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069 Spills-of-Opportunity Research

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SPILLS-OF-OPPORTUNITY
RESEARCH

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SUMMARY

This report presents an ordered sequence of studies to provide investigation of spills-of-opportunity (accidental oil spills). The recommended studies are based on following spilled oil from its point of release through to its subsequent fate and behaviour, on its biological effects, and on to the steps taken to control and remove it. Evaluation of countermeasures are recommended because such work has largely been excluded from previous spills-of-opportunity proposals. Whereas not all significant oil spill events will be amenable to study, the following specific topics are suggested for examination when circumstances allow:

a. Fate and behaviour:

- advection and spreading
- stranding of oil
- natural dispersion
- sedimentation
- oil properties and composition.

b. Biological studies:

- benthic studies: assessment of effects of oil on intertidal environments
- benthic studies: assessment of effects of oil on subtidal environments
- assessment of effects of oil on pelagic environments
- assessment of effects of oil on local bird populations
- assessment of effects of oil on marine mammals.

c. Countermeasures:

- containment
- physical recovery
- chemical dispersion

- temporary storage
- transfer
- ultimate disposal
- in-situ burning.

For each of these recommended topics, data are organized according to the following subsections:

- objective
- rationale
- location
- timing
- methodology
- requirements (for equipment, facilities, personnel, and services)
- costs
- success potential.

It is hoped that the general framework of studies presented herein will assist in pre-spill planning so that a consolidation of effort evolves in future spills-of-opportunity research. A coordinated, multidisciplinarian approach to data gathering is, therefore, encouraged and should reduce budget requirements for such work. The majority of the studies proposed have a high probablility of being successfully conducted.

RÉSUMÉ ADMINISTRATIF

Ce rapport présente une série d'études visant à enquêter sur les possibilités de déversement (déversements accidentels de pétrole). Les études recommandées sont fondées sur l'observation du pétrole déversé, sur l'analyse de son évolution et de son comportement depuis son point de décharge, sur ses effets biologiques ainsi que sur les mesures prises pour le contrôler et l'enlever. Une évaluation des contre-mesures y est recommandée, ce genre d'activité ayant été en grande partie exclue des propositions précédentes relatives aux possibilités de déversement. Bien que tous les déversements importants d'hydrocarbures ne se prêtent par à l'étude, nous nous proposons d'examiner les sujets suivants lorsque les circonstances le permettront.

a. Évolution et comportement:
- advection et épandage
- toronnage du pétrole
- dispersion naturelle
- sédimentation
- propriétés et composition du pétrole.

b. Études biologiques:
- études benthiques: évaluation des effets du pétrole sur le milieu intertidal
- études benthiques: évaluation des effets du pétrole sur le milieu infralittoral
- évaluation des effets du pétrole sur le milieu pélagique
- évaluation des effets du pétrole sur les populations locales d'oiseaux
- évaluation des effets du pétrole sur les mammifères marins.

c. Contre-mesures:
- limitation des épandages
- récupération physique
- dispersion chimique
- stockage temporaire
- transfert
- élimination définitive
- brûlage sur place.

Pour chacun de ces sujets, les données sont organisées de la façon suivante:
- objectif
- logique
- emplacement
- minutage
- méthodologie
- exigences (en terme d'outillage, d'installations, de personnel et de services)
- coûts
- réussite probable.

On espère que la présentation du cadre général de ces études facilitera la planification de situations précédant un déversement, permettant ainsi un effort conjoint dans la recherche future des possibilités de déversements. Il convient donc de mettre au point une méthode de collecte de données, coordonnée, et multidisciplinaire, qui soit susceptible de réduire les coûts entraînés par ce genre de travail. La plupart des études proposées ont, dès lors, de fortes chances de réussir.

INTRODUCTION

BACKGROUND

Spills-of-opportunity (accidental oil spills) have been viewed by many researchers as an excellent means of obtaining scientific data on oil spills and on the effectiveness of countermeasures. The concept is simply to use an actual oil spill as a research setting from which scientific and technical questions may be answered. Theoretically, limitations of both scale and environmental influences inherent in laboratory experiments and in controlled field trials can be overcome.

Many data have been collected after major oil spills, as early as the Torrey Canyon incident in 1967, but much of the methodology has been inconsistent thereby limiting their scientific usefulness (API 1977). In addition, data have been sought on an ad hoc basis. The specific topics chosen for study have reflected the background and interest of personnel sent to the accident site. Only the most conspicuous concerns that have received attention, such as the tracking and analysis of slicks and the determination of the effect of oil on birds and intertidal invertebrates. For the most part, an ordered approach to the comprehensive assessment of response and effect has been lacking at most major spills.

More recently, however, technical reports pertaining to spills, such as the National Oceanic and Atmospheric Administration and Environmental Protection Agency (NOAA/EPA) documentation of the Amoco Cadiz grounding (Hess 1978), have much improved our understanding of such accidents. In spite of the progress made in such work, certain knowledge gaps still exist. In particular, technical investigations of countermeasures systems have been largely neglected during most significant events involving oil releases. A reason for their omission is that the application of equipment with minimal interruption takes priority so that the effects of discharged oil can be mitigated as quickly as possible. Also, areas of more pure research, such as fate and effects studies, however complex, are easier to reckon with than investigations of chemical and physical clean-up systems which entail applied, critical evaluations of commercially available products (Fingas 1985). Response activities involving control technologies and materials have, therefore, been observed from afar or have been excluded from study altogether, whereas oil movement and aesthetic and biological effects have received closer scientific scrutiny.

The fact remains that much practical knowledge could be gained from examining in more depth various clean-up operations during actual spills. The main objectives of such work would be to improve available techniques and to optimize their use. Futhermore, the lack of a more-encompassing approach to investigating spills should be addressed so that a series of related studies is undertaken, tying in, for example, oil fate and behaviour not only to biological effects but also to the effectiveness of countermeasures. At present, their interrelationship is not always clearly reflected in much of the literature which report specific, esoteric technical studies.

Although several international meetings and workshops have recognized deficiencies (API 1977; ICES 1981; NRC 1975;), such efforts still need to be formalized and structured through a spills-of-opportunity plan and to answer several persistent questions.

To date potential projects have been identified on a subject-specific or regional basis, should significant spills-of-opportunity funding be forthcoming. In Canada, such work has been conducted by Ward and Tull (1977). Recent studies have also been proposed under the aegis of Environment Canada's Environmental Emergency Branch (Keizer 1982; Green et al. 1982; Mackay 1982; and Humphrey and Keizer 1984). Mackay (1982) reviewed the major contributions on this topic to the end of 1981, however, the preparation of a detailed research plan was beyond the scope of his work.

PURPOSE

The aim of this study is to produce a comprehensive plan that focuses beyond the description of several separate research projects, many of which have already been proposed. What now is provided is an ordered series of experimentally designed projects, including countermeasures studies, which should lead to statistically supportable conclusions for both scientific and operational purposes. Interrelating these to the extent possible should not only clarify the total information package gained from studying accidental spills (spills-of-opportunity) but should also indicate ways of gathering data common to the understanding of several disciplines.

This report introduces a general framework and more coordinated approach to undertaking studies of spill incidents. The proposed studies can also be readily expanded upon according to the technical criteria considered herein if additional fate, effect or countermeasures work is believed to be essential in assessment of any specific spill event.

APPROACH

The Environmental Studies Revolving Funds (ESRF) requested that this study address specifically:

- the fate, behaviour, effects, and control of spilled oil;
- the effectiveness of dispersants (if used); and
- the adequacy of countermeasures equipment.

As with many previous proposals for spills-of-opportunity research, a first priority was to rearrange the ESRF request to the following sequence of three topics, namely:

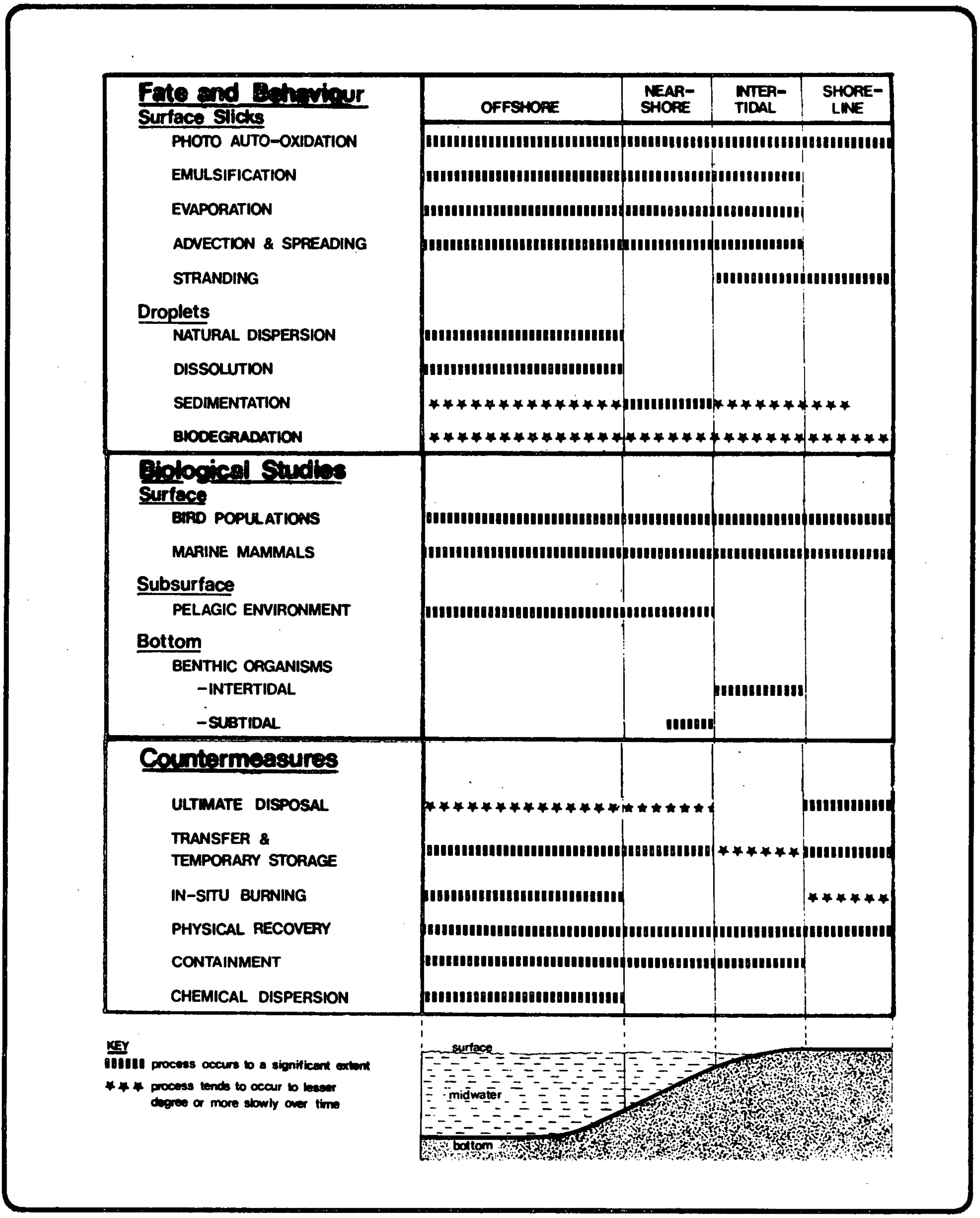
- the fate and behaviour of spilled oil;
- its biological effects; and
- countermeasures.

Each topic was then subdivided into categories well founded in the literature. A sequential approach was used in selecting each of the subcategories as well as in the consolidation of several of these. Essentially, it was decided that spilled oil should be followed in its movement through the environment, to its potential biological effect, and through a series of steps to control and remove it. Also taken into account were its location in the offshore, nearshore, intertidal, and shoreline zones and its possible transport from the sea surface, to midwater, and to the sea bed (Figure 1). Marine spills in Canadian waters, in which several hundred metric tons or more of crude oil originated from a tanker or well blowout, formed the basis for the proposed studies.

For each technical study proposed, the objective, rationale, location, timing, methodology, and requirements for equipment, facilities, personnel and services are outlined. For each, the main cost components are described. The probability of successfully achieving the study objective is also indicated, and factors that might influence the outcome. In several instances subsections have been added to clarify other aspects of the work. Appendix 1 summarizes the background material which formed the basis for the section on Biological Studies.

Even so, not all aspects will be amenable to study in particular cases, say a tanker accident occurring in adverse weather conditions in a remote area. The complexity of many uncontrolled variables coupled with the public pressure to clean up oil makes it harder to plan scientific studies for any accidental spill than for a controlled experiment.

Despite these apprehensions, studies are outlined specific to the role of response equipment and techniques used in various clean-up phases. Biological as well as fate and behaviour investigations are described. Whether or not these are always feasible to apply to any given event would have to be determined during the course of an actual spill. However, by planning such work on a pre-spill basis, it becomes evident that data can be gathered which relate to many research aspects, be these biological, physical, chemical, or mechanical in nature. Furthermore, this consolidation of effort is a necessary step for conducting spills-of-opportunity research within fixed budgets. In this regard, the cost estimates only indicate the main components that must be considered in a more detailed submission to obtain funding.



Fate and Behaviour	OFFSHORE	NEAR-SHORE	INTER-TIDAL	SHORE-LINE
Surface Slicks				
PHOTO AUTO-OXIDATION	▮▮▮▮▮▮	▮▮▮▮▮▮	▮▮▮▮▮▮	▮▮▮▮▮▮
EMULSIFICATION	▮▮▮▮▮▮	▮▮▮▮▮▮	▮▮▮▮▮▮	
EVAPORATION	▮▮▮▮▮▮	▮▮▮▮▮▮	▮▮▮▮▮▮	
ADVECTION & SPREADING	▮▮▮▮▮▮	▮▮▮▮▮▮	▮▮▮▮▮▮	
STRANDING			▮▮▮▮▮▮	▮▮▮▮▮▮
Droplets				
NATURAL DISPERSION	▮▮▮▮▮▮			
DISSOLUTION	▮▮▮▮▮▮			
SEDIMENTATION	✱✱✱	▮▮▮▮▮▮	✱✱✱	✱✱✱
BIODEGRADATION	✱✱✱	✱✱✱	✱✱✱	✱✱✱
Biological Studies				
Surface				
BIRD POPULATIONS	▮▮▮▮▮▮	▮▮▮▮▮▮	▮▮▮▮▮▮	▮▮▮▮▮▮
MARINE MAMMALS	▮▮▮▮▮▮	▮▮▮▮▮▮	▮▮▮▮▮▮	▮▮▮▮▮▮
Subsurface				
PELAGIC ENVIRONMENT	▮▮▮▮▮▮	▮▮▮▮▮▮		
Bottom				
BENTHIC ORGANISMS				
-INTERTIDAL			▮▮▮▮▮▮	
-SUBTIDAL		▮▮▮		
Countermeasures				
ULTIMATE DISPOSAL	✱✱✱	✱✱✱		▮▮▮▮▮▮
TRANSFER & TEMPORARY STORAGE	▮▮▮▮▮▮	▮▮▮▮▮▮	✱✱✱	▮▮▮▮▮▮
IN-SITU BURNING	▮▮▮▮▮▮			✱✱✱
PHYSICAL RECOVERY	▮▮▮▮▮▮	▮▮▮▮▮▮	▮▮▮▮▮▮	▮▮▮▮▮▮
CONTAINMENT	▮▮▮▮▮▮	▮▮▮▮▮▮	▮▮▮▮▮▮	
CHEMICAL DISPERSION	▮▮▮▮▮▮			

KEY

▮▮▮▮▮▮ process occurs to a significant extent

✱✱✱ process tends to occur to lesser degree or more slowly over time

Figure 1 SPILLS OF OPPORTUNITY STUDIES

FATE AND BEHAVIOUR

Oil spilled on water combines to a varying extent with the air, water, and particulate matter that it contacts. It can also move considerable distances from its original point of release. The pathways it takes and changes to its physical and chemical characteristics (Figure 2) can be attributed to processes (NRC 1985):

- advection and spreading
- evaporation
- emulsification
- natural dispersion
- sedimentation
- stranding
- dissolution
- photo-oxidation
- auto-oxidation
- biodegradation
- biological uptake.

Horizontal and vertical diffusion, and transport of oil droplets and particles in both the water column and air can also occur.

Whereas, all fate and behaviour processes and compositional and properties analyses are important in understanding the effects of oil spills, only the first seven of those processes as well as the analyses are recommended for field study during a spills-of-opportunity because of their more immediate and direct relationship to countermeasures operations.

These aspects can be further combined so that integrated studies are developed. Specifically, evaporation and emulsification can be studied through a systematic sampling program aimed ultimately at determining the compositional and physical and chemical characteristics of the oil. The laboratory analysis of oil should also add to the understanding of photo- and auto-oxidation and dissolution. Biodegradation studies are viewed to be comparatively less important for spills-of-opportunity (see also Appendix 1).

	OFFSHORE	NEAR-SHORE	INTER-TIDAL	SHORE-LINE
Surface Slicks				
PHOTO AUTO-OXIDATION	▮▮▮▮▮▮	▮▮▮▮▮▮	▮▮▮▮▮▮	▮▮▮▮▮▮
EMULSIFICATION	▮▮▮▮▮▮	▮▮▮▮▮▮	▮▮▮▮▮▮	
EVAPORATION	▮▮▮▮▮▮	▮▮▮▮▮▮	▮▮▮▮▮▮	
ADVECTION & SPREADING	▮▮▮▮▮▮	▮▮▮▮▮▮	▮▮▮▮▮▮	
STRANDING			▮▮▮▮▮▮	▮▮▮▮▮▮
Droplets				
NATURAL DISPERSION	▮▮▮▮▮▮			
DISSOLUTION	▮▮▮▮▮▮			
SEDIMENTATION	✱✱✱✱✱✱	▮▮▮▮▮▮	✱✱✱✱✱✱	✱✱✱
BIODEGRADATION	✱✱✱✱✱✱	✱✱✱✱✱✱	✱✱✱✱✱✱	✱✱✱✱✱✱

KEY

▮▮▮▮▮▮ process occurs to a significant extent

✱✱✱ process tends to occur to lesser degree or more slowly over time

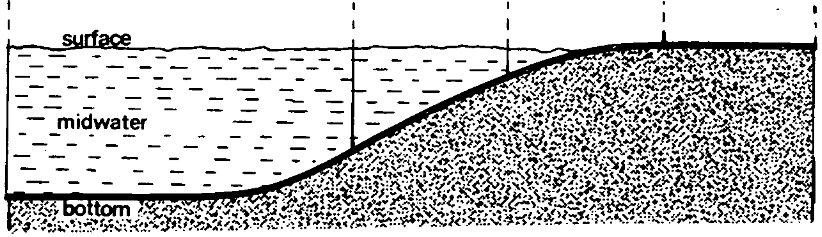


Figure 2 FATE AND BEHAVIOR STUDIES

For the purposes of this study, fate and behaviour research can, therefore, be consolidated into five basic areas of investigation, each of which is described seperately:

- advection and spreading
- stranding
- natural dispersion
- sedimentation
- oil properties and composition.

The uptake of oil by biological communities is a significant area of concern that relates to the fate of the oil. It is dealt with in a separate section on Biological Studies, in terms of the effect of spilled oil, rather than in this section which considers the oil's physical fate and behaviour. The correlation must still be made, however, between the two sections because analytical methods and the depiction of oil pathways should be adequately sensitive to, and consider hydrocarbons at, biologically significant levels, respectively. It is basic to a more precise understanding of how organisms are affected by oil. Furthermore, by coordinating both sets of studies as well as the countermeasures assessments, the work can be designed to be more cost-effective without being unduly complicated.

ADVECTION AND SPREADING

Objective

The objective of this area of investigation is to monitor and record the movement of waterborne surface slicks.

Rationale

Spilled oil can move considerable distances on the water's surface, influenced by wind and surface currents (advection) and, to a lesser but still significant degree, as a result of its own inertia, surface tension, other physical properties, and related processes (spreading). The location of the oil thus transported has a direct bearing on the extent and nature of control and clean-up technologies, biological, and other effects. The study of advection and spreading can also be correlated with trajectory models specifically designed to predict oil movement (Grose and Mattson 1977).

Location

Advected and spreading slicks should be studied primarily in each of the offshore and nearshore regimes and followed (a) to the point at sea where they are not likely to pose a threat and (b) to the intertidal zone where they will likely contact the shoreline (see also subsection on Stranding of Oil).

Timing

Ideally, released oil should be followed within several hours of the accident occurring and should be monitored continuously throughout significant movements of slicks, specifically those affecting potential field studies or otherwise requiring attention such as control and clean-up. Observations every 2-6 h. for the first 48-96 h., followed by daily notations, should be used to describe slick movement. The following factors influence the study of advection and spreading:

a. Abruptly changing sea and weather conditions under severe conditions can eliminate the opportunity to investigate slicks. Natural dissipation of oil can also occur rapidly during such periods, and the resulting documentation is unacceptably lacking in detail.

b. Changes in wind, wave, tide and current directions introduce complexities which render quantitative assessment difficult as different slick fronts intercept each other.

c. Initial reporting and alerting in delays if a spill in a remote area is not discovered for some time or is difficult to reach for scientific study. A batch spill involving an unknown quantity of oil released in the Arctic, for example, may not be suitable for the type of investigation suggested in this study.

d. A subsea blowout under Arctic ice occurring during winter would also not be amenable to study.

e. Slicks which eventually disperse hundreds of kilometres from the original discharge point following a sudden storm may not lend themselves to study because of the cost of logistical support or the supposition that equlibrium conditions had been previously attained.

Methodology

Step 1 - Tracking of surface slicks. Various means can be drawn upon to track the movement of slicks on the water's surface. The following factors should be considered:

a. Airborne remote sensors can be employed to follow slick movements, supplemented by visual observations and vertical photography. Equipment commonly used for this purpose has included:

- infra-red (IR) and ultra-violet (UV)
- low light level television (L^3TV)
- side-looking airborne radar (SLAR)
- laser fluorosensor

d. Global navigation systems (GNS) and inertial navigation systems (INS) can be used to locate slicks directly for tracking purposes.

c. Charts can be used to plot the location of slicks that incorporate onshore and offshore transects or grids appropriate to the size of the spill and the geographical area of concern (Hopper 1981).

e. Radio tracking buoys such as those manufactured in Canada by Orion and Novatech can be placed in the oil and followed by receivers located on board vessels or aircraft.

f. Other slick markers have been used, such as hula hoops, United States Coast Guard (USCG) datum marker buoys (DMBS), drift cards, large dye patches (for periods of hours), fluorescent-painted plywood sheets, and NOAA drifting buoys (Figure 3), as

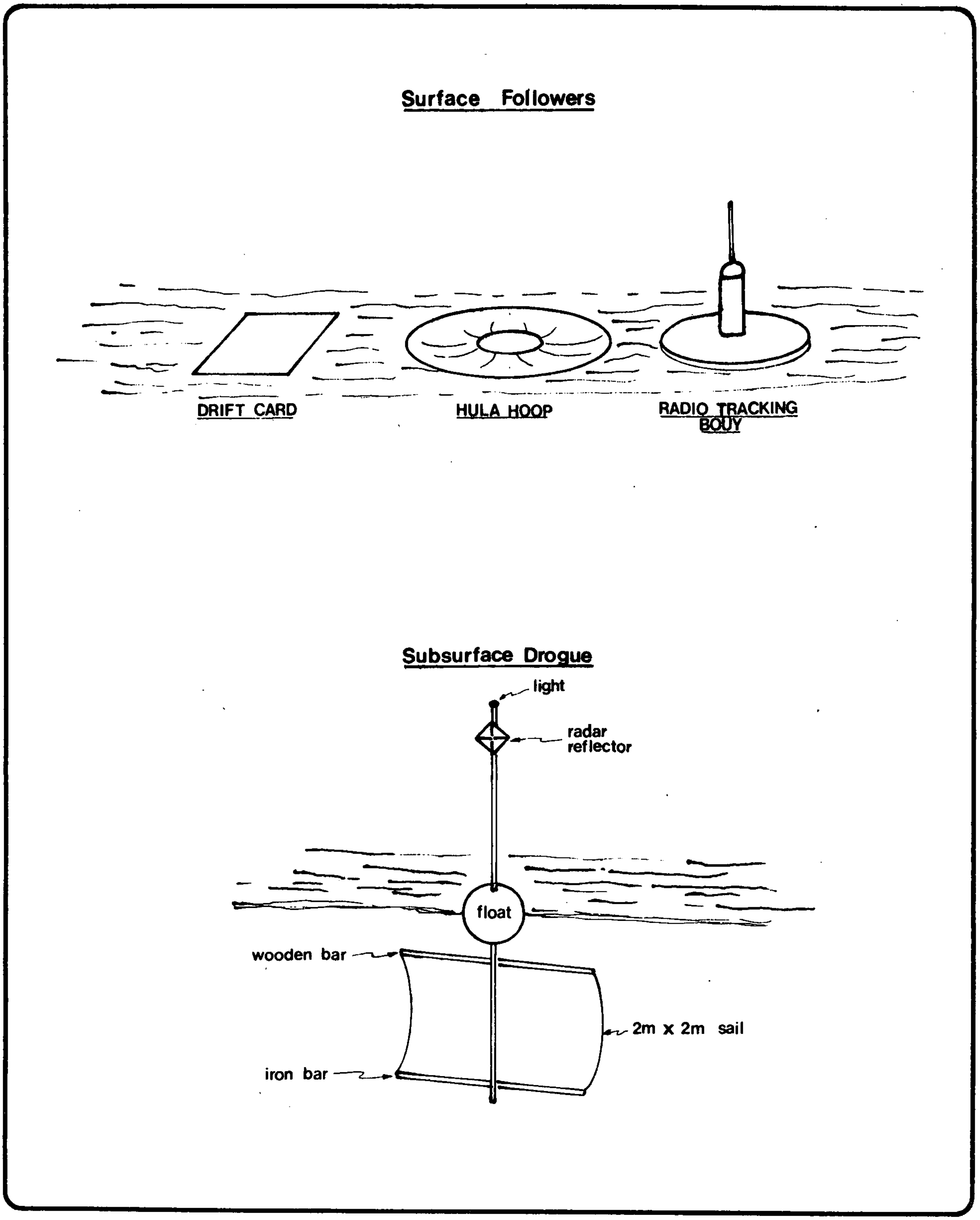


Figure 3 SLICK TRACKING DEVICES

(adapted from: Green, Humphrey & Fowler, 1982) available (Grose and Mattson 1977). Such techniques are less useful than currently available global navigation (GNS) or inertial navigation systems (INS), but suggest the use of simpler means if tracking units are not on hand or malfunction.

g. Landsat or other satellite images can provide useful data, but only if orbital position is appropriate, and clouds are not present.

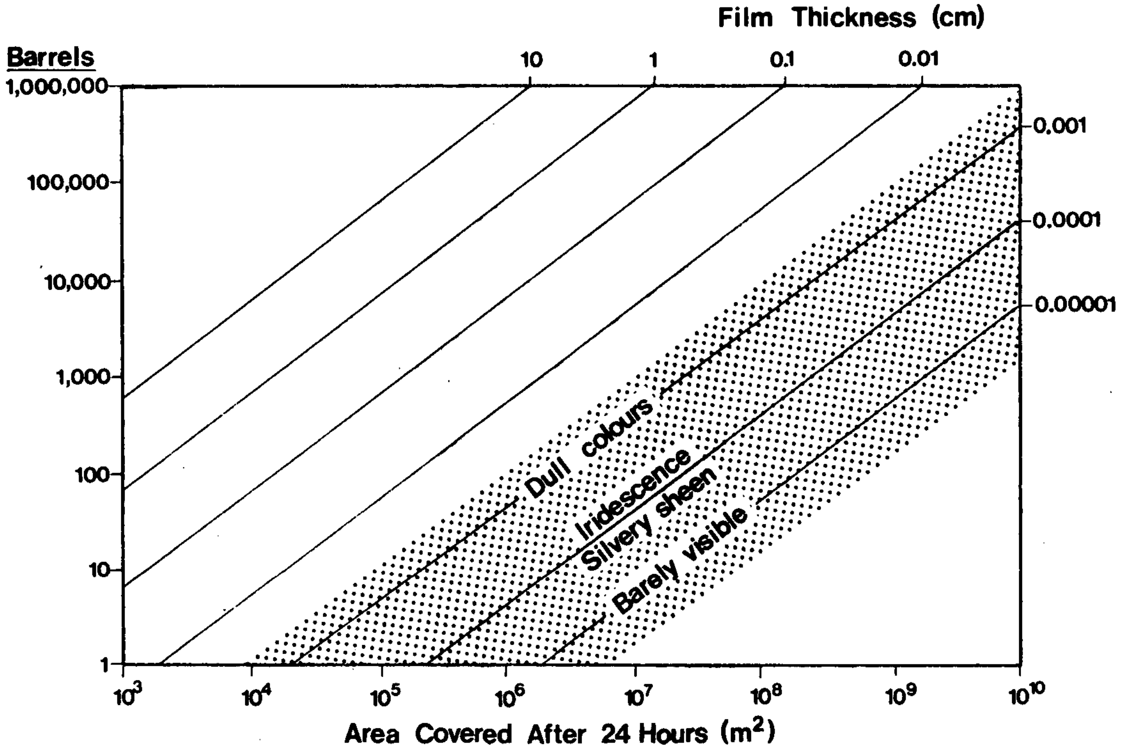
For large spills, daily oil slick maps should be developed for large spills showing flight tracks, the extent, nature and concentration of oil contamination and other related parameters, such as surface water temperature. Slicks can be plotted according to various contour levels, such as threshold-to-light, light-to-moderate, and moderate-to-heavy (Grose and Mattson 1977). Observations of oil at sea can also be used to approximate the thickness of slicks, although surface measurements should be carried out to confirm thicknesses using the Ross/Belore sampler for thick uniform slick thicknesses (Figures 4 and 5 and Methodology in subsection on Oil Properties and Composition) and the OHMSETT/Johnson sampler used at the EPA test facility in Leonardo, New Jersey.

Step 2 - Environmental determinations. Wind, waves, currents, tides, water depth, air and water temperature, and salinity are the environmental parameters of primary concern.

a. Currents: NOAA has reported on the use of several methods to define local, small-scale currents as well as larger circulation patterns. These should provide real-time current measurements that can be analysed to produce current fields representative of regional flow regimes and the requirements of on-scene, spill-trajectory modelling.

   Richardson current probes (packets of dye released at known time intervals) can be deployed by helicopter and can be monitored every few days. Increase coverage (four times daily) during times of atmospheric disturbance that might retard or reverse the current flow.

   Deploy radio-frequency drogues (set sails at 0-2 m) and monitor positions from radio direction-tracking shore stations (as in Figure 3). These provide more continuous



NOTE: Shaded area indicates the range of oil slick observations for which thickness and area covered can be determined by appearance. Any value below the shaded area would not be visible, and any area above would be dark brown or black.

(Concawe ,1981)

Figure 4

OIL SPILL VOLUME, FILM THICKNESS, AREA COVERED AND APPEARANCE OF OIL

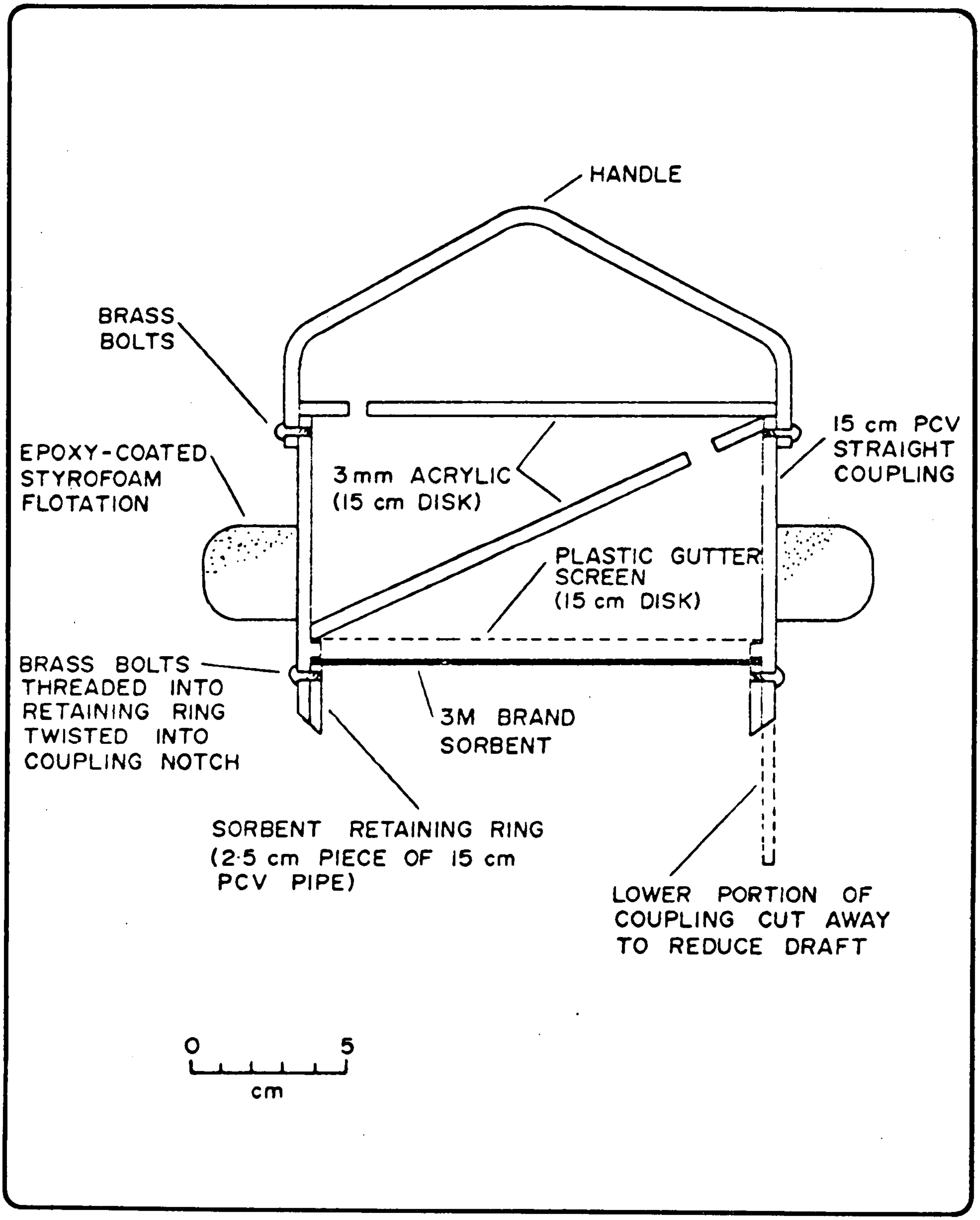


Figure 5 ROSS/BELORE SAMPLER

(Belore, 1982)

monitoring of currents but with significantly less spatial resolution. Satellite drogues can be used for the determination of large-scale circulation studies in the event of slick movement over hundreds of kilometres or more.

Regional features must be considered in detailed current studies, such as bathymetry using an expendable bathythermograph (XBT), coastline configuration, local dominant dynamics, and conservation of water theory. Both Eulerian (point) and Lagrangian (parcel) water-motion measurements should be obtained to define longer-term movement of oil better in coastal areas affected by complex wind, tide, and ocean current regimes.

Where oil sedimentation studies are pursued (see subsection on Sedimentation), investigations should be undertaken of near-bottom currents in waters adjacent to the shoreline that is expected to be affected when it is composed of sand and other fine-grain materials (see subsection on Stranding of Oil).

b. Meteorological data. Determinations should be made of wind speed and direction, air temperature, precipitation, relative humidity. Ideally, hourly meteorological surface data should be collected by Atmospheric Environment Service, Environment Canada personnel directly at the source of the spill for the first week following the mishap. Weather data collection should diminish or continue in intensity as necessitated by the nature of the oil release. A figure of 3.5% of the wind speed should prove adequate as a wind drift factor, although this approximation should be verified in view of wind-dominating spill trajectories and forecasting over the longer term.

On an immediate basis, vectoral addition of wind and tide velocities should serve to forecast local slick movements adequately . For longer-term, wider-spread slick movement forecasting, comprehensive weather data from Environment Canada stations should be used in conjunction with trajectory models, if available.

c. Other oceanographic water quality data. Wave height, direction of propagation, sea state description (Table 1), and salinity should be recorded. A Wave Rider Infor-

TABLE 1

DESCRIPTION OF WEATHER AND SEA CONDITIONS

BEAUFORT SCALE OF WIND FORCE						
Beaufort Wind Force	**Mean Wind Speed in knots**	**Limits of Wind Speed in knots**	**Descriptive Term**	**Sea Criterion** (*See* **photographs on 'State of Sea' card or in** *Marine Observer s Handbook*, **10th Edition—H.M.S.O.)**	**Probable Height of Waves in metres***	**Probable Maximum Height of Waves in metres***
	Measured at a height of 10 m. above sea level					
0	00	Less than 1	Calm	Sea like a mirror	—	—
1	02	1—3	Light air	Ripples with the appearance of scales are formed but without foam crests	0.1	0.1
2	05	4—6	Light breeze	Small wavelets, still short but more pronounced, crests have a glassy appearance and do not break	0.2	0.3
3	09	7—10	Gentle breeze	Large wavelets Crests begin to break Foam of glassy appearance Perhaps scattered white horses	0.6	1.0
4	13	11—16	Moderate breeze	Small waves becoming longer fairly frequent white horses	1.0	1.5
5	19	17—21	Fresh breeze	Moderate waves, taking a more pronounced long form, many white horses are formed (Chance of some spray)	2.0	2.5
6	24	22—27	Strong breeze	Large waves begin to form, the white foam crests are more extensive everywhere (Probably some spray)	3.0	4.0
7	30	28—33	Near gale	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind	4.0	5.5
8	37	34—40	Gale	Moderate high waves of greater length edges of crests begin to break into spindrift The foam is blown in well-marked streaks along the direction of the wind	5.5	7.5
9	44	41—47	Strong gale	High waves Dense streaks of foam along the direction of the wind Crests of waves begin to topple, tumble and roll over Spray may affect visibility	7.0	10.0
10	52	48—55	Storm	Very high waves with long overhanging crests The resulting foam in great patches is blown in dense white streaks along the direction of the wind On the whole the surface of the sea takes a white appearance Tumbling of the sea becomes heavy and shock-like Visibility affected	9.0	12.5
11	60	56—63	Violent storm	Exceptionally-high waves (Small and medium-sized ships might be for a time lost to view behind the waves) The sea is completely covered with long white patches of foam lying along the direction of the wind Everywhere the edges of the waves crests are blown into froth Visibility affected		
12	—	64 and over	Hurricane	The air is filled with foam and spray Sea completely white with driving spray, visibility very seriously affected	14 or over	—

* These columns are added as a guide to show roughly what may be expected in the open sea, remote from land In enclosed waters, or when near land with an off-shore wind, wave heights will be smaller and the waves steeper

Notes — (1) It must be realised that it may be difficult to estimate wind force by the sea criterion The wind force and direction may therefore be estimated by other means e g the feel of the wind or the smoke, making due allowance for course and speed of ship (*see Marine Observer s Handbook*, Table 23)

(2) The lag effect between the wind getting up and the sea increasing should be borne in mind

(3) Fetch, depth, swell, heavy rain and tide effects should be considered when estimating the wind force from the appearance of the sea

The Gale Warning Signal for coastal areas around the British Isles is hoisted for winds which reach force 8 or above For this purpose force 7 is not considered a gale

In the *Atlantic Bulletin for Shipping* for ocean areas storm warnings are only issued if the wind force is expected to reach force 10 or over

For details of this and other meteorological information for shipping (including the *International Meteorological Code*) see Met O 509 *Ships Code and Decode Book* or *Admiralty List of Radio Signals Vol III*

(Concawe ,1981)

mation Processing System buoy should be used for the comprehensive characterization of waves; alternatively, a simple spar buoy could prove adequate.

Step 3 - Oil sample collection. Aliquots of oil should be obtained, as possible, directly from the source of the spill as well as at timed intervals following its release. It is suggested that both thin and thick slicks be sampled hourly during the first 24 h. subsequent to its spillage and at less frequency (every 4 h.) for the next 24 h. Thereafter, oil samples should be collected in conjunction with the monitoring of specific countermeasures operations and biological impact assessments. Details of sampling procedures, compositional analysis and determination of physical and chemical or both, properties are presented in the subsection on Oil Properties and Composition.

Requirements

Equipment. The following equipment is required for each investigation of spreading:

- tracking: Canada Centre for Remote Sensing airborne slick-tracking package, (ING), GNS, (GPS) charts, video recording equipment, 35-mm camera plus filters;
- currents: radio tracking buoys, hula hoops, drift cards, other drift or atum buoys;
- other oceanographic data: Wave Rider buoy (if available), spar buoy (alternative choice);
- meteorological data: wet and dry bulb thermometers, anemometer; and
- oil collection: sampling requirements are given in subsection on Oil Properties and Composition.

Facilities. In the field, transportation provided during normal course of spill response will include offshore-going vessels, fixed-wing aircraft, and helicopters, as available.

In the laboratory, space, sample storage facilities, viscosimeter, and sample preservatives will be required.

Personnel. Several are required including an oceanographer, a remote sensing specialist, a spill technician, and a trajectory modelling specialist.

Services. Local weather forecasting capability, and laboratory for composition and properties analysis capability (see also the subsection on Oil Properties and Composition) are required.

Costs

Costs will vary widely depending upon the size and duraton of the spill as well as the extent of movement of slicks. An overlap of duties is anticipated for personnel assigned to this project with studies of chemical dispersion and natural dispersion. The main cost components are personnel, travel, and living, laboratory analyses, field provisions (sample bottles, oil preservatives, film, and miscellaneous supplies), and report preparation (data reduction, graphics, and word processing).

Offshore investigations, using aircraft and water-going vessels, should make use of units already dedicated to clean-up, if non-interference with response crews is assessed.

Success Potential

A high probability of documenting gross movements of surface slicks accurately, particularly in coastal waters, and of correlating slick drift with oceanographic and meteorological data, should be possible. A lower potential would be possible to pursue studies determining, on regular basis, location(s) of a multitude of slick fronts at significant distances from the release point. The data collected should be useful to trajectory modelling.

STRANDING OF OIL

Objectives

The objectives of this area of investigation is to document the volume, location, and timing of oil that contacts the shoreline, and to determine its subsequent fate and behaviour once stranded.

Rationale

Oil that comes ashore is of concern from an aesthetic, nuisance, and biological impact point of view. Its persistence varies depending upon the nature and type of the spill, the mixing energy and beach processes associated with the coastline, and the weathering effects on the oil. Experimental investigation is necessary to ascertain the extent of oiling, its residence time, its potential effects, and clean-up strategies.

Location

Once the surveying and mapping of polluted shoreline has been conducted, study plots should be located over a limited stretch of shoreline (2 to 3 km) so that varying beach and energy types are investigated (Green, et al. 1982). It is important to compare, if possible, plots of beach materials of similar composition subjected to oil, those uncontaminated, and those cleaned mechanically. Marsh and estuarine areas are particularly recommended for study because of the biological implications and persistence of oil in such zones. Sandy beaches should also be examined, especially those viewed as recreational amenities. Gravel, cobble, and other beaches should also be studied as and if these occur.

Timing

Shoreline studies should be considered whenever significant oiling occurs. It is recommended that oiled plots are selected as soon as possible after the first slicks strand, to allow comprehensive documentation of all subsequent related processes. Study intensity would decrease over time to document long-term effects.

A suggested post-spill schedule is daily for one to two weeks, weekly for three months, and then seasonally for one year (EPA 1978). The studies could be correlated with, and therefore correspond to, the sampling frequency associated with benthic studies of interdidal environments (see later section). The incidence of severe storms during the course of a normal sampling period should be reason for more immediate monitoring of study plots. Timing could also be affected by clean-up needs and strategies.

Methodology

Step 1 - Identification of study areas. A series of tasks is given below:

a. Control beach (or beaches) for study should be identified.

b. Extent of oiling should be determined by aerial (vertical) photography and remote-sensing package (GNS, INS, etc.).

c. Oiled beaches identified for study and control beaches should be classified according to type of beach materials e.g., rock, mud (flats), sand, sandy gravel, gravel cobble, marsh, etc.

d. Study plots should then be described according to location, fetch, length of intertidal zone, width of foreshore, and permeability (Owens and Trudel 1985).

e. Plots should be staked and marked so that subsequent visits can be made easily.

f. Three metre wide strips should be located running 0-5 metres above high tide to the apparent low tide mark. Characterize beach profile by measurement of stake height above active beach and monitor to track movement of beach material.

g. Mechnical or other means of clean-up applied to beaches under study should be noted.

h. Transects should be surveyed to obtain heights relative to mean sea level as a function along each transect. Ten stations would be located along each transect at intervals of about one tenth of the spring tidal range for the beach (Keizer 1982).

Step 2 - Sampling.

a. Oil: free-floating oil should be collected in 1 L glass sample jars during the initial stages of study (as in subsection on Oil Properties and Composition) for each beach type studied. Samples of beached slicks should also be collected during the period when oiling at the high-tide mark and beyond continues to occur.

b. Oil and sediment (Keizer 1982): sediment cores should be collected at each station starting at low water as the tide begins to flood. Samples of the swash should be collected at each station along one transect as the swash filled the hole left by the core. Two samples of sea-water behind the swash zone should be collected at high tide. Ideally, samples would be collected until an equilibrium condition had evolved.

The length of the cores would vary from beach to beach, depending upon the substrate.

For each beach, the cores should be split and then divided into three sections, the depths of which should be kept constant. Each section should be squeezed to obtain a sample of interstitial water. The samples of interstitial water, bulk sea-water, and sediment should be analysed for oil using fluorescence or infra-red spectrophotometry, or both. Some samples should be analysed by gas chromatography to assure that the study area had not been contaminated by another source. In some intertidal areas, there is considerable freshwater run-off at low tide, either from streams or from emerging ground water. Samples of freshwater runoff should be collected and analysed to determine if this was a significant route for oil transport.

Requirements

Equipment. Equipment needed in the field include stakes, sledge hammer, tape measure, travel shovel, beach profiling kit, one can spray paint, 35-mm camera, video recording equipment, 1-L sampling jars (200), surveyors level, and sediment corer.

Facilities. In the field, transportation is required to beach sites (boat, aircraft or four-wheel drive vehicle), and living accommodation.

Personnel. A geomorphologist and a technical assistant are required.

Services. A laboratory with analytical capability for IR/fluorescence spectrophotometry mass spectophotometry (MS), gas chromatography (GC) is required.

Costs

The initial study involves costs for a geomorphologist and technical assistant, travel and living, and miscellaneous field supplies.

Return visits would necessitate additional costs for personnel, for travel and living, and for miscellaneous supplies. Laboratory analysis will include IR determinations of total hydrocarbons and GC for oil composition. Report preparation costs will include data reduction, graphics, and word processing.

Success Potential

There is a high probability for the scientific monitoring of the persistence of oil for various beach types implicated in a range of spill conditions. Re-oiling may create some timing problems. If a longer-term clean-up is involved, studies should have a high significance for clean-up decisions, particularly when a large geographical area is effected by a spill and significant movement of slicks occurs over time. This study would also assist in future clean-up operations.

NATURAL DISPERSION

Objectives

The objective of this area of investigation is to monitor and record the dispersion of oil slicks occurring as a result of physical oceanographic factors.

Rationale

Determining the approximate percentage of released oil that disperses naturally would allow more accurate forecasting of the volume of oil remaining that must be dealt with by physical and chemical means.

Location

Oil slicks in the offshore and nearshore regimes would be studied primarily. The examination of the fate and behaviour of oil in other zones also has a direct bearing on the estimation of an oil budget so that data from this study must be correlated with information obtained from the Advection and Spreading and Stranding studies (in earlier subsections). When an accidental oil release occurs in nearshore waters, natural dispersion studies might be complicated by tidal currents, sedimentation processes, and the movement of oil to and from the shoreline.

Timing

Ideally, the study of natural dispersion should commence immediately - or as soon as possible - following the initial oil spillage. If a batch spill is involved, the first 24-48 h. would be essential to this study. For a continuous, longer-term discharge, timing of the study is less important. For sampling details see subsection on Oil Properties and Composition.

It is recommended that, where the opportunity presents itself, a discrete parcel of oil be studied intensively on an hourly basis for the first 24 h., every 4 h. for the second 24-h. period, and on a daily basis thereafter until equilibrium conditions are observed for factors such as oil concentration at depth, and slick thickness. For a detailed account of factors that may affect timing, refer to the Timing discussion in the subsection on Advection and Spreading.

Methodology

Step I - Characterization of surface slicks. Oil slicks of concern should be characterized in a comprehensive manner over time according to:

a. Slick position. A marker system should be used to demarcate an individual slick or oil parcel so that it is followed consistently during the study. Markers should be reapplied as necessary to ensure the continued study of slicks originally identified for investigation. Examples of markers are drift buoys, radio tracking buoys, drift cards, and hula hoops. GNS and INS can be employed for locating slicks. See also Methodology in Advection and Spreading subsection.

b. Oil properties and composition. Samples should be taken for thin and thick slicks (see also below) as the discrete oil parcel is followed. A sampling regime should be attempted whereby oil is collected every 1-2 h. for the first 24 h., at about 4-h. intervals during the second 24-h. period, and on a daily basis thereafter.

c. Slick thickness. Determinations of slick thickness should serve as the main thrust of this work, assuming reasonably accurate quantification is possible. If feasible, surface verification of the remote sensing results should be pursued by testing for the thickness of thick slicks directly (several mm or more) using the Ross/Belore sampler (see Figure 5), OHMSETT/Johnson Sampler, or other technique. Difficulties are likely to be encountered in the determination of thin slick thicknesses.

Vertical photography and low-light-level television could be used as part of a remote-sensing package to confirm and obtain visual imagery of slicks, which can then also be used to verify approximate slick thickness (see Figure 4).

Step 2 - Tracking slicks. The methodologies for tracking slicks outlined in the subsection on Advection and Spreading should be followed for the investigation of natural dispersion so that the two projects are coordinated and duplication of effort is avoided. The tracking will entail the use of GNS and INS systems for determining slick positions. For most large spills, then, slicks should be selected that will yield information on their surface movement (advection and spreading), areal extent, and subsurface dissipation (natural dispersion). Ideally, tracking should be linked directly to slick thickness by surface measurements but this might not always be possible. Areas of slicks should be measured using remote-sensing instrumentation, when possible and should be recorded over periods which will yield significant data on changing slick areas.

Step 3 - Environmental parameters. Refer also to Methodology and Equipment Requirements in subsections on Advection and Spreading, and Methodology and Requirements for Dispersant Effectiveness in section on Countermeasures for recording data on wind, waves, currents, tides, water depth, air temperature, water temperature, and salinity.

In addition to characterizing and tracking slicks, measuring and accounting for wave energy and turbulence are vital to investigations of the natural dispersion of slicks. Specific methodologies should be followed, as indicated above, to yield data as continuous as possible, on wave height and period, wind speed and direction, current or tidal speed and direction (see Table 1), air and water temperature, and salinity. Precipitation should also be noted according to form, frequency, and rate (if possible). The collection of environmental data for this study should be coordinated with studies of the advection and spreading of slicks as well as with the study of chemical dispersion, if conducted, so that duplication of effort is avoided. Note that essentially the same environmental information will be compiled for all three studies so that the use of available instrumentation and locations for data collection should be decided upon only after it has been determined which studies are being pursued collectively.

Step 4 - direct measurements of oil in water column. Although remote-sensing techniques combined with surface measurements should be used to quantify changing slick thickness, direct measurements can also be taken of oil concentrations in the water column. This latter work should serve primarily to indicate qualitatively that oil is dispersing at depth because of wave energy as distinct from slicks dissipating by other means, namely, spreading to equilibrium thicknesses, the loss of volatile fractions to atmosphere through evaporation, the dissolution of soluble components, and losses by other routes. Direct sampling may prove to be slow, inaccurate, and too localized to give a quantitative picture of the total volume of oil in droplet form at depth. This drawback is particularly true when compared to the capability provided by aerial surveillance packages which should result in quicker, wider coverage, depending upon weather conditions.

A decision would have to be made on a case-by-case basis as to whether or not useful data could be generated. Work in this area should be closely coordinated using the methodologies outlined in the Chemical Dispersion subsection on Countermeasures so that subsurface samples are collected, for example, at depths of 0.5, 1.0 and 2.0 m either during continuous monitoring exercises or for subsequent analysis. Occasionally oil should be taken at 5 to 20 m as well. A Turner Designs flow-through fluorometer or equivalent (see subsection on Equipment Requirements below) is recommended for measuring oil concentrations in the water column. Data for this study should be obtained for floating oil identified as control slicks in the determination of dispersant effectiveness, avoiding duplicate sampling requirements. For measurements of oil at depth, avoid using plastic samplers, such as the Niskin "Butterfly" sampler, unless transfer to glass containers is made within several minutes of obtaining oil and sea water mixtures (NOAA 1980).

Requirements

Equipment. The following equipment is required to study natural dispersion:

Characterization of slicks:

- positioning will require radio tracking buoys, hula hoops, drift cards, other drift or datum buoys, Loran-C capability, 35-mm camera, and video recording equipment;

- oil properties and composition will require 1-L. sample bottles, and refrigeration;
- slick thickness measurements will use a Ross/Belore or OHMSETT/Johnson sampler for slicks several mm or more thickness but thin slicks would have to be estimated for slick thickness by using visual techniques (see Figure 4).

Tracking: use remote-sensing packages as above.

Environmental parameter measurements: Wave Rider buoy, anemometer, and air and water thermometers (use simple spar buoy for wave characterizations if Wave Rider is not available); and

Oil droplets in water column: Turner Designs fluorometer (alternatives are Endeco Petrotrack, Q-Instrument, Chelsea), lamp, spare parts, recorder, submersible pump, tubing to reach 5# to 10 m depth, sample bottles, and grab samplers for oil-at-depth measurements.

Facilities. Larger vessels and aircraft will be used and usually these will be dedicated to the spill response operations. Non-interference with normal clean-up duties should be assured in connection with such arrangements. Smaller water-going craft could be used for both characterization of slicks and oil droplet concentration determinations for nearshore studies, sea conditions and logistics permitting.

Personnel. An oceanographer, a remote sensing specialist, and a chemical technician are required.

Services. Laboratory facilities are needed for analyses of oil samples.

Costs

Costs will vary depending upon location, nature, and size of spill as well as the extent of movement of slicks to offshore waters. Main cost components are personnel, travel and living, laboratory analyses, tracking equipment such as buoys, receiver, and cards, miscellaneous field equipment such as sample bottles, film, and fluorometer, and report preparation. Additional costs could include offshore travel, helicopter time, equipment rentals and repairs, and various costs associated with remote sensing.

Success Potential

There is a high probability of successfully achieving the main objectives of this study in terms of recorded observations of surface slick dissipation. There is a lower potential of success for quantifying oil droplet concentrations in the water column as part of formulating total oil budget. Adverse weather conditions, in particular, might interfere with monitoring procedures.

SEDIMENTATION

Objective

The objective of this area of investigation is to measure and record the sedimentation of oil droplets following a spill.

Rationale

A more prolonged effect of spilled oil is likely when the fate of petroleum hydrocarbons includes its transport into the sediment (NOAA 1980). Benthic organisms, which move relatively short distances, may be subjected to exposures over a period of years because of the persistence of oil accumulating in bottom sediments (Teel and Howath 1984). Comprehensive studies of oil sedimentation would provide an insight into the fate of slicks that might not be apparent from observations made of floating oil. Investigations should thus assist in determining the mechanisms by which oil becomes incorporated into sediment as well as its effects on organisms.

Location

The main focus of attention of this study should be given to fine-grained, muddy sediments in shallow water (less than 15#m), close to the spill source (D'Ozouville et al. 1979), to the intertidal zone, and to adjacent subtidal sediments (API 1976). When nearshore waters (within several kilometres of land) are involved, sedimentation studies are also recommended even where water depths of 50 m are involved. Studies are particularly encouraged where background benthic data have been collected for some time prior to the spill, although this situation is unlikely to occur.

Timing

Sedimentation studies should be initiated during the first 24-48 h. following the oil release. As a number of separate investigations should be conducted to give a complete study of sedimentation, timing will depend upon the nature of each undertaking. More specifically, sediment traps should be deployed as quickly as possible and preferably prior to 48 h. following the spill. They should continue to be used until background levels are reached.

Immediate sampling is also required of benthic sediments and organisms so that pre-spill conditions can be determined. For intertidal zones, a <u>suggested</u> post-spill schedule is daily for two weeks, weekly for three months, and then seasonally for one year (EPA 1978). This type of sampling program should be modified (i.e., reduced) if disruption to the local ecosystem would result from too ambitious an investigation. Nearshore benthic sampling should be weekly for the first four weeks, bi-weekly for the next eight weeks, and then monthly thereafter (Ward and Tull 1977). Again, seasonal sampling should also be implemented for a one-year period. In offshore, or deeper water zones, bi-weekly, monthly, and seasonal sampling, as above, should suffice for the collection of bottom sediments. Yearly site visits to affected intertidal zones are also suggested until background hydrocarbon levels are achieved.

Methodology

For spills-of-opportunity, the most important sedimentation processes include adsorption of oil to suspended particulate matter (including those of both plant and mineral origin), direct mixing of oil and sediments, ingestion of oil by zooplankton and incorporation into fecal pellets, and the weathering of oil (NAC 1985).

The sedimentation study needs to be coordinated with other studies. By doing so selected sampling sites could be visited with a minimum of interruption and a maximum of coordination with both Biological Effects studies and Fate and Behaviour work (Advection and Spreading, Stranding, and Natural Dispersion).

Weathering processes. One-litre samples of thin and thick slicks (i.e., water with surface oil taken at sampling point) should be collected while floating oil remains on the surface. A sampling schedule and station selection should correspond with procedures outlined for Advection and Spreading from which all data for this study would be derived. Therefore, no separate field study need be conducted for determinations of sedimentation based on oil-weathering processes. This aspect of the work, however, should focus on the dispersion of oil droplets from slicks, as these lose oil globules, and on the concomitant increase in specific gravity as the weathered oil enters the water column (see also the subsection on Natural Dispersion).

Suspended sediment. The deployment of at least four standard SPM sediment traps or equivalent is recommended where practical (Keizer 1982) each suspended 10-20 m below a floating buoy with a weight attached below the trap to stabilize it. Placement should have to be made so that the surface slick is not interfered with yet representative hydrocarbon and sediment samples are obtained. A specific trap design should be used to avoid overtrapping (NOAA 1980). Note that efficient collection and preservation techniques remain "an area of intense research and debate" (NRC 1985). Subsequent analyses can be divided into determinations of dry weight sediment and oil quantification.

If possible, one aspect that has been widely discussed in the literature and that could be explored during a spill is the difference in sedimentation rates below slicks that are untreated and slicks to which dispersants have been applied. An additional item for investigation is the tendency for oil droplets to associate with organic rather than mineral matter although this has largely been proven according to some researchers (MacKay and Hossain, 1982).

Pelagic studies. The Assessment of Effects of Oil on Pelagic Environments should be followed. In particular, the ingestion of small particles of oil by zooplankton should be studied by analyzing for hydrocarbons in their feces. These studies will assist in determining of the significance of deposition of oil-laden fecal pellets.

Benthic oil sampling. The reader is referred to Benthic Studies: Assessment of Effects of Oil on Intertidal Environments and to Benthic Studies: Assessment of Effects of Oil on Subtidal Environments in the next section.

Polluted and unpolluted sites would be sampled both for the uptake of hydrocarbons in benthic flora and fauna as well as for the level of petroleum in sediments. Coordination of this work with the biological effects studies is therefore essential. A tie-in will also have to be made with the results of the study on Stranding of Oil. "Surface" sediment should be obtained using a variety of sediment samplers appropriate for the conditions under study (NRC 1985):

- box corers for soft bottoms;
- grab samplers (Smith-MacIntyre, Van Veen) for all sediment types; sample wash-out may occur in gravel - or shell-laden sediments;
- gravity corers with liners to obtain sediment cores divisible for various analyses (Kajak, Asko) (NOAA 1980);
- hydrostatically damped corers such as the Craib tripod (NOAA 1980);
- sediment boundary layer collectors; and
- manually operated collectors (if feasible).

D'Ozouville et al. (1979) established 20 diving stations during the Amoco Cadiz spill and sampled sediments at four points at each station. These points were located along the perimeter of a circle with an 8-m radius and located at the north, west, south, and compass points. This arrangement or other well-defined sampling grid should be planned.

Reference and post-spill values could be ascertained using an oxygen meter or probes for oxygen content of the water above the sediment under study, although this procedure should be discontinued if significant deviations are not noted.

All sediment samples to be analysed for low-molecular weight hydrocarbons should fill sampling containers and should be frozen (-10°C to -20° C) for preservation. Alternatively, sediment can be held in hydrocarbon-free seawater containing sodium azide with helium or nitrogen in the head-space and the container inverted at near-freezing temperatures (NRC 1985).

The benthic sampling program should also be closely linked to the study on Stranding, because the mixing of oil and sediment can, in some cases, lead to the transport of such materials to beaches as part of the natural and continuous replacement process of sandy shorelines. Water currents near the sea floor would have to be determined to clarify the movement of sediments toward shore.

Environmental data. The environmental data compiled by other studies, most notably Advection and Spreading, Stranding, and Natural Dispersion, will provide information important to the understanding of sedimentation. Current and tidal regimes as well as weather and sea conditions will figure most prominently in determining the main influences on the rate and extent of mixing of sediments with oil. These other studies will also provide more direct information on sedimentation processes associated with ultimate environmental effects. Of particular interest are the extent and location of slick fronts, the concentration of oil at depth, and the rate of movement of oil and sediment in the flocculent layer at the sea bottom.

Requirements

Equipment. In the field, equipment should include:

- 1/2-m^2 quadrat frames, surveyors level, site markers, formalin, and sample bottles;
- four sediment traps and mooring assemblies, Bongo net arrays, and primary productivity equipment;
- box, gravity, hydrostatically damped or grab corers; and
- dissolved oxygen, salinity, and air and water temperature instrumentation.

Refer to studies 2.2, 2.3 and 2.4 for other environmental data collection needs.

In the laboratory, equipment should include microscopes, identification keys, and dissecting equipment.

Facilities. In the field, facilities should include a vessel with adequate winches, Loran-C or equivalent, accurate sounding equipment for coastal water work (17 to 20 m vessel), transport to beach sites (boat, plane, or truck), and living accommodation.

In the laboratory, facilities should include lab space, freezer and storage facilities

Personnel. A sedimentologist, a chemist, and a technician are required. Biologists are required for determination of oil uptake by organisms.

Services. The following services should be available:

- sediment, tissue analyses for hydrocarbons;
- statistical data analyses;
- divers for possible placement of sediment traps; separate towing vessel for handling sediment traps; and

- laboratory capable of providing soxhlet extraction or other solvent extraction techniques for sediment; alkaline digestion/extraction for petroleum hydrocarbons in plants and animals; glass capillary gas chromatography (GC^2) along with computer-assisted GC^2 plus mass spectrophotometry (GC^2/MS) for hydrocarbon analysis; high-pressure liquid chromatography (HPLC).

Costs

The costs of this study will vary depending upon the availability and charges, if any, for a support vessel, the use of divers, the location of the spill relative to laboratory facilities, and so on. It might not be feasible to conduct all facets of this study if mobilization could not be achieved quickly; pre-spill planning, including equipment maintenance and preparation, would have to be undertaken. A study of spills-of-opportunity for the Atlantic coast (Keizer 1982) has indicated costs of $10 - $20,000 for sedimentation investigations which included equipment maintenance and mobilization, rental charge for vessel, scientific personnel, divers (optional - two needed), analyses, and report preparation.

Significant increases over and above these amounts are anticipated for most large spill events, if sampling is to be conducted in a comprehensive and statistically meaningful way.

Success Potential

The ability to mobilize equipment, its deployment to the accident site, and limitations imposed by adverse sea and weather conditions, may limit the potential for this study to succeed. If it is possible to initiate these studies and to sustain them quickly, and if they are conducted in a well-planned and ordered manner, information should be collected that would add considerably to the understanding of various processes related to oil sedimentation.

OIL PROPERTIES AND COMPOSITION

Objective

The objective of this area of investigation is to determine the physical and chemical properties and composition of spilled oil over time by a comprehensive sampling program and subsequent laboratory analyses. The intent of this study is to provide coordination of the oil sampling needs for all spills-of-opportunity studies.

Rationale

Spilled oil will combine with the air, water, and particulate matter to which it is exposed with resultant changes in both its composition and properties. Whereas the studies proposed previously examine specifically the main processes which lead to such changes, separate directives are believed to be necessary that will allow for a comprehensive sampling program, analyses, and thus thorough characterization of oil. The results of such physical and chemical analyses will not only lead to a better understanding of fate and behaviour studies but also can be correlated with the selection and determined efficiencies of physical and chemical countermeasures approaches (see also the section on Countermeasures) as well as the biological effects investigations (in the section on Biological Studies).

Location

Oil samples should be collected at the following locations or operational sites:

- directly from the source of the release, if possible, prior to the oil's exposure to the environment;

- from slicks that are not being, nor will be, treated either mechanically or chemically (see subsection on Advection and Spreading);

- from floating oil that will be treated with chemical dispersant (see subsection on Chemical Dispersion);

- from oil that is physically contained or that will be mechanically removed (see subsections on Containment and Physical Recovery);

- at mid-water stations selected during the natural dispersion studies (see subsection on Natural Dispersion and chemical dispersion studies (see subsection on Biological Studies);

- as part of tissue and sediment samples obtained during the biological work (see subsection on Biological Studies);

- at beach plots established during the stranding studies (see subsection on Stranding of Oil); and

- at work sites where other countermeasures techniques are being examined such as storage, transfer and disposal (see subsections on Transfer, Ultimate Disposal and In-Situ Burning).

Timing

Because the properties of water-borne oil slicks change most dramatically during the first 24-48 h. following oil discharge, ideally sampling should be conducted on an hourly basis during the first day and every two to four hours on the second day. Following the initial, more rigorous collection of oil samples, the taking of a sample on a daily basis should be assured through the coordinated approach to spills-of-opportunity research. In addition to securing oil from source, discrete batches of oil that are unlikely either to strand or to be mechanically or chemically treated should be examined. This testing could be done in conjunction with other studies, such as Advection and Spreading or Natural Dispersion or other proposed studies as specified in each test protocol. The timing aspect of this work relates not only to the sequential gathering of samples as slicks age but also to a spatial distribution of oil as it evaporates, emulsifies, enters the water column, undergoes sedimentation, dissipates at sea, or becomes incorporated into beach materials.

Methodology

General. Oil samples from specific geographical areas should be assigned to more than one laboratory, if possible, where the same analyses can be conducted. Thus, at least possible differences in analytic techniques need not be confounded with natural variations (NRC 1985). Analyses for oil samples obtained by separate studies should be coordinated to obtain a comprehensive picture of the characteristics of the oil over space and time on both a pre- and post-spill basis.

A two-stage sampling program should be planned so that easily recorded data are first obtained which can then be used to provide direction in the processing and analysis of subsamples or further sample collection for continuing chemical and biological determinations. Replication of samples should be sought for floating oil patches using 1-L containers for their collection. Samples and ancillary gear such as containers should be clean.

Specific. For sedimentation studies, sediment samples should be chosen appropriate for the bottom type under study and over-trapping should be avoided when employing sediment traps to obtain oil and suspended particulates (see subsection on Fate and Behaviour Methodology). For benthic organism studies, animal samples should be obtained in close proximity, or as part of sediment samples based on analytical and statistical considerations, including optimum sample size, minimum detection limits, specific station data requirements, individual-to-individual variations, and so on.

For seawater samples, plastics should be avoided, such as the Niskin "Butterfly" sampler, unless transfer of samples to glass containers is made within several minutes of collection (NOAA 1980). Accumulators or large-volume water samplers should be used to detect hydrocarbons at lower concentration levels. Application of the Turner Designs towed fluorometer or equivalent is also recommended (see subsection on Natural Dispersion). Water samples should fill glass bottles, sealed with a Teflon cap, leaving no headspace and should be refrigerated until analysis. Agitation should be avoided. Sediment samples should be frozen or treated with sodium azide, with inert gas in the headspace, and inverted in sub-freezing storage (see subsection on Sedimentation).

All samples should be frozen at -10°C to -20°C after collection, if feasible. When preservation with a bacterial retardant is necessary, the technique selected should not prevent measurements of certain biochemical or physiological studies. Volatilization of hydrocarbons and microbial and photochemical oxidation of organics in samples are primary concerns to be addressed in sample preservation (NRC 1985). The specific preservation technique used such, as chloroform, methylene chloride, mercuric chloride, or sodium azide should be noted.

Samples should be of sufficient volume to allow replicate analyses for physical and chemical data and should be identified properly to include information on:

- collection location
- date
- time
- name of collector
- sampling device
- sample number
- preservative added.

Physical and chemical properties. Generally, measurements to characterize floating oil slicks, such as water content, specific gravity and viscosity, can be made quickly in the field to provide information pertinent to the selection of countermeasures. For comprehensive determinations of composition as well as physical and chemical characteristics, further analysis will be required. The physical and chemical properties of crude oil can be determined in the laboratory according to a series of exacting, well-defined tests (S.L. Ross 1985).

Extraction of organic matter. Individual samples of collected water, of sediment, and of tissue specimens must undergo specific extraction techniques for organic matter, followed by selection of the appropriate analytic technique to indentify petroleum hydrocarbons. Generally, compositional and quantitative data increase in detail with increasing laboratory processing. Sediments should be subjected to a combination of polar and non-polar solvents (see subsection on Stranding of Oil Methodology). Tissues can be extracted for hydrocarbons using techniques such as alkaline digestion and Soxhlet extraction and high-speed homogenization extraction (see also subsections on Stranding of Oil Methodology, Intertidal, and Subtital Benthic Studies).

Petroleum hydrocarbons can be isolated from seawater samples using extraction methods that depend upon the type of samples used and on the analytical method to be employed. In particular, the solvent used must be compatible with the analytical method of choice. Samples may be treated by one or several clean-up and fractionation techniques such as polarity, size, and chemical separations, to increase the precision and discrimination of all subsequent analysis.

Analytical methods. A variety of sophisticated analytical methods can be applied to the solvent extraction of samples to determine the levels and composition of hydrocarbons (see also subsection on Advection and Spreading Methodology). Each method must be reviewed thoroughly for its specific capabilities, accuracies, applications, advantages, and disadvantages. The reference NRC 1985, Chapter 3 Chemical and Biological Methods, is recommended for study. Techniques for petroleum characterization are as follows:

- for carbon 11 and high isotope non-volatile hydrocarbons:
    - gravimetric methods
    - infrared spectrophotometry (IR)
    - ultraviolet-visible fluorescence spectrophotometry (UV/FS)
    - rim layer chromatography (RLC)
    - high pressure liquid chromatography (HPLC)
    - gas chromatography (GC)
    - gas chromatographic mass spectrophotometry (GCMS)
    - nuclear magnetic resonance spectroscopy (NMRS); and
- for carbon 1 to 10 isotope hydrocarbons: specialized techniques must be used for isolating and analysing hydrocarbons of low molecular weight. Static head-space sampling, dynamic head-space purge, gas stripping, vacuum stripping or degassing, multiple phase equilibrium, and direct aqueous injection all rely on GC or GC/MS analysis, or both, as the final analytical instrument (NRC 1985).

Analytical methods should be chosen with appropriate sensitivity and resolution.

Requirements

Equipment. In the field, tracking, recording, and positioning of equipment is required, as specified in the previous Fate and Behaviour studies as well as sampling bottles and preservative.

Facilities. In the field, transport to water and land-based sites is needed, by appropriate water-going vessel, aircraft, or truck, and living accommodation is required.

In the laboratory, freezer, ambient storage, and space are required.

Personnel. A Chemist, and an environmental technician are required.

Services. Laboratory facilities are needed to conduct extraction and analyses of samples as specified. Statistical data analyses are also required.

Costs

Costs should be estimated in conjunction with previous costs for Fate and Behaviour studies for personnel, living accommodation, field provisions, and report preparation. For analyses, substantial costs would be involved with single sample analysis, costing from $40 to $50 up to $500 depending upon the technique employed.

Success Potential

A systematic sampling program should result in the comprehensive characterization of oil in relation to both its spatial and temporal distribution. Impeding the probability of success in achieving all objectives would be reduced by oil from source being unavailable for use as a reference, and by adverse sea and weather conditions.

BIOLOGICAL STUDIES

A review of proposed research for spills-of-opportunity suggests first that some studies are consistently recommended because they apply to most habitat types and have the highest probability of success, and secondly that, because they overlap in terms of equipment and personnel requirements, several types of studies should be integrated to maximize efficiencies of field efforts. Appendix 1 summarizes the past work that was examined during the course of this project. Furthermore, as recommended by NRC (1985), indices used for environmental impact assessment should come from as broad a base as possible:

> "Reliance on one measure of change, disturbance or stress is unwise and suites of measures are best employed because they offer greater reliability over the long-term."

Consequently, several commonly recommended studies have been selected and grouped according to their similarity of logistics needs, to arrive at a set of five biological effect assessment studies for oil spills. Figure 6 depicts the study areas selected; note that benthic investigations have been divided into intertidal and subtidal zones. These combination studies are particularly useful in reducing budgetary and logistical requirements. They also represent a means of obtaining a variety of effect indices. Furthermore, the approach of simplifying sampling strategy has several advantages.

a. It creates the potential for a two-stage sampling scheme as developed by W. Smith (1979) and proposed by the NRC (1985):

> "In the first stage, a large number of samples are collected in a systematic survey (grid or modified grid). Easy to record data such as sediment type and the presence of oil are recorded in the first stage.
>
> In the second stage of the sampling, the data from the first stage are used to stratify the samples. The original samples can then be subsampled for the more costly chemical and biological analyses. In oil spill work, this procedure has great advantage in that the first stage of the program can be implemented on short notice. The difficult sampling questions can be postponed to the second stage of the program when the legal, engineering and scientific questions that the oil spill raises have been better defined."

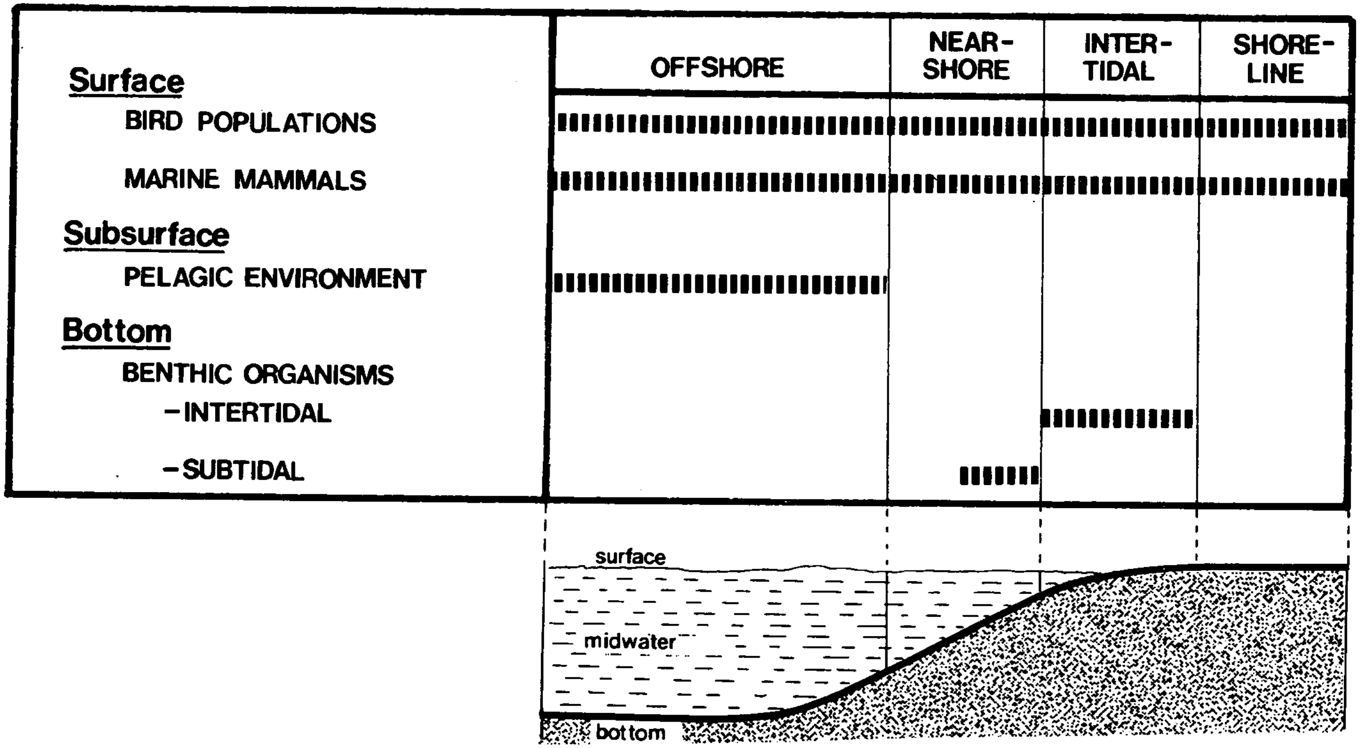


Figure 6 BIOLOGICAL STUDIES

b. As equipment and personnel requirements are easier to provide, simplified, well-defined strategies allow for quicker mobilization of field efforts. Consequently, the much-needed early stage and possible pre-spill conditions can be sampled.

c. Despite previous oil-spill studies, the inherent variability of natural systems and relatively minor environmental effects have prevented collections of much statistically conclusive data.

Thus, by focusing on those areas of highest probable success, rather than by spreading study effort out into more specific areas, some of the basic, yet large information gaps could be filled more effectively.

Any spill will have priority areas that differ from those of the studies outlined, for example, the need to look at the effects of oil on ecosystems dwelling under ice in arctic areas or, conversely, the folly of setting up an extensive plankton study program for a 1 km^2 oil spill. Thus, to allow tailoring of research plans to specific areas and spill types, some of the more common proposals for spills-of-opportunity research have been listed with several of their requirements and applications.

BENTHIC STUDIES: ASSESSMENT OF EFFECTS OF OIL ON INTERTIDAL ENVIRONMENTS

Objectives

- to assess the levels of hydrocarbon bioaccumulation (Keizer 1982; Ward and Tull 1977);

- to determine effects of oil on community structure: biomass, species composition, diversity, immediate mortality, and species succession, distribution (EPA 1978; Ward and Tull 1977; Keizer 1982); and

- to produce written and photo documentation of recovery (Green 1982).

Rationale

The intertidal zone is particularly susceptible to the effects of a large spill because of the diversity of life forms there and the possibility of slicks drifting ashore. Systematic investigations are required based on sound experimental design, to ascertain the biological effects of oil spills in important intertidal areas.

Location

Lower-energy environments should be studied, primarily such as wetlands, salt marshes, estuaries, and mudflats, as opposed to higher-energy coastlines such as rocky headlands. A priority for study locations would have to be determined so as to include intertidal regions characterized by various associated shore zones, such as cobble, pebble, shingle, and sand beaches.

Timing

Field investigations of intertidal zones should be considered when significant amounts of oil come in contact with the shoreline. Sampling should proceed intensively as soon as possible following notification of the spill event to allow documentation of immediate and possibly pre-spill conditions. Thereafter, sampling intensity would decrease in time to document long-term effects. A suggested post-spill schedule is daily for two weeks, weekly for three months, then seasonally for one year (EPA 1978). Long-term effects may be studied subsequently on a yearly basis at a reference season. Factors affecting timing may include:

- re-oiling of intertidal zone with successive tides;
- complexities introduced to studies by the effects of mechanical and chemical clean-up operations;
- seasonal variations in biota and life cycles;
- changes in meteorological and oceanographic conditions; and

- fate and behaviour of spilled oil.

Methodology

General. Grid and transect analyses should be performed to compare representative affected and unaffected sites, and to compare affected sites through time.

Specific. Vertical transect sites, referenced to datum if possible, should be located in representative affected and unaffected areas (stratified by community type). Within each area, a minimum of three sites should be located along a grid. Half-metre square quadrat samples should be taken along each transect line from high to low water levels at 1 m vertical intervals. On sand or mud beaches, a 1.0-1.5 mm sieve should be sufficient to retain most macrofauna, although samples for meiofaunal studies should also be retained.

"Key" organisms are to be sampled for meristics and tissue analyses. All organisms are retained for possible further studies.

Photographic and written observational records should be made of pre-spill conditions and unaffected and affected areas through time.

Physical monitoring. Vertical and horizontal distributions should be ascertained of oil in the sediments, temperature, salinity, dissolved oxygen.

Requirements

Equipment. In the field, 1/2 m^2 quadrats, surveyors level, site markers, sieves (for soft substrates), formalin, and sample bottles are required.

In the laboratory, Laboratory microscopes, detection equipment, sieves, and identification keys will be needed.

Facilities. In the field, transport will be needed to reach beach sites (boat, plane, or truck), plus living accommodation.

In the laboratory, space will be required with freezer and ambient storage space.

Personnel. Categories of personnel required are a marine botanist, a marine invertebrate taxonomist, and a invertebrate larval-development specialist.

Services. Tissue analyses for hydrocarbons and multi-varient statistical data analyses are required.

Costs

Costs will vary with location and selection and availability of personnel and equipment, as well as with maintenance, preparation, and mobilization expenses. Main cost components are personnel, travel and living, analyses (MS/GC, HPLC, etc.), boat and motor rental, field provisions such as bottles, formalin, markers, and film, and report preparation. Logistics-associated costs will vary considerably.

Success Potential

Accurate assessment of the implication to population levels may be difficult although it should be possible to determine hydrocarbon accumulations in individual organisms. Gross changes in population structure of dominant species should be identifiable, although storm surges and other factors could bias results to render population changes from oil pollution indistinguishable from natural causes; however, pre-spill, unaffected control sites should allow gross changes induced by oil to be detectable. Sublethal, chronic effects may be difficult to determine.

BENTHIC STUDIES: ASSESSMENT OF EFFECTS OF OIL ON SUBTIDAL ENVIRONMENTS

Objectives

Four objectives are envisioned for subtital benthic studies:

- to assess levels of hydrocarbon bioaccumulation (Ward and Tull 1977; Green et al. 1982; Keizer 1982; EPA 1978);

- to determine effects of oil on community structure: density, biomass, diversity, species composition, and distribution (Ward and Tull 1977; Green et al. 1982; Keizer 1982; EPA 1978);

- to prepare written and photographic documentation of affected and unaffected areas and their recovery (Green 1982); and

- to determine effects of oil on populations of specific taxa for more meaningful testing of laboratory-derived hypotheses (NRC 1985).

Rationale

Coastal waters often receive oil following a spill event. Upon the release of oil, sedimentation and other processes contribute to its transport and settling out at the sea bed (Teal and Howarth 1984). Should oil accumulate in sufficient quantities, effects on benthic organisms might occur. It is important to ascertain and to document such biological effects.

Location

Nearshore waters should be studied for the effects of oil on benthic organisms. Logistical considerations, as well as longer transportation times and lower concentrations of oil droplets in offshore regions, may preclude investigations there. Furthermore, it is likely that coastal waters associated with lower-energy shorelines will likely exhibit more pronounced effects - such as those in the vicinity of marshes and wetlands. Oil density, and tidal and other currents can also be determining factors which play a role in the transport and deposition of oil.

Timing

For nearshore environments, sampling should be weekly for the first four weeks, bi-weekly for the next eight weeks, then monthly thereafter (Ward and Tull 1977). For long-term monitoring, seasonal sampling would be sufficient (EPA 1977).

Offshore environments selected for study would require an initial sampling within three to four days to assess initial changes, and one week later to determine initial effect. Thereafter, seasonal monitoring would be sufficient (EPA 1977). Offshore studies may not be possible in many cases because of logistical and other constraints.

For factors affecting timing, see subsection on Timing for Intertidal Benthic studies.

Methodology

General. Using standard benthic sampling methods, affected sites are quantitatively compared through time with representative unaffected sites or, if possible, with pre-spill conditions.

Specific. Spade or box corers should be used to sample sedentary infauna and epifauna quantitatively (NRC 1985). Epibenthic sleds or dredges can be used to sample mobile hyperbenthos (EPA 1977). All samples are screened to a level sufficient to retain life-history stages of "important" species (about 0.5 mm for nearshore and 0.3 mm for offshore environments (NRC 1985) (i.e., field sieving should result in the retention of most organisms to allow a large variety of possible in-port spill studies later).

Site sampling should proceed until sufficient numbers of the dominant species are obtained to allow statistical comparisons (a minimum of three replicates per site). The number of sample sites would be determined by the area of the spill and types of habitats. For example, because of the importance of nearshore waters, these should be sampled with greater frequency that offshore waters. Within these strata, sampling sites should be set up in a grid pattern. This sampling pattern allow for further stratification or other types of subsampling at a later date (NRC 1985).

Captured organisms should be identified, enumerated, and morphometrically and chemically analysed to levels according to priorities for the particular spill program. If possible, representative oiled, unoiled or pre-spill sites should be documented photographically by divers or by submersible remote-operated cameras.

Physical monitoring. Vertical and horizontal distribution of oil in the sediments, temperature, dissolved oxygen, and salinity should be measured.

Requirements

Equipment. In the field, spade or box corers, epibenthic sleds or dredge, sieves, formalin, sample containers, water sampling equipment are required.

In the laboratory, dissecting scope, sieves, identification keys, photomicroscopy equipment, and dissection equipment will be needed.

Facilities. In the field, a boat is needed with adequate winches, Loran-C navigation (or equivalent), capable of offshore conditions (minimum of 50 ft), and accurate sounding equipment.

In the laboratory, adequate space will be required with freezer and ambient storage.

Personnel. A marine invertebrate taxonomist, and divers will be required to perform this research.

Services. Tissue analyses for hydrocarbons and multi-varient statistical data analyses will be required.

Applicable Conditions

Any spill is suitable. The intensity is determined by the depth and extent of the spill and the importance of the biota directly or indirectly related to the benthos.

Costs

Costs will vary significantly depending upon the nature and size of the spill, as well as on the mobilization costs and the extent to which subtidal environments are to be studied. Main cost components are personnel, travel, and living, vessel rental, analyses of MS/GC, HPLC, and so on, field provisions such as bottles, preservatives, and film, and report preparation. If an offshore-going vessel were required daily, rental would be paid plus fuel and food.

Success Potential

In shallow water (0 - 15 m), gross changes in population densities should be identifiable. Storm surges, seasonal variations in tidal and current regimes, as well as other influences on sedimentation could affect the interpretation of results. Hydrocarbon levels caused by the spill should be detectable although longer-term effects might prove more difficult to define in absolute terms.

ASSESSMENT OF EFFECTS OF OIL ON PELAGIC ENVIRONMENTS

Objectives

Four objectives are envisioned for studying the pelagic environment:

- to assess the levels of hydrocarbon bioaccumulation (Ward and Tull 1977; EPA 1978);
- to assess changes in planktonic community structure: abundance, species composition, diversity, morphometry, distribution, biomass (API 1977; NRC 1985; EPA 1977; Ward and Tull 1977);
- to determine effects on primary productivity (Ward and Tull 1977; EPA 1978; NRC 1985); and
- to assess effects on local fish populations and food chains.

Rationale

The fate, behaviour, and effects of oil spilled at sea are generally not well documented. Biological effects, however, are known to occur in primary productivity organisms, to result in hydrocarbon bioaccumulations, and to otherwise be evident in higher-order species, such as fish. In view of the potential importance of such oil spill consequences, studies are recommended on pelagic environments which will provide quantitative assessments of such effects.

Location

Study locations should be selected preferably in areas either where a commercial fishery exists or where other known resources have been generally documented. The distance offshore, areal influence of spill, and availability of logistical support will determine where specific sampling stations are designated. Difficulties may be encountered in offshore regions exposed to frequent storms, ice encroachment, or other environmental interferences. Appropriate unaffected zones should be selected from which to sample background hydrocarbon levels indicative of regional resources and biases.

Timing

Sampling should be initiated as soon as possible after the spill. A minimum of three samples should be taken from each station and a minimum of ten stations should be established in the vicinity of a moderately large oil spill. Monthly or bimonthly cruises, of about ten days per cruise, should continue until hydrocarbon levels return to background levels. For fish, sampling three times per year would be required beyond the time hydrocarbon contamination is undetectable in gut contents (EPA 1977). See also Intertidal Benthic studies for factors affecting timing.

Methodology

General. Phytoplankton, zooplankton, and ichthyoplankton should be sampled selectively, identified, and quantified in terms of distribution, biomass, species composition, diversity, and relative abundance. Primary productivity should be estimated in the esiphotic zone.

Local fish populations should be sampled, identified, and quantified in terms of numbers, biomass, age, and meristics. Gut content samples should be analysed to determine dominant food chains.

Fish and plankton samples should be collected for tissue analyses for hydrocarbon bioaccumulation.

Both contaminated and unaffected (control) sites should be sampled over time to allow resolution of the effects of the oil.

Specific. Standard double oblique tows should be made using a range of net sizes to selectively sample phytoplankton and zooplankton (NRC 1985; EPA 1977). Nets should be able to be opened below water to minimize surface contamination. A suggested apparatus is the use of a bongo net array (EPA 1977). A two-net array, each net being 21 cm wide (one 0.17 mm mesh net, the other 0.25 mm), equipped with flowmeter and bathytymograph, is suggested for phytoplankton sampling. A similar set-up using two 61 cm bongo nets (0.50 mm and 0.30 mm mesh) should be used for zooplankton sampling (EPA 1977).

Primary productivity should be determined by light versus dark carbon 14 or oxygen evolution technique using either anchored bottles or artificial light regimes (NRC 1985). Maximum photosynthetic rates should be normalized to chlorophyll to permit rather unambiguous comparison between sites (NRC 1985).

Where conditions and technology permit, continuous-sampling devices such as the Hardy-Longhurst sampler or towed fluorometers should be used to make continuous, quantitative, horizontal records of plankton distribution at specific depths (Keizer 1982; NRC 1985).

Fish populations should be sampled using stratified trawls to a maximum depth of 500 m (EPA 1977).

Samples of tissue and gut contents should be analyzed for hydrocarbon contamination. Gut contents are identified, standard meristics taken and ages estimated from otolithe, scale, or fin ray samples for each species to levels appropriate to species priorities.

Physical monitoring. Vertical and horizontal distribution of oil, temperature, and salinity should be measured.

Requirements

Equipment. In the field, bongo net arrays as described, water sampling equipment (Niskin bottles, and so on), and primary productivity equipment (light/dark bottles, C^{14} solutions and scintillation counter or Winkler apparatus, sample containers, preservative, water quality equipment) are required (see Figures 7 - 9, and Tables 2 and 3).

In the laboratory, compound microscopes, fractionators, and a Coulter counter are needed.

Facilities. In the field, facilities needed include minimum 18.3 m (60 ft.) vessel capable of working in offshore conditions with Loran-C navigation or equivalent, appropriate winches, lab space, an echo sounder, and freezer.

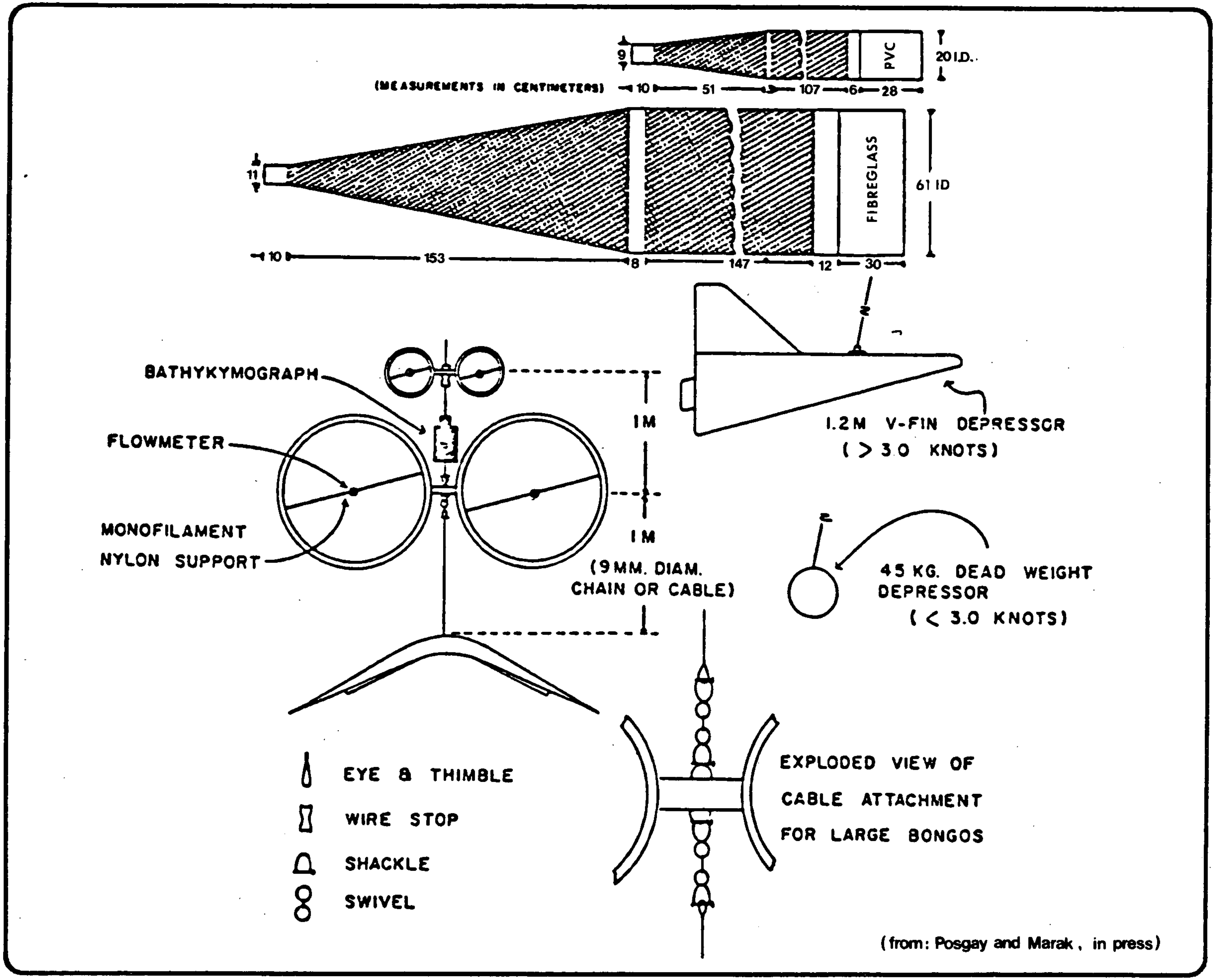
In the laboratory, space will be required with freezer and ambient storage.

Personnel. Phytoplankton, zooplankton, ichthyoplankton, and fish specialists will be required.

Services. Tissue analyses for hydrocarbons and statistical data analyses will be required.

Applicable Conditions

Because of the notoriously patchy distribution and unrestricted circulation of plankton populations, most spills do not merit significant pelagic impact assessments on such communities. Planktonic studies should only be undertaken where an entire ecosystem could possibly be destroyed, or where severe economic damage could result from losses of commercially important meroplankton and ichthyoplankton species (API 1977).



(from: Posgay and Marak, in press)

Figure 7

ARRANGEMENT OF "MARMAP" BONGO SAMPLERS ON TOW LINE

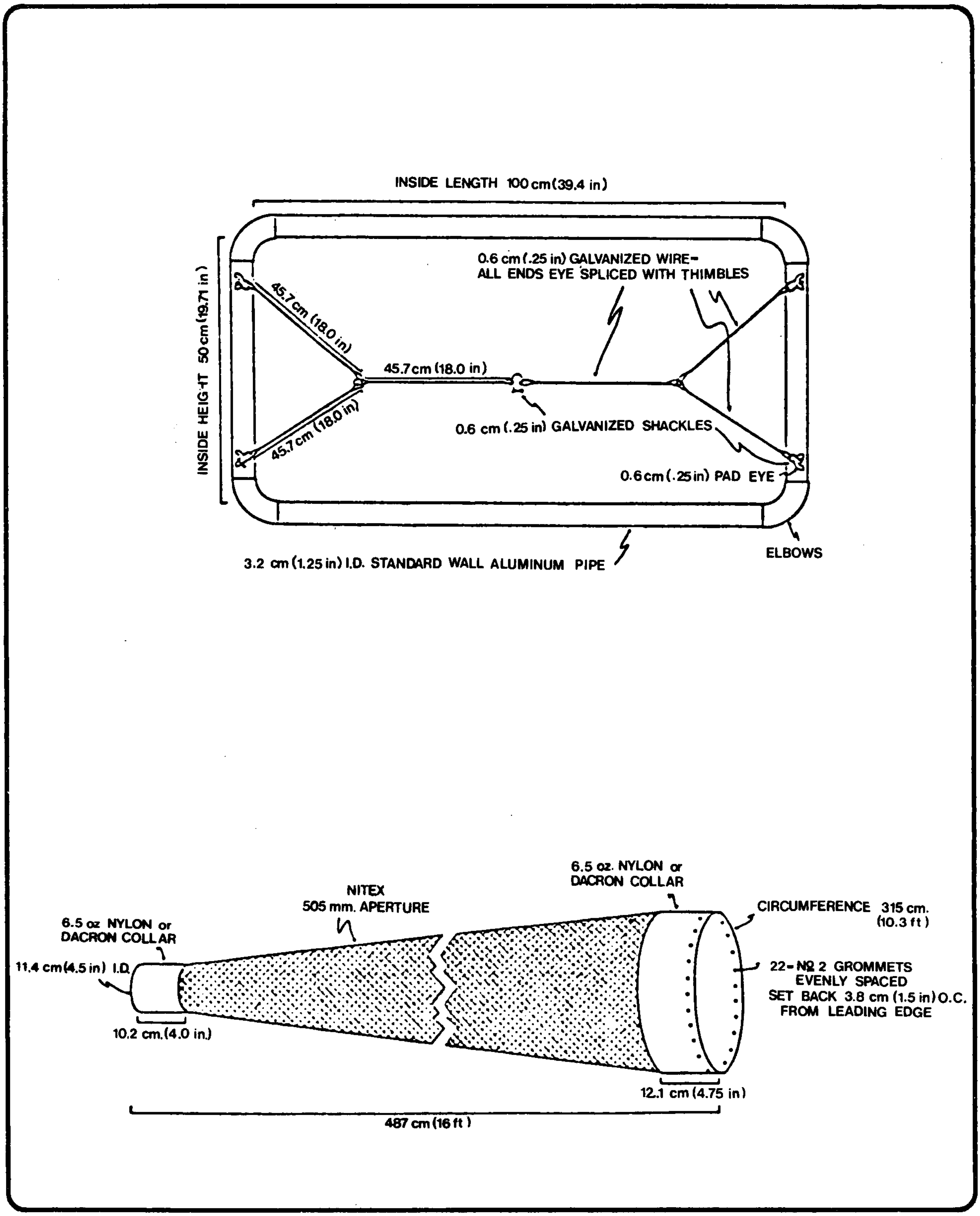
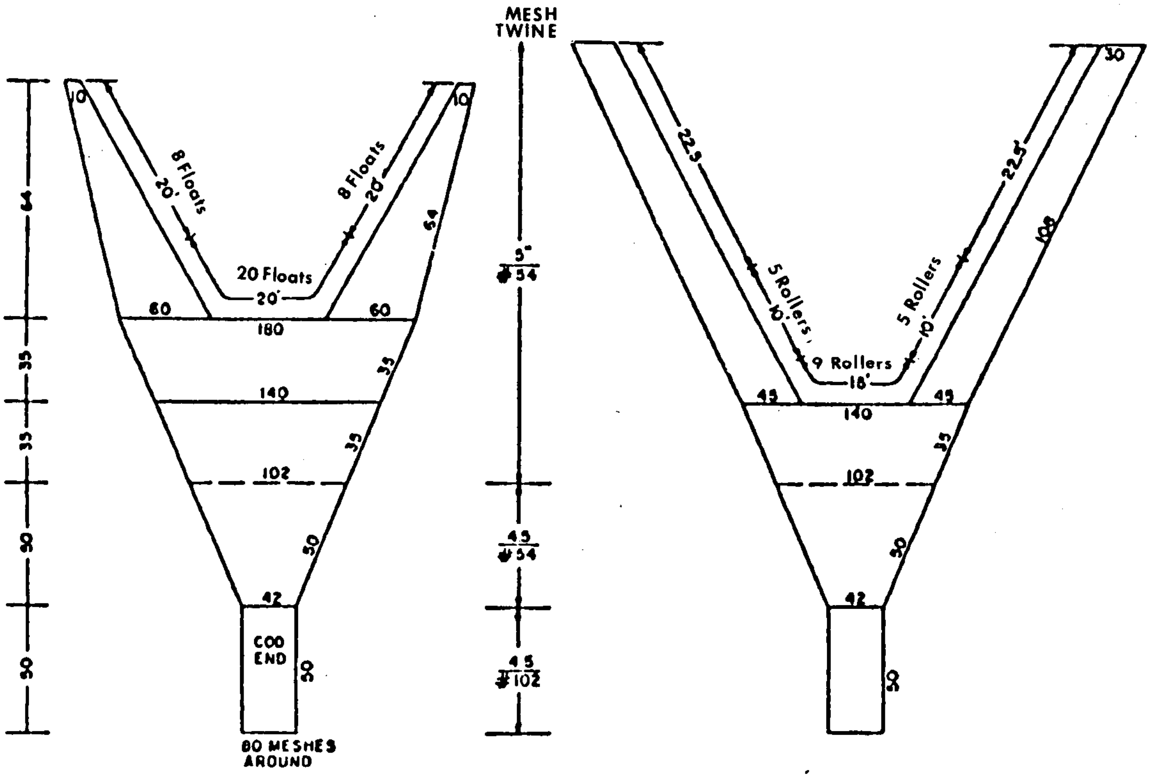


Figure 8 THE MARMAP NEUSTON SAMPLER

\# 36 YANKEE TRAWL



Trawl dimensions in meshes — Mesh sizes in inches — Footrope and headrope sections in feet.

Figure 9 SCHEMATIC DRAWING OF STANDARD TRAWL USED ON GROUNDFISH SURVEY BY BUREAU OF COMMERCIAL FISHERIES, BIOLOGICAL LABORATORY, WOODS HOLE, MASSACHUSETTS

TABLE 2

Representative Groundfish Survey Equipment List

Equipment	Description/Type	Notes
Standard Survey Trawl	Specification for standard groundfish survey #36 Yankee trawl developed by NEFC at Woods Hole, Massachusetts.	Prior to each survey, it is mandatory that the cruise coordinator and the mate in charge of trawl gear compare assembled trawls with the standard specifications. Experience indicates it is too easy for undesirable modifications to slip in as a result of temporary repairs becoming permanent, or because of a lack of proper spare net sections or other parts.
Other Nets	Bongo net.	
Dredge	Candidate device for sampling infauna has not been selected.	
Instrumentation	Bathythermograph Echo Sounders Salinity/Depth/Temperature (Measurement System) Miscellaneous instruments including: thermometers, stop watches, counters, meter wheels.	All of these instruments require maintenance, and their condition, including supplies of slides for BT's and paper for echo sounders, should be checked before each cruise.
Paper Supplies	Field logs, data sheets, envelopes and labels, cardboard boxes.	
Miscellaneous Hardware	Assorted jars, and vials plastic and cloth bags and cheesecloth for preserving samples. Measuring boards and punch strips. Spring scales and steel yards with weights. Steel baskets and plastic buckets and garbage pails. Knives, forceps and other dissecting instruments.	
Chemicals	Formalin, Glycerine, Alcohol	
Reference Books		Identification of fishes is facilitated by references found in the area.

TABLE 3

Specifications for the Standard Groundfish Survey Trawl Currently in use by the New England Groundfish Survey

Trawl Part	Construction Details
Overall length (wing ends to cod end)	Approximately 98
Material and mesh sizes (stretched mesh, certified)	
- Trawl	#54 Tan Nylon throughout, 5" mesh in wings, square and forward section of bellies; 4-1/2" mesh in aft section of bellies.
- Cod end	#102 White Nylon, 4-1/2" mesh, 80 meshes around, 50 meshes long.
- Liner	#147 Knotless White Nylon, 1/2" mesh, in two pieces; one piece attached 35 meshes up from aft end of top belly which lines about 80 meshes across center of top belly, and which extends about 2' into cod end; and one piece lining entire cod end and extended about 2' outside of cod end when open.
Headrope (total length)	60' in three 20' sections, 7/8" dia. comb. wire rope, eye at each end and joined by 7/8" patent (split) links.
- Headrope handing	
. Square (Bosom)	14'
. Wings	23'
Footrope (total length)	80' in five sections: 22-1/2', 10', 15', 10' and 22-1/2'; 3/4" dia. 6 x 25 galv. wire.
- Footrope handing	
. Lower belly	10'
. Wings	35'
Rollers	Hard rubber, 5" wide by 16" diameter separated by rubber spacers 6-7" wide by 5-1/2" diameter - center section of 15' with 9 rollers separated by two spacers - two 10' sections each with 5 rollers separated by three spacers.
Floats	8" diameter aluminum (spherical - no collar) deep sea type, 20 floats along center 20' section of headrope, and 8 floats evenly spaced on each 20' side section.

Costs

The costs of this study will vary depending upon the nature, size, and location of the spill. Main cost components will be expenses for travel, living, vessel rental, analyses extraction (such as MS/GC, and HPLC) and field equipment (such as sample bottles, preservatives, and film). The Department of Fisheries and Oceans should be contacted as regards the availability of specialized sampling equipment.

Success Potential

A comprehensive assessment should be able to relate the oiling of plankton and larval fish to the concentration levels of hydrocarbons in the water column. The results would not, however, be easily extrapolated to indicate effects on distribution and population levels (Keizer 1982). Focus should be on species composition and biomass determinations. This would generally be true for most pelagic species because sampling problems of scale and temporal and spatial variabilities in natural populations. The mobility of fish and their avoidance of oil at depth could also adversely affect results.

ASSESSMENT OF EFFECTS OF OIL ON LOCAL BIRD POPULATIONS

Objectives

Three objectives are envisioned for the study of oil on birds:

- to assess immediate mortality (Ward and Tull 1977; Green 1982; Keizer 1982; API 1977; EPA 1977);
- to determine the degree of oiling (EPA 1977); and
- to assess long-term effects on species abundance, reproduction, and any other sublethal effects.

Rationale

Historically, birds have received much media attention at many spills because of the emotional response illicited from the public by the image of dead and dying oiled seabirds. Many data on the effects of oil on birds have been compiled, that relate primarily to western European waters and, most recently, to the western Atlantic (NRC 1985). However, the negative effect of oil on seabird populations still remains to be addressed more comprehensively in Canada. Spills-of-opportunity research could contribute substantially in this area of study.

Location

Birds of coastal waters are at risk not only at their breeding colonies and in wintering areas but also on flyways and in other high-use zones including salt marshes, estuarine waters, and mudflats. Depending upon seasonal behaviour patterns, surveys should be made of such areas, as well as of beaches where mortality counts and sampling can be conducted (see also Methodology).

Timing

Short-term. Assessments would require bi-weekly, aerial monitoring (Ward and Tull 1977) from the time of spill until one month after the oil has visibly dissipated and could no longer be traced by air (EPA 1978). Shipboard surveys should be one week per month (EPA 1978). Daily beach surveys should continue beyond the duration of the spill until beached birds suspected of being oiled stop appearing (EPA 1978).

Long-term. Bird breeding colonies would be surveyed about two months after the breeding season at the peak nesting period for reproductive and population studies. Ideally, population studies are recommended for a minimum of ten years to resolve oil-induced variations from natural variation (EPA 1977), although much shorter investigations are more likely to be possible (see also the subsection on Timing for the Intertidal Benthic Environment Study for other factors).

Methodology

General:

Short-term. Species composition, distribution, approximate population size, and numbers of affected birds (oiled, dead, and alive) should be determined by aerial, shipboard, and shore surveys. Classification of mortalities (age, sex, cause of death, and degree of oiling, and so on should be made from dead or moribund bird collections.

Long-term. Changes and effects on populations should be determined, where applicable, from surveys of breeding colonies.

Specific:

Short-term. For short-term data of low-density bird populations, aerial surveys should be conducted over pre-selected stratified grids to sample contaminated and adjacent areas randomly. A high-wing aircraft is flown at about 30 m (100 ft) at 160 km/h (100 mph). For ten-minute intervals; all birds within a 300 m-wide transect are counted and identified, locations are fixed and the degree of oiling is recorded. Transects should be narrow enough to allow for visual definition of the slick and wide enough not to scare birds from adjacent transects (EPA 1977). Colonies and other high-density bird groupings can be counted and identified from fixed observation platforms (boat or land vantage points). Shipboard surveys can provide confirmational information for aerial surveys (i.e., birds are counted for ten-minute intervals along a 300 m-wide transect line). Mortalities should be noted as separate counts.

Where high mortalities occur, for example, where birds migrating to the Arctic may perceive oil slicks on ice to be patches of open water, helicopter surveys should be used for better resolution (Ward and Tull 1977) of mortality data.

Beached bird surveys should be used to improve accounting of mortalities and to provide samples for necropsies. Counted birds should be tagged (in consultation with Canadian Wildlife Service) to allow estimates of scavenging and to prevent repeat counts from being made (Ward and Tull 1977).

Long-term. Where long-term baseline data are available or where logistics permit long-term monitoring, local, affected breeding colonies should be surveyed on an extended basis. Population size, clutch size, growth rates of young, or embryological concerns may be studied through time to determine oil effects.

Physical monitoring. The horizontal extent of oil, weather conditions and storm records should be monitored.

Requirements

Equipment. In the field, cameras with 200 to 400 mm zoom lenses, film, 8 x 40 binoculars, cassette tape recorders, dip nets, and storage bags are required.

In the laboratory, dissection equipment, and dissecting microscopes will be needed.

Facilities. In the field, high-wing aircraft or helicopter (or both), surface vessel appropriate for the local conditions, freezer storage for bird and tissue samples, and possible use of land vehicles for beach surveys.

In the laboratory, space will be required for dissections, and for freezer storage.

Personnel. An ornithologist, and histopathologists are required.

Services. Tissue analyses for hydrocarbon contamination and statistical analyses of bird counts will be required.

Applicable Conditions

At least a 50-metric-ton spill would be necessary in an area of high bird concentrations (Green 1982) or where public contact demands such effort (Ward and Tull 1977). For long-term studies, some baseline data would be required on distribution and abundance of the species affected.

Costs

Main costs are for personnel plus their travel and living expenses; for lab analyses; for a coastal vessel, including fuel and food, the cost of which varies depending upon the size of vessel needed and the location of the spill; for aircraft (costs will vary widely depending upon availability and type of aircraft); for field provisions such as sample containers, film, and miscellaneous items; and for report preparation.

Success Potential

Estimates of mortalities definitely caused by oiling may be difficult based on shipboard, aerial, and beach counts although a systematic survey effort should result in good documentation of the species affected. Subsequent analyses should assist in the determination of degree of oiling, loss of thermal insulation, amount of oil ingested, and a variety of resultant physiological changes.

ASSESSMENT OF EFFECTS OF OIL ON MARINE MAMMALS

Objectives

Three objectives are envisioned in the study of oil on marine mammals:

- to assess behavioural response (avoidance, haul-out behaviour, and distribution changes with respect to oil) (Keizer 1982; Ward and Tull 1977; EPA 1977; NRC 1985; Green 1982);

- to assess the effects of ingested or surface contamination of oil in fouled animals (NRC 1985; EPA 1977; Ward and Tull 1977); and

- to assess species composition, relative abundance, and degree of interaction with spilled oil (EPA 1977).

Rationale

Potentially many species of marine mammals can contact floating slicks or suspended hydrocarbon droplets after an oil spill. A range of physiological effects are then suspected to be possible, based on the results of limited experimental studies and reviews of actual incidents. In view of the lack of information on the toxicological effects of oil on higher species, studies are proposed that will permit the more comprehensive documentation of such data.

Location

Difficulty may be encountered in following animals such as seals, sea lions, and whales offshore because of their mobility. The effects of oil on mammals in breeding, feeding, or more limited activity areas may prove more worthwhile for investigation. Examples of such locations would be seal rookeries in open waters or, in the case of the Arctic, in leads, at ice edges, at breathing holes, and, more generally, in the transition zone (NRC 1985; Ward and Tull 1977; Green et al. 1982). Shore-based work would entail sampling of species for mortality and physiological determinations.

Timing

Studies should cover the duration of the spill plus two weeks after the spill is no longer detectable by aircraft. One survey flight per week and ten ship-days per month would be required. Local rookeries generally each necessitate four days of study. (See also the subsection on Timing from the Intertidal Benthic Environment Study.)

Methodology

General. Aerial and shipboard surveys should be used to identify local populations, their distribution, abundance and interaction with oil. Beached or obviously fouled animals should be collected where possible for necropsies or physiological sampling.

Specific. Fixed-wing aircraft, flown at 150-300 m should be used to make species counts and to identify distribution with respect to the spill area. Shipboard and/or shore surveys should be used to confirm contact of marine mammals with oil and to document their reaction to the oil in terms of attraction and avoidance or interference with swimming or feeding (EPA 1977). Boat and shore collections of obviously fouled animals should be used for necropsy and physiological sampling. Organ, blood, or tissue samples from live or dead animals can provide insight into potential stress levels (Keizer 1982).

Animals released after examination and cleaning should be tagged to allow a degree of monitoring of their movements.

Local rookeries should be surveyed on a short-term basis to observe perturbations, such as mother/pup behaviour, and obvious population declines.

Physical monitoring. Horizontal distribution of oil and the distribution of ice-free areas should be monitored where appropriate.

Requirements

Equipment. In the field, equipment should include cameras with 200 to 400 mm zoom lenses, film, tape recorders, 8 x 40 binoculars, capture nets, physiological sampling equipment (e.g., thermometers, syringe, and measuring tape), and sample containers.

In the laboratory, dissection equipment and microscopes will be required.

Facilities. In the field, high-wing aircraft, a surface vessel appropriate for the local conditions, freezer storage for samples, and possible use of land vehicles for beach surveys are required.

In the laboratory, space for dissections, and freezer space for sample storage will be required.

Personnel. A marine mammologist, and a histopathologist will be required.

Services. Tissue analyses for hydrocarbon contamination and possible biochemical analyses will be required.

Applicable Conditions

Anywhere significant numbers of marine mammals are present or where public contact is high may be applicable for study. Because detailed population data are lacking on most marine mammals, accurate mortality and population level effects evaluation is not possible (API 1977). The activities outlined in this study should be "piggy-backed" with bird studies because they require similar logistics.

Costs

Bird and mammal studies could be combined for most spills. Where incidents take place in areas frequented by species of more obvious concern, more attention would have to be paid to documenting the effects of the spill. Marine mammals, such as sea otters, narwhal, bowhead whales, polar bears, ringed grey harbour and harp seals, are species that may have to be investigated separately. (See subsection for costing of study on Bird Populations.)

Success Potential

Systematic counts should assist significantly in documenting species composition, relative abundance, and the degree of interaction with oil, including behavioural reponses. Determinations of clinical and toxicological responses to petroleum at sublethal concentrations should also be possible. Post-mortem examinations can generally be successfully used to indicate cause of death in most species.

COUNTERMEASURES

Seven studies are prescribed to enable the comprehensive investigation of countermeasures (Figure 10). These are:

- containment
- physical recovery
- chemical dispersion
- temporary storage
- transfer
- ultimate disposal
- in-situ burning.

For the most part, technical evaluations are recommended which can be coordinated with other spills-of-opportunity work, particularly in the area of fate and behaviour.

CONTAINMENT

Objective

To document the use of oil spill barriers applied to contain, deflect and concentrate floating slicks is the single objective.

Rationale

The usual first step in a physical countermeasures operation is the confinement and concentration of spilled oil for subsequent mechanical removal. A comprehensive record of observations of boom operations would assist in determining the physical specifications of barriers that best suit any given clean-up situation. This study would also more generally provide assessment data on the performance of booms and their optimum application.

	OFFSHORE	NEAR-SHORE	INTER-TIDAL	SHORE-LINE
ULTIMATE DISPOSAL	✶✶✶	✶✶✶		▮▮▮▮▮▮
TRANSFER & TEMPORARY STORAGE	▮▮▮▮▮▮	▮▮▮▮▮▮	✶✶✶	▮▮▮▮▮▮
IN-SITU BURNING	▮▮▮▮▮▮			✶✶✶
PHYSICAL RECOVERY	▮▮▮▮▮▮	▮▮▮▮▮▮	▮▮▮▮▮▮	▮▮▮▮▮▮
CONTAINMENT	▮▮▮▮▮▮	▮▮▮▮▮▮	▮▮▮▮▮▮	
CHEMICAL DISPERSION	▮▮▮▮▮▮			

KEY

▮▮▮▮▮▮ process occurs to a significant extent

✶✶✶ process tends to occur to lesser degree or more slowly over time

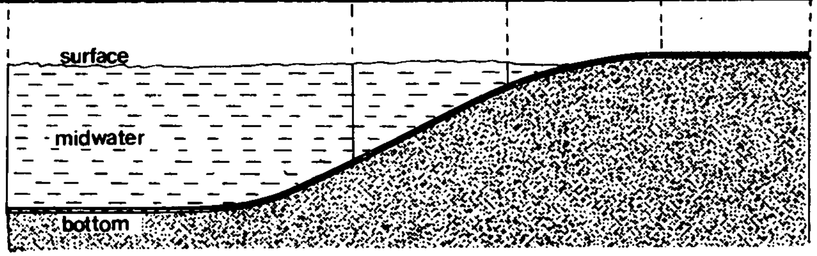


Figure 10 COUNTERMEASURES

Location

Containment activities should be monitored primarily in both the offshore and nearshore zones. If booms are used in intertidal areas, their use there should also be examined. The location of oil containment operations will often relate to the protection of resources, particularly those associated with nearshore, intertidal, and shoreline zones.

Timing

The application of oil booms should be investigated beginning with their initial use and continuing ideally over a period of two to three weeks in a variety of environmental conditions and in various deployment modes. Evaluations would likely be conducted on an intermittent basis over that time with each assessment period lasting several hours.

Factors affecting timing may include:

- the arrival of different booms during the response period;
- changes in weather and sea conditions;
- the optimization of boom operations as spill clean-up progresses; and
- changes in the nature of countermeasures operations as oil fate and behavioural processes run their course.

Methodology

Step 1 - Identification. Each boom under study should be identified according to:

- manufacturer
- model designation
- owner/operator.

Ideally, comprehensive physical specifications should be ultimately obtained for each boom examined (Solsberg 1983). Otherwise, a colour photograph should be taken and main features (dimensions, flotation, fabric, and tension members) should be noted as possible. Additional data should be obtained from owner or operator, manufacturer or catalogues.

Dimensions:

- height (cm)
- freeboard/flotation element (cm)
- draught (cm)
- section length (m)
- storage volume (m^3/m)
- total length used (m)
- weight per unit length (kg/m).

Fabric:

- colour
- type
- tensile strength (kg/2.54 cm)
- tear strength (kg)
- cold crack temperature (°C)
- weight (g/m^2).

Flotation:

- type, material
- shape
- size (cm)
- buoyancy: weight ratio.

Connector type, material.

Ballast/lower tension member:

- type, material
- size (mm)
- weight (kg, kg/m, etc.)
- ultimate tensile strength (kg).

Top tension member:

- type, material
- size (mm)
- ultimate tensile strength (kg).

Other data (note interval in metres and material types(s)):

- anchor points
- navigation lights
- handholds
- vertical stiffeners
- age/number of previous uses.

Step 2 - Mode of use. Use should be characterized according to offshore, nearshore, or intertidal application. Records should be kept of whether boom is used in stationary situation, drifting with slicks, deflecting oil in current, sweeping oil in conjunction with skimmers, protecting shoreline amenities (marina, marsh, aquaculture facility, etc.), or other use. The configuration should be noted.

Step 3 - Performance.

a. Environmental parameters: weather and sea conditions influence the performance of booms. Hourly readings should be obtained of, or noted as appropriate, wave height and period, wind speed and direction, near-surface current speed and direction, and air and water temperature. (See subsection on Methodology for Fate and Behaviour Study for more detailed information.)

b. Oil properties: oil type and behaviour also have a bearing, albeit to a lesser extent, on the ability of booms to function. Samples of surface oil should be obtained and average slick thickness should be estimated (see also subsection on Oil Properties and Composition).

c. Deployment, operation, retrieval: ease of deployment, retrieval should be recorded and analogous details for retrieval should be noted.

Is boom pre-connected?
Does connection require mechanical tools?
Is mechanical air inflation required?
Is boom stored on reel, in container, on deck?
Is lifting gear or other special equipment required?
Is boom damaged during deployment?

Details of operation should be recorded. If anchoring, mooring, and towing systems are used, these should be identified. Measures undertaken to maintain boom in operating mode should also be listed. Instances of damage caused by vessel traffic, initial set-up, other operational factors should be cited. Does boom exhibit strength and durability consistent with its intended purpose? In particular, condition of fabric junctures at connectors, handholds, anchoring points, flotation element, and near tension members should be noted. When feasible, a hand-over-hand inspection of the entire length of the boom should be made to determine if it has incurred any damage (such as abrasion, tears, or punctures).

d. Oil containment: it will be difficult to eliminate all subjectivity from field assessments of booms because precise quantitative measurements of oil losses cannot be practically implemented. Operational data used in combination with other observational records should provide good insight into boom performance. Replicate samples to determine slick thickness could be collected to provide some measure of significant losses from a boom, if this procedure were feasible.

e. Wave response: whether the boom rides the predominant wave form should be noted. Boom bridging between wave crests indicates problems in this regard and probable oil losses which should be visible as intermittent slick pulses.

f. Stability: excessive lean of a boom usually means that oil losses are also likely to occur. High wind and current conditions and problems with tension members or external bridal systems can lead to boom instability. The vertical attitude of boom should be noted. In some models, a concave shape towards the oil layer is intentionally achieved and will not in itself result in oil escaping the boom.

Visual examinations for slicks downdrift from the boom should reveal any problems, unless the level of suspended sediments is particularly high.

g. Splashover/drainage: in small, steep wave forms, oil can overtop the boom (splashover) or be lost directly under it (drainage). An examination should be made to determine whether such lossess are occurring. Splashover is easily visible while drainage is also usually apparent.

   Losses can be estimated on a volume per unit time basis (L/min) knowing the thickness of the escaping slick and its areal extent developing over a timed interval. Usually, however, it should be sufficient to describe the losses as excessive (unacceptable), significant (substantial containment of oil is still being achieved), or minor (most oil is being retained). It should be noted that thin slicks which are multi-coloured may cover large areas but are only microns in thickness and do not account for a high percentage of losses when oil several millimetres or more is being held by booms (see Figure 4).

h. Entrainment: in river and tidal currents, oil droplets can break away from a head wave of oil building against a boom and can be entrained in the water column. It will likely only be feasible to describe oil escaping the boom in such circumstances (it will be visible upon resurfacing) as excessive, significant, or minor.

Requirements

(See also subsection on Oil Properties and Composition for sampling needs.)

Equipment - Environmental. Wave Rider buoy (if available), or simple spar buoy, anemometer, air/water thermometers will be needed; also visual observations of sea conditions should be made (see Table 1).

Equipment - Oil Properties. Slick thickness device (OHMSETT/Johnson Sampler), 1 L sample bottles, 35 mm camera, and video tape equipment will be required (see Oil Properties and Composition).

Facilities. Small support vessel (Boston Whaler or similar type) for nearshore and intertidal studies, and larger craft, as available and appropriate, for offshore boom operations will be needed.

Flyover in fixed-wing aircraft or in a helicopter would allow better concept of areal extent of losses as well as photographic record of same for both nearshore and offshore work.

Note: Verification of observations of the surface should follow flights prior to the estimation of oil losses and effectiveness of booms. Quantitative measurements of such losses can be attempted by determinations of slick thickness - should conditions be amenable to such studies. Oil dispersal resulting from entrainment, as well as sampling difficulties, could preclude such work.

Personnel. An experienced spill control equipment specialist will be required.

Services. Oil composition and properties analyses will be required.

Costs

Main cost components include personnel, travel and living, laboratory analyses, field provisions (sample bottles, oil preservatives, film, and miscellaneous supplies), vessel rental for (a) nearshore operations and/or (b) offshore operations, and report preparation.

Expenses may be substantially reduced for offshore operations monitoring if a boom deployment vessel is available to personnel undertaking this study. Another alternative is to combine the offshore segment of this study with other investigations involving the measurements of slick thickness as part of studies on Advection and Spreading or Natural Dispersion.

Success potential

There is a high probability that the performance and adequacy of oil-spill containment barriers used in various slick-control situations can be documented comprehensively. Optimum designs and applications should become apparent.

PHYSICAL RECOVERY

Objectives

The objectives of this part of the study are to identify the mechanical oil collection systems used to remove spilled oil and to determine and record the effectiveness of their application.

Rationale

Countermeasures operations often involve the use of skimmers and other hardware to recover floating slicks and to pick up stranded oil. Documenting the types of machines used for spill clean-up and quantifying the physical oil removal process would serve to define more accurately their relative role in the response process. It would also highlight the most efficient and expeditious means to remove oil mechanically from the environment.

Location

Physical recovery operations should be investigated in all regimes including offshore, nearshore, intertidal, and shoreline zones.

Timing

Ideally, oil removal should be monitored from the time of its implementation at a spill site until all systems ultimately used have been examined comprehensively.

Factors affecting timing that may be of significance include:

- the arrival over time of various types of oil removal equipment, other logistical constraints;
- changes in hardware requirements as the weathering and movement of the oil run their course;
- changes in weather and sea conditions;
- mechanical problems with recovery gear; and
- improved efficiency of operation as the most appropriate techniques are selected and their use is optimized.

Methodology

Step 1 - Identification. Each oil removal device under study should be identified:

- manufacturer
- model designation
- owner/operator.

a. Collection principle: the oil pick-up mechanisms being observed should be classified and briefly described:

  - weir - simple, self-levelling, stationary, advancing
  - oleophilic - belt, rope mop, disc, drum
  - hydrodynamic - rotating vane, vortex, submerging belt, cyclonic chamber
  - suction - vacuum, air conveyor, etc.
  - other - boom/weir skimmer, paddle wheel, acoustic, handtool, etc.

b. Physical specifications: each device used should, if possible, be photographed and described, referring to the following terms as appropriate:

  - length (cm/m)
  - width (cm/m)
  - weight (cm/m)
  - draught (cm)

- weight (kg)
- sweep width (cm/m)
- materials of construction
- propulsion
- prime mover
- pump (type, power, capacity)
- flotation type
- debris processing capability (screen, grill, etc.)
- storage capacity (m^3/L)
- discharge hose diameter (cm)
- other information (oil/water separation, operating speed, etc.)

Step 2 - Mode of use. Use should be characterized according to offshore, nearshore, intertidal, or shoreline application.

Mode of use should be recorded, i.e., if device is applied to stationary, boomed slicks; if device is advanced through free-floating oil; whether or not it is used from a vessel of opportunity; if it is deployed in conjunction with sweeping booms, barges or; operated on sandy or cobblestone beaches. Configuration of use should be noted.

Step 3 - Performance.

a. Environmental parameters. for water-borne devices, weather and sea conditions strongly influence the performance of skimmers. Hourly readings should be obtained of wave height and period, wind speed and direction, current (tidal) speed and direction, and air and water temperature. (See Advection and Spreading for more detailed data.)

b. Oil properties: oil type and behaviour also have a direct bearing on the potential capability of most oil removal machinery to function. Obtain samples of oil from the area to which the oil collection equipment is being applied. Estimate average slick thickness in which device is being used (see also Advection and Spreading - Figure 5).

c. Deployment, operation and retrieval: ease of deployment, operation, retrieval should be recorded as applicable, and the following questions should be considered:

- Is remote power source required that is readily available, operated?
- Are ramp, lifting gear or other special tools and equipment required for deployment and retrieval?
- Does operation of device jeopardize safety?
- Describe mechanical complexities, difficulties apparent in use, repairs needed.

d. Stability, wave response: if device is waterborne, the capability of oil recovery equipment to respond properly to waves, currents, and wind should be recorded. Excessive pitch and roll, reflected wave activity at oil inlet, splashing, the shedding of vortices, unintended submergence of intake can all contribute to a decrease in oil collection performance. In particular, environmental conditions that lead to inefficient operation should be noted. Also, a check should be made to see if oil is being entrained at depth behind the skimmer.

e. Debris: type and presence of debris (kelp, logs, branches, flotsam, and jetsam) and interaction with oil recovery unit should be noted and the following question should be answered:

- Is its operation impeded because of specific debris forms?

f. Oil removal: the following steps should be taken:

- determine oil type and characteristics, slick thickness, environmental conditions (as for Fate and Behaviour);
- record relative velocity of machine to oil (m/s), if applicable;
- note rotational speed of disc, belt, rope mop, or drum (rpm);
- determine volume of oil being recovered (L/min or m^3/h);
- collect oil sample for later determination of oil content in recovered oil phase (express oil content as %);
- correct oil recovery rate for water-in-oil phase;
- determine collection rate of water, if possible (L/min or m^3/h);
- repeat procedure for test runs in similar environmental, slick conditions as well as in a range of situations;
- note main factors that appear to influence oil recovery rate; and
- report data according to the following main headings:

- test number
- oil: type
    - thickness
    - viscosity (m Pa.s or cp)
    - density (g/ml)
    - pour point (°C)
    - age (hours-days)
- wave height period (m, s)
- air, water temperature (°C)
- speed of oil pick-up mechanism (e.g., rpm for disc skimmers, m/s for belt skimmers)
- oil recovery rate (m^3/h)
- oil content (%)
- water recovery rate (m^3/h).

Requirements

Equipment requirements. A Wave Rider buoy (if practical), anemometer, and air and water thermometers will be required, and visual observations should be made of sea conditions at time of observations (see Table 1).

Equipment - oil properties, performance. A slick thickness device (cookie cutter or Ross/Belore sampler - see Figure 5); 1 L sample bottles; 35 mm camera; video equipment; stop watch; and tape measure will be required. (See Advection and Spreading.)

Facilities. In the field, a small support vessel (Boston Whaler or similar type) for nearshore and intertidal study locations will be required. Larger vessels could be used either as mother ship or working platform from which skimming systems could be deployed, operated, and retrieved. Permisson to board must be secured; no facility requirement is anticipated in this regard. If shore-based clean-up operations are being observed, a four-wheel-drive vehicle, or other means of transportation, should be available.

In the laboratory, sample storage facilities, centrifuge, solvents will be required.

Personnel. An experienced spill control equipment specialist will be required.

Services. Laboratory analyses for oil composition and properties will be needed.

Costs

Study costs are similar to those described for Containment except that a wider range of devices might be applied to recover oil, particularly when a large spill results in the stranding of slicks over a significant length of coastline. Costs will therefore vary widely depending upon the location, nature, and size of the release.

The main cost components include personnel, travel, living, laboratory analyses, field provisions (sample bottles, oil preservatives, film, and miscellaneous items), vessel rental for nearshore or offshore operations (or both), and report preparation.

Expenses will depend upon the type and availability of vessel chosen to monitor offshore operations as well as salaries (per diem) of personnel assigned to this work.

Success Potential

There is high potential for successfully achieving the objectives of this study. Systematic and objective documentation of most oil recovery systems should be possible. The efficiency with which most devices operate and their optimum application should become apparent during the course of this work.

CHEMICAL DISPERSION

Objective

The single objective of this study is to determine the effectiveness with which chemical dispersants to dissipate floating slicks.

Rationale

Chemically dispersing offshore oil slicks is an alternative countermeasure that appeals in many respects. As a one-step, oil removal process, it is less personnel-intensive than mechanical oil removal techniques and, moreover, can be quickly used on large areas. Questions remain, however, as to the effectiveness of chemical agents on large, offshore spills (Fingas, 1985a). The purpose of this study is to record and analyse data pertinent to chemical dispersion to optimize such operations in future spills.

Location

Chemical dispersion will likely be considered for offshore spills that are amenable to such treatment and that have been ascertained to potentially encroach, generally, upon nearshore and shoreline zones or, more specifically, on environmentally sensitive regions. Safety or health risks could be other considerations for their use (Environment Canada 1984). Study locations will also likely involve areas in relative close proximity to the source of the release.

Timing

This study must be coordinated with chemical dispersion activities that would be likely to involve floating oil remaining on the surface less than 24-48 h. subsequent to its release.

Other factors related to timing may include:

a. Higher sea states may preclude the necessity of chemical dispersion operations.

b. Rough seas could also hinder the surface verification of dispersant effectiveness in terms both of the dissipation of oil by natural mixing energy, and of the capability of support vessels and sampling equipment to cope with high wave conditions.

c. The physical and chemical properties of the spilled oil may change quickly with time to render oil less amenable to chemical dispersion.

d. Various dispersing agents may be used if a long-term oil release, such as a blowout, occurs.

In Canada, the decision to use dispersants is made jointly by federal officials in consultation with provincial and territorial authorities. Delays in the decision-making process may occur as a result of local environmental concerns and priorities.

Methodology

Dispersant effectiveness studies should be undertaken, if possible, for both aerially broadcast and vessel-based chemical applications.

Step 1 - Identification. Each individual dispersing agent should be identified for the specific operations under study according to:

- manufacturer;
- dispersant designation;
- type: hydrocarbon solvent-based ("conventional"), other solvent (water, glycol, alcohol) base ("concentrate"); and
- water solubility.

The manufacturer should be consulted for further information, if required, to identify and characterize dispersant.

Step 2 - Use. The following should be completed:

- characterizing use in terms of location of application;
- specifying whether support vessels and/or aircraft are used to broadcast dispersant;
- noting application hardware (spray systems, nozzles, breaker boards, pumps);
- determining nominal dispersant-to-oil ratio by simply dividing the number of litres of dispersant used by the area and slick thickness over which it is used; and
- noting also (as a percentage) if concentrate dispersant is diluted with water prior to its application.

Step 3 - Effectiveness. (Gill et al. 1985; Lichenthaler and Daling 1985)

a. Environmental parameters: weather and particularly sea conditions strongly influence the effectiveness of dispersants. Hourly readings should be obtained or noted as appropriate precipitation, of wave height and period, wind speed and direction, relative humidity, current or tidal speed and direction, air and water temperature. Salinity of water should also be recorded for the area under study.

b. Oil properties: oil type and behaviour also have a major bearing on the ability of chemical agents to disperse slicks. Samples of oil should be obtained and average slick thickness should be estimated for areas that either are suitable as a control or, if practical, that are to receive dispersant shortly (within 1-2 h.). The laboratory analysis for composition and chemical and physical properties of the oil samples collected should follow. (See also Natural Dispersion and Oil Properties and Composition for analysis and properties information.) Such data should help in the post-spill analysis, but are not likely to be received in time to assist dispersion operations.

c. Positioning: position of surface slicks and sampling vessels can be determined by GNS and INS, optical range finder (if applicable). Remote sensing (conventional colour, IR, and UV sensors, laser fluorosensor, SLAR, L^3 TV) can be used to track slicks, to differentiate oil thicknesses within the slick, and to assist in positioning sample vessels.

Subsurface movement of dispersed oil should be followed using drogues and current meters so that sampling at depth can be reasonably carried out, even though dispersed oil is no longer directly under the original slick.

Ideally, the slicks to be studied should be identified by markers so that the same oil patches are monitored throughout the work. This will not always be possible, particularly for longer-term investigations.

d. Oil dispersion: the dissipation of oil by chemical dispersants can be measured both in terms of the oil droplets in the water column and as a floating layer of oil diminishing in thickness (when studied with immediate relevance to the application of dispersants). Subsurface studies are recommended although difficulties are believed to be present in accurately determining an effect entirely attributable to the dispersant. Such investigations should, however, assist in other work namely Natural Dispersion and Sedimentation. The alternative method presented below of remotely sensing slick thickness is the method of choice for more immediate determinations of dispersant effectiveness.

e. Subsurface oil concentration: subsurface samples can be collected according to a predetermined grid at approximate depths of 0.5, 1.0 and 2.0 m below the water's surface for both the control (untreated) and treated slicks. Surface-following samples are also needed and likely are of most importance. Factors contributing to uncertainty of results include:

- turbulence and interference created by sampling boat;
- swells and waves altering sampling depth;
- non-uniformity either in application of dispersant or in slick thickness;
- resurfacing of oil;
- variation in characteristics between control slick and treated slick; and
- failure of dispersant to hit oil.

By addressing each concern in turn, each of the above factors can be lessened in the influence it has on the data collected. For continuous measurements of oil concentration at depth, a Turner Designs flow-through fluorometer (Model 10-005) has been used, or other equivalent machine (see Natural Dispersion - Requirements), but recent investigations in the Beaufort Sea have shown subsurface sampling to have limitations re: localized concentration determinations as indicated above.

f. Surface oil: alternatively and ideally, dispersant effectiveness can be determined by the examination of thick slick thickness using UV/IR sensors to identify areas of thick and thin oil and the surface verification techniques (Ross/Belore, OHMSETT/Johnson samplers) described in Fate and Behaviour. These techniques can be used to monitor treated and untreated slicks from fixed-wing aircraft and compared. For slicks subjected to the same sea conditions over a fixed time interval, the amount of oil dissipated by chemical dispersants can be approximated by observing changes in the areal extent of slicks and the colouration (see Figure 6). Predetermined transects can be flown to ensure that the area under study is comprehensively covered.

Laboratory testing of oil samples with dispersant using accepted procedures and apparatus, such as the Environment Canada-specified Mackay-Nadeau Steelman or Mackay methods, will yield effectiveness values and dosage rates that do not necessarily reflect field applications. Laboratory analysis is therefore not recommended to be used as a basis for determining dispersant effectiveness.

Requirements

(See also Oil Properties and Composition for sampling procedures and equipment requirements.)

Equipment - Environmental. Wave Rider buoys, anemometer, air and water thermometers, and salinity meter will be needed; also visual observations of sea conditions should be made.

Equipment - Oil Properties. A slick thickness device (cookie cutter or Ross/Belore sampler); 1 L sample bottles; 35 mm camera; video recording equipment; aircraft equipped with UV/IR remote scanners, laser fluorosensor, L3TV will all be needed.

Equipment - Slick Dispersion.

a. Slick tracking: slick tracking devices, as described; 5-10 Orion or Novatech tracking buoys and receiver; surface current drogues with 0-2 m depth sails for following the movement of surface water layer will be needed.

b. Oil in water column: towed (in situ) fluorometer and a Turner Designs or Q-Instrument will be required.

Horizontal transects transects to measure oil-in-water concentrations could be done with the Turner Designs towed underwater fluorometry system owned by the Environmental Protection Service.

One flow-through fluorescence kit should be available for vertical profiling of oil concentrations. The kit should contain a flow-through fluorometer with oil detection filters and lamp, spare parts, recorder, submersible pump, tubing to reach to 5 to 10 m depth, and sample bottles. The sample bottles should consist of 50 x 1 L bottles, and 10 x 4 L bottles, all hydrocarbon-cleaned. 50 mg Soxhlet-extracted mercuric chloride should be added to each bottle as a preservative. A back-up fluorometer should be provided in the event of an instrument failure.

Facilities. In the field, transportation to study area by remote-sensing aircraft or by the vessel deploying dispersant, as well as vessel platform to conduct pre- and post-application studies of dispersant application will be required.

In the laboratory, freezer or ambient storage facilities for collected samples, and laboratory space will be needed.

Personnel. A chemist with a chemical technician and a remote-sensing specialist with an assistant will be required.

Services. Laboratory analyses for oil composition and properties will be needed.

Costs

Costs will vary depending upon the availability of aircraft, fluorometry equipment from government agencies. Main cost components will be personnel, living, accommodation, laboratory analyses, field provisions (such as bottles, preservatives, film, and sampling gear), offshore vessel, and report preparation.

Success Potential

Adverse weather and sea conditions will impede attempts to measure the effectiveness of dispersion operations. However, a combination of surface and subsurface examinations of slick dissipation closely related to the recording of environmental data should serve to provide an insight into factors essential to using chemical countermeasures.

TEMPORARY STORAGE

Objective

The single objective of this study is to document the equipment and techniques used for the interim storage of collected oil and oily materials.

Rationale

The mechanical removal of oil and oily substances usually results in the need to store these materials temporarily prior to their transfer to ultimate disposal facilities. The designation of various appropriate storage options then becomes vital to managing the logistics of the entire physical clean-up operation. A study of the type of equipment used to hold collected materials on a temporary basis would assist in the selection and use of such facilities in future incidents.

Location

Temporary storage hardware can be required in the offshore and nearshore regions, as well as on shorelines and at inland locations. In most cases, a distinction between nearshore and offshore water-based facilities and on-shore methods should suffice for the purposes of this study.

Timing

The monitoring of temporary storage devices and techniques should commence with the implementation of oil recovery activities and should continue until all approaches used to a significant extent, or those that are ultimately discarded, are recorded, insofar as is practical. The accident site should be monitored during the first two weeks following the spill and periodically for two to four months, depending upon the size and duration of the release to determine if storage methods change.

Factors that could affect the timing of this study include:

- the changes in weather, sea state, temperature, and other environmental aspects affecting the choice of storage options;
- the weathering of oil;
- the nature of debris that the oil contacts over time; and
- the changes in the volume of oil collected and the location of primary oil recovery activities as the spill clean-up progresses.

Methodology

Five basic areas of information on storage should be determined, namely, the location of use, the methods used, the types of materials being stored, capacities, and operational/application aspects. Therefore, this study should be approached as a straightforward, technical documentation and not as a detailed engineering analysis. Long-term aspects of use would generally be excluded from study except where observational data can be reported for related considerations such as corrosion, wear, stability, leakage, etc.

Step 1 - Identification. The following steps should be completed:

- characterizing location of use according to onshore, nearshore or offshore zone;
- noting the type of storage facility involved using the following list as a guide:

a. Onshore:

- excavated pit - lined or unlined
- diked area - note material(s) of berm
- prefabricated kit - swimming pool, water storage, portable tank
- 45-gallon drum
- rigid tank - plastic, fibreglass, steel, other; with closed or open top
- flexible tank - supported, bermed, other details
- truck - tank, vacuum, dump, pick-up, flatbed
- plastic bags
- waste bins (skips).

b. Nearshore, offshore:

- oil tanker
- barge
- workboat
- skimmer
- flexible bladder
- platform facilities.

Step 2 - Characterize waste material. The type(s) of material being collected should be recorded.

- oil type - crude, bunker, diesel, etc.
- state - fresh, weathered, emulsified, solidified
- debris - logs, sticks, seaweed, sand, flotsam, etc.

One litre oil samples should be collected for properties and composition analysis (see also Oil Properties and Composition).

Step 3 - Capacity of storage units. The approximate capacity of the receiving unit and the volume of materials being held should be determined.

- dimensions of unit
- estimated volume of oil collected
- estimated volume of free water present
- estimated volume/weight of debris.

Step 4 - Performance. In assessing the operational aspects of the device under study, the following questions should serve as a guide:

- Are deployment, retrieval, portability/mobility, and other implementational aspects appropriate? (Comment on weight, stability, set-up, if applicable.)
- Is ancillary equipment required such as tools for assembly, lifting gear, towing vessel, etc? (Specify.)
- Can collected material be readily transferred to disposal facilities?
- Is the device expensive to operate? (Comment on fuel needs, maintenance, if applicable.)
- Are problems apparent that may lead to the unintentional release of material? (Comment on corrosion, abrasion, tears, instability, etc.)

Step 5 - Environmental data. Air, water temperature, precipitation, other environmental data should be noted in terms of how these may affect storage. (See also Fate and Behaviour.)

Requirements

Equipment. A tape measure, 1 L sample bottles, 35 mm camera, video equipment, air/water thermometers will be needed. Visual observations should be made of sea and weather conditions at time of study. Refererence should be made also to such data collected in more detail for other studies (see Table 1).

Facilities. A small vessel for nearshore locations and a larger vessel, used for other spill response purposes, for offshore observations should be available. A four-wheel-drive vehicle, or other appropriate means of transportation should be available for review of shore-based facilities.

Personnel. A chemical or mechanical engineering technologist and a spill-control specialist will be required.

Services. Laboratory analyses for oil composition and properties will be needed.

Costs

Costs will vary depending upon the accident site. Personnel should be assigned other duties related to the assessment of physical countermeasures systems.

Main cost components are comprised of personnel, travel and living expenses, laboratory analyses, boat and motor rental (nearshore), field provisions (such as film and bottles), and report preparation.

Investigation of facilities, particularly water-based and offshore units, should use transportation dedicated to clean-up, if non-interference with response crews is assured.

Success Potential

There is a high probability of accurately documenting best practicable storage options according to oil and debris types, and operational needs. A lower potential exists to identify longer-term associated problems.

TRANSFER

Objective

The single objective of this study is to record and assess the use of mechanical systems employed to transfer oil and oily substances during clean-up operations.

Rationale

Procedures for the physical removal of oil necessitate the transfer of collected liquids and oiled materials to storage vessels and disposal facilities. Documenting the performance of pumps and other mechanical means used for such purposes will assist in the future selection of transfer methods best suited to various response circumstances.

Location

Transfer operations involving the clean-up of marine spills of oil could be conducted as lightering operations in coastal waters, in offshore locations between skimmers and receiving vessels, at dock facilities used for the unloading of collected materials, and at shorelines where oil and debris removal take place.

Timing

The use of pumps and other transfer gear could be monitored during lightering operations, and from time to time, for other situations during the clean-up process. Ideally, initial response efforts should be reviewed during the first two weeks of the spill, with smaller unit operations being evaluated periodically in subsequent weeks or months, depending upon the size and location of the release. Factors affecting timing which should be considered include:

- changing physical and chemical properties of the oil as it ages and/or mixes with water and debris; and

- changing volumes of oil that are mechanically removed and that require transfer. This factor will depend upon the location(s) of the collection operations, weather and sea state, the nature and duration of the spill, and the clean-up phase involved.

Methodology

Lightering. Lightering comprises a special case of transfer in which a hydrocarbon product - fuel or cargo - is pumped from a disabled vessel to a suitable receiving unit. The lightering operation requires special experience which, in Canada, rests with the Canadian Coast Guard and with salvage companies. The following areas are suggested for evaluation during a lightering procedure:

1. Mooring equipment:

   - mooring mode either alongside or stern-to-stern configuration;
   - type, model, number, size, and weight of fenders used as well as associated mooring gear, and the adequacy of same; and
   - adequacy of total mooring package.

2. Pumping equipment:

   - record type, model designation, rated capacity, power pack for pump used in lightering operation;
   - diameter, type of discharge hose, connectors;
   - record type(s) of liquid being pumped;
   - assessment of portability, deployment, connection, start-up, and other features relating to facilitation of pumping;
   - ease or continuity of operation of total transfer system including prime mover and pump;
   - rate of transfer (m^3/h) of total liquid moved;

- use of ancillary systems such as inerting equipment including ducting, and gas generators, as well as salvage tugs, and beach gear (if applicable); and
- record number of personnel involved in lightering including supervisors, engineers, labourers, machinists, divers, and so on.

3. Environmental information: weather and sea conditions should be noted on daily basis, or shorter intervals if appropriate, throughout lightering operation, together with air and water temperature, and precipitation.

General transfer operations. Smaller pumping units used for the transfer of oily mixtures can be studied in more detail. Evaluation methods can be found in Purves and Solsberg (1978).

Step 1 - Identification: pump type and its physical specifications should be noted:

- manufacturer
- model designation
- type (centrifugal, vane, piston, and diaphragm)
- rated capacity
- size
- weight
- portability
- prime mover and power source
- connectors
- drain plug
- trash screen
- other features.

Step 2 - Operating parameters: operating conditions should be noted:

- environmental - air and water temperature
- type of fluid transferred
- location of operation
- presence of debris
- temperature of fluid transferred

- pumping parameters (suction head, pressure head, hose diameter(s), and pump speed (rpm)).

Step 3 - Performance: performance should be evaluated:

- ease of start-up
- self-priming capability
- loss of suction
- effects of running dry
- ease of operation
- pumping rate
- viscosity and emulsion tolerance
- repair and maintenance requirements
- debris tolerance
- emulsion formation
- cold weather operation
- noise level
- excessive movement ("walking").

Requirements

Equipment. stop watch, 35 mm camera, video recording equipment (primarily for lightering), and 1 L sample bottles will be needed.

Facilities. Transportation to disabled vessel should be sought on an opportunity-basis only by persons undertaking lightering assessment. Support vessel for nearshore operations, four-wheel drive vehicle or other appropriate transportation means should be readily available for other monitoring work.

Personnel. An oil spill specialist with technician for pump studies, and a lightering specialist from Canadian Coast Guard will be needed.

Services. Laboratory analyses for oil composition and properties will be needed.

Costs

Costs will vary depending upon type of spill incident and transfer requirements. Main cost components are personnel, travel, living, laboratory analyses, boat and motor rental, field provisions (sample bottles, film, and miscellaneous supplies), and report preparation. Additional costs may include offshore travel and accommodation, and helicopter transportation to remote site.

Success Potential

There is a high probability of successfully achieving the objectives of this study, particularly if observations of transfer equipment span several weeks or more.

ULTIMATE DISPOSAL

Objective

The two objectives of this study are to document and to assess quantitatively the techniques used to dispose of collected oil and oily debris.

Rationale

Physical removal of spilled oil requires the disposition of liquid oil and oiled materials as one of the last steps in the clean-up process. The determination of the most successful disposal methods, in terms of the quantities involved and the disposal rates, would provide direction on the most appropriate facilities to consider using in future incidents. Lower volume and less efficient approaches should also become apparent.

Location

Disposal should be investigated primarily as it is applied at land-based facilities. In some cases, offshore units may be used such as burners located on production platforms or clean-up barges.

Timing

Documentation of disposal operations should begin during the first week of clean-up and should continue until it can be ascertained that sufficient data have been compiled for the purposes of this study, and that all alternative approaches involving the ultimate disposal of significant amounts of materials have been examined.

For combustion methods, the spill site should be visited on two or three days, during the first several weeks subsequent to the release. Biological techniques should be investigated during the initial three days of their operation and, if possible, at subsequent monthly intervals thereafter for a period of one year (or obtain records of data indicated herein).

Processing should be similarly reviewed during the first several days of its implementation and at least on one other day in a subsequent week.

Factors affecting timing may include:

a. The ultimate effectiveness of some techniques such as landfilling and landfarming may not be known for some time subsequent to their implementation. This study would concentrate on immediate results although follow-up data collection should be considered for some methods because it is essential in understanding their real worth, particularly where biological breakdown of the oil over time occurs or other longer-term disposal processes are involved.

b. Various disposal alternatives may be tried as the spill clean-up progresses.

c. Changing oil properties could affect the choice of disposal methods.

Methodology

Combustion Methods:

Step 1 - Identification: The technique or device under study should be identified. The following list should serve as a guide:

- Combustion Methods (in-situ burning, open pit burning, portable incinerators, and burners, and process incinerators)
- Biological methods (landfill, burial pits, and landfarming)
- Processing (reprocessing, recycling, and reclaiming).

The site manufacturer, and model designation, if applicable, should be cited, and the location of use should be stated. The combustion mechanism or principle, if appropriate, should be clarified.

Step 2 - Physical specifications: The device or technique used should be photographed and described:

- length (cm/m)
- width (cm/m)
- height/depth (cm/m)
- weight (kg)
- materials of construction
- prime mover, air blower
- flotation
- debris handling
- combustion promoter
- lifting lugs, insulation, drain plug, loading, clean out.

Step 3 - Performance:

a. Oil type and properties: 1 L sample of oil should be obtained and submitted for chemical and physical properties and composition analysis (see also Oil Properties and Composition).

b. Environmental parameters: weather and sea conditions should be described that might relate to operation under study (e.g., precipitation, air temperature, and sea state).

c. Debris: describe nature, type, and amount of debris and manner in which combustion device deals with it should be described, including impedances and positive aspects.

d. Deployment, set-up: manner, time in which device or technique is brought to operational status should be described.

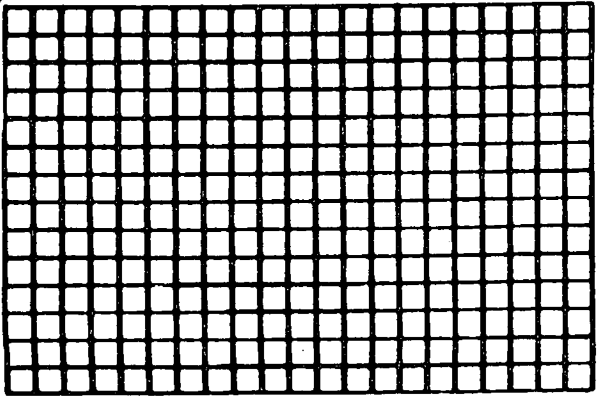
- Are special tools, power source, fuel, site selection, lifting gear, precise alignment, or transportation methods required?
- Are heated surfaces separated from permafrost, other sensitivities?
- Was damage incurred during transportation and set-up?

e. Operation: the following should be connected and reported on:

- Continuity and ease of operation. Can ash and non-combustibles be readily cleaned out? Is loading easily accomplished?
- combustion rate (m^3/h);
- smoke emission noted as very low, low, medium, or high by visually comparing smoke with Ringlemann smoke charts (see Figure 11). Is combustion uniform?
- field maintenance and repair;
- leakage of fluid, residual materials, effect on surrounding terrain and vegetation, durability of construction, safety aspects; and
- optimum flow rate of air or blower speed, flame temperature, and temperature of inside surface and exterior walls using thermocouples.

Biological methods. Generally, longer-term processes are involved that do not easily lend themselves to detailed spills-of-opportunity research projects. During the course of, and subsequent to a spill, however, it should still be possible to ascertain useful data pertinent to biological methods employed for disposal.

Step 1 - Identification. Specific disposal means employed and location used should be identified.



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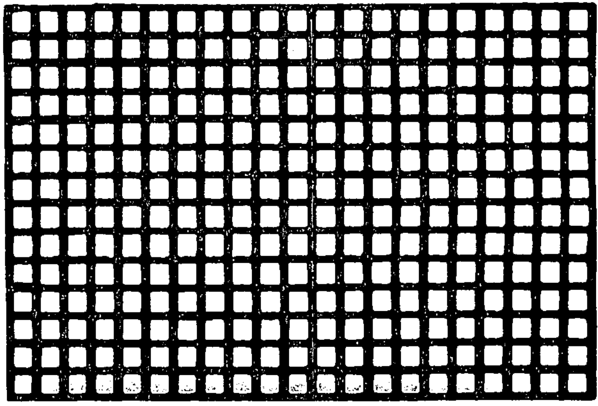

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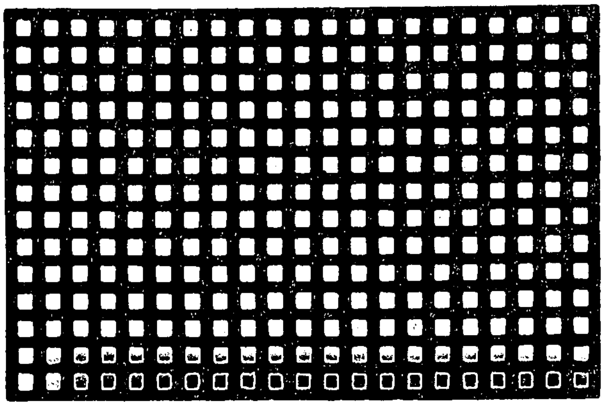

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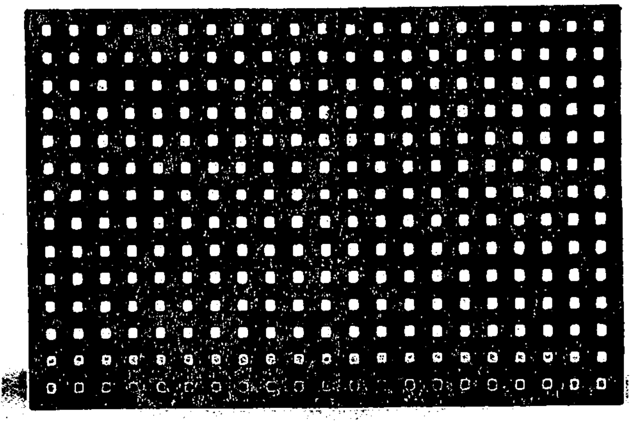

No. 4

Chart No.	Width black lines (mm)	Width white lines (mm)	Percentage black
0	all white		0
1	1.0	9.0	20
2	2.3	7.7	40
3	3.7	6.3	60
4	5.5	4.3	80
5	all black		100

Figure 11 RINGLEMANN SMOKE CHARTS

Step 2 - Oil properties/environmental data:

a. Oil type and properties: 1 L sample of oil should be obtained and submitted for chemical and physical properties and composition analysis. (See also Oil Properties and Composition.)

b. Environmental parameters: records of air temperature and precipitation over duration of concern should be obtained. (In landfarming operations, a period of months is usually involved.)

Step 3 - Performance:

a. Debris: nature, type, and amount of debris (if any) involved on a unit weight basis of oil, if appropriate should be described, noting means of exclusion or sorting out of debris if this is a necessary step.

b. Operation: the following should be recorded:

- area involved (hectares), amount of oil per unit area, and/or depth of burial (cm-m);
- ancillary equipment use to excavate, spread, and cultivate and/or bury debris;
- measurements of soil permeability, runoff and drainage control factors, pH adjustment, soil conditions, addition of fertilizers/water, etc., use of liners, and soil or vegetation cover;
- operator, regulatory agency, monitoring bodies involved; and
- if odour problems, slow oil decomposition, low temperature, debris, contaminants, etc., interfere with operations but would be burned (see Combustion).

Processing. Petroleum facilities, thermal generating stations, or other means might be employed to dispose of collected oil. For the most part, debris would not be dealt with using processing techniques but would be burned (see Combustion).

Step 1 - Identification: Specific disposal techniques should be identified and characterized according to type of facility, owner or operation, and location.

Step 2 - Performance:

a. Oil type and properties: 1 L sample of oil should be obtained and submitted for later analysis for chemical and physical properties and composition.

b. Operation: determine volume of oil processed on a unit time basis (per hour or day) should be determined.

Details should be noted, as obtainable and appropriate, for operation such as end product produced, special processing requirements (e.g. contaminant removal), combustion temperature, maximum volume of oil accepted, and regulatory restrictions on use.

Requirements

Field equipment. Video recording equipment, 35 mm camera, air thermometer, tape measure, high temperature thermocouples (for combustion devices), 1 L sample bottles, and anemometer will be needed.

Facilities. Vessel, if appropriate, for observation of water-based devices; a four-wheel drive vehicle; a helicopter or other means of air transportation, if travel required to remote, inaccessible locations will be required.

Personnel. An oil spill clean-up and combustion specialist will be required.

Services. Laboratory analyses for oil properties and composition will be needed.

Costs

Costs will vary widely depending upon the nature of the accidental release and the type and location of the disposal techniques tried. Basic cost components, exclusive of instrumentation and travel to the spill site are personnel, travel, accommodation, laboratory analyses, field provisions including film, and report preparation. This estimate assumes availability of laboratory equipment, anemometer, thermometers, and video recorders as well as transportation means to remote areas.

Success Potential

Comprehensive documentation should be possible for determining the optimum disposal methods used and their primary operating characteristics. There is a relatively lower probability of obtaining detailed, day-to-day operational data and an account of problems for longer-term approaches, in particular, those comprising biological degradation.

IN-SITU BURNING

Objectives

The objectives are to document and to assess the application of in-situ combustion techniques as a means of removing floating oil slicks.

Rationale

Burning oil on water has been widely researched as a means of spill control. Fireproof booms, wicking agents, air-deployable igniters, acoustic burners, laser systems, and other techniques have been developed for this purpose. Ideally, a one-step oil-removal process results. The purpose of this study is to observe, record, and assess the use of oil ignition techniques in spill response with a view toward identifying optimum approaches for specific situations.

Location

The intentional (controlled) in-situ burning of oil would likely be attempted relatively close to its original release point, in most cases. As such, offshore and, to a lesser extent, nearshore sites will be implicated in burning. An exception would be the ignition of slicks at ice edges or oil surfacing in melt pools in sea ice over a broader area.

Timing

In-situ ignition of spilled oil would likely be conducted on slicks floating on the water's surface less than 24-48 h. following a spill incident. Oil in melt pools generally surfaces and is confined for a period of several days or less during spring break-up in the Beaufort Sea. In-situ burning would only apply to the newly surfaced, confined oil.

Other factors affecting timing of this study could encompass:

a. The changing physical and chemical properties of the spilled oil and, in particular, the evaporative losses of lighter fractions and emulsification of water in oil could eliminate the potential to burn oil in-situ.

b. Weather and sea state could also alter to put a halt to oil combustion techniques either temporarily or for the duration of the spill clean-up.

c. Safety considerations could influence the decision to initiate or continue burning operations.

Methodology

Step 1 - Oil characteristics. Oil-related parameters should be determined and recorded:

- oil type;
- average slick thickness (sample in thin, thick slicks); and

- oil properties/composition (collect 1 L samples for subsequent analysis).

Representative slick(s) should be selected as practical.

Step 2 - Environmental data. Environmental parameters should be recorded:

- air temperature;
- wind speed and direction;
- precipitation;
- sea state;
- water temperature;
- current speed and direction; and
- presence of ice (describe thickness, continuity, condition).

Step 3 - Performance. Specifics related to nature of burn should be noted:

- location (offshore/nearshore, open water/bay);
- containment device used or free floating;
- proximity to release point;
- time elapsed between oil discharge and initiation of burn; and
- device used to achieve ignition.

Details of ignition and burn should be recorded (S.L. Ross 1983):

- number of attempts to achieve ignition;
- preheat time (time required for burn to sustain itself);
- ignition time (time required to establish 1 m^2 of flame);
- burn time versus flame area (estimate only);
- burn efficiency (recover post-burn surface oil with known weight of sorbent pad and compare with pre-burn oil sample to determine % removed by burning); burn residue must be accounted for as seperate entity;
- smoke emission (use Ringlemann charts - see Figure 11); and
- continuity of operation.

Other aspects of burning operation should be connected on:

- number of ignition devices used;
- mechanical, maintenance, or other problems;
- logistics of operation; in particular, support vessels, aircraft used;
- estimate of percent oil treated by burning; and
- reasons for improvements in burn, abandonment of combustion efforts.

Requirements

Field equipment. Ross/Belore or other oil thickness measuring device; stop watch; video recording equipment; 35 mm camera; air/water thermometer; Wave Rider buoy; anemometer; current meter; 1 L sample bottles; and preweighed sorbent pieces will all be needed.

Facilities. In the field, a vessel of appropriate size for sampling and for use as observation platform will be needed. Aircraft should be used for aerial photography if extensive burn develops or in case of multitude of burns by igniters, and laser, over extensive areas involving open water, melt pools, or ice edges.

In the laboratory, analysis of oil samples and extraction, and weighing of collected oil residue (re: calculations of burn efficiency) will need to be conducted.

Personnel. A combustion engineer or engineering technologist and an oil spill combustion specialist will be needed.

Services. Laboratory analyses for oil composition and properties will be required.

Costs

Costs will largely depend on the availability of transportation to burn sites, particularly for offshore and ice-related combustion exercises where larger vessels and helicopters are involved.

Main cost components include personnel, travel, accommodation, laboratory analyses, field sampling and provisions (including sorbent, film, and sample bottles), and report preparation.

Success Potential

Some difficulties may arise in quantifying accurately combustion techniques and in assessing their relative value:

a. Uncontrolled field operations are involved subject to many variables. For example, ice, weather, and sea conditions could change rapidly prior to the completion of a comprehensive evaluation.

b. Unburned oil could mix with burn residue to render sampling difficult.

c. Perceived air pollution problems could end attempts to try additional burns in some areas.

d. Documentation of techniques, conditions of applications as well as relatively good indication of results should be obtainable.

APPENDIX 1: BACKGROUND TO PROPOSED BIOLOGICAL STUDIES

Projects previously proposed for the study of biological impacts of spills of opportunity were reviewed. These were examined in terms of regional application, ecological or taxonomic focus (e.g. benthos, plankton), logistical requirements, budgetary preparation, statistical design, as well as consideration of dispersants (Table A-1).

Although the literature contains many studies pertinent to various regions on a global scale, the proposals considered have appeared for the most part in reports directed at specific locations in Canada. The early work of Ward and Tull (1977) was directed at the Beaufort Sea. It was later edited and submitted to the Treasury Board for funding (Fisheries and Oceans 1979). Keizer (1982) compiled a similar group of projects oriented at the Atlantic; Green and his colleagues (1982) identified projects relevant to the Pacific. In spite of their regional focus, 19 of the 32 biological projects are relevant to all three areas, with little or no modification required.

Ideally, all proposals should include the following sections: rationale or null hypothesis, objectives, methods, critical periods and conditions (or timing), study team and leader (or personnel), equipment and facilities requirements, budget, study feasibility and potential for success. Very few proposals meet this ideal. In particular, rationale and null hypothesis are either not stated or they are merely inferred. Several proposals consist of only several paragraphs of narrative. (At this stage, no rewrite or completion has been attempted of the past, proposed studies. It is believed that this is more appropriately the responsibility of the designated study team leaders, who in many cases conceived and wrote the proposals. The mandate of this study is to provide a plan, which would allow these proposals to be implemented by categorizing and reorganizing the studies into an ordered set of investigations.)

Project Categorization

Projects proposed to date, primarily from Canada, have been categorized on the basis of regional, ecological, logistical and related requirements (Table A-1). In this way, the basic content of the proposals can be summarized.

Table A-1. Biological Research Proposals for Spills of Opportunity.

Project Number and Title	Source*	Regional Application	Related Studies	Deep Water Vessel	Nearshore Vessel	Fixed-Wing Aircraft	Helicopter	CCRS Aircraft	Completed Budget	Statistical Design
	LOGISTICS									
1. Assessment of the effects of vegetation in the coastal zone	1	G	11				X	X	X	-
2. Microbial decomposition of oil	1	G	23, 24	X	X		X		X	-
3. Toxicity of spilled oil	1	G	19						X	-
4. Effects of oil on coastal ecosystems	1	G	20, 25				X		X	-
5. Primary productivity in oiled and unoiled ice	1	A, At	24				X		X	-
6. Densities of invertebrates on under-ice surfaces in oiled and unoiled areas	1	A, At	7, 22				X		X	-
7. Effects of oil on plankton and fish populatons	1	G	19, 22	X			X		X	-
8. Bird mortality during spring migration	1	A	-			X			X	-
9. Mortality of moulting sea-ducks	1	G	10, 27, 29			X			X	-
10. Mortality of birds in offshore open waters	1	G	9, 27, 29			X			X	-
11. Effects of storm surges on birds	1	A	1, 29				X		X	-
12. Effects on spring distribution and numbers of seals	1	A	28			X			X	-
13. Effects on seals in the fast ice zone	1	A	-				X		X	-
14. Effects on seals in the transition zone	1	A	-				X		X	-
15. Effects of oil on polar bears	1	A	-				X		X	-
16. Effects on whales during spring	1	A	-			X			X	-
17. Effects on whales during summer	1	A	30			X			X	-

Table A-1. (Cont'd.)

Project Number and Title	Source*	Regional Application	Related Studies	LOGISTICS					Completed Budget	Statistical Design
				Deep Water Vessel	Nearshore Vessel	Fixed-Wing Aircraft	Helicopter	CCRS Aircraft		
18. Effects on human utilization of wildlife	1	A	-						X	-
19. Biochemical detoxification mechanisms in fish eggs and larvae	2	G	3		X				-	-
20. Incorporation of oil in benthic biota after a spill	2	G	4, 25		X				-	-
21. Population level assessments	2	G	-						-	-
22. Effects of oil on zooplankton	2	G	7	X	X				-	-
23. Stimulation of oleoclastic bacterial growth under an oil slick	2	G	1, 24		X				-	-
24. Growth of oleoclastic bacteria under and in oil-contaminated ice	2	A, At	1, 5, 23		X				-	-
25. Macrofaunal and macroalgal losses from intertidal oiling	2	G	4		X		X		-	-
26. Effects of oiling on lobsters and ecosystem interactions with kelp and sea urchins	2	At	-		X				X	-
27. Effects of oil on seabirds	2	G	9, 10, 29			X			-	-
28. Effects of oil on seals	2	G	30				X		-	-
29. Bird mortality survey	3	G	9, 10, 27			X			X	-
30. Marine mammal observation	3	G	28				X		X	-
31. Intertidal biological effects	3	G	4, 25						X	-
32. Subtidal Biological effects	3	G	4, 20		X				X	-

* Sources: 1 - Ward and Tull 1977; 2 - Keizer 1982; 3 - Green et al. 1982.

Most (19) of the 32 proposals have general application (i.e., they could be conducted anywhere in Canada). The other main category was Arctic with 12 specific projects (Table A-1). This reflects the recent emphasis on oil spill planning and countermeasures in the Beaufort Sea. Many of these cover ice-related phenomena.

Major taxonomic groups have been differentiated. This has been done to alert the reader to areas on which emphasis has been placed. It is an awkward division, since it includes benthos and plankton, terms which describe diverse collections of plants and animals.

Proposed studies on marine mammals (8), benthos (7), and birds (6) have received the greatest emphasis. In the case of benthos, it is possible to plan long-term studies in littoral-benthic environments where sampling strategies are easier to implement, inexpensive to fund, and the potential for success is high. Monitoring studies directed at marine birds and mammals are primarily descriptive. Their large numbers clearly reflect conservation concerns in the Beaufort Sea. Logistical constraints, expense and problems with sampling and interpretation probably explain the lower number of studies directed at plankton (4), fish (3), and bacteria (3). Only one study considered the socio-economic impact of resource loss, specifically the human utilization of wildlife.

Most studies have been budgetted, although the ones proposed for the Arctic reflect dated costing (Fisheries and Oceans 1979). However, they provide sufficient detail to allow updating.

One important omission of the proposed studies is the consideration of specific statistical methodologies or approaches (Table A-1), although Keizer (1982) makes frequent reference to the problem of inference. One of the first scientific meetings convened to address oil spill studies pointed out that one of the chief weaknesses of studies to that time (1976) was their "varied - if any - statistical methodologies" (API 1977). An entire chapter in the published proceedings addressed this topic. Subsequent reports, with one exception (Keizer 1982), ignore this emphasis. Not one is explicit about experimental design, or clear about what hypothesis is being tested. As a consequence, the reader is left wondering whether the data collected can be linked with any statistically-supportable conclusions. Since funding is a key unknown in the future, this omission could clearly scuttle any significant increases beyond the limited support for this work now provided by the Environmental Emergency Branch of Environment Canada. Some projects admittedly are clearly intended to be descriptive, and would provide a valuable function as input (damage assessment) into the oil spill operation.

The projects were reviewed in terms of their focus on taxonomically or ecologically distinct groups. A project-by-project evaluation is not provided since there are merits in all proposals, however unevenly presented. An aim of this study was to group and combine research projects according to common sets of impact assessments. Alternatively, other samples of feasible projects could have been selected which could then be considered for future spills. Either way, designated teams could be alerted and thus be prepared should a spill of opportunity occur. All biological study areas reviewed are now briefly discussed; as can be noted, these do not correspond to the five categories of biological studies finally selected for inclusion in the plan, since the rejection of some subjects and regrouping of others were found to be necessary.

Bacteria

Microbial (or bacterial) degradation is one component of the natural dissipation of oil spills. It is in this context that microbiota are most frequently related to oil spills. Some of their basic attributes have been reviewed (ICES 1981), and are not repeated in detail here. Biodegradation rates are inversely related to temperature (Higgins and Gilbert 1978) from which one might infer that the activity of oleoclastic bacteria is significantly slower in Canadian waters vis-a-vis ocean environments in warmer climates.

A negative impact of oil spills is that non-oleoclastic bacteria may be killed. On a large scale, this could interrupt the breakdown of naturally-occurring organic material.

Three projects listed in Table A-1 (Nos. 2, 23, 24) address microbial activity. Two of them (2, 23) are similar in their overall objectives, although they differ in sampling strategy. In both cases, continuous sampling of bacteria under the oil slick is recommended, until the slick disperses or reaches the shore. From following a slick in such a way, i.e. sampling microbial organisms regularly, it may be possible to draw inferences about microbial decomposition of oil. A third proposed study (24) addresses similar questions in ice.

In all cases, sampling effectively under the oil may be, at the very least, a technical challenge. Moreover, based on studies reported in the literature, there is little reason to expect microbial activity to be a useful element in the clean-up process over the shorter term. Further studies to pursue this unique countermeasures notion do not appear to warrant a high priority status. They are therefore excluded as any major part of a proposed study in this work.

None of the three proposals consider dispersants. Theoretically, there is reason to predict enhanced biodegradation with chemically dispersed oil, but it has yet to be tested.

Plankton

Four projects (5, 6, 7 and 22) address the effects of oil spills on the planktonic components of pelagic ecosystems (Table A-1). Because of sampling and interpretive constraints, empirical data on the response of plankton to oil have been limited. Most current information comes from laboratory studies. To generalize, there is evidence that under specific conditions oil stimulates phytoplankton growth, but depresses survival and reproduction in zooplankton, and survival in ichthyoplankton (ICES 1981). The trophic and commercial importance of zooplankton and ichthyoplankton warrants continued examination to improve quantification and potentially to identify protection strategies.

Two of the proposed projects (5, 6) are directly related to under-ice flora and fauna, during a brief 4-6 week period of high biological activity. The other two (7, 22) address pelagic ecosystems, specifically sampling plankton in oil-contaminated waters. There are sampling challenges which are discussed by Keizer (1982), and these would have to be overcome prior to project mobilization.

As with bacteria, none of the projects directed at plankton discuss the operational use of dispersants as an experimental "treatment". Owing to the limited experimental design, the inclusion of dispersants would be relatively straightforward.

Benthos

When oil comes ashore, it is the biota of the littoral-benthic communities which become the conspicuous victims. The intertidal component of this area is readily accessible, and so has produced some of the best documentation of short- and long-term ecological effects from oil spills (e.g. Southward and Southward 1978; Vandermeulen and Gordon 1976). Eight spills of opportunity projects (1, 4, 20, 21, 25, 26, 31 and 32) are directed at the benthos (Table 1). Most of these focus on sedentary invertebrates, but two address vegetation.

The proposed projects have several common elements:

1. control, or non-oiled, study sites, as an important part of the sampling strategy;

2. water column sampling to identify oil at depth in nearshore areas;

3. hydrocarbon analysis of sediment samples;

4. sampling of target species and communities: vegetation, invertebrates; and

5. hydrocarbon analysis of invertebrate tissue.

The rationale for collecting such data is not always clear in the proposed projects. This raises an element of doubt about justification; therefore, some reiteration is appropriate.

The most important studies fall under the term "damage assessment". Some sort of ecological balance sheet is a minimum requirement for large spills in parts of the world, such as Canada, where natural resources are managed at an advanced level. Second, the daily plotting of countermeasures strategies under the direction of the On-Scene-Commander requires the frequent input of damage assessment data. The focus of most of these assessments is the benthic communities: intertidal, subtidal, and marshes. Thirdly, the effectiveness of different countermeasures strategies should be evaluated in terms of resource protection. The results can be useful for managing the spill at hand, as well as future spills. Lastly, relatively simple experiments can potentially identify the effects of specific countermeasures, such as dispersant application. Comparative data of this sort would be most useful to operational staff in determining whether future countermeasures should expend greater or lesser effort on the option of chemical dispersion.

To meet these requirements, a reasonable level of experimental design is needed. In the case of dispersant application, there are a number of alternative non-parametric and parametric approaches at varying levels of complexity (API 1977). The goal of any data gathering exercise during or after a spill is the testing of some hypothesis; otherwise, an opportunity is lost to clarify several operationally-relevant questions. However, the "naturalist" style of observation proposed by Green et al. (1982) might be the only available option for some spills.

Several of the benthos proposals adopt a qualitative or "naturalist" approach (31, 32). At least three (1, 4, 26) provide considerable detail, but although systematic procedures are described, it is vague how these support the overall project design and it is left up to the reader to determine this.

As yet, there are no proposed projects to examine the impact of oil on raft cultures of shellfish and similar mariculture facilities near the littoral-benthic zone.

It appears that benthic communities are easily accessible, and have other attributes which make them highly suitable for Spills of Opportunity research. Thus, even though specific proposals may be incomplete in some respects, their basic ideas should be pursued.

Fish

Impacts of oil on marine fish are poorly known. The reported examples of fish mortality are few and as a result raise more questions than they answer (Grose and Mattson 1977; Mackie et al. 1978). The reported incidents refer to conspicuous fish kills; but this does not mean that impacts to fish do not occur in other cases. To generalize, recorded cases of mortality have occurred to fish reared in pens, and the pelagic larvae of fish. Varying levels of tainting is another impact. Interruption of commercial fisheries is a frequent consequence of oil spills, but tends to be overlooked in the literature. The current hypothesis is that pelagic eggs and larvae represent the most vulnerable life history stages.

Assessing oil spill impacts on highly mobile organisms is not practical. Not surprisingly, the projects proposed (4, 7, 19) address topics where useful data can be gathered. Although effects on mortality cannot easily be studied, the presence of oil in fish tissue (4, 7) is important to the commercially-sensitive issue of tainting. Future population recruitment can be reduced by negative impacts on fish eggs and larvae, the focus of one proposal (7). A further proposal (19) addresses the dynamics of detoxification mechanisms in fish eggs and larvae.

Studies to collect samples of fish for tissue analysis would appear to be a high priority, because of commercial usefulness and high probability of success. However, prior to these being implemented, the existing proposals require modification to clarify rationale and experimental design. The alternative approach presented in this study has been the proposal of a range of investigations which consider the bioaccumulation and other effects of hydrocarbons on various members of pelagic communities.

Birds

Birds are usually the most conspicuous victims of oil spills. The literature is replete with numerous examples of major bird kills from oil spills, including the Torrey Canyon (Bourne et al. 1967), Amoco Cadiz (Spooner 1978), and the Kurdistan (Brown and Johnson 1980).

A total of six projects have been proposed (8, 9, 10, 11, 27, 29). Their objectives are largely descriptive, and thus the function of the data collected falls under the practical category of damage assessment rather than research. They propose to determine the species and number of birds oiled and/or killed (8, 9, 10), and one of these (9) proposes to compare such numbers with recent survey data. This might be a suitable test of the Bird Oil Index proposed by Wahl et al. (1981). Observations on the reactions of birds to oil (8, 9) seem to have less operational usefulness.

Mammals

There are reports of sea lions and their pups being oiled as a result of the Santa Barbara oil spill (LeBoeuf 1971; Brownell and LeBoeuf 1971), but there is no clear evidence that this led directly to any mortality at Santa Barbara, or as a result of any other reported spill. However, the concern persists, particularly in areas of high marine mammal utilization. Eight projects have been proposed (12, 13, 14, 15, 16, 17, 28, 30), six of which are directed at Arctic marine mammals.

Oil contamination in leads and polynyas is a major concern. Because these are restricted habitats, oil would be difficult to avoid, and pupping for some species occurs here. Three studies (12, 13, 14) address different aspects of this question, and a fourth (15) examines a trophically-related species, the polar bear.

Although the probable mortality impacts appear to be much lower with bowhead and white whales, similar questions remain about the possible response to encountering oil in constricted leads. Two projects (16, 17) are directed at this question.

These investigations are essentially descriptive, and the results would be based on observations of whales as they encountered oily waters as seen from the air. Owing to resource sensitivities, such observations would be keenly awaited.

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