosene, not only because of the base constituents, but also because of additives. Volatility is often controlled by blending with butane, which boils at -0.5 °C. The volatility of gasoline is determined by the Reid vapor pressure (RVP) test. The desired volatility depends on the ambient temperature.

In hot weather, gasoline components of higher molecular weight and thus lower volatility are used. In hot weather, excessive volatility results in what is known as "vapor lock", where combustion fails to occur, because the liquid fuel has changed to a gaseous fuel in the fuel lines, rendering the fuel pump ineffective and starving the engine of fuel. This effect mainly applies to camshaft-driven (engine mounted) fuel pumps which lack a fuel return line. Vehicles with fuel injection require the fuel to be pressurized, to within a set range. Because camshaft speed is nearly zero before the engine is started, an electric pump is used. It is located in the fuel tank so the fuel may also cool the high-pressure pump. Pressure regulation is achieved by returning unused fuel to the tank. Therefore, vapor lock is almost never a problem in a vehicle with fuel injection.

Gasoline vapours are injurious to human health and are carcinogen in nature so there are certain regulations to control its emission. In Canada, volatility is regulated in large cities to reduce the emission of unburned hydrocarbons by the use of so-called reformulated gasoline that is less prone to evaporation. Modern automobiles are also equipped with an evaporative emissions control system (called an EVAP system in automotive jargon), which collects evaporated fuel from the fuel tank in a charcoal-filled canister while the engine is stopped, and then releases the collected vapors into the engine intake for burning when the engine is running (usually only after it has reached normal operating temperature). The evaporative emissions control system also includes a sealed gas cap to prevent vapors from escaping via the fuel filler tube.

Figure 13.4: Gasoline sample

13.2.1 Toxic ingredients of gasoline:

Gasoline contains the following toxic chemicals subject to reporting requirements of section 313 of Emergency Planning a Community Right-To-Know Act.

Ingredient Name (CAS Number)	Concentration WT. Percent
Benzene (71-43-2)	0.1 to 4.9 (0.1 to 1.3 for reformulated gasoline
Ethyl benzene (100-41-4	<3
n-Hexane (110-54-3)	0.5 to 4
Methyl-tertiary butyl ether (MTBE) (1634-04-4)	0 to 15.0
Toluene (108-88-3)	1 to 15
1, 2, 4 Trimethylbenzene (95-63-3)	<6
Xylene, mixed isomers (1330-20-7)	1-15

Ingredient name CAS number	Concentration –Parts per million (ppm) by weight
Polycyclic aromatic compounds (PACs)	17
Benzo (g,h,i), perylene (191-24-2)	2.55
Lead (7439-92-1)	0.079

13.2.2 Combustible and Physical Properties of gasoline:

Flammable Properties:

Flash point:	-45°F (-43°C)
Auto ignition temperature:	Highly variable;>530°F (>280°C)
OSHA/NFPA Flammability Class;	1A (Flammable Liquid)
Lower Explosive Limit (%):	1.4%
Upper Explosive Limit (%):	7.6%

Odour-A strong, characteristic aromatic hydrocarbon odour. Oxygenated gasoline with MTBE and/or TAME may have a sweet, ether-like odour and is detectable at a lower concentration then non-oxygenated gasoline.

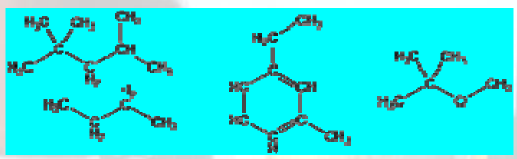
Odour Threshold	Odour Detection	Odour Recognition
Non-oxygenated gasoline:	0.5-0.6ppm	0.8-1.1ppm
Gasoline with 15% MTBE:	0.2-0.3ppm	0.4-0.7ppm
Gasoline with 15% TAME:	0.1ppm	0.2pm

Basic Physical Properties

Boiling Range:	85 to 437°F (39-200°C)
Vapour pressure:	6.4-15 RVP @ 100°F (38°C) (275-475mm Hg @ 68°F (20°C)
Vapour Density (air=1):	AP 3 to 4
Specific Gravity (H^2O+1):	0.70-0.78
Evaporation Rate:	10-11 (n-butyl acetate=1)
Percent Volatiles:	100%
Solubility (H^2O):	Non-oxygenated gasoline-negligible (<0.1%@77°F). Gasoline with 15% MTBE-Slight (0.1-3%@77°F); ethanol is readily soluble in water

Combustibility of gasoline is measured in terms of its octane rating which is determined relative to a mixture of 2,2,4-trimethylpentane (an isomer of octane) and n-heptane. There are different conventions for expressing octane ratings, so a fuel may have several different octane ratings based on the measure used.

The octane rating became important as the military sought higher output for aircraft engines in the late 1930s and the 1940s. A higher octane rating allows a higher compression ratio, and thus higher temperatures and pressures, which translate to higher power output. Some scientists even predicted that a nation with a good supply of high octane gasoline would have the advantage in air power. The specific gravity (or relative density) of gasoline ranges from 0.71–0.77 (719.7 kg/m3 ; 0.026 lbs./in3; 6.073 lbs./US gal; 7.29 lbs./imp gal), higher densities having a greater volume of aromatics. Gasoline floats on water; water cannot generally be used to extinguish a gasoline fire, unless used in a fine mist. Gasoline is produced in oil refineries.
Material that is separated from crude oil via distillation, called virgin or straight-run gasoline, does not meet the required specifications for modern engines (in particular octane rating; see below), but will form part of the blend.



Some of the main components of gasoline: isooctane, butane, an aromatic compound, and the octane enhancer MTBE. The bulk of a typical gasoline consists of hydrocarbons with between 4 and 12 carbon atoms per molecule (commonly referred to as C4-C12). The various refinery streams blended to make gasoline have different characteristics. Some important streams are:

- Straight-run gasoline is distilled directly from crude oil. Once the leading source of fuel, its low octane rating required lead additives. It is low in aromatics (depending on the grade of crude oil), containing some naphthenes (cycloalkanes) and no olefins. About 0-20% of gasoline is derived from this material, in part because the supply of this fraction is insufficient and its RON is too low.
- Reformate, produced in a catalytic reformer with a high octane rating and high aromatic content, and very low olefins (alkenes). Most of the benzene, toluene, and xylene (the so-called BTX) are more valuable as chemical feed stocks and are thus removed to some extent.
- Cat cracked gasoline or cat cracked naphtha, produced from a catalytic cracker, with a moderate octane rating, high olefins (alkene) content, and moderate aromatics level.

- Hydrocrackate (heavy, mid, and light) produced from a hydrocracker, with medium to low octane rating and moderate aromatic levels.
- Alkylate is produced in an alkylation unit, involving the addition of isobutane to alkenes giving branched chains but low aromatics.
- Isomerate is obtained by isomerising low octane straight run gasoline to isoparafins (like isooctane).

The terms above are the jargon used in the oil industry but terminology varies. Overall, a typical gasoline is predominantly a mixture of paraffins (alkanes), naphthenes (cycloalkanes), and olefins (alkenes).The actual ratio depends on the oil refinery that makes the gasoline, as not all refineries have the same set of processing units; crude oil feed used by the refinery; the grade of gasoline, in particular, the octane rating

Figure13.5: Burning of gasoline produce large quantities of soot

13.2.3 Gasoline storage:

Good quality gasoline should be stable almost indefinitely if stored properly. Such storage should be in an airtight container, to prevent oxidation or water vapors mixing, and at a stable cool temperature, to reduce the chance of the container leaking. When gasoline is not stored correctly, gums and solids may accumulate resulting in "stale fuel". The presence of these degradation products in fuel tank, lines, and carburetor or fuel injection components, make it harder to start the engine. Upon the resumption of regular vehicle usage, though, the buildups should eventually be cleaned up by the flow of fresh petrol. Users have been advised to keep gasoline containers and tanks more than half full and properly capped to reduce air exposure, to avoid storage at high temperatures, to run an engine for ten minutes to circulate the stabilizer through all components prior to storage, and to run the engine at intervals to purge stale fuel from the carburetor.

13.2.4 Energy value of gasoline:

Gasoline contains about 35 MJ/L (9.7 kW·h/L, 132 MJ/US gal, 36.6 kWh/US gal) (Higher heating value) or 13 kWh/kg. Gasoline blends differ, and therefore actual energy content varies according to the season to season and producer by up to 4% more or less than the average. The lower energy content (per litre) of LPG in comparison to gasoline is mainly due to its lower density. Energy content per kilogram is higher than for gasoline (higher hydrogen to carbon ratio). Currently many countries set limits on gasoline aromatics in general, benzene in particular, and olefin (alkene) content. Such regulations led to increasing preference for high octane pure paraffin (alkane) components, such as alkylate, and is forcing refineries to add processing units to reduce benzene content.

Gasoline can also contain other organic compounds, such as organic ethers (deliberately added), plus small levels of contaminants, in particular organic sulfur compounds, but these are usually removed at the refinery. Gasolines are also treated with metal deactivators, which are compounds that sequester (deactivate) metal salts that otherwise accelerate the formation of gummy residues. The metal impurities might arise from the engine itself or as contaminants in the fuel. Gasoline, as delivered at the pump, also contains additives to reduce internal engine carbon buildups, improve combustion, and to allow easier starting in cold climates.

13.2.5 Safety & environmental issues related to gasoline:

Energy is obtained from the combustion of gasoline, the conversion of a hydrocarbon to carbon dioxide and water. The combustion of octane follows this reaction:

$$2\ C_8H_{18} + 25\ O_2 \rightarrow 16\ CO_2 + 18\ H_2O$$

Combustion of one US gallon of gasoline produces about 19.4 pounds (8.8 kg) of carbon dioxide (converts to 2.33 kg/litre), a greenhouse gas. Gasoline is one of the hazardous substances and is regulated in United States and Canada by the Occupational Safety and Health Administration. The material safety data sheet for unleaded gasoline shows at least 15 hazardous chemicals occurring in various amounts, including benzene (up to 5% by volume), toluene (up to 35% by volume), naphthalene (up to 1% by volume), tri-methyl benzene (up to 7% by volume), methyl tert-butyl ether (MTBE) (up to 18% by volume, in some provinces) and about ten others. Benzene and many anti knocking additives are carcinogenic. The chief risks of such leaks come not from vehicles, but from gasoline delivery truck accidents and leaks from storage tanks. Because of this risk, most storage tanks now have extensive measures in place to detect and prevent any such leaks, such as sacrificial anodes.

The main concern with gasoline on the environment, aside from the complications of its extraction and refining, are the potential effect on the climate. Unburned gasoline and evaporation from the tank, when in the atmosphere, react in sunlight to produce photochemical smog. Addition of ethanol increases the volatility of gasoline, potentially worsening the problem. Gasoline, when used in high-compression internal combustion engines, has a tendency to auto ignite (detonate) causing damaging "engine knocking" (also called "pinging" or "pinking") noise. The discovery that lead additives modified this behavior led to the widespread adoption of additives use in the 1920s and therefore more powerful, higher compression engines.

The most popular additive was tetra-ethyl lead. With the discovery of the extent of environmental and health damage caused by the lead, however, and the incompatibility of lead with catalytic converters found on virtually all newly sold automobiles since 1975, this practice began to wane (encouraged by many governments introducing differential tax rates) in the 1980s. In North America, where lead had been blended with gasoline (primarily to boost octane levels) since the early 1920s, standards to phase out leaded gasoline were first implemented in 1973. Most countries have phased out leaded fuel now. Different additives have replaced the lead compounds.

The most popular additives include aromatic hydrocarbons, ethers and alcohol (usually ethanol or methanol). Like other alkanes, gasoline burns in a limited range of its vapor phase and, coupled with its volatility, this makes leaks highly dangerous when sources of ignition are present. Gasoline has a lower explosion limit of 1.4% by volume and an upper explosion limit of 7.6%. If the concentration is below 1.4% the air- gasoline mixture is too lean and will not ignite. If the concentration is above 7.6% the mixture is too rich and also will not ignite. However, gasoline vapor rapidly mixes and spreads with air, making unconstrained gasoline quickly flammable. Many accidents involve gasoline being used in an attempt to light bonfires; rather than helping the material on the bonfire to burn, some of the gasoline vaporizes quickly after being poured and mixes with the surrounding air, so when the fire is lit a moment later, the vapor surrounding the bonfire instantly ignites in a large fireball, engulfing the unwary user. The vapor is also heavier than air and tends to collect in garage inspection pits.

13.3 Jet fuel:

Product Name:	Jet A-1
CAS Number:	8008-20-6
Formula:	C_9H_{20} to $C_{16}H_{34}$
Chemical Family:	Petroleum Hydrocarbon

Synonyms: Aviation Fuel-Jet A, Turbo Fuel A, Aviation Turbine Fuel

Jet fuel is a type of aviation fuel designed for use in aircraft powered by gas-turbine engines. It is clear to straw-colored in appearance. Petroleum Products Division of Government of Nunavut only sells Jet A-1 which is produced to a standardized international specification. Jet fuel is a mixture of a large number of different hydrocarbons. The range of their sizes (molecular weights or carbon numbers) is restricted by the requirements for the product, for example, the freezing point or smoke point. Kerosene-type jet fuel (Jet A-1) has a carbon number distribution between about 8 and 16 carbon numbers. Jet A-1 Fuel must meet the specification for DEF STAN 91-91 (Jet A-1), ASTM specification D1655 (Jet A-1) and IATA Guidance Material (Kerosene Type), NATO Code F-35.

13.3.1 Physical Properties:

Boiling Point:	300-570 ^{o}F
Vapour Pressure:	0.50mm Hg
Vapour Density (Air = 1):	Greater than 1
Solubility in Water:	Less than 0.1%
Odour Threshold:	N.A
Specific Gravity (Water=1):	0.78 - 0.84
Auto Ignition Temp:	410 ^{o}F
Physical Hazard:	Combustible Liquid and Flammable Vapour, May accumulate static charge
Freezing Point	-47°C (-52.6°F)
Open air burning temperatures	260-315°C (500-599°F)
Density at 15°C (59°F)	0.804 kg/L
Specific energy	43.15 MJ/kg
Energy density	34.7 MJ/L

The first jet fuels were based on kerosene or a gasoline-kerosene mix, and most jet fuels are still kerosene-based. The details of specifications were adjusted, such as minimum freezing point, to balance performance requirements and availability of fuels. Very low temperature freezing points reduce the availability of fuel. Higher flash point products required for use on aircraft carriers are more expensive to produce. Jet A-1 is safer to handle than traditional avgas. The primary differences between Jet A and Jet A-1 are the higher freezing point of Jet A (−40 °C vs. −47 °C for Jet A-1), and the mandatory requirement for the addition of an anti-static additive to Jet A-1.

13.3.2 Jet A-1 additives:

Jet A-1 specifications allow for certain additives to be used to jet fuel,

- Antioxidants to prevent gumming usually based on alkylated phenols, e.g., AO-30, AO-31, or AO-37;
- Antistatic agents, to dissipate static electricity and prevent sparking; Stadis 450, with dinonylnaphthylsulfonic acid (DINNSA) as the active ingredient, is an example
- Corrosion inhibitors, e.g., DCI-4A used for civilian and military fuels, and DCI- 6A used for military fuels;
- Fuel System Icing Inhibitor (FSII) agents, e.g., Di-EGME; FSII is often mixed at the point-of-sale so that users with heated fuel lines do not have to pay the extra expense.
- Biocides are to remediate microbial (i.e., bacterial and fungal) growth present in aircraft fuel systems. Currently, two biocides are approved for use by most aircraft and turbine engine original equipment manufacturers (OEMs); Kathon FP1.5 Microbiocide and Biobor JF.
- Metal deactivator can be added to remediate the deleterious effects of trace metals on the thermal stability of the fuel. The one allowable additive is N, N'- disalicylidene 1,2-propanediamine.

13.3.3 Water in Jet fuel:

It is very important that jet fuel be free from water contamination. During flight, the temperature of the fuel in the tanks decreases, due to the low temperatures in the upper atmosphere. This causes precipitation of the dissolved water from the fuel. The separated water then drops to the bottom of the tank, because it is denser than the fuel. From this time on, as the water is no longer in solution, it can freeze, blocking fuel inlet pipes. Removing all water from fuel is impractical; therefore fuel heaters are usually used on commercial aircraft to prevent water in fuel from freezing.

There are several methods for detecting water in jet fuel. A visual check may detect high concentrations of suspended water, as this will cause the fuel to become hazy in appearance. An industry standard chemical test for the detection of free water in jet fuel uses a water-sensitive filter pad that turns green if the fuel exceeds the specification limit of 30ppm (parts per million) free water.

13.3.4 Hazardous nature of Jet fuel:

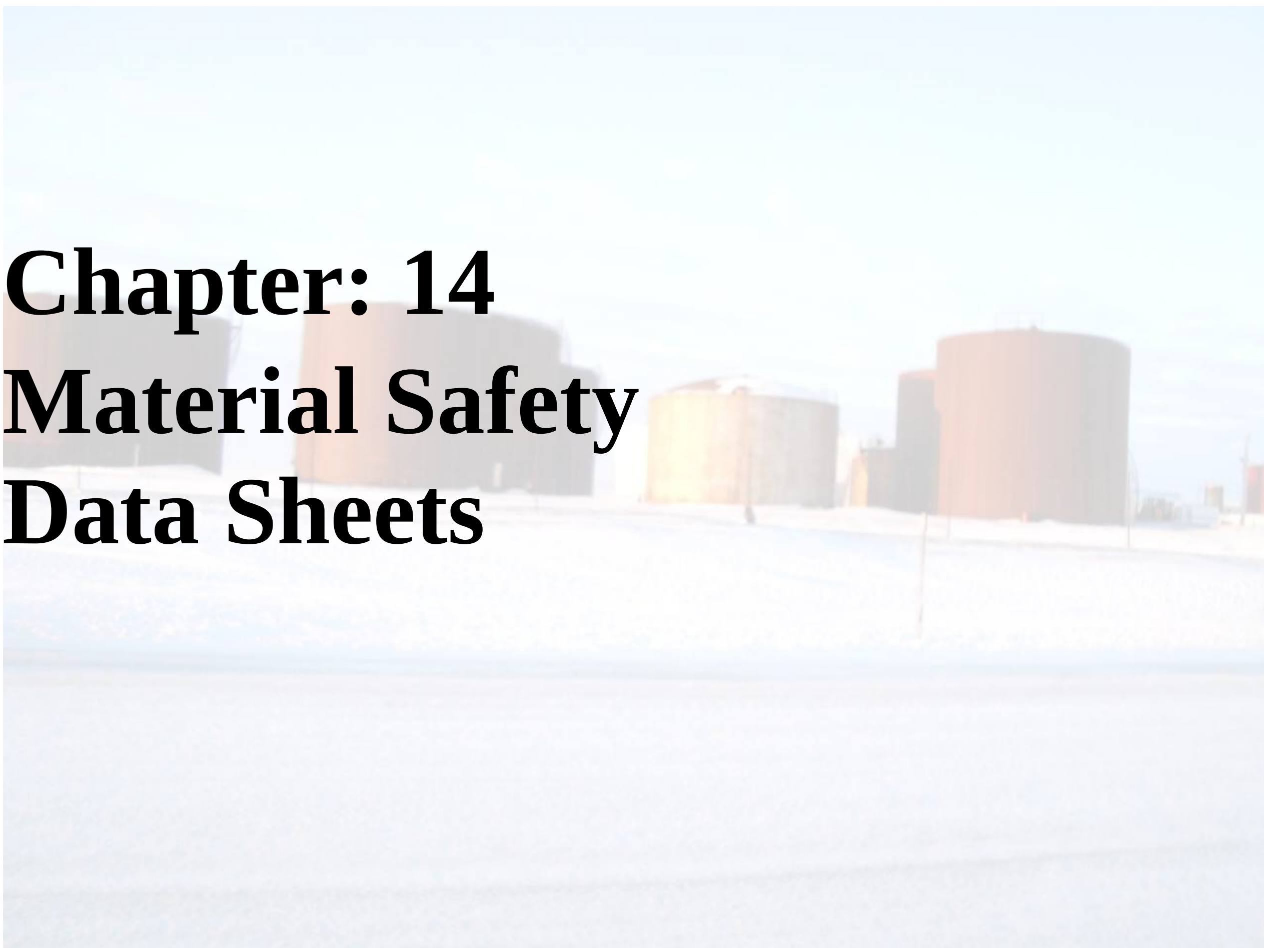
The air transport industry is responsible for 2 percent of man-made carbon dioxide emitted. Due to a fairly high percentage of aromatics (10 to 20%), Jet fuel is associated with many potential environmental hazards, including short- and long-term potential effects. Jet fuel in the water column can depress Daphnia (Zooplankton) populations for several weeks, resulting in algae blooms. Short-term (acute) hazards of the some of the lighter, more volatile and water soluble aromatic compounds (such as benzenes, toluene, and xylenes) in Jet include potential acute toxicity to aquatic life in the water column (especially in relatively confined areas) as well as potential inhalation hazards. Benzenes, toluene, and xylenes (all common components of jet fuels) tend to cause narcosis. Jet fuels possess moderate to high acute toxicity to biota with product-specific toxicity related to the type and concentration of aromatic compounds. Since Je A-1 is a mix of middle distillates and gasoline, some of the same compounds found in gasoline are also found in Jet. As might be expected, there is therefore some overlap between the toxic effects potentially resulting from Jet spills and gasoline spills.

Jet fuel spills could result in potential acute toxicity to some forms of aquatic life. Oil coating of birds, sea otters, or other aquatic life which come in direct contact with the spilled oil is another potential short term hazard. In the short term, spilled oil will tend to float on the surface; water uses threatened by spills include: recreation; fisheries; industrial; and irrigation. Long-term (chronic) potential hazards of the some of the lighter, more volatile and water soluble aromatic compounds in Jet include contamination of groundwater. Chronic effects associated with middle distillates are mainly due to exposure to aromatic compounds, which are found primarily in all types of Jet fuel. Chronic effects of some of the constituents in jet fuel (benzene, toluene, xylenes, naphthalene's, alkyl benzenes, and various alkyl PAHs) include changes in the liver and harmful effects on the kidneys, heart, lungs, and nervous system.

Although PAHs, particularly heavy PAHs, do not make up a large percentage of jet fuels by weight, there are some PAHs in jet fuels, including naphthalene, and alkyl naphthalenes. Due to their relative persistence and potential for various chronic effects (like carcinogenicity), PAHs (and particularly the alkyl PAHs) as well as alkyl benzenes such as xylenes, can contribute to long-term (chronic) hazards of jet fuels in contaminated soils, sediments, and ground waters. Present up to 3% by weight, the PAH naphthalene can absorb to soil particles and is soluble in groundwater. Note: PAHs in general are more frequently associated with chronic risks. These risks include cancer and often are the result of exposures to complex mixtures of chronic-risk aromatics (such as PAHs, alkyl PAHs, benzenes, and alkyl benzenes), rather than exposures to low levels of a single compound. Some fuel additives may contribute to environmental problems.

One source states that methyl cyclic hexane may be one of the more toxic components of jet fuel. This compound (cyclohexane, methyl, also known as toluene hexahydride, CAS# 108-87-2) can account for 2-16% of jet fuel 4 by weight. Exposure to jet fuel vapors has been reported to cause neurobehavioral symptoms, including dizziness, headache, nausea and fatigue. Some of the PAHs in this product can move into plants and some have either harmful or positive effects on plants. Many of the PAHs found in this product are phototoxic, that is they display greatly enhanced toxicity in sunlight or other UV source than elsewhere.

Chapter: 14 Material Safety Data Sheets



MATERIAL SAFETY DATA SHEETS (MSDS) are provided for each petroleum product. These MSDS documents are included as information packages in this plan.

For Copy of (M)SDS: Internet: www.petro-canada.ca/msds
Canada-wide: telephone: 1-800-668-0220; fax: 1-800-837-1227
For Product Safety Information: (905) 804-4752

Notice to reader

To the best of our knowledge, the information contained herein is accurate. However, neither the above-named supplier, nor any of its subsidiaries, assumes any liability whatsoever for the accuracy or completeness of the information contained herein.

Final determination of suitability of any material is the sole responsibility of the user. All materials may present unknown hazards and should be used with caution. Although certain hazards are described herein, we cannot guarantee that these are the only hazards that exist.

PLEASE BE PREPARED TO USE THE MSDS FOR THE PRODUCT SPILLED.

14.1MSDS for Diesel (Information from petro-canada.ca) Material Safety Data Sheet

DIESEL FUEL

1. Product and company identification

Product Name: DIESEL FUEL

Synonym: Seasonal Diesel, #1 Diesel, #2 Heating Oil, #1 Heating Oil, D50, D60, P40, P50, Arctic Diesel, Farm Diesel, Marine Diesel, Low Sulphur Diesel, LSD, Ultra Low Sulphur Diesel ULSD, Mining Diesel, Naval Distillate, Dyed Diesel, Marked Diesel, Coloured Diesel, Furnace special, Biodiesel blend, B1, B2, B5, Diesel Low Cloud (LC).

Code: W104, W293

Material Uses: Diesel fuels are distillate fuels suitable for use in high and medium speed internal Combustion engines of the compression ignition type. Mining diesels, marine diesels, MDO and naval distillates may have a higher flash point requirement.

Manufacturer: PETRO-CANADA
P.O. Box 2844
150 –6th Avenue South-West
Calgary, Alberta

T2P 3E3

In case of emergency: Petro-Canada: 403-296-3000
Canutec Transportation: 613-996-6666
Poison Control Centre: Consult local telephone directory for emergency number(s).

2. Hazards identification

Physical State: Bright oily liquid
Odour: Mild petroleum oil like.

WHMIS (Canada):
Class B-3: Combustible liquid with a flash point between 37.8°C (100°F) and 93.3°C (200°F)
Class D-2A: Material causing other toxic effects (Very toxic)
Class D-2B: Material causing other toxic effects (Toxic)

OSHA/HCS status: This material is considered hazardous by the OSHA Hazard Communication Standard.

Emergency overview: WARNING!
COMBUSTIBLE LIQUID AND VAPOUR. CAUSES EYE AND SKIN IRRITATION.
Combustible liquid. Severely irritating to the skin. Irritating to eyes. Keep away from heat, sparks and flame. Do not get in eyes. Avoid breathing vapour or mist. Avoid contact with skin and clothing. Use only with adequate ventilation. Wash thoroughly after handling.

Routes of entry: Dermal contact. Eye contact. Inhalation. Ingestion.

<u>Potential acute health effects</u>

Inhalation: Inhalation of this product may cause respiratory tract irritation and Central Nervous System (CNS) depression, symptoms of which may include; weakness, dizziness, slurred speech, drowsiness, unconsciousness and in case of severe overexposure; coma and death.

Ingestion: Ingestion of this product may cause gastro-intestinal irritation. Aspiration of this product may result in severe irritation or burns to the respiratory tract.

Skin: Severely irritating to the skin.

Eyes: Irritating to eyes.

<u>Potential chronic health effects</u>

Chronic effects: No known significant effects or critical hazards.

Carcinogenicity: Diesel engine exhaust particulate is probably carcinogenic to humans (IARC Group 2A).

Mutagenicity: No known significant effects or critical hazards.

Teratogenicity: No known significant effects or critical hazards.

Developmental effects: No known significant effects or critical hazards.

Fertility effects: No known significant effects or critical hazards.

Medical conditions aggravated by overexposure: Avoid prolonged or repeated skin contact to diesel fuels which can lead to dermal irritation and may be associated with an increased risk of skin cancer.

See toxicological information (Section 11)

3. Composition/information or ingredients

Name	CAS number	%
Hydro-treated Renewable Diesel/ fuels, diesel/Fuel Oil No.1/ Fuel Oil No. 2	64742-81-0/ 68334-30-5/ 8008-20-6/ 68476-30-2	95-100
Alkanes, C10-20 Branched and linear (R100)	958771-01-1	10-20
Fatty acids methyl esters	61788-61-2/ 67784-80-9 73891-99-3	0-5

There are no additional ingredients present which, within the current knowledge of the supplier and in the concentrations applicable, are classified as hazardous to health or the environment and hence require reporting in this section.

4. First-aid measures

Eye contact: Check for and remove and contact lenses. Immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical attention immediately.

Skin contact: In case of contact, immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Wash skin thoroughly with soap and water or use recognized skin cleanser. Wash clothing before reuse. Clean shoes thoroughly before reuse. Get medical attention immediately.

Inhalation: Move exposed person to fresh air. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention immediately.

Ingestion: Wash out mouth with water. Do not induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. Get medical attention immediately.

Protection of first aiders: No action shall be taken involving any personal risk or without suitable training.

It may be dangerous to the person providing aid to give mouth to mouth resuscitation.

Notes to physician: No specific treatment. Treat symptomatically. Contact poison treatment specialist immediately if large quantities have been ingested or inhaled.

5. Fire-fighting measures

Flammability of the product: Combustible liquid

Extinguishing media

Suitable: Use dry chemical, CO_2, water spray (fog) or foam.

Unsuitable: Do not use water jet.

Special exposure hazards: Promptly isolate the scene by removing all persons from the vicinity of the incident if there is a fire. No actions shall be taken involving any personal risk or without suitable training. Move containers from fire area if this can be done without risk. Use water spray to keep fire-exposed containers cool.

Products of combustion: Carbon oxides (CO, CO_2), nitrogen oxides (NOx), sulfur oxides (SOx), sulfur compounds (H_2S), smoke and irritating vapours as products of incomplete combustion.

Special protective equipment for fire-fighters: Fire-fighters wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in a positive pressure mode.

Special remarks on fire hazards: Flammable in presence of open flame, spark, and heat. Vapours are heavier than air and may travel considerable distance to sources of ignition and flash back. This product can accumulate static charge and ignite.

Special remarks on explosion hazard: Do not pressurize, cut, weld, braze, solder, drill, grind or expose containers to heat or sources of ignition. Runoff to sewer may create fire or explosion hazard.

6. Accidental release measures

Personal precautions: No action shall be taken involving any personal risk or without suitable training. Evacuate surrounding areas. Keep unnecessary and unprotected personnel from entering. Do not touch or walk through spill material. Shut off all ignition sources. No flares, smoking or flames in hazard area. Avoid breathing vapour or mist. Provide adequate ventilation. Wear appropriate personal protective equipment (see Section 8).

Environmental precautions: Avoid dispersal of spilt material and runoff and contact with soil, waterways, drains and sewers. Inform the relevant authorities if the product has caused environmental pollution (sewers, waterways, soil or air).

Methods for cleaning up:

Small spills: Stop leak if without risk. Move containers from spill area. Dilute with water and mop up if water soluble. Alternatively, or if water insoluble, absorb with an inert dry material and place in an appropriate waste disposal container. Use spark-proof tools and explosion-proof equipment. Dispose of via a licensed waste disposal contractor.

Large spills: Stop leak if without risk. Move containers from spill area. Approach the release from upwind. Prevent entry into sewers, water courses, basements or confined areas. Wash spillages into an effluent treatment plant or proceed as follows. Contain and collect spillage with noncombustible, absorbent material e.g. sand, earth, vermiculite or diatomaceous earth and place in container for disposal according to local regulations (see section 13). Use spark-proof tools and explosion-proof equipment. Dispose of via a licensed waste disposal contractor. Contaminated absorbent material may pose the same hazard as the spilt product. Note: see section 1 for emergency contact information and section 13 for waste disposal.

7. Handling and storage

Handling: Put on appropriate personal protective equipment (see section 8). Eating, drinking and smoking should be prohibited in areas where this material is handled, stored and processed. Workers should wash hands and face before eating, drinking and smoking. Remove contaminated clothing and protective equipment before entering eating areas. Do not ingest. Avoid contact with eyes, skin and clothing. Avoid breathing vapour or mist. Use only with adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Do not enter storage areas and confined spaces unless adequately ventilated. Keep in the original container or an approved alternative made from a compatible material, kept tightly closed when not in use. Store and use away from heat, sparks, open flame or any other ignition source. Use explosion-proof electrical (ventilating, lighting and material handling) equipment. Use non-sparking tools. Take precautionary measures against electrostatic discharges. To avoid fire or explosion, dissipate static electricity during transfer by earthing and bonding containers and equipment before transferring material. Empty containers retain product residue and can be hazardous. Do not reuse container.

Storage: Store in accordance with local regulations store in a segregated and approved area. Store in original container protected from direct sunlight in a dry, cool and well-ventilated area, away from incompatible materials (see section 10) and food and drink. Eliminate all ignition sources. Separate from oxidizing materials. Keep container tightly closed and sealed until ready to use. Containers that have been opened must be carefully resealed and kept upright to prevent leakage. Do not store in unlabeled containers. Use appropriate containment to avoid environmental containment. Ensure the storage containers are grounded/ bonded.

8. Exposure controls/personal protection

Ingredient	Exposure limits
Fuels, diesel	**ACGIH TLV (United States). Absorbed through skin,** TWA: 100mg/m3, (inhalable fraction and vapour)8 hour(s)
Fuel oil No. 2	**ACGIH TLV (United States). Absorbed through skin.** TWA: 100mg/m3, (inhalable fraction and vapour) 8 hour(s)
Hydro-treated Renewable Diesel	**ACGIH TLV (United States). Absorbed through skin.** TWA: 200mg/m3, (inhalable fraction and vapour) 8
Fuel oil No. 1	**ACGIH TLV (United States). Absorbed through skin.** TWA: 200mg/m3, (inhalable fraction and vapour) 8

Consult local authorities for acceptable exposure limits.

Recommended monitoring procedures: If this product contains ingredients with exposure limits, personal, workplace atmosphere or biological monitoring may be required to determine the effectiveness of the ventilation or other control measures and/or the necessity to use respiratory protective equipment.

Engineering measures: Use only with adequate ventilation. Use process enclosures, local exhaust ventilation or other engineering controls to keep worker exposure to airborne contaminants below any recommended or statutory limits. The engineering controls also need to keep gas, vapour or dust concentrations below any lower explosive limits. Use explosion-proof ventilation equipment.

Hygiene measures: Wash hands, forearms, and face thoroughly after handling chemical products, before eating, smoking and using the lavatory and at the end of the working period. Appropriate techniques should be used to remove potentially contaminated clothing. Wash contaminated clothing before reusing. Ensure that eyewash stations and safety showers are close to the workstation location.

Personal protection

Respiratory: Use a properly fitted, air purifying or air-fed respirator complying with an approved standard if a risk assessment indicates this is necessary. Respirator selection must be based on known or anticipated exposure levels, the hazards of the product and the safe working limits of the selected respirator. Recommended: organic vapour cartridge or canister may be permissible under certain circumstances where airborne concentrations are expected to exceed exposure limits. Protection provided by air-purifying respirators is limited. Use a positive-pressure, air-supplied respirator if there is any potential for uncontrolled release, exposure levels are unknown, or any other circumstance where air-purifying respirators may not provide adequate protection.

Hands: Chemical-resistant, impervious gloves complying with an approved standard should be worn at all times when handling chemical products if a risk assessment indicates this is necessary. Recommended: nitrile, neoprene, polyvinyl alcohol (PVA), Viton®. Consult your PPE provider for breakthrough times and the specific glove that is best for you based on your use patterns. It should be realized that eventually any materials regardless of their imperviousness, will get permeated by chemicals. Therefore, protective gloves should be regularly checked for wear and tear. At the first signs of hardening and cracks, they should be changed.

Eyes: Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists or dusts.

Skin: Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.

Environmental exposure controls: Emissions from ventilation or work process equipment should be checked to ensure they comply with the requirements of environmental protection legislation. In some cases, fume scrubbers, filters or engineering modifications to process equipment will be necessary to reduce emissions to acceptable levels.

9. Physical and chemical properties

Physical state: Bright oily liquid

Flash point: Diesel fuel and other distillate fuels: Closed cup: ≥40°C (≥104°F)
Marine Diesel/MDO/Naval Distillate: Closed cup: ≥60°C (≥140°F)
Mining Diesel: Closed cup: ≥52°C (≥126°F)

Auto-ignition temperature: 225°C (437°F)

Flammable limits: Lower: 0.7% Upper: 6%

Colour: Clear to yellow (This product may be dyed red for taxation purposes)

Odour: Mild petroleum oil like.

Odour threshold: Not available

pH: Not available

Boiling/condensation point: 150 to 371°C (302 to 699.8°F)

Melting/freezing point: Not available

Relative density: 0.80 to 0.88 kg/L @ 15°C (59°F)

Vapour pressure: 1kPa (7.5 mm Hg) @ 20°C (68°F)

Vapour density: 4.5 [Air=1]

Volatility: Not available

Evaporation rate: Not available

Viscosity: Diesel fuel: 1.3-4.1 cSt @ 40°C (104°F) Marine Diesel Fuel: 1.3-4.4 cSt @40°C (104°F)

Pour point: Not available

Solubility: Insoluble in cold water, soluble in non-polar hydrocarbon solvents.

10. Stability and reactivity

Chemical stability: The product is stable.

Hazardous polymerization: Under normal conditions of storage and use, hazardous polymerization will not occur.

Materials to avoid: Reactive with oxidizing agents and acids.

Hazardous decomposition products: May release COx, NOx, H2S, smoke and irritating vapours when heated to decomposition.

11. Toxicological information

Acute toxicity

Product/ingredient name	Result	Species	Dose	Exposure
Fuels, diesel	LD50 Dermal	Mouse	24500mg/kg	---
	LD50 Oral	Rat	7500mg/kg	---
Fuel oil No. 2	LD50 Oral	Rat	12000mg/kg	---
Fuel oil No. 1	LD50 Dermal	Rabbit	>2000mg/kg	---
	LD50 Oral	Rat	>5000mg/kg	---
	LC50 Inhalation	Rat	>5000mg/m3	4 hours Vapour
Hydrotreated Renewable Diesel	LD50 Dermal	Rabbit	>2000mg/kg	---
	LD50 Oral	Rat	>5000mg/kg	---
	LC50 Inhalation	Rat	>5200mg/m3	4 hours Vapour

Conclusion/Summary: Not available

Chronic toxicity:

Conclusion/Summary: Not available

Irritation/Corrosion

Conclusion/Summary: Not available

Sensitizer

Conclusion/Summary: Not available

Carcinogenicity

Conclusion/Summary: Diesel engine exhaust particulate is probably carcinogenic to humans (IARC Group 2A).

Classification

Product/ingredient name	ACGIH	IARC	EPA	NIOSH	NTP	OSHA
Fuels, diesel	A3	3	---	---	---	---
Fuel oil No. 1	A3	3	---	---	---	---
Fuel oil No. 2	A3	3	---	---	---	---
Hydrotreated Renewable Diesel	A3	3	---	---	---	---

Mutagenicity

Conclusion/Summary Not available

Teratogenicity

Conclusion/Summary Not available

Reproductive toxicity

Conclusion/Summary Not available

12. Ecological information

Environmental effects: No known significant effects or critical hazards.

Aquatic ecotoxicity

Conclusion/Summary: Not available

Biodegradability

Conclusion/Summary: Not available

13. Disposal considerations

Waste Disposal: The generation of waste should be avoided or minimized wherever possible. Significant quantities of waste product residues should not be disposed of via the foul sewer but processed in a suitable effluent treatment plant. Dispose of surplus and non-recyclable products via a licensed disposal contractor. Disposal of this product, solutions and any by-products should at all times comply with the requirements of environmental protection and waste disposal legislation and any regional local authority requirements. Waste packaging should be recycled. Incineration or landfill should only be considered when recycling is not feasible. This material and its container must be disposed of in a safe way. Care should be taken when handling emptied containers that have not been cleaned or rinsed out. Empty containers or liners may retain some product residues. Vapour from product residues may create highly flammable or explosive atmosphere inside the container. Do not cut, weld, grind used containers unless they have been cleaned thoroughly internally. Avoid dispersal of split material and runoff and contact with soil, waterways, drains and sewers.

Disposal should be in accordance with applicable regional, national and local laws and regulations. Refer to Section 7: Handling and Storage and Section 8: Exposure Controls/Personal Protection for additional handling information and protection of employees

14. Transport information

Regulatory Information	UN Number	Proper shipping Name	Class	PG*	Label	Additional Information
TDG Classification	UN1202	DIESEL FUEL	3	III		----
DOT Classification	Not Available	Not Available	Not Available	----	----	----

PG*: Packing group

15. Regulatory Information

United States

HCS Classification: Combustible liquid
Irritating material

Canada: Class B-3: Combustible liquid with a flash point between 37.8°C (100°F) and 93.3°C (200°F)
Class D-2A: Material causing other toxic effects (Very toxic).
Class D-2B: Material causing other toxic effects (Toxic).

This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations and the MSDS contains all the information required by the Controlled Products Regulations.

International regulations

Canada inventory: All components are listed or exempted.
United States inventory (TSCA 8b): All components are listed or exempted.
Europe inventory: All components are listed or exempted.

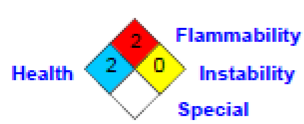
16. Other information

Label requirements: COMBUSTIBLE LIQUID AND VAPOUR. CAUSES EYE AND SKIN IRRITATION.

Hazardous Material Information System:

Health	**2**
Flammability	**2**
Physical hazards	**0**
Personal protection	**H**

National Fire Protection Association (USA):



References: Available upon request.
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Date of Printing: **6/28/2013.**
Date of issue: 28 June 2013
Date of previous issue: 6/28/2013

Responsible name: Sécurité de produit – KKB

- **Indicates information that has changed from the previous version.**

For Copy of (M)SDS: Internet: www.petro-canada.ca/msds
Canada-wide: telephone: 1-800-668-0220; fax: 1-800-837-1227
For Product Safety Information: (905) 804-4752

Notice to reader

To the best of our knowledge, the information contained herein is accurate. However, neither the above-named supplier, nor any of its subsidiaries, assumes any liability whatsoever for the accuracy or completeness of the information contained herein.

Final determination of suitability of any material is the sole responsibility of the user. All materials may present unknown hazards and should be used with caution. Although certain hazards are described herein, we cannot guarantee that these are the only hazards that exist.

14.2MSDS for Automotive Gasoline, (Information from petro-canada.ca) Material Safety Data Sheet

GASOLINE, UNLEADED

1. Product and company identification

Product Name: GASOLINE, UNLEADED

Synonym: Regular, Unleaded Gasoline (US Grade), Mid-Grade, Plus, Super, WinterGas, SummerGas, Supreme, SuperClean WinterGas, RegularClean, PlusClean, Premium, marked or dyed gasoline, TQRUL, transitional quality regular unleaded, BOB, Blendstock for Oxygenate Blending

Code: W102E, SAP: 102 to 117

Material Uses: Unleaded gasoline is used in spark ignition engines including motor vehicles, inboard and outboard boat motors, small engines such as chain saws and lawn mowers, and recreational vehicles.

Manufacturer: PETRO-CANADA
P.O. Box 2844
150 –6th Avenue South-West
Calgary, Alberta
T2P 3E3

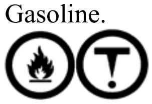
In case of emergency: Petro-Canada: 403-296-3000
Canutec Transportation: 613-996-6666
Poison Control Centre: Consult local telephone directory for emergency number(s).

2. Hazards identification

Physical State: Clear liquid

Odour: Gasoline.

WHMIS (Canada):



Class B-2: Flammable liquid
Class D-2A: Material causing other toxic effects (Very toxic)
Class D-2B: Material causing other toxic effects (Toxic)

OSHA/HCS status: This material is considered hazardous by the OSHA Hazard Communication Standard. (29 CFR 1910. 1200)

Emergency overview: WARNING!

FLAMMABLE LIQUID AND VAPOUR. CAUSES RESPIRATORY TRACT, EYE AND SKIN IRRITATION. CANCER HAZARD – CONTAINS MATERIAL WHICH CAN CAUSE CANCER. CONTAINS MATERIAL WHICH CAN CAUSE HERITABLE GENETIC EFFECTS.

Flammable liquid. Irritating to eyes, respiratory system and skin. Keep away from heat, sparks and flame. Avoid exposure – obtain special instructions before use. Do not breathe vapour or mist. Avoid contact with eyes, skin and clothing. Contains material which can cause cancer. Risk of cancer depends on duration and level of exposure. Contains material which can cause heritable genetic effects. Use only with adequate ventilation. Keep container tightly closed and sealed until ready to use. Wash thoroughly after handling.

Routes of entry: Dermal contact. Eye contact. Inhalation. Ingestion.

Potential acute health effects

Inhalation: Inhalation of this product may cause respiratory tract irritation and Central Nervous System (CNS) depression, symptoms of which may include; weakness, dizziness, slurred speech, drowsiness, unconsciousness and in case of severe overexposure; coma and death.

Ingestion: Ingestion of this product may cause gastro-intestinal irritation. Aspiration of this product may result in severe irritation or burns to the respiratory tract. Ingestion of this product may cause respiratory tract irritation and Central Nervous System (CNS) depression, symptoms of which may include; weakness, dizziness, slurred speech, drowsiness, unconsciousness and in case of severe overexposure; coma and death.

Skin: Irritating to the skin.

Eyes: Irritating to eyes.

Potential chronic health effects

Chronic effects: This product contains an ingredient or ingredients, which have been shown to cause chronic toxic effects. Repeated or prolonged exposure to the substance can produce blood disorders.

Carcinogenicity: Contains material which can cause cancer. Risk of cancer depends on duration and level on exposure.

Mutagenicity: Contains material which can cause heritable genetic effects.

Teratogenicity: No known significant effects or critical hazards.

Developmental effects: No known significant effects or critical hazards.

Fertility effects: No known significant effects or critical hazards.

Medical conditions aggravated by overexposure:

Repeated or prolonged contact with spray or mist may produce chronic eye irritation and severe skin irritation. Repeated skin exposure can produce local skin destruction or dermatitis.

See toxicological information (section 11)

3. Composition/information or ingredients

Name	CAS number	%
Gasoline	86290-81-5	85-100
Ethanol	64-17-5	0.1-1
Benzene	71-43-2	0.5-1.5
Toluene	108-88-3	15-40*

*Montreal: may vary from 3-40%
*Edmonton: may vary from 1-5%

There are no additional ingredients present which, within the current knowledge of the supplier and in the concentrations applicable, are classified as hazardous to health or the environment and hence require reporting in this section.

4. First-aid measures

Eye contact: Check for and remove and contact lenses. Immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical attention immediately.

Skin contact: In case of contact, immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Wash skin thoroughly with soap and water or use recognized skin cleanser. Wash clothing before reuse. Clean shoes thoroughly before reuse. Get medical attention immediately.

Inhalation: Move exposed person to fresh air. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention immediately.

Ingestion: Wash out mouth with water. Do not induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. Get medical attention immediately.

Protection of first aiders: No action shall be taken involving any personal risk or without suitable training. If it is suspected that fumes are still present, the rescuer should wear an appropriate mask or self-contained breathing apparatus. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation. Wash contaminated clothing thoroughly with water before removing it, or wear gloves.

Notes to physician: No specific treatment. Treat symptomatically. Contact poison treatment specialist

immediately if large quantities have been ingested or inhaled.

5. Fire-fighting measures

Flammability of the product: Flammable liquid (NFPA).

<u>Extinguishing media</u>

Suitable: Use dry chemical, CO_2, water spray (fog) or foam.

Unsuitable: Do not use water jet.

Special exposure hazards: Promptly isolate the scene by removing all persons from the vicinity of the incident if there is a fire. No actions shall be taken involving any personal risk or without suitable training. Move containers from fire area if this can be done without risk. Use water spray to keep fire-exposed containers cool.

Products of combustion: Carbon oxides (CO, CO_2), nitrogen oxides (NO_x), polynuclear aromatic hydrocarbons, phenols, aldehydes, ketones, smoke and irritating vapours as product of incomplete combustion.

Special protective equipment for fire-fighters: Fire-fighters wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in a positive pressure mode.

Special remarks on fire hazards: Extremely flammable in presence of open flame, spark, shocks, and heat. Vapours are heavier than air and may travel considerable distance to sources of ignition and flash back. Rapid escape of vapour may generate static charge causing ignition. May accumulate in confined spaces.

Special remarks on explosion hazard: Do not pressurize, cut, weld, braze, solder, drill, grind or expose containers to heat or sources of ignition. Containers may explode in heat of fire. Vapours may form explosive mixtures with air.

6. Accidental release measures

Personal precautions: No action shall be taken involving any personal risk or without suitable training. Evacuate surrounding areas. Keep unnecessary and unprotected personnel from entering. Do not touch or walk through spill material. Shut off all ignition sources. No flares, smoking or flames in hazard area. Avoid breathing vapour or mist. Provide adequate ventilation. Wear appropriate Respirator when ventilation is inadequate. Put on personal protective equipment (see Section 8).

Environmental precautions: Avoid dispersal of spilt material and runoff and contact with soil, waterways, drains and sewers. Inform the relevant authorities if the product has caused environmental pollution (sewers, waterways, soil or air).

<u>Methods for cleaning up:</u>

Small spills: Stop leak if without risk. Move containers from spill area. Dilute with water and mop up if water soluble or absorb with an inert dry material and place in an appropriate waste disposal container. Use spark-proof and explosive-proof equipment. Dispose of via a licensed waste disposal contractor.

Large spills: Stop leak if without risk. Move containers from spill area. Approach the release from upwind. Prevent entry into sewers, water courses, basements or confined areas. Wash spillages into an effluent treatment plant or proceed as follows. Contain and collect spillage with noncombustible, absorbent material e.g. sand, earth, vermiculite or diatomaceous earth and place in container for disposal according to local regulations (see section 13). Use spark-proof tools and explosion-proof equipment. Dispose of via a licensed waste disposal contractor. Contaminated absorbent material may pose the same hazard as the spilt product. Note: see section 1 for emergency contact information and section 13 for waste disposal.

7. Handling and storage

Handling: Put on appropriate personal protective equipment (see section 8).
Eating, drinking and smoking should be prohibited in areas where this material is handled, stored and processed. Workers should wash hands and face before eating, drinking and smoking. Remove contaminated clothing and protective equipment before entering eating areas. Do not ingest. Avoid contact with eyes, skin and clothing. Avoid breathing vapour or mist. Use only with adequate ventilation.
Wear appropriate respirator when ventilation is inadequate. Do not enter storage areas and confined spaces unless adequately ventilated. Keep in the original container or an approved alternative made from a compatible material, kept tightly closed when not in use. Store and use away from heat, sparks, open flame or any other ignition source. Use explosion-proof electrical (ventilating, lighting and material handling) equipment. Use non-sparking tools. Take precautionary measures against electrostatic discharges. To avoid fire or explosion, dissipate static electricity during transfer by earthing and bonding containers and equipment before transferring material. Empty containers retain product residue and can be hazardous. Do not reuse container.

Storage: Store in accordance with local regulations. Store in a segregated and approved areas. Store in original container protected from direct sunlight in a dry, cool and well-ventilated area, away from incompatible materials (see section 10) and food and drink. Eliminate all ignition sources. Separate from oxidizing materials. Keep container tightly closed and sealed until ready to use. Containers that have been opened must be carefully resealed and kept upright to prevent leakage. Do not store in unlabeled containers. Use appropriate containment to avoid environmental containment. Ensure the storage containers are grounded/ bonded.

8. Exposure controls/personal protection

Ingredient	Exposure limits
Gasoline	**ACGIH TLV (United States)**. TWA: 300 ppm 8 hour(s). STEL: 500 ppm 15 minutes(s)
Ethanol	**ACGIH TLV (United States).** STEL: 1000 ppm 15 minute(s)
Benzene	**ACGIH TLV (United States).** TWA: 0.5 ppm 8 hour(s) STEL; 2.5 ppm 15 minute(s)
Toluene	**ACGIH TLV (United States).** TWA: 20 ppm 8 hour(s)

Consult local authorities for acceptable exposure limits.

Recommended monitoring procedures: If this product contains ingredients with exposure limits, personal, workplace atmosphere or biological monitoring may be required to determine the effectiveness of the ventilation or other control measures and/or the necessity to use respiratory protective equipment.

Engineering measures: Use only with adequate ventilation. Use process enclosures, local exhaust ventilation or other engineering controls to keep worker exposure to airborne contaminants below any recommended or statutory limits. The engineering controls also need to keep gas, vapour or dust concentrations below any lower explosive limits. Use explosion-proof ventilation equipment.

Hygiene measures: Wash hands, forearms, and face thoroughly after handling chemical products, before eating, smoking and using the lavatory and at the end of the working period. Appropriate techniques should be used to remove potentially contaminated clothing. Wash contaminated clothing before reusing. Ensure that eyewash stations and safety showers are close to the workstation location.

Personal protection

Respiratory: Use a properly fitted, air purifying or air-fed respirator complying with an approved standard if a risk assessment indicates this is necessary. Respirator selection must be based on known or anticipated exposure levels, the hazards of the product and the safe working limits of the selected respirator.

Recommended: A NIOSH-approved air-purifying respirator with an organic vapour cartridge or canister may be permissible under certain circumstances where airborne concentrations are expected to exceed exposure limits. Protection provided by air-purifying respirators is limited. Use a positive-pressure, air-supplied respirator if there is any potential for uncontrolled release, exposure levels are unknown, or any other circumstance where air-purifying respirators may not provide adequate protection.

Hands: Chemical-resistant, impervious gloves complying with an approved standard should be worn at all times when handling chemical products if a risk assessment indicates this is necessary. Recommended: polyvinyl alcohol (PVA), Viton. Consult your PPE provider for breakthrough times and the specific glove that is best for you based on your use patterns. It should be realized that eventually any materials regardless of their imperviousness, will get permeated by chemicals. Therefore, protective gloves should be regularly checked for wear and tear. At the first signs of hardening and cracks, they should be changed.

Eyes: Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists or dusts.

Skin: Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.

Environmental exposure controls: Emissions from ventilation or work process equipment should be checked to ensure they comply with the requirements of environmental protection legislation. In some cases, fume scrubbers, filters or engineering modifications to process equipment will be necessary to reduce emissions to acceptable levels.

9. Physical and chemical properties

Physical state: Clear liquid
Flash point: Closed cup: -50 to -38°C (-58 to -36.4°F) [Tagliabue]
Auto-ignition temperature: 257°C (494.6°F) (NFPA)
Flammable limits: Lower: 1.3% Upper: 7.6%
Colour: Clear to slightly yellow or green, undyed liquid. May be dyed red for taxation purposes
Odour: Gasoline
Odour threshold: Not available
pH: Not available
Boiling/condensation point: 25 to 220°C (77 to 428°F) (ASTM D86)
Melting/freezing point: Not available
Relative density: 0.685 to 0.8 kg/L @ 15°C (59°F)
Vapour pressure: <107kPa (<802.5 mm Hg) @ 37.8°C (100°F)
Vapour density: 3 to 4 [Air=1] (NFPA)
Volatility: Not available
Evaporation rate: Not available
Viscosity: Not available

Pour point : Not available

Solubility : Hydrocarbon components virtually insoluble in water. Soluble in alcohol, ether, chloroform and benzene. Dissolves fats, oils and natural resins.

10. Stability and reactivity

Chemical stability: The product is stable.

Hazardous polymerization: Under normal conditions of storage and use, hazardous polymerization will not occur.

Materials to avoid: Reactive with oxidizing agents, acids and interhalogens.

Hazardous decomposition products: May release COx, NOx, phenols, polycyclic aromatic hydrocarbons, aldehydes, ketones, smoke and irritating vapours when heated to decomposition.

11. Toxicological information

Acute toxicity

Product/ingredient name	Result	Species	Dose	Exposure
Gasoline	LD50 Dermal	Rabbit	>5000mg/kg	----
	LD50 Oral	Rat	13600mg/kg	----
Ethanol	LD50 Dermal	Rabbit	>15800mg/kg	----
	LD50 Oral	Mouse	3450 mg/kg	----
	LC50 Inhalation Vapour	Rat	8850 mg/m3	4 hours
Benzene	LD50 Dermal	Rabbit	>8240mg/kg	----
	LD50 Oral	Rat	930mg/kg	----
	LC50 Inhalation Vapour	Rat	13228 ppm	4 hours
Toluene	LD50 Dermal	Rabbit	12125mg/kg	----
	LD50 Oral	Rat	636mg/kg	----
	LC50 Inhalation Vapour	Rat	7585mg/m3	4 hours

Conclusion/Summary: Not available

Chronic toxicity:

Conclusion/Summary: Not available

Irritation/Corrosion

Conclusion/Summary: Not available

Sensitizer

Conclusion/Summary: Not available

Carcinogenicity

Conclusion/Summary: Not available

Classification

Product/ingredient name	ACGIH	IARC	EPA	NIOSH	NTP	OSHA
Gasoline	A3	3B	---	---	---	---
Ethanol	A3	---	---	---	---	---
Benzene	A1	1	A	+	Proven	+
Toluene	A4	3	D	---	---	---

Mutagenicity

Conclusion/Summary Not available

Teratogenicity

Conclusion/Summary There is wealth of information about the teratogenic hazards of toluene in the literature; however, based upon professional judgment regarding the body of evidence, WHMIS classification as a teratogen is not warranted.

Reproductive toxicity

Conclusion/Summary Not available

12. Ecological information

Environmental effects: No known significant effects or critical hazards.

Aquatic ecotoxicity

Conclusion/Summary: Not available

Biodegradability

Conclusion/Summary: Not available

13. Disposal considerations

Waste Disposal: The generation of waste should be avoided or minimized wherever possible. Empty containers or liners may retain some product residues. This material and its container must be disposed of in a safe way. Dispose the surplus and non-recyclable products via a licensed waste disposal contractor. Disposal of this product, solutions and any by-products should at all times comply with the requirements of environmental protection and waste disposal legislation and any regional local authority requirements. Avoid dispersal of split material and runoff and contact with soil, waterways, drains and sewers.

Disposal should be in accordance with applicable regional, national and local laws and regulations. Refer to Section 7: Handling and Storage and Section 8: Exposure Controls/Personal Protection for additional handling information and protection of employees

14. Transport information

Regulatory Information	UN Number	Proper shipping Name	Class	PG*	Label	Additional Information
TDG Classification	UN1203	Gasoline	3	III		----
DOT Classification	Not Available	Not Available	Not Available	----	----	----

PG*: Packing group

15. Regulatory Information

United States

HCS Classification: Flammable liquid
Irritating material
Carcinogen

Canada:

WHMIS (Canada)
Class B-2: Flammable liquid
Class D-2A: Material causing other toxic effects (Very toxic).
Class D-2B: Material causing other toxic effects (Toxic).

This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations and the MSDS contains all the information required by the Controlled Products Regulations.

International regulations

Canada inventory: All components are listed or exempted.
United States inventory (TSCA 8b): All components are listed or exempted.
Europe inventory: All components are listed or exempted.

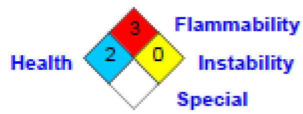
16. Other information

Label requirements: FLAMMABLE LIQUID AND VAPOUR. CAUSES RESPIRATORY TRACT, EYE AND SKIN IRRITATION. CANCER HAZARD- CONTAINS MATERIAL WHICH CAN CAUSE CANCER. CONTAINS MATERIAL WHICH CAN CAUSE HERITABLE GENETIC EFFECTS.

Hazardous Material Information System:

Health	2
Flammability	3
Physical hazards	0
Personal protection	H

National Fire Protection Association (USA):



References: Available upon request.
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Date of Printing: **4/21/2010**

Date of issue: 9 April 2010

Date of previous issue: No previous validation

Responsible name: Product Safety - RS

- Indicates information that has changed from the previous version.

For Copy of (M)SDS: Internet: www.petro-canada.ca/msds
Canada-wide: telephone: 1-800-668-0220; fax: 1-800-837-1227
For Product Safety Information: (905) 804-4752

Notice to reader

To the best of our knowledge, the information contained herein is accurate. However, neither the above-named supplier, nor any of its subsidiaries, assumes any liability whatsoever for the accuracy or completeness of the information contained herein.
Final determination of suitability of any material is the sole responsibility of the user. All materials may present unknown hazards and should be used with caution. Although certain hazards are described herein, we cannot guarantee that these are the only hazards that exist.

14.3 MSDS for Jet A-1, (Information from petro-canada.ca) Material Safety Data Sheet

JET A/A-1 AVIATION TURBINE FUEL

1. Product and company identification

Product Name: JET A/A-1 AVIATION TURBINE FUEL

Synonym: Jet A-1; Jet A-1-DI; Aviation Turbine Kerosene (ATK); JP-8; NATOF-34; Jet-34; Turbine fuel, Aviation, Kerosene Type (CAN/CGSB-3.32)

Code: W213, SAP: 149

Material Uses: Used as aviation turbine fuel. May contain a fuel system icing inhibitor. In the arctic, jet A-1 may also be used as diesel fuel (if it contains a lubricity additive) and heating oil.

Manufacturer: PETRO-CANADA
P.O. Box 2844
150 –6th Avenue South-West
Calgary, Alberta
T2P 3E3

In case of emergency: Petro-Canada: 403-296-3000
Canutec Transportation: 613-996-6666
Poison Control Centre: Consult local telephone directory for emergency number(s).

2. Hazards identification

Physical State: Clear liquid
Odour: Kerosene-like.

WHMIS (Canada):

Class B-3: Combustible liquid with a flash point between 37.8°C (100°F) and 93.3°C (200°F)
Class D-2A: Material causing other toxic effects (Very toxic)

The WHMIS classification of Jet A/A1 is B3.
The WHMIS classification of Jet A/A1-DI, JP-8, Jet 34 and NATO F-34, which all contain FSII (Diethylene Glycol Monomethyl Ether), is B3, D2A.

OSHA/HCS status: This material is considered hazardous by the OSHA Hazard Communication Standard. (29 CFR 1910. 1200)

Emergency overview: CAUTION!

COMBUSTIBLE LIQUID AND VAPOUR. MAY CAUSE EYE AND SKIN IRRITATION. POSSIBLE BIRTH DEFECTS HAZARD- CONTAINS MATERIAL WHICH MAY CAUSE BIRTH DEFECTS, BASED ON ANIMAL DATA.
Combustible liquid. Slightly irritating to eyes and skin. Keep away from heat, sparks and flame. Avoid exposure- obtain special instructions before use. Do not breathe vapour or mist. Avoid contact with eyes, skin and clothing. Contains material which may cause birth defects, based on animal data. Avoid exposure during pregnancy. Use only with adequate ventilation. Wash thoroughly after handling.

Routes of entry: Dermal contact. Eye contact. Inhalation. Ingestion.

<u>Potential acute health effects</u>

Inhalation: Inhalation of this product may cause respiratory tract irritation and Central Nervous System (CNS) depression, symptoms of which may include; weakness, dizziness, slurred speech, drowsiness, unconsciousness and in case of severe overexposure; coma and death.

Ingestion: Ingestion of this product may cause gastro-intestinal irritation. Aspiration of this product may result in severe irritation or burns to the respiratory tract.

Skin: Slightly irritating to the skin.

Eyes: Slightly irritating to eyes.

<u>Potential chronic health effects</u>

Chronic effects: No know significant effects or critical hazards.

Carcinogenicity: No know significant effects or critical hazards
Mutagenicity: No know significant effects or critical hazards
Teratogenicity: Contains material which may cause birth defects, based on animal data.
Developmental effects: No known significant effects or critical hazards.
Fertility effects: No known significant effects or critical hazards.
Medical conditions aggravated by overexposure: Repeated skin exposure can produce local skin destruction or dermatitis.

See toxicological information (Section 11)

3. Composition/information or ingredients

Name	CAS number	%
Complex mixture of petroleum hydrocarbons (C9-C16)*(Kerosene)	8008-20-6	99.9
Fuel System Icing Inhibitor (FSII) (If added**) (Diethylene Glycol Monomethyl Ether)	111-77-3	0.1-0.15
Anti-static, antioxidant and metal deactivator additives	Not applicable	<0.1

*Aromatic content is 25% Maximum (benzene: nil)
**Please note that Jet A-1-DI, JP-8, Jet-34 and NATO F-34 all contain Fuel System Icing Inhibitor.
There are no additional ingredients present which, within the current knowledge of the supplier and in the concentrations applicable, are classified as hazardous to health or the environment and hence require reporting in this section.

4. First-aid measures

Eye contact: Check for and remove and contact lenses. Immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical attention immediately.

Skin contact: In case of contact, immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Wash skin thoroughly with soap and water or use recognized skin cleanser. Wash clothing before reuse. Clean shoes thoroughly before reuse. Get medical attention immediately.

Inhalation: Move exposed person to fresh air. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention immediately.

Ingestion: Wash out mouth with water. Do not induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. Get medical attention immediately.

Protection of first aiders: No action shall be taken involving any personal risk or without suitable training. If it is suspected that fumes are still present, the rescuer should wear an appropriate mask or self-contained breathing apparatus. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation. Wash contaminated clothing thoroughly with water before removing it, or wear gloves.

Notes to physician: No specific treatment. Treat symptomatically. Contact poison treatment specialist immediately if large quantities have been ingested or inhaled.

5. Fire-fighting measures

Flammability of the product: Class II- combustible liquid (NFPA).

<u>Extinguishing media</u>
Suitable: Use dry chemical, CO2, water spray (fog) or foam.
Unsuitable: Do not use water jet.
Special exposure hazards: Promptly isolate the scene by removing all persons from the vicinity of the incident if there is a fire.
No actions shall be taken involving any personal risk or without suitable training. Move containers from fire area if this can be done without risk. Use water spray to keep fire-exposed containers cool.
Products of combustion: Carbon oxides (CO, CO2), nitrogen oxides (NOx), sulfur oxides (SOx), smoke and irritating vapours as product of incomplete combustion.
Special protective equipment for fire-fighters: Fire-fighters wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in a positive pressure mode.
Special remarks on fire hazards: Flammable in presence of open flame, spark, shocks, and heat. Vapours are heavier than air and may travel considerable distance to sources of ignition and flash back. This product can accumulate static charge and ignite. May accumulate in confined spaces.
Special remarks on explosion hazard: Do not pressurize, cut, weld, braze, solder, drill, grind or expose containers to heat or sources of ignition. Containers may explode in heat of fire.

6. Accidental release measures

Personal precautions: No action shall be taken involving any personal risk or without suitable training. Evacuate surrounding areas. Keep unnecessary and unprotected personnel from entering. Do not touch or walk through spill material. Shut off all ignition sources.

No flares, smoking or flames in hazard area. Avoid breathing vapour or mist. Provide adequate ventilation. Wear appropriate Respirator when ventilation is inadequate. Put on personal protective equipment (see Section 8).

Environmental precautions: Avoid dispersal of spilt material and runoff and contact with soil, waterways, drains and sewers. Inform the relevant authorities if the product has caused environmental pollution (sewers, waterways, soil or air).

Methods for cleaning up:

Small spills: Stop leak if without risk. Move containers from spill area. Dilute with water and mop up if water soluble. Alternatively, or if water-insoluble, absorb with an inert dry material and place in an appropriate waste disposal container. Use spark-proof and explosive-proof equipment. Dispose of via a licensed waste disposal contractor.

Large spills: Stop leak if without risk. Move containers from spill area. Approach the release from upwind. Prevent entry into sewers, water courses, basements or confined areas. Wash spillages into an effluent treatment plant or proceed as follows. Contain and collect spillage with noncombustible, absorbent material e.g. sand, earth, vermiculite or diatomaceous earth and place in container for disposal according to local regulations (see section 13). Use spark-proof tools and explosion-proof equipment. Dispose of via a licensed waste disposal contractor. Contaminated absorbent material may pose the same hazard as the spilt product. Note: see section 1 for emergency contact information and section 13 for waste disposal.

7. Handling and storage

Handling: Put on appropriate personal protective equipment (see section 8). Eating, drinking and smoking should be prohibited in areas where this material is handled, stored and processed. Workers should wash hands and face before eating, drinking and smoking. Remove contaminated clothing and protective equipment before entering eating areas. Avoid exposure during pregnancy. Do not get in eyes or on skin or clothing. Do not ingest. Avoid breathing vapour or mist. Use only with adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Do not enter storage areas and confined spaces unless adequately ventilated. Keep in the original container or an approved alternative made from a compatible material, kept tightly closed when not in use. Store and use away from heat, sparks, open flame or any other ignition source. Use explosion-proof electrical (ventilating, lighting and material handling) equipment. Use non-sparking tools. Take precautionary measures against electrostatic discharges. To avoid fire or explosion, dissipate static electricity during transfer by earthing and bonding containers and equipment before transferring material. Empty containers retain product residue and can be hazardous. Do not reuse container.

Storage: Store in accordance with local regulations. Store in a segregated and approved area. Store in original container protected from direct sunlight in a dry, cool and well-ventilated area, away from incompatible materials (see section 10) and food and drink. Eliminate all ignition sources. Separate from oxidizing materials. Keep container tightly closed and sealed until ready to use. Containers that have been opened must be carefully resealed and kept upright to prevent leakage. Do not store in unlabelled containers. Use appropriate containment to avoid environmental containment. Ensure the storage containers are grounded/ bonded.

8. Exposure controls/personal protection

Ingredient	Exposure limits
Kerosene	**ACGIH TLV (United States)**. TWA: 200 mg/m³ 8 hour(s).

Consult local authorities for acceptable exposure limits.

Recommended monitoring procedures: If this product contains ingredients with exposure limits, personal, workplace atmosphere or biological monitoring may be required to determine the effectiveness of the ventilation or other control measures and/or the necessity to use respiratory protective equipment.

Engineering measures: Use only with adequate ventilation. Use process enclosures, local exhaust ventilation or other engineering controls to keep worker exposure to airborne contaminants below any recommended or statutory limits. The engineering controls also need to keep gas, vapour or dust concentrations below any lower explosive limits. Use explosion-proof ventilation equipment.

Hygiene measures: Wash hands, forearms, and face thoroughly after handling chemical products, before eating, smoking and using the lavatory and at the end of the working period. Appropriate techniques should be used to remove potentially contaminated clothing. Wash contaminated clothing before reusing. Ensure that eyewash stations and safety showers are close to the workstation location.

Personal protection

Respiratory: Use a properly fitted, air purifying or air-fed respirator complying with an approved standard if a risk assessment indicates this is necessary. Respirator selection must be based on known or anticipated exposure levels, the hazards of the product and the safe working limits of the selected respirator. Recommended: A NIOSH-approved air-purifying respirator with an organic vapour cartridge or canister may be permissible under certain circumstances where airborne concentrations are expected to exceed exposure limits. Protection provided by air-purifying respirators is limited. Use a positive-pressure, air-supplied respirator if there is any potential for uncontrolled release, exposure levels are unknown, or any other circumstance where air-purifying respirators may not provide adequate protection.

Hands: Chemical-resistant, impervious gloves complying with an approved standard should be worn at all times when handling chemical products if a risk assessment indicates this is necessary. Recommended: polyvinyl alcohol (PVA), Viton®. Consult your PPE provider for breakthrough times and the specific glove that is best for you based on your use patterns. It should be realized that eventually any materials regardless of their imperviousness, will get permeated by chemicals.
Therefore, protective gloves should be regularly checked for wear and tear. At the first signs of hardening and cracks, they should be changed.

Eyes: Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists or dusts.

Skin: Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.

Environmental exposure controls: Emissions from ventilation or work process equipment should be checked to ensure they comply with the requirements of environmental protection legislation. In some cases, fume scrubbers, filters or engineering modifications to process equipment will be necessary to reduce emissions to acceptable levels.

9. Physical and chemical properties

Physical state: Clear liquid
Flash point: Closed cup: ≥38°C ≥100.4°F) [tag. Closed cup]
Auto-ignition temperature: 210°C (410°F) (NFPA)
Flammable limits: Lower: 0.7% Upper: 5%
Colour: Clear and colourless
Odour: Kerosene-like
Odour threshold: Not available
pH: Not available
Boiling/condensation point: 140 to 300°C (284 to 572°F)
Melting/freezing point: Not available
Relative density: 0.775 to 0.84 (Water=1)
Vapour pressure: 0.7 kPa (5.25 mm Hg) @ 20°C (68°F)
Vapour density: 4.5 [Air=1]
Volatility: Volatile

Evaporation rate: Not available
Viscosity: 1.0 – 1.9 cSt @ 40°C (104°F)
Pour point: <-51°C (<-60°F)
Solubility: Insoluble in water. Partially miscible in some alcohols. Miscible with other petroleum solvents.

10. Stability and reactivity

Chemical stability: The product is stable.
Hazardous polymerization: Under normal conditions of storage and use, hazardous polymerization will not occur.
Materials to avoid: Reactive with oxidizing agents, acids and alkalis.
Hazardous decomposition products: May release COx, NOx, SOx, aldehydes, acids, ketones, smoke and irritating vapours when heated to decomposition.

11. Toxicological information

<u>Acute toxicity</u>

Product/ingredient name	**Result**	**Species**	**Dose**	**Exposure**
Kerosene	LD50 Dermal	Rabbit	>2000mg/kg	----
	LD50 Oral	Rat	5000mg/kg	----
	LC50 Inhalation Vapour	Rat	>5000 mg/m³	4 hours

Conclusion/Summary: Not available
<u>Chronic toxicity:</u>
Conclusion/Summary: Not available
<u>Irritation/Corrosion</u>
Conclusion/Summary: Not available
<u>Sensitizer</u>
Conclusion/Summary: Not available
<u>Carcinogenicity</u>
Conclusion/Summary: Not available
<u>Classification</u>

Product/ingredient name	**ACGIH**	**IARC**	**EPA**	**NIOSH**	**NTP**	**OSHA**
Kerosene	A3	3	---	---	---	---

<u>Mutagenicity</u>
Conclusion/Summary Not available
<u>Teratogenicity</u>
Conclusion/Summary Not Available
<u>Reproductive toxicity</u>
Conclusion/Summary Not available

12. Ecological information

Environmental effects: No known significant effects or critical hazards.
<u>Aquatic ecotoxicity</u>
Conclusion/Summary: Not available
<u>Biodegradability</u>
Conclusion/Summary: Not available

13. Disposal considerations

Waste Disposal: The generation of waste should be avoided or minimized wherever possible. Significant quantities of waste product residues should not be disposed of via the foul sewer but processed in a suitable effluent treatment plant. Dispose the surplus and non-recyclable products via a licensed waste disposal contractor. Disposal of this product, solutions and any by-products should at all times comply with the requirements of environmental protection and waste disposal legislation and any regional local authority requirements. Waste packaging should be recycled.

Incineration or landfill should only be considered when recycling is not feasible. This material and its container must be disposed of in a safe way. Care should be taken when handling emptied containers that have not been cleaned or rinsed out. Empty containers or liners may retain some product residues. Vapour from product residues may create a highly flammable or explosive atmosphere inside a container. Do not cut, weld or grind used containers unless they have been cleaned thoroughly internally. Avoid dispersal of split material and runoff and contact with soil, waterways, drains and sewers.

Disposal should be in accordance with applicable regional, national and local laws and regulations. Refer to Section 7: Handling and Storage and Section 8: Exposure Controls/Personal Protection for additional handling information and protection of employees

14. Transport information

Regulatory Information	UN Number	Proper shipping Name	Class	PG*	Label	Additional Information
TDG Classification	UN1863	FUEL,AVIATION, TURBINE ENGINE	3	III		----
DOT Classification	Not Available	Not Available	Not Available	----	----	----

PG*: Packing group

15. Regulatory Information

<u>**United States**</u>

HCS Classification: Combustible liquid

<u>**Canada:**</u>

WHMIS (Canada) Class B-3: Combustible liquid with a flash point between 37.8°C (100°F) and 93.3°C (200°F)

Class D-2A: Material causing other toxic effects (Very toxic).

The WHMIS classification of Jet A/A1 is B3.

The WHMIS classification of Jet A/A1-DI, JP-8, Jet 34 and NATO F-34, which all contain FSII (Diethylene Glycol Monomethyl Ether), is B3, D2A.

This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations and the MSDS contains all the information required by the Controlled Products Regulations.

<u>**International regulations**</u>

Canada inventory: All components are listed or exempted.

United States inventory (TSCA 8b): All components are listed or exempted.

Europe inventory: All components are listed or exempted.

16. Other information

Label requirements: COMBUSTIBLE LIQUID AND VAPOUR. MAY CAUSE EYE AND SKIN IRRITATION. POSSIBLE BIRTH DEFECT HAZARD- CONTAINS MATERIAL WHICH MAY CAUSE BIRTH DEFECTS, BASED ON ANIMAL DATA.

Hazardous Material Information System:

Health	**2**
Flammability	**2**
Physical hazards	**0**
Personal protection	**H**

National Fire Protection Association (USA):

References: Available upon request.
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Date of Printing: **5/24/2012**
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Date of previous issue: 5/24/2012
Responsible name: Product Safety - DSR
- Indicates information that has changed from the previous version.

For Copy of (M)SDS: Internet: www.petro-canada.ca/msds
Canada-wide: telephone: 1-800-668-0220; fax: 1-800-837-1227
For Product Safety Information: (905) 804-4752

Notice to reader

To the best of our knowledge, the information contained herein is accurate. However, neither the above-named supplier, nor any of its subsidiaries, assumes any liability whatsoever for the accuracy or completeness of the information contained herein. Final determination of suitability of any material is the sole responsibility of the user. All materials may present unknown hazards and should be used with caution. Although certain hazards are described herein, we cannot guarantee that these are the only hazards that exist.

14.4 MSDS for Naphtha, (Information from petro-canada.ca) Material Safety Data Sheet

NAPHTHA (SWEET)

1. Product and company identification

Product Name: NAPHTHA (SWEET)

Synonym: Light Naphtha, Heavy Naphtha, Reformer feed, Platformer feed, Hydrodesulfurized Naphtha, Hydrotreated Naphtha.

Code: W344

Material Uses: Light and heavy naphthas are intermediate refinery products used as feedstocks to platformer units for the production of high octane motor gasoline blending components.

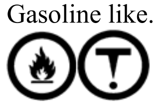
Manufacturer: PETRO-CANADA
P.O. Box 2844
150 –6th Avenue South-West
Calgary, Alberta
T2P 3E3

In case of emergency: Petro-Canada: 403-296-3000
Canutec Transportation: 613-996-6666
Poison Control Centre: Consult local telephone directory for emergency number(s).

2. Hazards identification

Physical State: Liquid
Odour: Gasoline like.

WHMIS (Canada):



Class B-2: Flammable liquid
Class D-2A: Material causing other toxic effects (Very toxic)

Class D-2B: Material causing other toxic effects (Toxic)

OSHA/HCS status: This material is considered hazardous by the OSHA Hazard Communication Standard. (29 CFR 1910. 1200)

Emergency overview: WARNING!
FLAMMABLE LIQUID AND VAPOUR. CAUSES EYE AND SKIN IRRITATION. CANCER HAZARD – CONTAINS MATERIAL WHICH CAN CAUSE CANCER. POSSIBLE BIRTH DEFECT HAZARD- CONTAINS MATERIAL WHICH MAY CAUSE BIRTH DEFECTS, BASED IN ANIMAL DATA. CONTAINS MATERIAL WHICH MAY CAUSE HERITABLE GENETIC EFFECTS.
Flammable liquid. Irritating to eyes and skin. Keep away from heat, sparks and flame. Avoid exposure – obtain special instructions before use. Do not breathe vapour or mist. Avoid contact with eyes, skin and clothing. Contains material which can cause cancer. Risk of cancer depends on duration and level of exposure. Contains material which can cause heritable genetic effects. Contains material which may cause birth defects, based on animal data. Avoid exposure during pregnancy. Use only with adequate ventilation. Keep container tightly closed and sealed until ready to use. Wash thoroughly after handling.

Routes of entry: Dermal contact. Eye contact. Inhalation. Ingestion.

<u>**Potential acute health effects**</u>

Inhalation: Inhalation of this product may cause respiratory tract irritation and Central Nervous System (CNS) depression, symptoms of which may include; weakness, dizziness, slurred speech, drowsiness, unconsciousness and in case of severe overexposure; coma and death.

Ingestion: Ingestion of this product may cause gastro-intestinal irritation. Aspiration of this product may result in severe irritation or burns to the respiratory tract.

Skin: Irritating to the skin.

Eyes: Irritating to eyes.

<u>**Potential chronic health effects**</u>

Chronic effects: This product contains an ingredient or ingredients, which have been shown to cause chronic toxic effects. Repeated or prolonged exposure to the substance can produce blood disorders.

Carcinogenicity: Contains material which can cause cancer. Risk of cancer depends on duration and level on exposure.

Mutagenicity: Contains material which may cause heritable genetic effects.

Teratogenicity: Contains material which may cause birth defects, based on animal data..

Developmental effects: No known significant effects or critical hazards.

Fertility effects: No known significant effects or critical hazards.

Medical conditions aggravated by overexposure: Repeated skin exposure can produce local skin destruction or dermatitis.

See toxicological information (section 11)

3. Composition/information or ingredients

Name	CAS number	%
Complex mixture of aliphatic and aromatic hydrocarbons (C4-C12)	64741-69-1 64741-42-0 64741-41-9 64741-46-4 64741-78-2	85-100
Toluene	108-88-3	3 - 7
Xylene	1330-20-7	3 - 6
Benzene	71-43-2	1 – 2

There are no additional ingredients present which, within the current knowledge of the supplier and in the concentrations applicable, are classified as hazardous to health or the environment and hence require reporting in this section.

4. First-aid measures

Eye contact: Check for and remove and contact lenses. Immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical attention immediately.

Skin contact: In case of contact, immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Wash skin thoroughly with soap and water or use recognized skin cleanser. Wash clothing before reuse. Clean shoes thoroughly before reuse. Get medical attention immediately.

Inhalation: Move exposed person to fresh air. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention immediately.

Ingestion: Wash out mouth with water. Do not induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. Get medical attention immediately.

Protection of first aiders: No action shall be taken involving any personal risk or without suitable training. If it is suspected that fumes are still present, the rescuer should wear an appropriate mask or self-contained breathing apparatus. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation. Wash contaminated clothing thoroughly with water before removing it, or wear gloves.

Notes to physician: No specific treatment. Treat symptomatically. Contact poison treatment specialist immediately if large quantities have been ingested or inhaled.

5. Fire-fighting measures

Flammability of the product: Flammable

<u>**Extinguishing media**</u>

Suitable: Use dry chemical, CO_2, water spray (fog) or foam.

Unsuitable: Do not use water jet.

Special exposure hazards: Promptly isolate the scene by removing all persons from the vicinity of the incident if there is a fire. No actions shall be taken involving any personal risk or without suitable training. Move containers from fire area if this can be done without risk. Use water spray to keep fire-exposed containers cool.

Products of combustion: Carbon oxides (CO, CO_2), reactive hydrocarbons, aldehydes, ketones, smoke and irritating vapours as product of incomplete combustion.

Special protective equipment for fire-fighters: Fire-fighters wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in a positive pressure mode.

Special remarks on fire hazards: Flammable in presence of open flame, spark, shocks, and heat. Vapours are heavier than air and may travel considerable distance to sources of ignition and flash back. May accumulate in confined spaces. Rapid escape of vapour may generate static charge causing ignition.

Special remarks on explosion hazard: Do not pressurize, cut, weld, braze, solder, drill, grind or expose containers to heat or sources of ignition.

6. Accidental release measures

Personal precautions: No action shall be taken involving any personal risk or without suitable training. Evacuate surrounding areas. Keep unnecessary and unprotected personnel from entering. Do not touch or walk through spill material. Shut off all ignition sources. No flares, smoking or flames in hazard area. Avoid breathing vapour or mist. Provide adequate ventilation. Wear appropriate Respirator when ventilation is inadequate. Put on personal protective equipment (see Section 8).

Environmental precautions: Avoid dispersal of spilt material and runoff and contact with soil, waterways, drains and sewers. Inform the relevant authorities if the product has caused environmental pollution (sewers, waterways, soil or air).

Methods for cleaning up:

Small spills: Stop leak if without risk. Move containers from spill area. Dilute with water and mop up if water soluble. Alternatively, or if water insoluble, absorb with an inert dry material and place in an appropriate waste disposal container. Use spark-proof and explosive-proof equipment. Dispose of via a licensed waste disposal contractor.

Large spills: Stop leak if without risk. Move containers from spill area. Approach the release from upwind. Prevent entry into sewers, water courses, basements or confined areas. Wash spillages into an effluent treatment plant or proceed as follows. Contain and collect spillage with noncombustible, absorbent material e.g. sand, earth, vermiculite or diatomaceous earth and place in container for disposal according to local regulations (see section 13). Use spark-proof tools and explosion-proof equipment. Dispose of via a licensed waste disposal contractor. Contaminated absorbent material may pose the same hazard as the spilt product. Note: see section 1 for emergency contact information and section 13 for waste disposal.

7. Handling and storage

Handling: Put on appropriate personal protective equipment (see section 8). Eating, drinking and smoking should be prohibited in areas where this material is handled, stored and processed. Workers should wash hands and face before eating, drinking and smoking. Remove contaminated clothing and protective equipment before entering eating areas. Avoid exposure- obtain special instructions before use. Avoid exposure during pregnancy. Do not get in eyes, or on skin and clothing. Do not ingest. Avoid breathing vapour or mist. Use only with adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Do not enter storage areas and confined spaces unless adequately ventilated. Keep in the original container or an approved alternative made from a compatible material, kept tightly closed when not in use. Store and use away from heat, sparks, open flame or any other ignition source. Use explosion-proof electrical (ventilating, lighting and material handling) equipment. Use non-sparking tools. Take precautionary measures against electrostatic discharges. To avoid fire or explosion, dissipate static electricity during transfer by earthing and bonding containers and equipment before transferring material. Empty containers retain product residue and can be hazardous. Do not reuse container.

Storage: Store in accordance with local regulations. Store in a segregated and approved area. Store in original container protected from direct sunlight in a dry, cool and well-ventilated area, away from incompatible materials (see section 10) and food and drink. Eliminate all ignition sources. Separate from oxidizing materials.

Keep container tightly closed and sealed until ready to use. Containers that have been opened must be carefully resealed and kept upright to prevent leakage. Do not store in unlabeled containers. Use appropriate containment to avoid environmental containment. Ensure the storage containers are grounded/ bonded.

8. Exposure controls/personal protection

Ingredient	Exposure limits
Toluene	**ACGIH TLV (United States)**. TWA: 20 ppm 8 hour(s).
Xylene	**ACGIH TLV (United States).** TWA: 100 ppm 8 hour(s) STEL: 150 ppm 8 hours(s)
Benzene	**ACGIH TLV (United States). Absorbed though skin** TWA: 0.5 ppm 8 hour(s) STEL: 2.5 ppm 15 minute(s)

Consult local authorities for acceptable exposure limits.

Recommended monitoring procedures: If this product contains ingredients with exposure limits, personal, workplace atmosphere or biological monitoring may be required to determine the effectiveness of the ventilation or other control measures and/or the necessity to use respiratory protective equipment.

Engineering measures: Use only with adequate ventilation. Use process enclosures, local exhaust ventilation or other engineering controls to keep worker exposure to airborne contaminants below any recommended or statutory limits. The engineering controls also need to keep gas, vapour or dust concentrations below any lower explosive limits. Use explosion-proof ventilation equipment.

Hygiene measures: Wash hands, forearms, and face thoroughly after handling chemical products, before eating, smoking and using the lavatory and at the end of the working period. Appropriate techniques should be used to remove potentially contaminated clothing. Wash contaminated clothing before reusing. Ensure that eyewash stations and safety showers are close to the workstation location.

Personal protection

Respiratory: Use a properly fitted, air purifying or air-fed respirator complying with an approved standard if a risk assessment indicates this is necessary. Respirator selection must be based on known or anticipated exposure levels, the hazards of the product and the safe working limits of the selected respirator.
Recommended: organic vapour cartridge or canister may be permissible under certain circumstances where airborne concentrations are expected to exceed exposure limits. Protection provided by air-purifying respirators is limited.

Hands: Chemical-resistant, impervious gloves complying with an approved standard should be worn at all times when handling chemical products if a risk assessment indicates this is necessary. Recommended: polyvinyl alcohol (PVA), Viton®.

Eyes: Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists or dusts.

Skin: Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.

Environmental exposure controls: Emissions from ventilation or work process equipment should be checked to ensure they comply with the requirements of environmental protection legislation. In some cases, fume scrubbers, filters or engineering modifications to process equipment will be necessary to reduce emissions to acceptable levels.

9. Physical and chemical properties

Physical state: Liquid
Flash point: Closed cup: <-18°C (<-0.4°F)
Auto-ignition temperature: 288°C (550.4°F)
Flammable limits: Lower: 1% Upper: 7.5%
Colour: Yellowish to clear
Odour: Gasoline like
Odour threshold: Not available
pH: Not available
Boiling/condensation point: Montreal: IBP >60°C (140°F)
Edmonton: IBP >65°C (149°F)
IBP (for LN) = 102°C (215°F)
Melting/freezing point: Not available
Relative density: 0.7 to 0.75
Vapour pressure: 14 - 20kPa 105-150 mm Hg) @ 37.8°C (100.4°F)
Vapour density: Not available
Volatility: Not available
Evaporation rate: Not available
Viscosity: Not available
Pour point: Not available
Solubility: Hydrocarbon components virtually insoluble in water. Soluble in alcohol, ether, chloroform and benzene.

10. Stability and reactivity

Chemical stability: The product is stable.

Hazardous polymerization: Under normal conditions of storage and use, hazardous polymerization will not occur.

Materials to avoid: Reactive with oxidizing agents, acids and interhalogens.

Hazardous decomposition products: May release COx, reactive hydrocarbons, aldehydes, ketones, smoke and irritating vapours when heated to decomposition.

11. Toxicological information

Acute toxicity

Product/ingredient name	Result	Species	Dose	Exposure
Toluene	LD50 Dermal	Rabbit	12125mg/kg	----
	LD50 Oral	Rat	636mg/kg	----
	LC50 Inhalation	Rat	7585 ppm	4 hours Vapour
Xylene	LD50 Dermal	Rabbit	>1700mg/kg	----
	LD50 Oral	Rat	4300 mg/kg	----
	LC50 Inhalation	Rat	5000 ppm	4 hours Vapour
Benzene	LD50 Dermal	Rabbit	>9400mg/kg	----
	LD50 Oral	Rat	930mg/kg	----
	LC50 Inhalation	Rat	13200 ppm	4 hours Vapour

Conclusion/Summary: Not available

Chronic toxicity:

Conclusion/Summary: Not available

Irritation/Corrosion

Conclusion/Summary: Not available

Sensitizer

Conclusion/Summary: Not available

Carcinogenicity

Conclusion/Summary: Not available

Classification

Product/ingredient name	ACGIH	IARC	EPA	NIOSH	NTP	OSHA
Toluene	A4	3	D	---	---	---
Xylene	A4	3	D	---	---	---
Benzene	A1	1	A	+	Proven	+

Conclusion/Summary Not available

Teratogenicity

Conclusion/Summary Not available

Reproductive toxicity

Conclusion/Summary Not available

12. Ecological information

Environmental effects: No known significant effects or critical hazards.

Aquatic ecotoxicity

Conclusion/Summary: Not available

Biodegradability

Conclusion/Summary: Not available

13. Disposal considerations

Waste Disposal: The generation of waste should be avoided or minimized wherever possible. Significant quantities of waste product residues should not be disposed of via the foul sewer but processed in a suitable effluent treatment plant. Dispose the surplus and non-recyclable products via a licensed waste disposal contractor. Disposal of this product, solutions and any by-products should at all times comply with the requirements of environmental protection and waste disposal legislation and any regional local authority requirements. Waste packaging should be recycled. Incineration or landfill should only be considered when recycling is not feasible.

This material and its container must be disposed of in a safe way. Care should be taken when handling emptied containers that have not been cleaned or rinsed. Empty containers or liners may retain some product residues. Vapour from product residues may create a highly flammable or explosive atmosphere inside the container. Avoid dispersal of split material and runoff and contact with soil, waterways, drains and sewers.

Disposal should be in accordance with applicable regional, national and local laws and regulations. Refer to Section 7: HANDLING AND STORAGE and Section 8: EXPOSURE CONTROL/PERSONAL PROTECTION for additional handling information and protection of employees.

14. Transport information

Regulatory Information	UN Number	Proper shipping Name	Class	PG*	Label	Additional Information
TDG Classification	UN1268	PETROLEUM DISTILLATES, N.O.S.	3	II		----
DOT Classification	Not Available	Not Available	Not Available	----	----	----

PG*: Packing group

15. Regulatory Information

United States

HCS Classification: Flammable liquid
Irritating material
Carcinogen

Canada: Class B-2: Flammable liquid

WHMIS (Canada) Class D-2A: Material causing other toxic effects (Very toxic).
Class D-2B: Material causing other toxic effects (Toxic).

This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations and the MSDS contains all the information required by the Controlled Products Regulations.

International regulations

Canada inventory: All components are listed or exempted.
United States inventory (TSCA 8b): All components are listed or exempted.
Europe inventory: All components are listed or exempted.

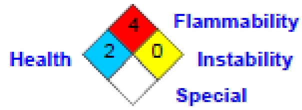
16. Other information

Label requirements: FLAMMABLE LIQUID AND VAPOUR. CAUSES EYE AND SKIN IRRITATION. CANCER HAZARD- CONTAINS MATERIAL WHICH CAN CAUSE CANCER. POSSIBLE BIRTH DEFECTS HAZARDS- CONTAINS MATERIAL WHICH MAY CAUSE BIRTH DEFECTS, BASED ON ANIMAL DATA. CONTAINS MATERIAL WHICH CAN CAUSE HERITABLE GENETIC EFFECTS.

Hazardous Material Information System:

Health	**2**
Flammability	**4**
Physical hazards	**0**
Personal protection	**H**

National Fire Protection Association (USA):



References: Available upon request.
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- Indicates information that has changed from the previous version.

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