TABLE OF CONTENTS

Page

Page

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE

This course manual for spill containment and clean-up has been prepared by the Government of the Northwest Territories -- Department of Renewable Resources. The Department of Renewable Resources has a mandate to monitor spill containment and clean-up activities in the Northwest Territories and to provide education and training programs aimed at achieving effective spill response and clean-up measures.

Due to the sparsity of the population and the diversity of activities in the Territories, a number of government agencies and industries can be called upon to provide direction and guidance in the event of a spill. In an effort to coordinate spill response, the Department of Indian Affairs and Northern Development maintains a 24-hour telephone line manned by staff with technical background and experience in spill procedures.

The purpose of this manual is to provide the technical and practical background needed for effective spill response in the Northwest Territories, recognizing the unique conditions that exist here.

Special conditions in the Northwest Territories dictate a unique approach to spill response. In particular, the severity and wide variations of climate, the sparsity of population and resource activities, and the pristine and sensitive nature of the environment require special consideration. In addition, the remoteness and wide separation of communities, and the problems associated with access and travel also provide unique factors that must be addressed in the development of spill response programs for the NWT.

The approach and content provided within this manual has been prepared with the following workshop participants in mind:

* Community based spill response personnel;
* Local municipal, regional, and territorial government officials;
* Barge and truck operators; and
* Government petroleum distribution contractors.

This manual provides the background needed for spill response by presenting information on the characteristics, properties and hazards of spilled materials, by providing suggested response, clean-up and site restoration actions, and by discussing the potential public health and environmental effects. Emphasis is directed to spills of petroleum products.

1.2 BACKGROUND

In recent years, mining and oil exploration activities, community growth, and construction have generated an increase in the transportation, storage and use of hazardous materials in the Territories. As a result, accidental spills of these materials have occurred. Their effects on the sensitive northern environment are of increasing concern. It is recognized that an effective program for preventing, responding to, and cleaning up such spills will minimize impacts to the environment and to public health.

Approaches to spill prevention and response may be found in several technical references; however, these in general, do not focus on the specific conditions in the Territories. Reference to northern conditions found in these documents has been extracted and forms a basis for the information presented in this manual.

The participant will learn to control spills of petroleum and other products by using available equipment and materials in a safe and effective manner.

This course has the following specific objectives:

1. Learn proper response procedures stressing personal and public safety.

2. Practice spill control in the field on simulated problems.

3. Understand the behaviour of petroleum products under various conditions and the hazards associated with them.

4. Learn the importance of prevention and planning regarding potential problems.

5. Review and discuss case studies of spills that have occurred in the N.W.T.

2.0 SPILL EXPERIENCE IN THE NORTHWEST TERRITORIES

2.1 REPORTING REQUIREMENTS

The 24 hour spill report line is a telephone line dedicated for reporting spills or potential spills to government departments in the Northwest Territories. **All spills or potential spills of hazardous materials must be reported through the (403) 920-8130 telephone number.** Having a single point of contact for notifying government simplifies the reporting of spills and ensures that a coordinated investigation is undertaken by the appropriate government agency.

The Department of Renewable Resources maintains computer stored statistics on reported spills. To provide a focus for the content and approach of this manual, statistics on spills reported during the period of 1981 -- 1988, which have occurred in the Northwest Territories are summarized in this section.

2.2 STATISTICS ON PREVIOUS SPILLS

2.2.1 Material Types

The majority of hazardous materials spilled in the Northwest Territories are petroleum products. Petroleum products account for 84% of spills; chemicals 4%, wastewater including mine and mill tailings and sewage 9% and drilling muds 1%. Spills by material types and number of spills reported for the period of 1981 -- 1988 are presented in Figure 1.

Inspection of Figure 1 shows that the predominance of petroleum product spills are of fuel oil. Fuel oil accounts for 58% of the spills of petroleum products. 2% of petroleum product spills involve gasolines, unrefined crude oils, lubricating oils, waste oils and others. A total of 4.9 million litres of petroleum was spilled during the period of 1981 - 1988. Approximately 70% of these spills were on land and 30% involved either marine or fresh water.

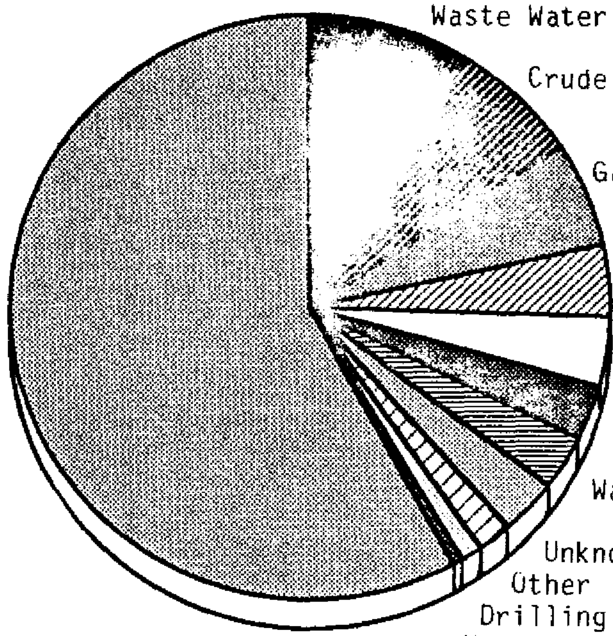
NOTE Further discussion of spill statistics in this manual shall include spills of petroleum products only.

2.2.2 Spills By Location

The majority of petroleum product spills occur in the Fort Smith and Inuvik Regions. Fort Smith Region accounted for 34% and Inuvik Region for 39% of reported spills of petroleum products during the period 1981 -- 1988. Spills

FIGURE 1

HAZARDOUS MATERIALS SPILLS IN THE N.W.T.
BY THE NUMBER OF SPILLS REPORTED 1981 - 1988



Commodity	Number of Spills	% of Spills
Fuel Oil (heating, diesel,aviation)	538	58
Crude Oil	62	7
Gasoline	51	6
Other Oil (hydraulic, bunker, asphalt)	39	4
Waste Oil (slops, sludge)	30	3
Unknown Oil	28	3
Lubricating Oil	23	3
Sub-Total - Petroleum Products	771	84
Waste Water (mine/mill tailings, sewage)	86	9
Chemicals (PCB's, pesticides, acids, ferric sulphate, sodium fluoride, zinc bromide)	36	4
Other	14	2
Drilling Muds	10	1
Unknown	3	<1
Total	920	100

in the Inuvik Region are due primarily to the intensive petroleum exploration activities in the Beaufort Sea and the production and transportation of petroleum and petroleum products in Norman Wells. Spills in the Fort Smith Region are largely associated with bulk transportation of fuel on highways and spills associated with barge transport and unloading operations. The Baffin Region accounts for 11% of reported spills of petroleum products, Keewatin Region 8% and Kitikmeot Region 8%. All regions experience spills associated with the supply and storage of fuel in communities.

2.2.3 Spills By Facility Type And Transportation Mode

Spills by facility type and transportation mode for the period 1981 - 1988 are presented in Figure 2. Transportation between and vehicle distribution within communities accounts for 30% of reported spills. The means of transportation from which spills occur, in order of decreasing frequency, are trucks, marine vessels, aircraft, other means of transportation and trains. Stationary storage tanks account for 30% of reported spills and pipelines, including hoses, 22%. When one assumes that the majority of pipelines are associated with stationary storage tanks, the largest proportion of reported spills occur at fuel storage facilities.

2.2.4 Spills By Parties Responsible

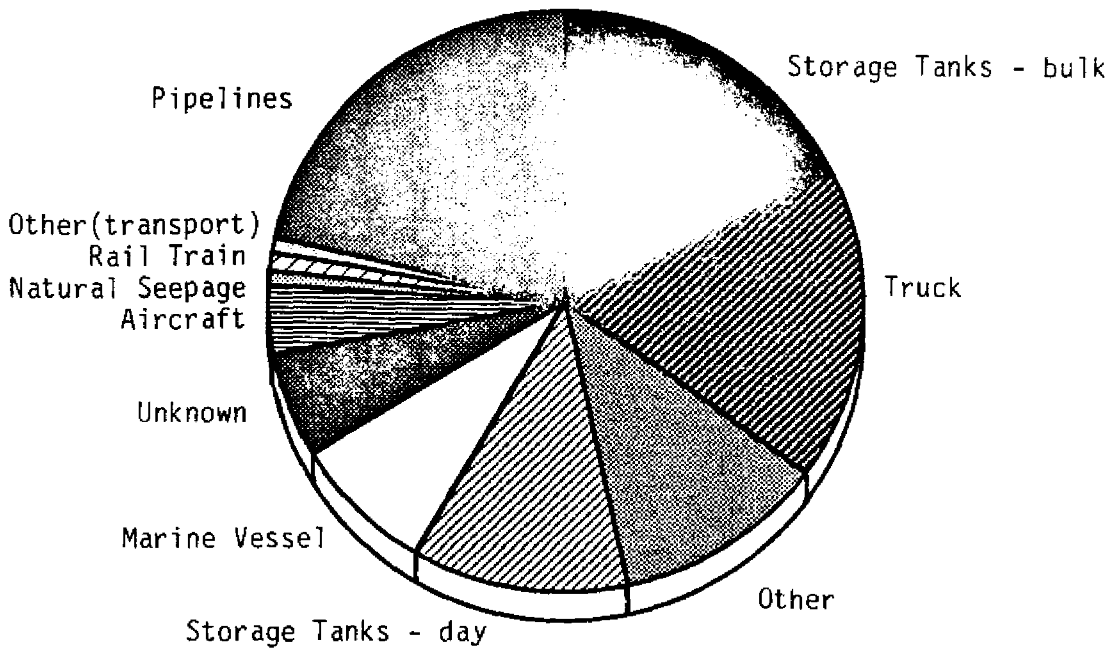
Figure 3 presents reported spills by sectors of the economy. As previously discussed in section 2.2.3 the transportation industry accounts for 23-30% of reported spills of petroleum products. Petroleum companies whether in the exploration, refining, or storage phases of operation account for 24% of reported spills. The various levels of government account for 24% of reported spills; Territorial Government and its contractors and Federal Crown Corporations formerly including NCPC account for 10% and 7% of the total spills respectively because of their involvement in fuel storage for community heating and energy requirements. Mining companies account for 11% of reported spills as all companies maintain fuel storage facilities at their sites.

2.2.5 Spills By Contributing Factors And Type Of Failure

Spills of petroleum products may be due to the failure of a component containing the product, failure of the entire vessel or vehicle, human error, climatic factors, intentional acts of vandalism or acts of God. Evaluation of contributing factors and types of failures for spills reported during the period 1981 - 1988 is represented in Figure 4.

FIGURE 2

PETROLEUM PRODUCT SPILLS IN THE N.W.T.
BY FACILITY TYPE AND TRANSPORTATION MODE 1981 -1988

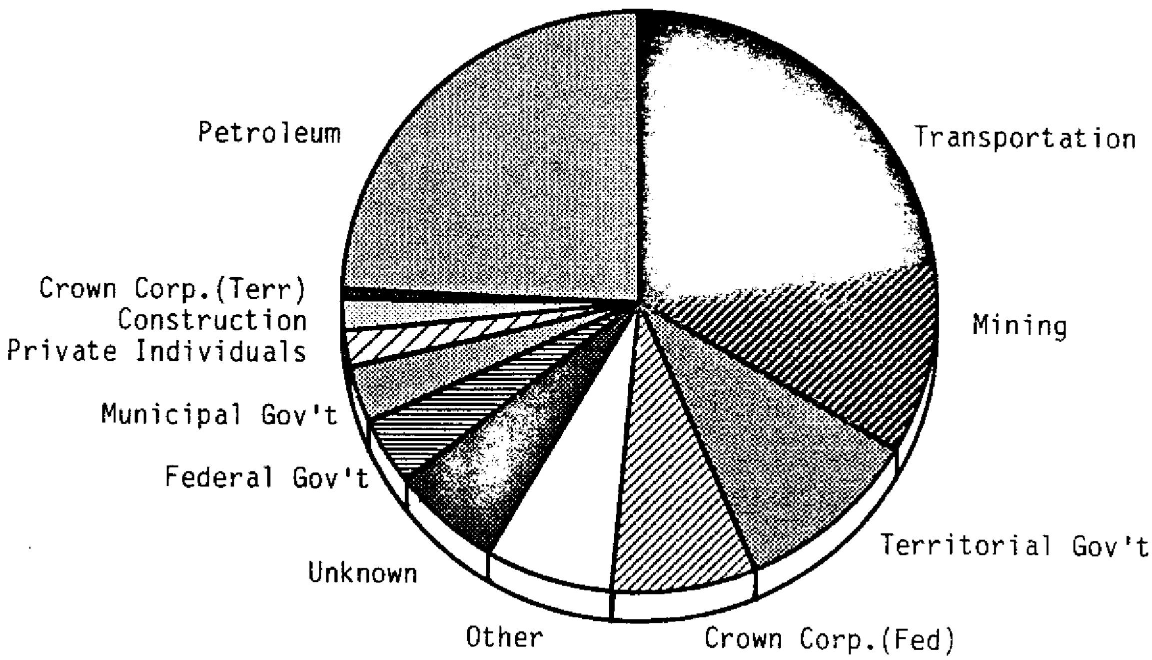


Source	Number of Spills		% of Spills	
Pipelines (pipes, hoses, nozzles)		204		22
Storage Tanks - bulk (>4000 litres)	169		18	
Storage Tanks - day tanks (<4000 litres)	108		12	
Sub-Total - Storage Tanks		277		30
Truck (tankers, drums on trucks)	163		18	
Marine Vessels (barges, drums on vessels)	69		8	
Aircraft (drums/tanks on aircraft)	35		4	
Rail Train	2		<1	
Other (cat trains)	1		<1	
Sub-Total - Transportation		270		30
Other (oil wells, sewage lagoons, tailings ponds)		109		12
Unknown		55		6
Natural Seepage (Norman Wells area)		5		<1
Total		920		100

Human error and failure of materials and equipment account for 25% and 34% of reported spills respectively. The failure of materials and equipment can, however, sometimes be a result of human error -- ie. not conducting regular maintenance inspections. Stricter adherence to recognized fuel transfer procedures, regular maintenance and inspections and training of operators can result in fewer spills attributed to human error and failure of materials and equipment. Climatic factors account for 7% of reported spills and vandalism 3%. Three percent of all spills were intentional.

FIGURE 3

PETROLEUM PRODUCT SPILLS IN THE N.W.T.
BY SECTORS OF THE ECONOMY 1981 - 1988

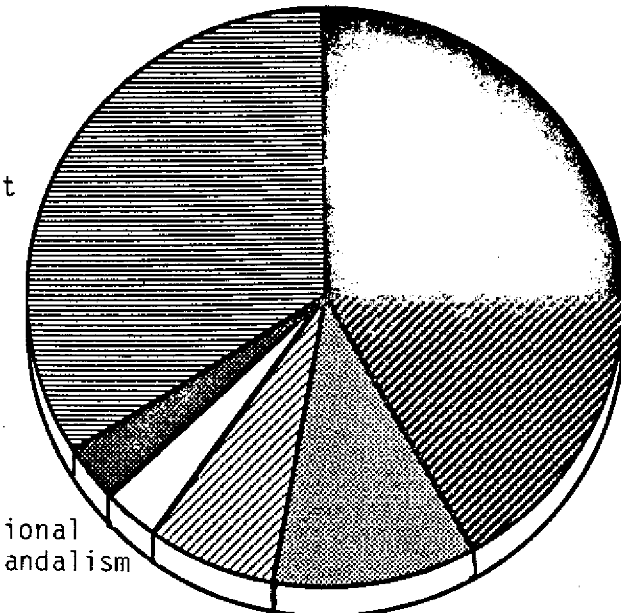


Sector	Number of Spills		% of Spills	
Petroleum (commercial bulk fuel storage, oil explore/refine facilities)		222		24
Transportation (transport, loading/offloading)		211		23
Mining		104		11
Territorial Gov't (DPW, POL contractors)	96		10	
Federal Crown Corporations (NCPC)	54		7	
Federal Gov't (DND, MOT, INAC)	33		4	
Municipal Gov't	32		3	
Territorial Crown Corporations (NWTPC)	5		<1	
Sub- total - Government		220		24
Other (community Co-ops, contractors)		68		8
Unknown		53		6
Private Individuals		22		2
Construction		20		2
Total		920		100

FIGURE 4

PETROLEUM PRODUCT SPILLS IN THE N.W.T.

BY CONTRIBUTING FACTORS AND TYPE OF FAILURE 1981 - 1988



Factor	Number of Spills	% of Spills
Materials and Equipment Failure (weld/ joint failure, corrosion)	254	34
Human Error	173	25
Unknown	155	17
Other (power failures, tanks falling over, lines hit by vehicles)	105	11
Climatic factors (storm, fire, flood)	64	7
Vandalism	26	3
Intentional	25	3
Total	920	100

3.0 PROPERTIES AND CHARACTERISTICS

3.1 OIL CHARACTERISTICS AND BEHAVIOUR

3.1.1 Characteristics

Crude oil and its refined products are complex mixtures of hydrocarbons (compounds composed of hydrogen and carbon only) and nonhydrocarbons (compounds containing small amounts of sulphur, oxygen, and nitrogen compounds as well as other trace elements). Refined products are derived through processes called catalytic cracking and fractional distillation. The resultant products possess different physical and chemical properties which will determine how they will move if they are spilled, how they will affect organisms, including man, and how fast they will degrade or disappear from the environment. Several key definitions follow.

Specific Gravity

Specific gravity (S.G.) is defined as the ratio of the mass of a substance to the mass of an equal volume of water. The specific gravity of water is 1.0, while most oils are less than 1.0 (which means they will float).

Generally, oils with low specific gravities have low viscosities (see definition below), low adhesion properties, and emulsify with water easily. Oils with high specific gravities have high viscosities, high adhesion properties and limited tendencies to emulsify.

Viscosity

Viscosity is a measure of a fluid's resistance to flow. The greater the viscosity, the less readily it flows. Gasoline has a low viscosity and bunker oil has a high viscosity. Oils become less viscous with increasing temperature or more viscous with decreasing temperature. Low viscosity oils tend to form emulsions readily. Viscosity will determine the rate of spreading of a slick, its penetration into the ground and the ability of pumps to remove oil from the surface.

Volatility

The volatility is a qualitative measure of the tendency of a solid or liquid to pass into the vapour state. Generally, low carbon number hydrocarbons (methane, ethane, etc.) are extremely volatile and quickly pass into the gaseous state (volatilize) when exposed to the air. Gasoline contains a high proportion of volatile compounds. Bunker fuels contain limited volatiles because they are removed during the refining process.

Flash Point

Flash point is the lowest temperature at which a particular oil will ignite, that is, the flash point is an indication of the oil's volatility. Gasoline has a flash point of less than -40 C; most arctic crude oils will ignite, but the flash points are high. Diesel oil is difficult to ignite but will burn readily once the flash point is reached. Bunker and heavy fuel oils are difficult to ignite at ordinary atmospheric temperatures.

Solubility

The solubility of a substance indicates its tendency to dissolve in a solvent, commonly water. Low solubility is typical of many petroleum products. However, compounds within each product exhibit some solubility. This has a bearing on the toxicity of the particular product to aquatic organisms. Miscibility is the degree to which a substance is capable of mixing with water without separating into two phases. Gasoline is not miscible in water.

The following table (Table 1) compares the previously discussed parameters for several petroleum products. Note in this table that in going from gasoline to #6 fuel oil, that specific gravity, flash point and viscosity increase corresponding to the greater fraction of heavier hydrocarbons within the product.

TABLE 1

COMPARISONS OF PHYSICAL CHARACTERISTICS OF CRUDE OILS AND SOME REFINED PETROLEUM PRODUCTS

	Specific Gravity (15 C)	Viscosity cs units	Flash Point (C)
Crude Oil	0.8-0.95	20-1000	Variable
Gasoline	0.65-0.75	0.5-1	-40
Kerosene	0.80	2-5	55
#1 Fuel Oil (furnace, stove, diesel)	0.807	2-4	46
#2 Fuel Oil (furnace, stove, diesel)	0.840	10-15	53
#4 Fuel Oil (plant, heating)	0.9	50	60
#5 Fuel Oil (Bunker B)	0.95	100	65
#6 Fuel Oil (Bunker C)	0.98	300-3000	80

3.1.2 Movement on Land

Introduction

Several factors influence the extent and rate of movement of oil on land. These include the type of oil product spilled, its viscosity, pour point and temperature. Other equally important factors include the presence of snow, types of soils, vegetation and season of the year.

Snow

The nature of the snow cover is dependent upon terrain conditions. In forested areas, such as the taiga, the snow may be quite light, fluffy and deep, whereas on the tundra, wind action may compact the snow and make it hard and dense. This will affect the penetration of spilled oil.

Snow is a very effective absorbent for oil having the ability to contain more than 50% oil by volume, depending upon the nature of the snow. Light, fluffy snow will absorb more oil than will hard, dense snow. Hard, dense snow can also act as an effective physical barrier; therefore it should be used whenever possible for dyking and containing oil spills.

Oil can also flow for considerable distances under snow cover without being seen from above.

Soils and Vegetation

The movement of oil through soils and rocks is complex and largely unpredictable. The topography will determine the direction of oil flow and the shape of the spill. Movement downward will depend on the type of overlying soil, vegetation and the presence of impervious layers of clay or permafrost.

Soils and rocks consist of small fragments or grains, which, when compacted together, form small openings or pores. Interconnected pores allow a material to be permeable to fluids such as oil and water. Clay, silt or shale have very small pores which are not extensively interconnected and act as barriers to oil movement. In the treeless tundra, the mineral soil is overlain by 20 to 30 cm of organic detritus such as mosses, sedges, and lichens. In the taiga, the organic detritus layer may be 30 to 100 cm deep. Mineral soils generally have a very high absorptive capacity for oil, especially in the late summer when the frost level and water table are low.

The organic mat overlying the permafrost in the tundra and taiga regions has a high insulating value and any modification to its thermal properties by oil may cause an increase in thaw depth, possibly leading to thermocarst conditions. The tree canopy in the taiga forest reduces the solar radiation reaching the ground. If this canopy is destroyed by oil spreading or burning, a significant increase in the active layer depth may result. Care in clean-up and protection methods must be taken to ensure that this overlying vegetative mat is not disturbed and that the use of heavy machinery is limited. Thermocarst problems may be more environmentally damaging than the oil itself.

The extent of vertical oil penetration will be controlled by the absorptive capacity of the ground. Table 2 presents some rough estimates of absorptive capacities for various soils. The absolute values are less important than the relative differences. Note that the finer the soil, the greater the absorptive capacity; the exception being clay and shale which will absorb very little. Tundra will typically absorb 60 L/m^2 of crude oil.

TABLE 2

ABSORPTIVE CAPACITY OF VARIOUS SOILS AND VEGETATIONS

Soil Texture	Oil Absorptive Capacity (l/m^3)
Stone -- coarse gravel	5
Gravel -- coarse sand	8
Coarse -- medium sand	15
Medium -- fine sand	25
Fine sand -- silt	40

(Modified from Deslauriers et al., 1982)

Low viscosity oils will produce the fastest rate and greatest depth of penetration into the soil. In seasonally frozen soil or permafrost, the rate of oil penetration will be very slow and will proceed only through melting caused by the oil as it spreads over the frozen soil. Many soils in the Northwest Territories permit fast water movement. This means oil spilled in such areas would be difficult to contain.

If the amount of product spilled is not large, or the water table is low, the oil will be absorbed during its descent, and will leave behind a trail of relatively immobile material in a roughly vertical column. Rainfall may cause further downward movement of the oil and leach out water soluble components. If the main body of the liquid slug reaches the water table, there could be significant pollution. The rate of downward movement depends primarily on product spilled and the permeability of the soil layers. Figure 5 illustrates possible shapes of oil spreading.

Viscous fuel oils and some crudes will not penetrate the soil to a great depth and the rate of movement is slow. Movement of the slug will continue until it is either absorbed by the soil (or tundra), is stopped by an impermeable layer (clay, permafrost), or it reaches the ground water (Figure 6). The spilled oil

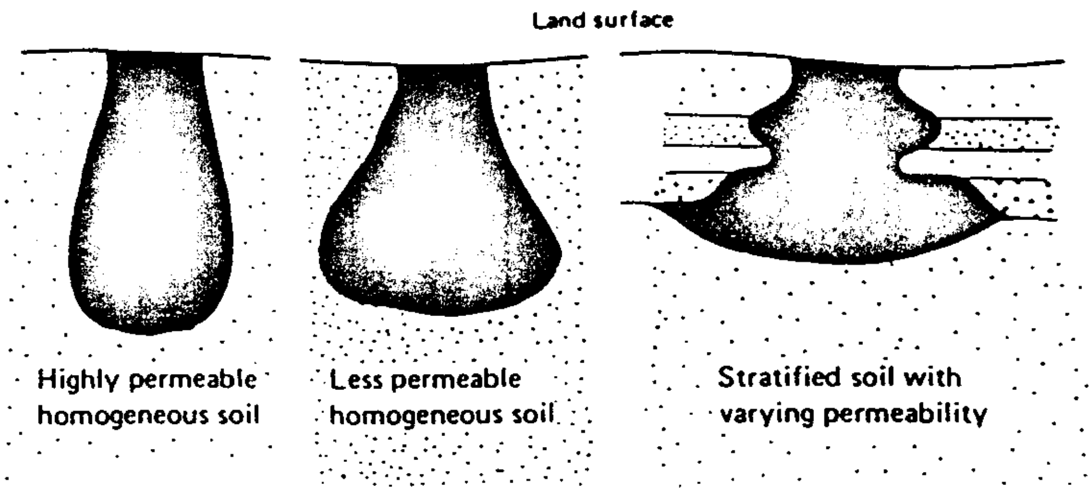


FIGURE 5
THEORETICAL CONTAMINANT SPREADING CONES
(Basic 1983)

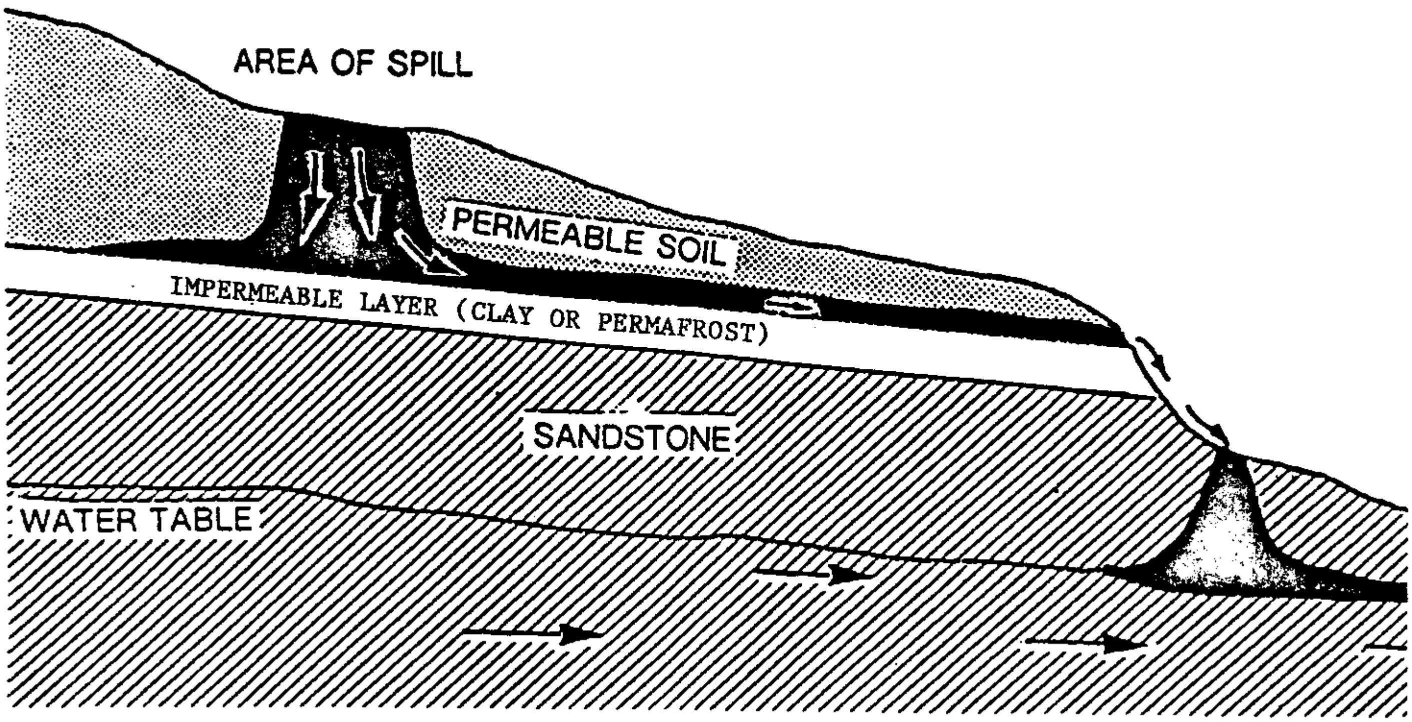


FIGURE 6
POSSIBLE PATH OF CONTAMINATION MIGRATION
(Basic, 1983)

may move along the top of the permafrost layer until it finds its lowest level, but it will not sink into the permafrost layer as long as the soil is completely saturated (dry frozen soils can be penetrated by oil whose temperature is above the pour point).

The shape and spreading rates of the oil slug will vary with subsoil variations and time. Forty to seventy percent (40 - 70%) of the final spread extent can be reached within 24 hours of the spill; 60 - 90% in one week. Spreading can continue for long periods especially if the product reaches groundwater. This may lead to chronic contamination of groundwater supplies and may eventually result in pollution of surface waters.

3.1.3 Movement on Water/Ice

Oil on Water

Oils spilled on water will spread rapidly. The behaviour of the slick formed will depend on the type of oil spilled, the temperature, wind velocity, waves and current. Its persistence will be governed by the same factors which affect the weathering of the oil. Table 3 relates surface water appearance to the approximate quantity of oil per km^2. This is very approximate and depends on temperature, water quality, type and age of the oil.

Water-in-oil (chocolate mousse) or oil-in-water emulsions may form and create additional clean-up problems by increasing the volume of material to be recovered. These emulsions can also be difficult to pump.

Oil on or Under Ice

Oil spilled onto ice will spread laterally depending upon ice surface irregularities and viscosity of the oil. The presence of pores and fractures in the ice and oil viscosity will dictate vertical movement through or into the ice block. The rate of absorption of solar energy and hence the rate of ice melting can be increased by the presence of oil in or on the ice surface. This ice melting may eventually cause oil trapped in ice to migrate to the surface of melt water, making it available for recovery. (Figure 7).

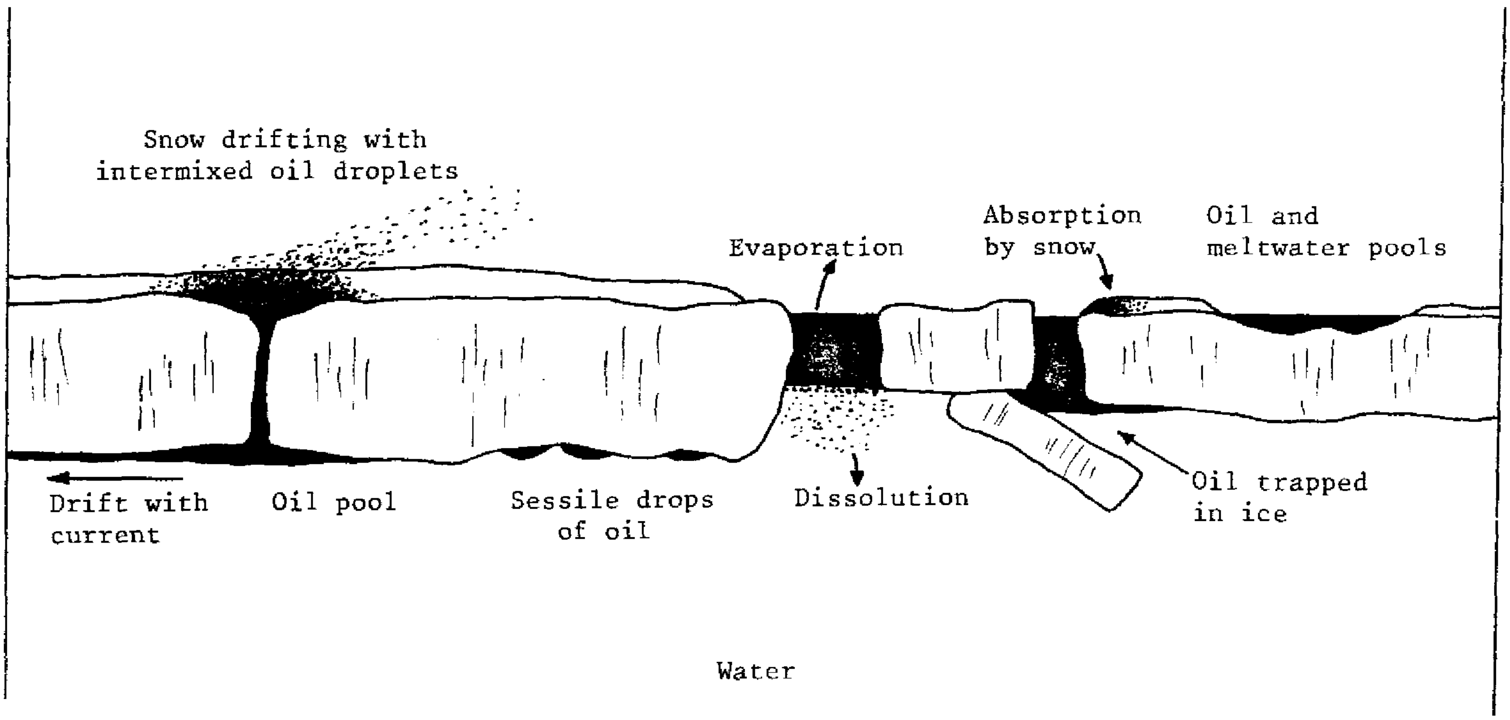


FIGURE 7

BEHAVIOUR AND FATE OF OIL IN WATER

TABLE 3

SURFACE WATER APPEARANCE

Approximate Quantity of Oil		Appearance
Gallons/ sq.mile	Litres/ km^2	
25	45	Barely visible under very good light conditions
50	90	A visible silvery sheen on the water surface
100	180	First traces of colour are observable
200	360	Bright bands of colour
665	1165	Colours becoming dull
1330	2330	Colours are much darker

3.1.4 Seasons and Oil Movement

Spills in the winter present the least problems; snow is present to absorb the oil and frozen ground prevents downward movement. Frozen conditions can provide a solid base for heavy equipment operation while protecting the fragile active layer.

Spring is the worst season for an oil spill because the oil is prevented from being absorbed into the water-logged ground and is forced to flow over a wide area, assisted by flowing melt water. The spilled product can be quickly carried away and climatic conditions make it difficult to contain. As in the summer, heavy equipment and excessive manpower must be avoided on the active layer.

In summer the soil's active layer is characterized by a steadily increasing depth of thawed soil. The thaw depth reaches its maximum by late August or early September. In the event of an oil spill in summer, the oil will flow over the terrain, flowing downhill over the surface and penetrating downward into the soil until it reaches groundwater, an impervious layer of clay or rock, the frost level or permafrost.

Figure 8 illustrates predicted spill areas occupied by spilled oil during the different seasons. Too many factors make the absolute values unreliable; it is the relative differences between seasons that is of consequence.

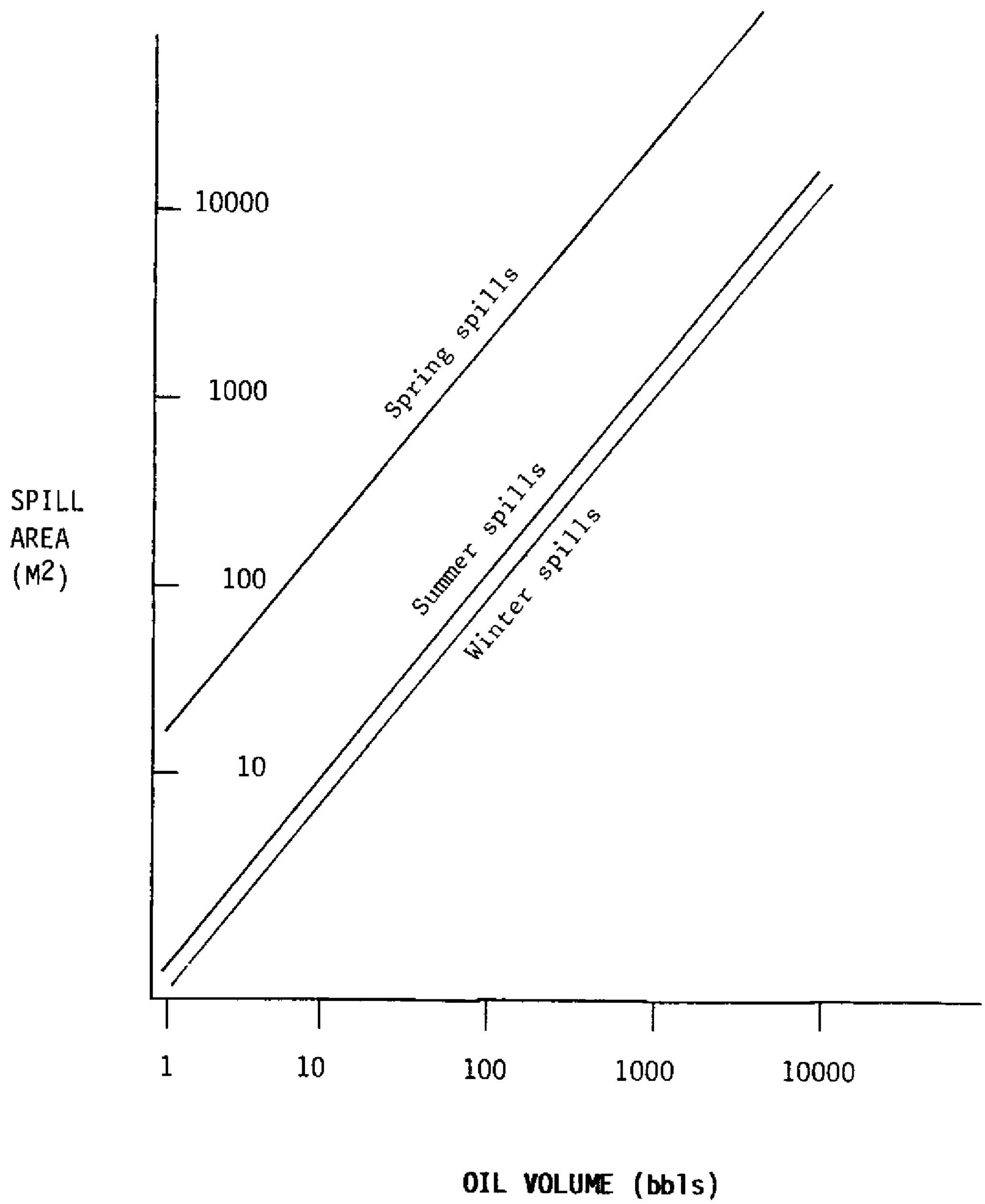


FIGURE 8
PREDICTED OIL SPILL AREAS

3.1.5 Weathering

Weathering describes the ultimate fate of spilled oil in the environment. Weathering induces a progressive series of changes in physical and chemical proper ties of the oil, and begins as soon as the oil has been spilled. The rate of weathering depends on the various factors involved which include: evaporation, dissolution, oxidation, microbial degradation and emulsification. These are all natural processes and depend on site conditions and the type of oil spilled. Light crudes and gasolines weather faster than heavy crudes or fuel oils. This is mainly because light oils have a higher proportion of volatile fractions and thus a higher rate of evaporation.

Evaporation

The rate of evaporation of an oil is influenced by its temperature, water turbulence, wind and oil spill spreading or surface area exposed. The lighter components in the oil are generally more volatile and will evaporate faster than heavier components. As evaporation proceeds less volitive components remain. The remaining fraction - a residue - is more viscous and has a higher specific gravity than the original oil. This residue may become so dense that it may sink in water, but this usually only occurs when other materials such as clay or silt are present to allow the residue to adhere to them.

Crude oil may lose 25% of its total volume within one day; Nos. 2, 4 and 6 fuel oils may lose 13%, 3% and 2% of their total volume at 23 C in 40 hours, respectively. Gasoline may lose 50% of its original volume within 7 - 8 minutes at 20 C. Generally, the more volatile an oil, the greater the fire hazard.

Oxidation

Oxidation is a term used to describe the chemical combination of oxygen with hydrocarbons. Oxidation occurs at an air-oil interface and therefore will proceed more quickly when the oil is spread out. Oxidation is a slow process in comparison to other weathering processes.

Biodegradation

Several species of bacteria, fungi and yeasts oxidize hydrocarbons by using these compounds as food energy. These organisms are generally found everywhere, but are more common in areas of chronic oil spills.

The rate of biodegradation is highly dependent on temperature, decreasing with lower temperatures. Consequently, under freezing temperatures, biodegradation is extremely slow.

Biodegradation is the principle upon which land cultivation of oil and oil debris is based. Spills left unrecovered will eventually become reduced through biodegradation.

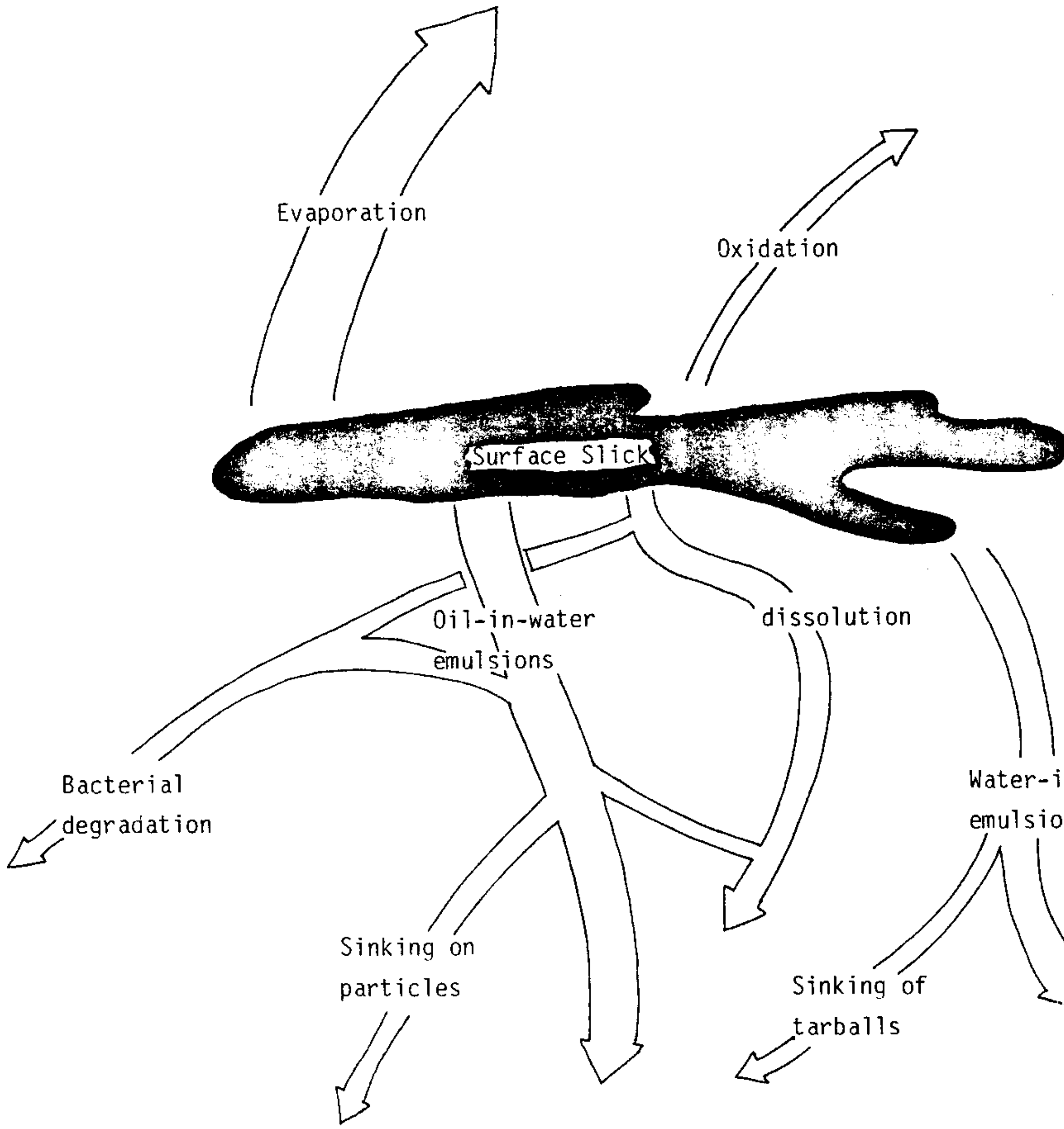
Emulsification

This term describes the mixture of one liquid in another. An emulsion is not one mixture dissolved in another; it is a mixture of small droplets - often microscopic. With respect to oil, two types of emulsions can occur, an oil-in-water emulsion or a water-in-oil emulsion. Either type of emulsion can persist for months or years. Stable emulsions refer to those emulsions that persist.

"Chocolate mousse" is a water-in-oil emulsion. It is brown in color and greaselike in consistency. It can form from wind and wave action. Further weathering of these emulsions may be very slow because the surface area open to chemical and biological reactions is relatively small.

Dissolution

Soluble hydrocarbons and nonhydrocarbons in oil will dissolve in water through the process of dissolution. Most hydrocarbons have limited solubility, but several sulphur, nitrogen and oxygen compounds present in oil (nonhydrocarbons) exhibit significant solubilities. Oxidation and microbial degradation of oil also tend to produce water soluble compounds.



Chemical and bacterial degradation on bottom

FIGURE 9

MAJOR PROCESSES BY WHICH OIL IS WEATHERED