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Shoreline Monitoring Programs for Oil Spills-of-Opportunity

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SHORELINE MONITORING PROGRAMS FOR OIL SPILLS-OF-OPPORTUNITY

John R. Harper

Dobrocky Seatech Ltd.
9865 West Saanich Road
Sidney, British Columbia

Edward H. Owens

Woodward-Clyde Oceaneering
Abbotswell Road, West Tollos
Aberdeen, Scotland

Scientific Adviser: Wishart Robson

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SUMMARY

This report outlines procedures for conducting shoreline monitoring programs of opportunity for accidental oil spills; the procedures outlined apply to documentation of oil contamination levels only and do not address biological concerns. The report outlines the general methodology for providing an observation and sampling program to estimate the extent and volume of oil stranded in the shore zone. A critical step in the selection of an appropriate monitoring program is the definition of the program objective because these objectives will determine the scope and therefore cost of the program. Objectives may range from (a) reconnaissance level observations either to determine if cleanup is required or to assist in the allocation of cleanup crews to (b) detailed oil-sample analyses to assist in litigation proceedings or to support long-term scientific research.

A hierarchical approach to conducting the monitoring program is recommended and concentrates on documenting general distributions of contamination first and moving towards progressively more detailed data acquisition. Components include:

- **aerial reconnaissance surveys** (first-order survey), in which systematic visual observations are used to define the extent and range of contamination;

- **ground surveys** (second-order survey), in which systematic visual observations at selected sites are used to verify and "calibrate" aerial observations; and

- **sample collection surveys** (third-order survey), in which samples are collected in conjunction with ground surveys and analysis results are used to quantify visual observations.

The use of a phased, hierarchical approach is important because it not only allows flexibility in selecting a monitoring program appropriate to the budget, but also provides an objective means of selecting sites for ground surveys and sample collection that will maximize sample representivity. An important aspect of the hierarchical approach is that data from a more general program is a prerequisite to design and implementation of more detailed programs. The use of reconnaissance level data in the design of the detailed sampling programs greatly improves the ability to detect real change.

RÉSUMÉ

Ce rapport détermine les modalités de gestion des programmes de surveillance du littoral en cas de déversements accidentels de pétrole; les méthodes énoncées ne s'appliquent qu'a la documentation relative aux degrés de pollution par les hydrocarbures et non à des préoccupations d'ordre biologique. Le rapport décrit les méthodes générales pour établir un programme d'observation et d'échantillonnage destiné à évaluer l'étendue et le volume de pétrole répandu sur le littoral. L'une des étapes essentielles de la sélection d'un programme de surveillance adéquat consiste à définir les objectifs du programme, car ce sont eux qui vont déterminer l'envergure et, par conséquent, le coût du programme. Les objectifs peuvent aller a) d'observations au simple stade de la reconnaissance, soit pour déterminer si un nettoyage est nécessaire, soit pour aider à affecter les équipes de nettoyage à b) des analyses détaillées d'échantillons de pétrole, afin d'apporter une part de contribution aux procédures de litige ou une aide à la recherche scientifique à long terme.

Pour gérer ce programme de surveillance, il est recommandé de procéder hiérarchiquement en s'efforçant d'abord de fournir la documentation nécessaire sur la diffusion générale de la pollution, puis en essayant de recueillir des données de plus en plus détaillées. Les composantes du programme comprennent:

- des recensements aériens de reconnaissance (recensement de premier ordre) au cours desquels on utilise les observations systématiques visuelles pour établir l'étendue et l'amplitude de la contamination;

- des recensements au sol (recensement de second ordre) au cours desquels on utilise les observations systématiques visuelles effectuées dans certains endroits pour vérifier et "calibrer" les observations aériennes;

- des recensements par prélèvements d'échantillons (recensement de troisième ordre) au cours desquels, parallèlement aux recensements au sol, on prélève des échantillons dont on utilise les résultats d'analyse pour justifier les observations visuelles.

L'approche hiérarchique par phases est importante; en effet elle offre non seulement de la souplesse dans la sélection d'un programme de surveillance adapté au budget, mais aussi un moyen objectif de choisir des endroits propices aux recensements au sol et à la collecte d'échantillons qui maximiseront leur représentativité. L'approche hiérarchique comporte un aspect important: il est nécessaire d'avoir les données d'un programme plus général avant de concevoir et de mettre en application des programmes plus détaillés. L'utilisation de données au stade de la reconnaissance dans la conception de programmes d'échantillonnage détaillés améliore sensiblement la faculté de discerner de réels changements.

INTRODUCTION

This report provides an initial summary of a project for developing shoreline monitoring programs of oil spills-of-opportunity. The report outlines the general methodology for providing an observation and sampling program to estimate the extent and volume of oil stranded in the shore zone.

STATEMENT OF THE PROBLEM

Numerous studies have been conducted to develop monitoring programs for oil spills (e.g., Baca et al. 1983; Cox et al. 1980; Green et al. 1982; Keizer 1982; Moore and McLaughlin 1978; Smith 1979; Ward and Tull 1977) but few of these programs have looked specifically at shorelines and even fewer have identified defensible monitoring programs.

Sample results from the Baffin Island Oil Spill (BIOS), a mesoscale experimental oil-spill study in the Arctic, provide an index of the complexity of the problem. A number of small, oiled test plots were established in the supratidal and intertidal zone to evaluate the fate of oil in the Arctic marine environment. Despite the fact that oil was applied uniformly over very small areas and that subsequent samples were collected from within a few metres of each other, samples showed an order-of-magnitude difference in total hydrocarbon content within the same plot (Woodward-Clyde 1981). It became clear during the experiment that spatial variability of sediment oil contents was the most significant problem faced in the monitoring programs.

Recent attempts to document the oil cover and volume for one of the BIOS experimental bays using a very detailed sample and observation program (Owens 1984a) produced ranges of over 25% using various techniques. This sampling and accounting problem is accentuated by certain substrate types and coastal processes and is likely to be even more of a problem where oiling is non-uniform, such as in an accidental spill.

The principal problem with previous monitoring programs is that they have relied on a single technique for estimating the volume of oil stranded in the shore zone. There is **no single technique** that can be used to map or monitor the extent of oil-contaminated shoreline on a universal basis.

OBJECTIVES OF THE PROGRAM

The objective of this project was to develop a methodology that could be used to document the spatial extent of oil spilled on a shoreline (including oil in sediments) and to monitor the change in extent of the oil over time if necessary. A prerequisite was that the methodology must include a range of observation and sampling techniques to accommodate a wide range of coastal types, coastal processes, countermeasure techniques, and spill characteristics that affect the fate of stranded oil. A hierarchical approach was envisaged to allow monitoring programs to be matched to budgets and to provide a range of survey levels.

PROJECT SCOPE

During the project previous oil-spill monitoring programs were reviewed (up to January 1985) as were potential remote sensing techniques and analytical techniques. The review of these projects, as well as the project team members' personal experience with spills-of-opportunity and monitoring programs, provided the basis for outlining a hierarchical approach to shoreline monitoring programs. A summary of appropriate programs is outlined as a function of the amount of effort (or funding) available.

DEFINITION OF MONITORING OBJECTIVES

Monitoring objectives must be defined early in the spill to determine the appropriate monitoring effort. Three possible objectives, which require varying response efforts, are:

(1) monitoring for operational use (e.g., to outline areas contaminated and general levels of contamination) that will assist in the spill response (e.g., cleanup priorities, etc.); requires a minimal monitoring effort.

(2) monitoring for scientific use in long-term evaluations of spill impacts; monitoring effort may vary from general to very detailed.

(3) monitoring for <u>legal use</u> where documentation of spill effects may be required for use in litigation proceedings; this objective usually corresponds to the most detailed monitoring effort because defensible quantitative effects must be evaluated.

It is important to establish the objective of the monitoring program early in the oil spill (or even before a spill) as this will determine the most appropriate monitoring effort, required resources, and potential monitoring costs.

Other factors that may influence the monitoring objectives are:

- spill size
- oil types (adhesion properties, toxicity)
- shoreline types
- environmental concerns (perceived or real).

BACKGROUND

As a prerequisite to establishing a flexible monitoring plan, previous monitoring programs were reviewed for strengths and weaknesses; pertinent studies are summarized in the following sections. This overview relates to published or unpublished material to January 1985. In addition, other techniques that are potentially useful but have not been used as part of previous monitoring programs are reviewed. Statistical sampling techniques and contraints also are reviewed.

A discussion provides an overview of potential techniques and forms the basis for the recommendations made as part of this study.

PREVIOUS MONITORING PROGRAMS

Comprehensive monitoring programs are rare and when reported, usually focus on the results of the analyses rather than on the methods used to obtain results. The following studies are relevant and were reviewed as part of this study:

- the *Burmah Agate* spill, which took place in Galveston, Texas (Thebeau and Kana 1981);
- the *Amoco Cadiz* spill (Gundlach et al. 1983);
- the Cape Fear River spill, where marsh was extensively oiled (Baca et al. 1983);
- the Eagle Creek diesel fuel spill on the Queen Charlotte Islands of British Columbia (McLaren 1985); and
- the Baffin Island oil spill, where a four-year experimental study is ongoing (Owens et al. 1982; 1983; Owens 1984a; 1984b).

These studies provide information on monitoring oil spills at a range of scales from the very large catastrophic type spill (the *Amoco Cadiz*) to fuel oil spills (McLaren 1985) to experimental spills (Owens 1984a).

Burmah Agate Oil Spill. The *Burmah Agate* spill occurred in Galveston, Texas, with a total loss of oil in the range of 39,750 m^3 (250,000 bbl). A monitoring program was established shortly after the spill to estimate the quantity of oil stranded in the shore zone (Maynard 1981; Thebeau and

Kana 1981). The program was established quickly after the spill as a result of previous work that had been done on the Ixtoc spill. The program established volumes of oil stranded on various beaches in the Galveston area.

The monitoring program is noteworthy in that more than one technique was employed to quantify the amount of oil that was stranded in the shore zone. The program was used also to document the effectiveness of spill cleanup operations. Principal features were:

- aerial surveys of the spill area were used to regionally document the extent of the spill;

- ground-truth surveys, including sediment sample collection and surveying, were conducted to verify the aerial observations;

- the estimates were converted into equivalent volumes of oil for one-mile sections of coastlines (Fig. 1).

The technique is of interest in that it uses a hierarchical approach to sampling; however, there are no reported details of the specific sampling methods or sample analysis results. Nor is there any specific information on exactly how the ground surveys were related to the aerial surveys. As a result of these deficiencies, it is uncertain if the program could be used to provide a long-term (weeks to months) documentation of natural cleaning processes.

Amoco Cadiz Oil Spill. The Amoco Cadiz event is the largest and most-studied tanker spill in history. The entire cargo of $2.6 \times 10^5 m^3$ (1.6×10^6 bbl) was spilled within a few kilometres of the shore. An extensive study was mounted by National Oceanic and Atmospheric Administration (NOAA) at the time of the spill (Hess 1978), which included a shoreline monitoring program. The shoreline program followed a similar approach to that in the Burmah Agate spill. The researchers used this information to reconstruct an oil budget for the spill (Gundlach et al. 1983). The approach involved:

- aerial surveys to document the regional extent of oil contamination;

- ground-truth surveys to systematically record observations of oil in the intertidal zone; and

- sample analysis to quantify volumes of oil actually on or incorporated into the sediments.

The information was used to document the change in oil extent over a three-year period (Fig. 2). The confidence of the technique is uncertain because little of the data is presented nor are there specific details of

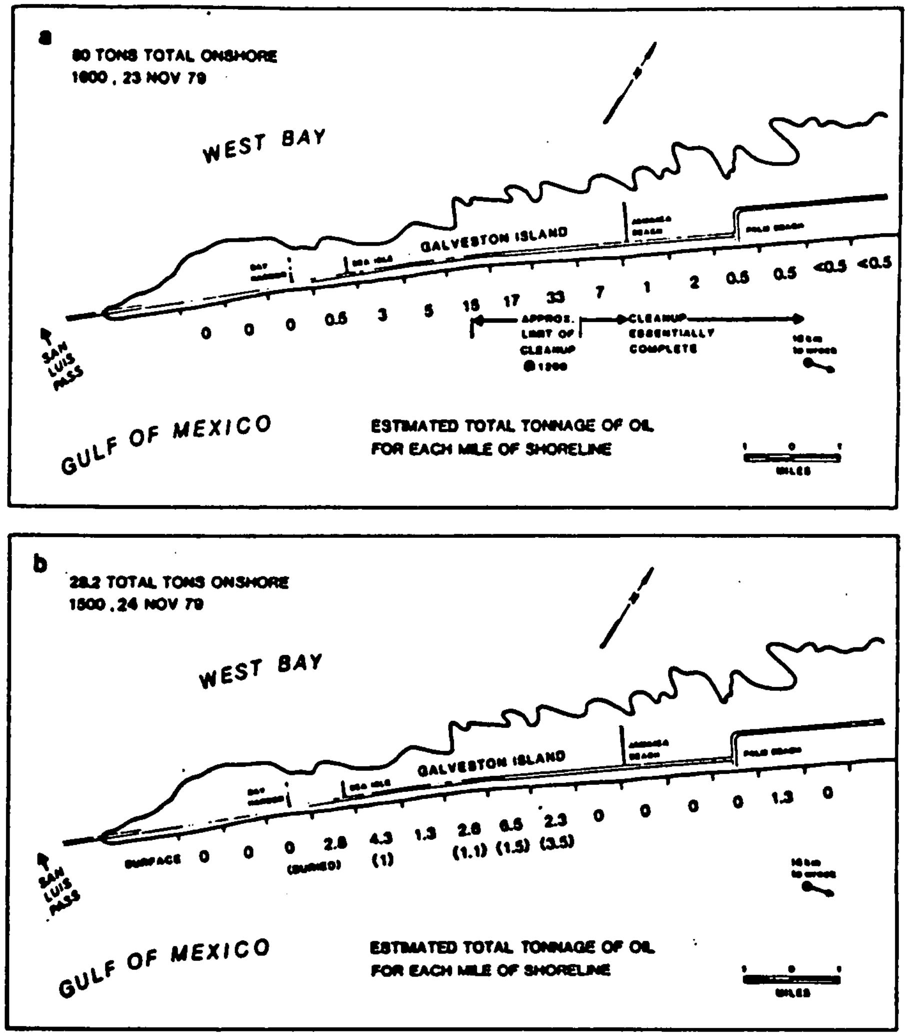

Figure 1. Shoreline contamination levels at the Burmah Agate spill, Galveston, Texas, on consecutive days (from Thebeau and Kana 1981).

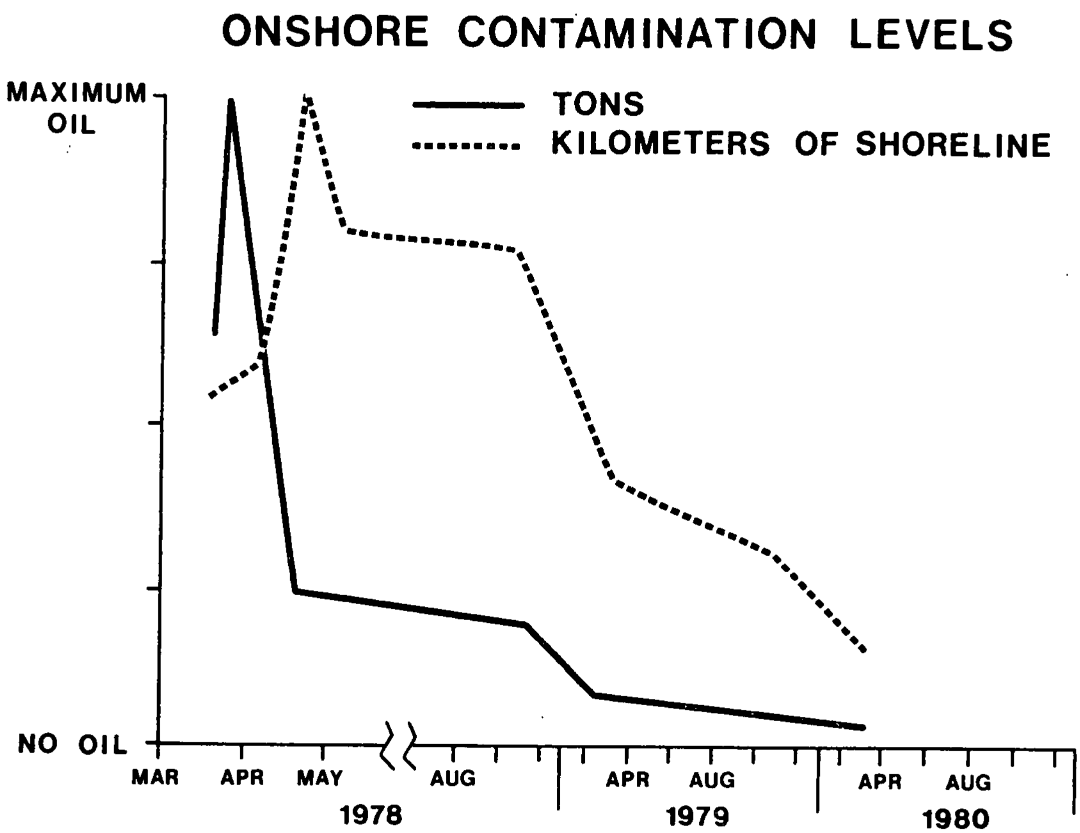

Figure 2. Changes in shoreline contamination levels over three-year period, Amoco Cadiz oil spill (after Gundlach et al. 1983).

how the ground surveys are related to the aerial surveys or how the sampling surveys are related to the ground surveys.

Figure 2 illustrates the problem of reporting kilometres of shoreline oiled versus volume of oil retained on the shore; **while the total length of contaminated shoreline decreased slowly, the volumetric reductions in shore-zone oil content were rapid.** Many spill reports provide an estimate of length of shoreline contaminated without an index of volume of material involved or degree of contamination. As the diagram indicates, the results can be quite misleading (Fig. 2).

Cape Fear River Oil Spill. The Cape Fear River oil spill involved in the order of 3.8 to 760 m^3 (24 to 4,780 bbl) of fuel oil that extensively contaminated marsh areas of the Cape Fear River. The monitoring program was unique in that a method for quantitatively estimating the extent of oiling in vegetation was developed (Baca et al. 1983). The following procedures were used:

- aerial overflights were used to map the distribution of dominant marsh species and to map six levels of contamination, ranging from very heavy to light;

- twenty-one ground-truth stations were established that were used to verify aerial observations and to provide additional detail of the oiling such as widths of fringing marsh that was oiled; and

- oiled plant specimens were collected to determine (a) density of species per unit area, (b) area to which oil was clinging on the plants, and (c) average thickness of oil on the plants.

The detailed field data then was used to estimate the volume of oil associated with each contamination category and to provide volumetric estimates of oil on the shoreline. The technique is defensible in that a hierarchical approach was used to systematically define more detailed sampling sites. As such, the technique explicitly identifies representative sites for sample collection and each sample that is analysed can be assumed to be "representative" with a high degree confidence.

Eagle Creek Oil Spill. The Eagle Creek oil spill occurred in British Columbia's Queen Charlotte Islands in 1984 and involved an estimated 144 m^3 (908 bbl) of diesel fuel and 33 m^3 (207 bbl) of gasoline. A monitoring program was established to document (a) the amount of oil stranded in the shore zone and (b) the natural dispersion of the oil (McLaren 1985). The monitoring program was on a small scale, as is appropriate to this type of spill, but is notable in that it documented the importance of the groundwater-table in controlling apparent oil concentrations in the shore zone.

The extent of the oiling was small and less than one kilometre along the beach was sampled. The sampling program continued over a two-month period from early March until the end of April 1984. Samples collected in this period were used to document the rate of natural cleaning. The sample results clearly illustrate the importance of ground water table fluctuations in controlling the oil distribution in the shore zone. Figure 3 schematically illustrates the process.

These results have important implications to monitoring programs in that they show (a) oil distribution in the shore zone is strongly influenced by the presence of groundwater in the beach sediments, (b) one or two or even a few samples may not adequately account for the spatial oil variability (i.e., highest concentrations may occur where the ground water table crops out on the beach), and (c) the oil distribution in beach sediments is not static but rather is mobile and can migrate significantly in only a few hours, possibly on a cyclical basis (Fig. 3).

Baffin Island Oil Spill (BIOS). The BIOS program is an experimental oil spill study and contrasts to the previously described spills in that the experimental design was determined prior to the spill and the spread of oil was comparatively uniform. Despite the fact that oil was applied uniformly over very small areas and that subsequent samples were collected within a few metres of each other, it was not uncommon for samples to show an order-of-magnitude difference in total hydrocarbon content within the same plot (Woodward-Clyde 1981). It became apparent that spatial variability of sediment oil contents was the most significant problem faced in the monitoring program. Recent attempts to estimate the total volume of oil initially stranded on one of the experimental bays produced a range of over 40% (Humphrey 1983; Owens 1984a). Given that the oiling in these experiments was extremely uniform and that sampling was intensive, the results are somewhat discouraging in terms of establishing effective monitoring programs for-spills-of opportunity. The results do emphasize the need for a stratified sampling approach that can be used to minimize natural variability.

Other Monitoring Programs for Spills-of-Opportunity. The Environmental Protection Service (Environment Canada) recently funded a series of projects to outline scientific research projects for spills-of-opportunity (Humphrey and Keizer 1984; Green et al. 1982; Keizer 1982; MacKay 1982; Ward and Tull 1977). These reports provide only a cursory review of shoreline monitoring programs and fail to identify a program that is flexible enough to accommodate a wide range of shoreline types, processes, and spills. Although all of the reports recommend detailed site sampling and surveys, there is no description of how these sample sites are to be related to a regional context or if they are representative of the coastline as a whole. Without some type of stratified approach to the sampling program, the utility of a detailed sampling program is questionable.

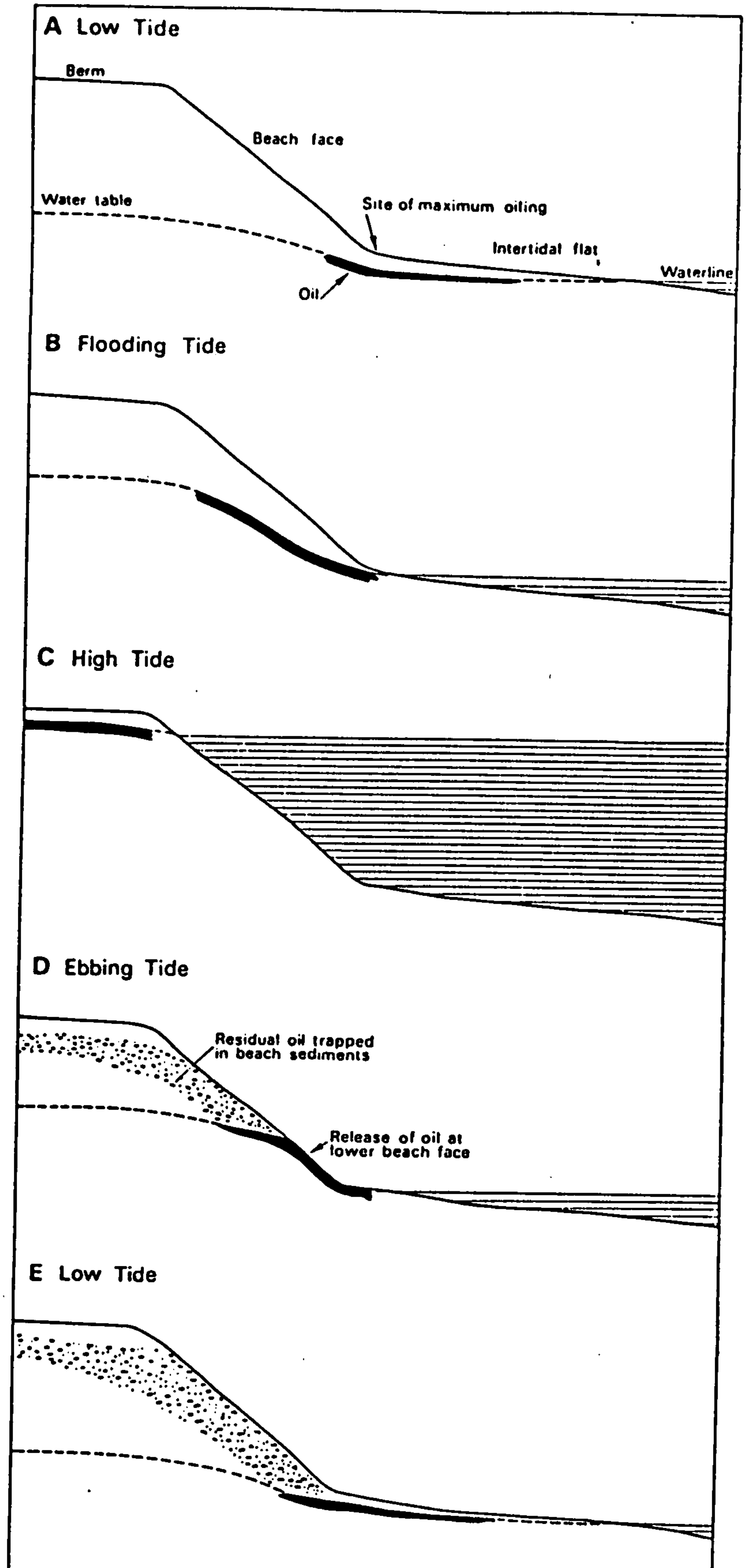

Figure 3. Changes in oil distribution during the Eagle Creek spill (from McLaren 1985).

REMOTE SENSING TECHNIQUES

In the monitoring programs discussed above, several investigators used aerial observations to provide regional overviews for more detailed ground surveys and sampling. These aerial observations are typically carried out by experienced spill personnel making systematic notes of the contamination levels along the shoreline. Remote sensing techniques, which have been widely investigated for use in tracking spills offshore, may provide a means of objectively delineating spills on shorelines. For this reason, potentially useful remote sensing techniques that could be used on shoreline spills are provided. To date, no remote sensing techniques have been used quantitatively to estimate contamination levels along shorelines.

Various remote sensors techniques for use in offshore oil spills are described in Fingas (1979), Logan et al. (1975), Neville et al. (1979) and White and Schmidt (1981). These include:

- low-light-level video (LLLV)
- colour photography
- laser fluorosensors
- multispectral scanners
- ultraviolet photography
- synthetic aperture radars
- microwave scatterometers
- infra-red/ultraviolet scanners (IR/UV scanners).

Review of performance tests suggests that only some of these sensors may be appropriate for documentation of shoreline spills.

Instruments that rely on changes in the surface roughness of water, such as the synthetic aperture radar and the microwave scatterometers, are not appropriate to shoreline spills. Other instrumentation that may be usable, but which requires special support aircraft, is less likely to be used on spills because of high mobilization and operating costs; these include laser fluorosensors, multispectral scanners and IR/UV scanners.

Readily available off-the-shelf equipment includes (a) low-light-level video cameras, (b) colour photography and (c) IR or UV-photography. Advantages of each are summarized below:

- low-light-level video cameras are readily available, may be easily transported into the field, provide real-time imagery and also can be used to record a narrative of the spill conditions There is the potential to add near-IR filters to enhance contrast between oiled and unoiled sediment.

- colour-film photography is available for a wide range of 35-mm cameras. Instant 35-mm film is now available commercially thus providing near real-time imagery. The colour images can be enhanced with computer video techniques on a near real-time basis.

- UV and IR film photography can be used with conventional cameras, thus offering easy use with a wide range of accessories. Since the reflection characteristics are similar between oiled and unoiled sediment in the UV range, the utility of UV film in the shore zone is probably minimal (Fig. 4). However, the use of IR film may enhance reflectance characteristics.

A combination of 35-mm colour photographs and low-high video imagery appears to offer the most versatile and flexible means of acquiring imagery of contaminated shorelines. Their sensors require no special aircraft or power supplies and offer real-time results that can be used immediately to refine a monitoring program. Their comparatively low cost increases the probability that they will be used early and frequently throughout the spill response.

There are presently no published results on enhancements that would improve these sensor's sensitivity to detecting shoreline spills. For example, experiments would be useful to determine if IR filters on low-light-level video would improve contrast between oiled and unoiled sediment. Similarly, it would be helpful to know the most appropriate conventional 35-mm films and filters for use in delineating contaminated shorelines.

STATISTICAL SAMPLING APPROACHES

Beach sampling programs have often provided the basis for long-term monitoring of shoreline oil retention levels. For the most part these programs have not been developed with a sound statistical design, and the significance of many of the findings are therefore suspect. Cox et al. (1980) outline basic statistical design for sampling on shorelines; this approach is essentially a special case of bulk materials sampling for chemical analyses (Kratochvil and Taylor 1981; Kratochvil et al. 1984).

The critical question evaluated by monitoring programs is: has there been a significant (or measurable) change in shoreline oil content over time? This is more correctly stated as: is there a significant difference between samples collected at t_o and t_1 assuming a given confidence interval? An important corollary to these questions is: do the sample or

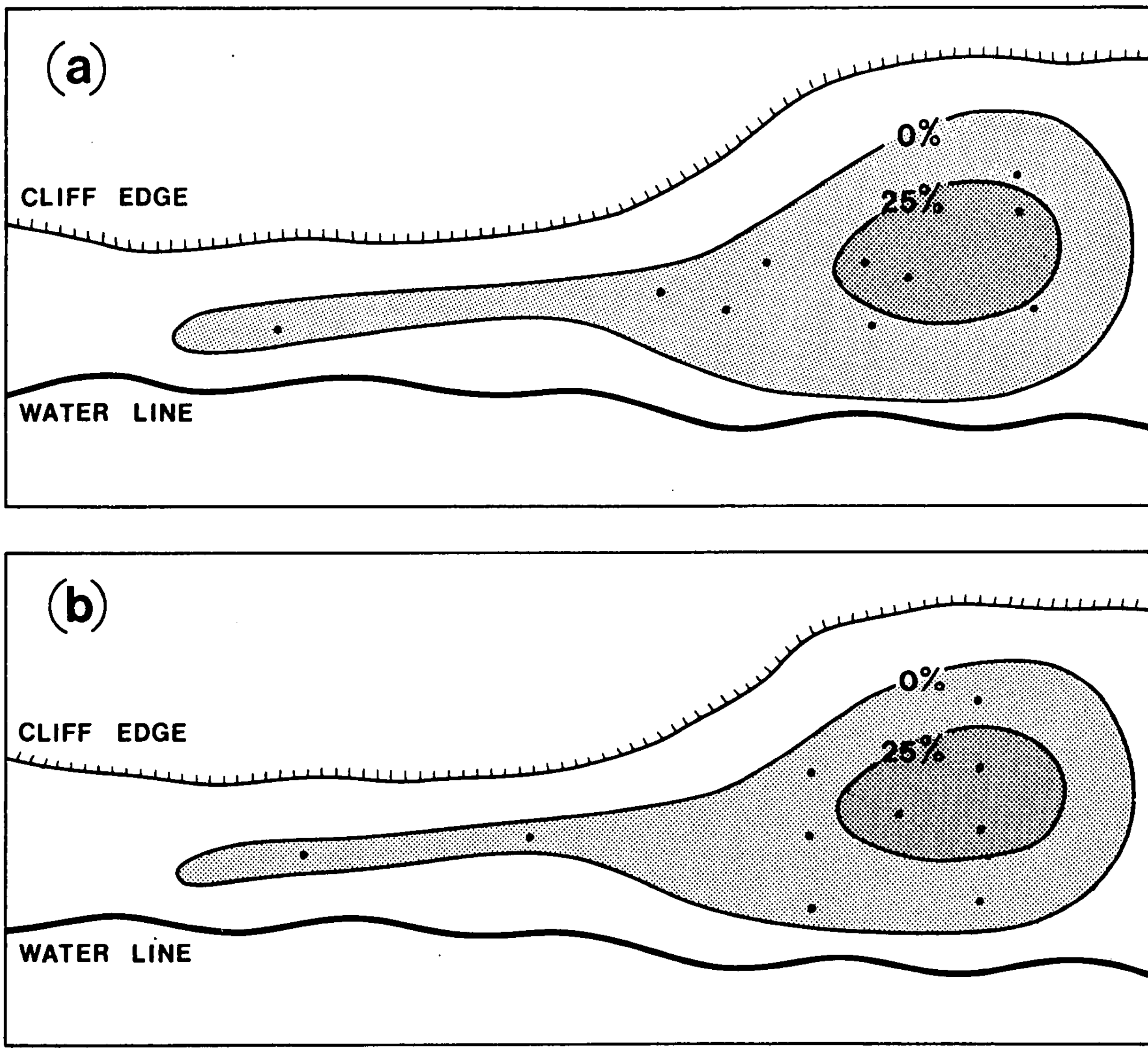

Figure 4. Schematic illustration of (a) stratified-random sampling approach and (b) stratified-systematic sampling approach for the same oil spill (contours indicate per cent oil cover).

samples collected adequately define the populations (assuming a normal distribution) from which they are collected? The random sampling strategy designed to answer these questions can be characterized by the equation (Cox et al. 1980):

$$n = \left(\frac{z\ \sigma d}{e}\right)^2$$

where n = the number of replicates or samples required;

σd = the standard deviation of concentrations anticipated;

e = the acceptable error [e = $\bar{X}$ x R, $\bar{X}$ is the mean and R is the acceptable deviation in the mean];

z = the "t" value for 95% confidence limit (two-tailed).

Two examples illustrate the use of the equation. The first uses data from the BIOS backshore experimental plots (Woodward-Clyde 1981) where (a) the standard deviation (σd) of hydrocarbon concentrations in a plot was 1,800 mg/kg, (b) the objective is to determine the true population mean within a factor of 20% (R = 0.2, $\bar{X}$ = 4,900 mg/kg); and (c) z is 1.96 for 95% confidence limit. The required number of samples or replicates within this plot is then 13 samples (analysis cost approximately $650). This is for a "uniformly" oiled plot! Another hypothetical example of a naturally oiled shoreline where σd is 5,000 mg/kg, e is 1,000 (R = 0.2; $\bar{X}$ = 5,000 mg/kg) and z is 1.96, yields an appropriate sample number of 96. If a greater error is acceptable, for example an estimate of the true mean within 50%, 15 samples would be required. The results clearly indicate that is important to provide a systematic approach to minimize sample variance (i.e., provide more representative samples).

In <u>stratified sampling</u> the populations are divided into strata, in which variance is smaller than the population as a whole. The strata then can be sampled randomly (<u>stratified-random sampling</u>) or systematically (<u>stratified-systematic sampling</u>), provided that individuals of the population are randomly distributed within the strata (Cox et al. 1980). A systematic sampling program is more easily implemented in the field.

Several examples illustrate the use of stratified sampling approach. If, for example, a beach is classified in terms of three levels of contamination from visual ground survey, then samples should be collected from each of the three contamination zones. The samples can either be sampled randomly from each contamination zone (i.e., using a random sampling design) or sampled systematically (i.e., using a grid). In general, systematic sampling is more easily accomplished in the field because it is easier to set up a grid than random sample locations (Fig. 4).

It is clear from the above discussions that if a sampling program is to provide meaningful results, some type of classification or stratification must be used to minimize sample variance and effectively reduce the number of samples required. Other aspects of natural shorelines that complicate the sampling process include:

- particle size is an important consideration in that the less uniform a population is, the harder it is to sample (i.e., larger volume samples are required, Kratochvil et al. 1984);

- sampling areas should be large relative to patchiness.

These effects provide important constraints to the design and potential usefulness of detailed sampling surveys. If the sampling program is not very carefully designed, the sample results may be meaningless.

SAMPLE ANALYSES

There are two types of sample analyses that are used in the documentation of shoreline spills: (1) **total hydrocarbon** analyses, which, provide a quantitative estimate of the amount of oil in the sediment (usually expressed as the weight percent of oil in sediment), and (2) **compositional** analyses, which provide an estimate of the chemical constituents of the oil. Both techniques are conducted usually in the laboratory although under certain circumstances, it may be possible to set up a field laboratory.

The total hydrocarbon analysis can be performed by a variety of techniques, the most common of which is by infra-red absorption (see Green et al. 1982). The results are reported typically as the weight percentage of oil in the oil/sediment sample of oil (mg of oil per kg of oil sediment). As such, this type of analysis is used as the basis for quantitatively estimating the volume of oil on a particular beach (i.e., establishing an oil budget). Commercial costs (in 1985) are approximately $50 per sample. Sample size for gravelly sand sediments should be in the order of 1 L; special handling and preservation techniques may be required and will depend on particular techniques used in the analyses.

Compositional analyses are used to define the constituents of oil and provide the basis for documenting weathering characteristics. Gas chromatograph and mass spectrophotometer techniques are used to define the relative proportion of constituents within the oil. Changes in the constituent proportions over time indicate weathering (i.e., evaporation, biodegradation) of oil costs for specific types of analyses vary in sophistication with a corresponding range of processing costs ($175-1,000 per sample, 1985 prices).

DISCUSSION OF REVIEW

The previous review provides the basis for design of an effective shoreline monitoring program. The review of statistical sample design emphasizes the need to establish some type of blocking or stratification to improve the representivity of collected samples. The representivity of samples is particularly important in being able to extrapolate results to unsampled areas.

The primary means of providing stratification in previous spills was to use systematic aerial observations and then to calibrate these observations with ground-truthing and samples (Baca et al. 1983; Gundlach et al. 1983; Thebeau and Kana 1981). Unfortunately there is little detail on exactly how these ground and aerial observations were related, and, as such, the confidence in the techniques is highly uncertain (i.e., is it ±50%, ±100%, ±300%?).

The brief review of remote sensing techniques suggests that there are appropriate means to record shoreline contamination, at least in the visible spectrum, using conventional low-light-level video or film, and there may be means to enhance contrasts between oiled and non-oiled contrasts in the near-IR or with other enhancement techniques. The real-time capability of these systems is amenable to their use in spill monitoring programs, particularly in the establishment of more detailed survey levels. Modified conventional or dedicated scanner systems offer the potential to quantify aerial survey observations and thus provide a totally objective means of blocking or stratifying a sampling program.

As a result of these reviews, and the experience of project-team members, a hierarchical monitoring program is recommended, which is flexible and appropriate to a wide range of funding levels.

HIERARCHICAL SHORELINE MONITORING PROGRAM

INTRODUCTION

The development of a shoreline monitoring program must take into account a wide range of potential oil-spill types, shoreline types, and coastal processes. The principal assumption to be made is that initial oil distribution and ultimately retention are likely to be highly variable as a result of the natural variability of oil and shoreline characteristics. The monitoring program must provide a means of adequately categorizing oil contamination.

The review of appropriate sampling statistics indicates that some type of stratified sampling approach is essential to the establishment of a long-term monitoring program.

- Aerial reconnaissance and remote sensing (first-order survey) - provide a regional overview of contaminated areas and an approximation of the degree of contamination; aerial observations provide only a very general index of surface contamination and provide no information of oil penetration into sediments.

- Ground reconnaissance (second-order survey) - provides an additional level of information beyond the aerial surveys and allows correlations between sediment characteristics, oil covering, oil penetration and coastal processes to be made; such surveys can be conducted rapidly at the time of the spill.

- Sampling surveys (third-order survey) - may be used to quantify estimates made from aerial and ground surveys and to allow volumetric oil retention levels to be estimated.

The program structure outlined above should provide the means of categorizing or stratifying variability of contamination at the time of a spill. Recommendations for implementing these techniques are provided in the following sections.

The monitoring program outlined is pragmatic. In general, only monitoring schemes which are comparatively easy to implement and which are of reasonable cost are recommended. The techniques can be implemented on a general or specific basis: aerial observations when a minimal response effort is dictated, aerial and ground observations when a moderate monitoring effort is dictated and all three levels when a major monitoring effort is required.

AERIAL SURVEYS

Aerial observations have been made routinely in spill monitoring programs for use in both operational assessments and scientific studies. Results are usually summarized on maps, but these maps are often discarded during the spill and notations on the maps are frequently sketchy. An outline for systematically recording information is included in Table 1. Comparison of rapid reconnaissance aerial observations with detailed ground observations indicate an agreement within 10 to 15% (Owens 1984b).

These observations are simple and easily made. The use of only four contamination categories minimizes the number of recordings to be made in the aircraft, and sectional topographic maps, placed in order and in a three-ring binder, facilitates recording in the small aircraft cockpit. **It is important to note that if more than one observer is used, (a) standards for estimating contaminant levels are provided to each observer and (b) a section of shoreline is delineated for the "calibration" of observations.** Differing observations of contaminant levels has been a problem in past spills (C. Margison 1984, Canadian Coast Guard, pers. comm.). Periodic ground stops will assist in the continuous calibration of aerial observations. Additional options that could be used to increase the level of detail are listed in Table 1. The use of low-light-level video offers a means to make continuous, hard copy documentation (with narration) of shoreline contamination at minimal cost (Owens 1983). The videotapes can be used immediately and provide a means of briefing other response team personnel.

A variety of film types are available for standard 35-mm cameras including specialized films such as colour infra-red film and instant slide film. The selection of these films depend on the spill character, shoreline character, and conditions at the time of the spill; in addition a professional photographer should be consulted to assist with film selection. As a minimum, it is recommended that a high-speed (more than 200 ASA) colour slide film be used. Image enhancement of photographs or slides offers the potential to objectively quantify contamination levels after the spill, although some image-enhancement systems are portable and could be used in the field.

The use of dedicated, narrow-band scanners may be of use, but to date, no convincing tests of their effectiveness on delineating contaminated shorelines have been made.

Potential problems of visual aerial reconnaissance programs include variability of observations between individuals, the use of experienced versus inexperienced individuals, and the effect of weather conditions on spill observations. A conscious effort to minimize these effects must be made by the monitoring program supervisor. Calibration photographs (instant photographs of different beach sections and contamination levels)

TABLE 1

Minimum Requirements for Aerial Surveys

METHODS REQUIRED

- visual observations systematically recorded on maps;
- visual observations to include as a minimum:
  - four levels of contamination (oil absent, patchy, discontinuous or continuous)
  - length of shoreline contaminated
  - width of shoreline contaminated;
- oblique aerial photographs of both upper and lower intertidal zones (note: also photograph areas where oil is absent); locations plotted on map and annotated with automatic date/time annotator;
- overflights to be flown as close to low tide as possible;
- periodic ground stops be made to verify aerial observations;
- personnel making observations should use a "test" area to serve as a standard (i.e., make sure different observers are making comparable observations);
- surveys to be conducted at approximately the same altitude to facilitate comparisons between surveys;
- optimum flight characteristics are:
  - altitude less than 150 m (500 ft)
  - speed less than 145 km/h (80 knots);
- surveys to be repeated as required by objectives of monitoring program.

EQUIPMENT REQUIRED

- set of the most-detailed topographic maps available, sectioned into 8.5 x 11 inch size and placed in three-ring binders; to be retained after the survey;

TABLE 1

Aerial Surveys (continued)

- pencils and coloured marking pens;
- 35-mm camera with appropriate film and automatic frame annotator;
- tide-tables; and
- helicopter strongly recommended; however, for fixed-wing alternative, use high wing, short take off and landing (STOL) design.

OPTIONS

- video imagery of survey area - provides continuous hard-copy documentation of observations and provides a means of recording a narrative;
- specialized imagery such as vertical aerial photographs, which are very useful in making exact comparisons over time, and dedicated scanners; note that tone targets should be supplied for sensor calibration.

SOURCES OF EXPERTISE ON SURVEILLANCE PROGRAMS

Remote Sensing: Canadian Centre for Remote Sensing
717 Belfast
Ottawa, Ontario K1A 0Y7

Coastal Processes: Atlantic Geoscience Centre
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia B2Y 4A2

TABLE 1

Aerial Surveys (continued)

Pacific Geoscience Centre
Institute of Ocean Sciences
P.O. Box 6000
Sidney, British Columbia V8L 4B2

General: Regional Offices of the
Environmental Protection Service (Environment Canada)

ESTIMATED COSTS OF PROGRAM

Including four-seat helicopter (est. $600 per hr), videotape recorder and camera, 35-mm camera, film, maps, communications system, one video technician, and assuming four hours per day of flying time:

Mobilization/demobilization $700 (exclusive of airfare)
Day rate $3,400 per day

and designation of test sections will help to minimize observer effects. Unoiled areas, especially on vegetated coasts, should be inspected to establish a zero baseline. Weather conditions must be recorded and considered carefully in the program as studies have shown that visual observations are very sensitive to wet or dry conditions of the shore zone (Owens 1984b).

The results from an aerial observation program provide the first order basis for stratification of an overall monitoring program. An example of the type of information that would be produced is included in Figure 5. From this data, appropriate representative ground sites can be identified for more detailed studies. For example, locations A, B and C on Figure 5 would provide representative ground-truth stations with minimal access problems. However, location D would be less desirable because it represents a transition zone between continuous and patchy oil loading. The information on distribution of contamination provides a critical constraint to selection of more detailed sites.

GROUND SURVEYS

Should the objective of the monitoring program require a more detailed documentation of contamination, then the use of visual observations from ground sites may be desirable (i.e., a second-order survey required). A ground survey program will serve two purposes: (1) to provide an additional level of observational information at a moderate cost and (2) to provide a framework for sample collection schemes (i.e., it provides a basis for stratified sample collection). Selection of representative sites and observation methods are described in the following sections.

Site Selection

Ground-survey sites must be selected on the basis of more general reconnaissance such as that provided by the aerial surveys. Ground surveys should provide an adequate representation of contamination levels, shoreline types, and coastal processes. The final selection of ground-truth sites will involve trade-offs among selection of representative sites, achieving uniformity in distribution of sites (i.e., probably not a good idea to cluster all stations in one small geographic area), access, and cost constraints.

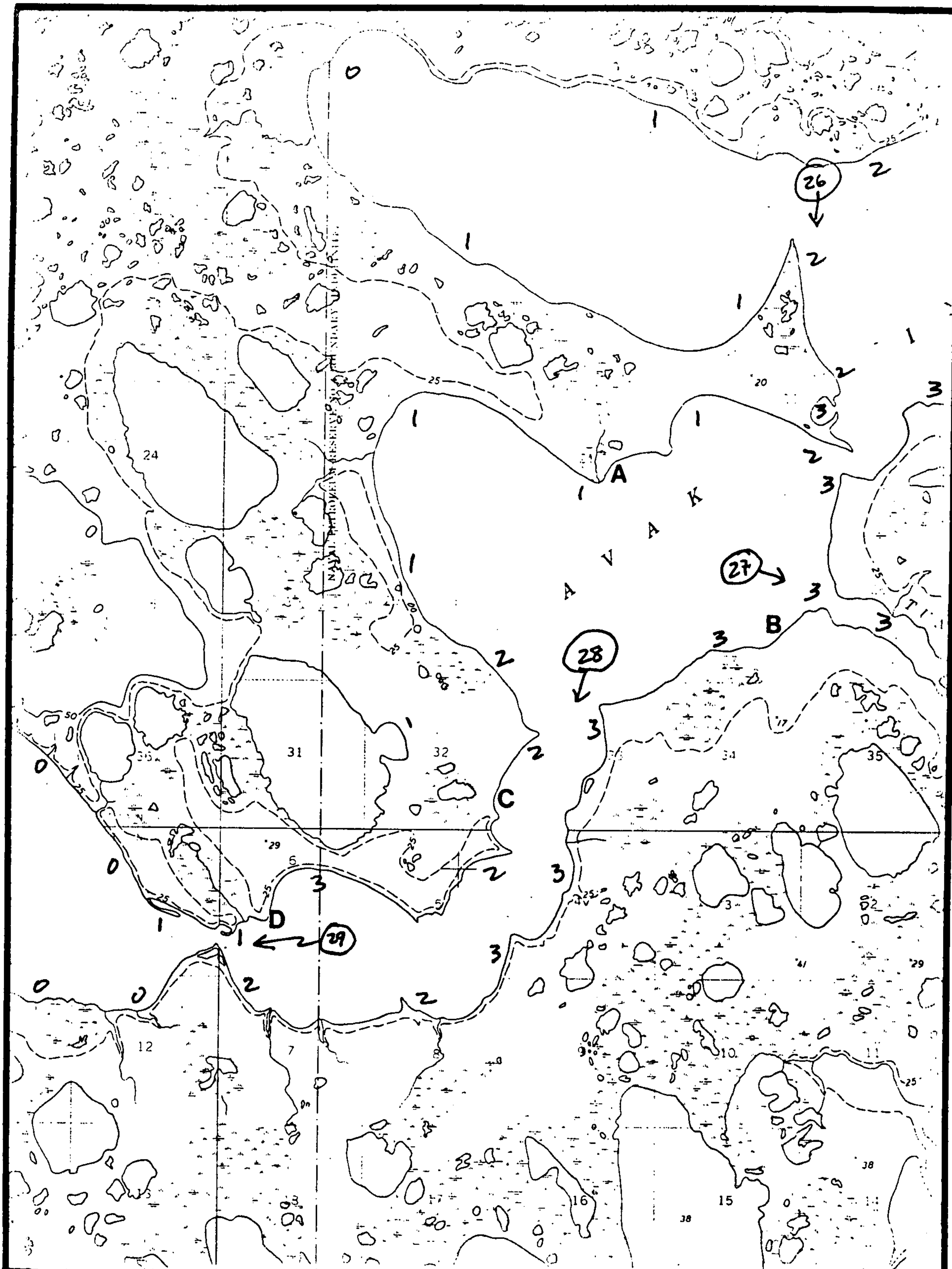

Figure 5. Example of a field map of oil contamination as estimated from aerial surveys (0 = no oil; 1 = patches of oil; 2 = discontinuous oiling; 3 = continuous oiling; circles and arrows indicate photo locations; points A to D are discussed in the text).

Although spills and shorelines will vary considerably, we recommend that ground surveys cover approximately 10% of the contaminated shoreline. This sample fraction has been chosen arbitrarily and is based on the experience of the authors. More complex shorelines or complex oil contamination levels may require a greater proportion of survey area whereas uniform shorelines may require a smaller proportion of survey area. A further recommendation is that the ground surveys at any particular site cover at least 100 m of shoreline (minimum area 2,000 m^2). These two criteria, the 10% rule and 100 m - minimum rule, provide a means of selecting the required number of ground-truth sites.

The selection of ground-survey sites is a function of oiling levels and shore-zone types, where shore-zone type is determined by substrate, wave exposure and morphology. For a section of coast where four shoreline types occur and there are four levels of oil contamination (as in Fig. 5), then there are 16 potential combinations (Fig. 6). Three potential combinations do not occur in the project area, leaving 13 representative types for sites. Ten kilometres of shoreline are oiled, so ten 100-m long sites would be appropriate. Representative sites of all heavily oiled areas are selected. Sites on the most common shoreline types (1 and 2) are preferred over sites from less common shoreline types (3 and 4). Two control areas are selected of shorelines identified from the air as being unoiled. The selection process will vary from spill to spill, but such a methodology produces a traceable and defensible selection of representative sites.

Survey Methods

Simple systematic observations of oil covering and oil penetration can provide extremely useful information on the microscale variability of oil distributions on contaminated shorelines. In the BIOS experiment, these ground observations provided an essential link between aerial observations and sample data (Owens et al. 1982; 1983). Variations in oil cover and oil penetration depths were documented over spatial scales of 1 to 2 m.

Critical components of a ground observation program are outlined in Table 2 and illustrated in Figure 7. The ground observations provide a rapid, inexpensive means of recording oil contamination levels. Minimal equipment is required, thus assuming maximum flexibility for different spill situations.

Several points of caution are appropriate. First, studies have shown that observations are sensitive to wetness (Owens 1984); therefore tests should be made under both wet and dry conditions to ascertain sensitivity during a particular spill incident. Observations on pebble or cobble beaches are particularly sensitive to wetness. Secondly, the technique is sensitive to observer subjectivity and each observer must be calibrated

SHORE-ZONE TYPE

OILING LEVEL	1	2	3	4
0	(1)	(2)	3	4
1	(5)	~~6~~	(7)	~~8~~
2	~~9~~	(10)	11	(12)
3	(13)	(14)	(15)	(16)

Figure 6. Contamination matrix for shore-zone type and level of oil contamination. Combinations that did not occur in the impacted area are illustrated by "X"; combinations selected for ground surveys are circled.

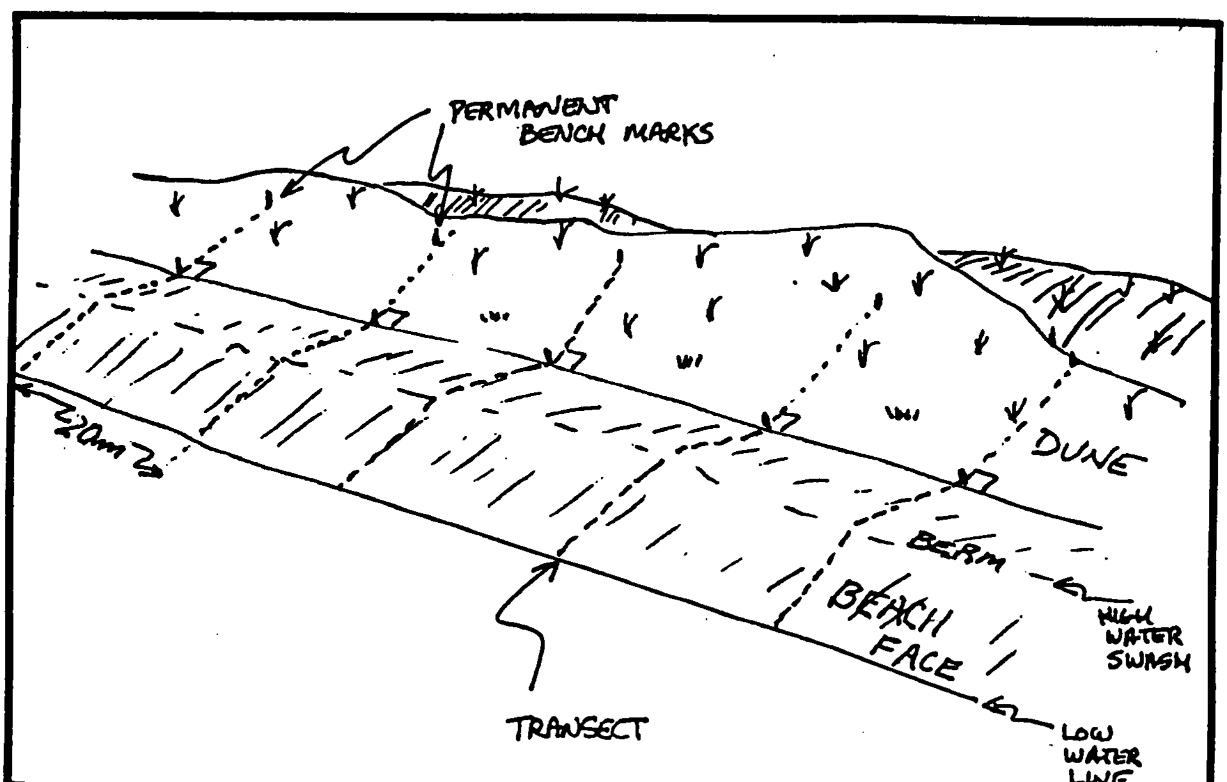

Figure 7. Ground-survey benchmark and transect layouts.

TABLE 2

Requirements for a Ground Observation Survey

REQUIREMENTS

- permanent survey stakes must be established to permit resurvey of the exact same across-shore transects; across-shore transects should be at approximately 20 m intervals or less (Fig. 7);
- survey stakes must be marked clearly and unambiguously for later relocation;
- calibrate between people and between crews;
- a survey tape, laid across the shore-zone, provides a reference system for visual observations;
- surveys to be conducted at low tide;
- survey observations must include notations of:
  - substrate type
  - oil cover using five classes (no oil; 0-25%; 25-50%; 50-75%; 75-100%)
  - oil penetration depth
  - morphologic features
- observations are most easily plotted if made at regular intervals (e.g., every 2 m);
- across-shore topographic profiles are required to be surveyed to tie observations to tidal, river, or lake datum;
- photographs taken of each transect line looking in both alongshore directions and looking inland from the waterline along the transect;
- photographs of the five oil-cover classes; and
- surveys to be conducted on both dry and wet days to calibrate the wetness factor.

TABLE 2

Requirements for a Ground Observation Survey (Continued)

EQUIPMENT

- wooden or steel benchmarks;
- survey tape;
- sledge hammer(s);
- level with horizontal circle and survey staff;
- tide tables;
- waterproof notebooks;
- shovels, trowels;
- aerial survey markers;
- camera and film; photo scale.

SOURCES OF EXPERTISE

Coastal Processes:	Atlantic Geoscience Centre Bedford Institute of Oceanography P.O. Box 1006 Dartmouth, Nova Scotia B2Y 4A2
	Pacific Geoscience Centre Institute of Ocean Sciences P.O. Box 6000 Sidney, British Columbia V8L 4B2
General:	Regional offices of the Environmental Protection Service (Environment Canada)

TABLE 2

Requirements for a Ground Observation Survey (Continued)

ESTIMATED SURVEY COSTS

Including rental costs of above-cited equipment plus one crew of an experienced coastal process specialist and a field assistant. Estimated low-tide working window is four hours per day and approximate shoreline coverage is 500 m per day (complexity of shoreline and of oiling will affect survey rate):

Mobilization costs (exclusive of air fares): $1,000
Field survey costs: $1,100 per day per crew (assumes access and logistics locally available)

against a standard; photographs collected during the observation survey will assist in standardization. Thirdly, observations should be plotted immediately following the spill in map form and all relevant geomorphic features and benchmarks noted. Experience with past programs indicates that attention to these details will significantly reduce later data interpretation problems.

The need to establish a good benchmark grid is essential to making consecutive survey observations comparative. The survey grid is required to relocate transect lines, to tie observations to a vertical datum and to determine if significant sediment erosion or deposition has taken place. The use of a self-leveling level with horizontal circle greatly facilitates establishment of a benchmark grid and collection of across-shore topographic data.

An example of a data product is provided in Figure 8 and illustrates the detail available from such a program. The maps provide an objective basis for a specific sample collection program, should such a program be required. For example, samples would be collected systematically from each of the five oil classes illustrated and as a result the ground observations are "calibrated" by sample analysis data. As such, the visual observations (a second-order survey) provide an objective means of extrapolating the sample results (a third-order survey). In other words, the ground observations and oil cover classes (Fig. 8) provide the basis for stratified-systematic sampling and for reducing sample variance.

SAMPLE SURVEYS

Sample Collection

Sample collection is potentially the most expensive part of any monitoring program. Sample collection is labour- and time-intensive, and analytical procedures may be expensive as well. However, quantitative analysis of sediment oil content provides the basis for linking the first- and second-order observational data to volumes of oil stranded.

Samples may be collected for total hydrocarbon analysis, which measures the weight percentage of oil as compared to the dry weight percentage of sediment, and for compositional analyses, which document the relative proportion of oil fractions and are used to establish the toxicity of the oil. Sample collection procedures, handling and storage procedures are different for each of the two analyses, and must be directed by individuals experienced in the analyses.

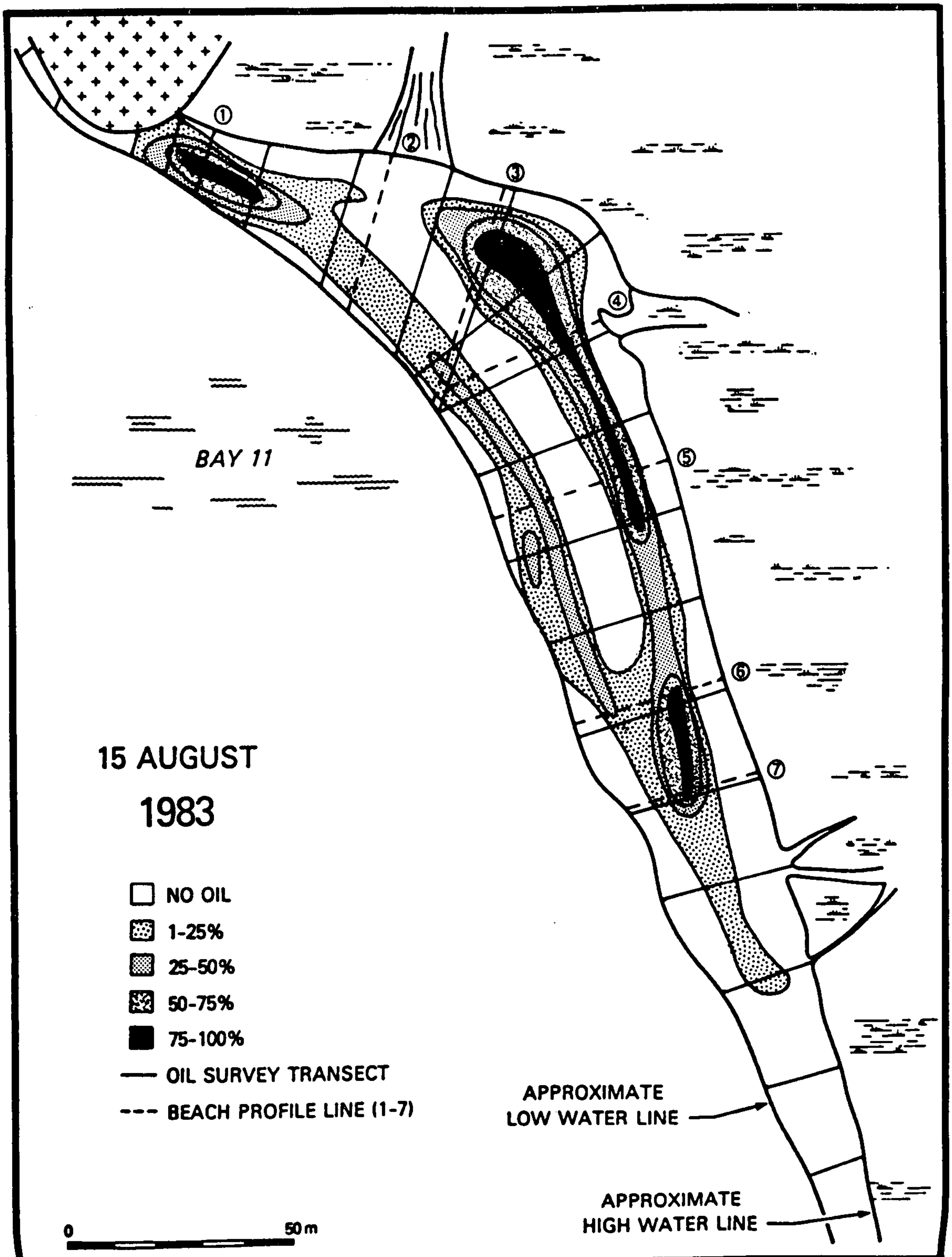

Figure 8. Summary map of ground observations in a small coastal bay.

Simple statistical calculations indicate that a stratified sampling approach is essential to minimize the number of samples collected. It is, therefore, important that sampling only be conducted after aerial and ground observation surveys have established representative sampling sites and locations. As such, the sampling surveys serve as a quantitative calibration of these more subjective surveys.

The critical components of sample collection and analysis programs are listed in Table 3. Critical components of the sampling program are that: (a) representative samples should be collected from strata defined by the first- and second-order surveys, (b) sample collection locations should be located accurately, (c) the effective number of samples is increased by compositing subsamples, and (d) the sampling technique must be defined at the start of the program and rigorously adhered to for all subsequent sample collection.

A key element of the sample collection program is that someone experienced with analytical procedures and sample handling should be involved during the collection program to assure that: (a) cross-contamination of samples does not occur, (b) proper sample containers are used, and (c) samples are properly handled and stored. Usually an experienced chemist on the sampling team is sufficient to assure quality control. Replicates should be collect at some of the sites (approximately 10% of the total number of samples) to estimate sampling error.

Special requirements for sample collections to be used in legal proceedings are outlined in Appendix 1.

Sample Analysis

Types of sample analyses will depend on the objectives of the monitoring program. Total hydrocarbon content can be determined comparatively inexpensively by infra-red analysis ($50 per sample) whereas composition analysis by gas chromatograph and mass spectrophotometer are comparatively expensive ($200-500 per sample). If simple documentation of oil content in sediments is required, total hydrocarbon analyses are sufficient; if weathering is a concern, compositional analyses will be required. It is recommended that samples be collected for compositional analysis and stored even if analysis is unlikely because the incremental cost of collecting samples is very small.

TABLE 3

Sample Collection Requirements

REQUIREMENTS

- collected samples are to be used for total hydrocarbon analysis and compositional analysis;
- samples must be representative of populations from which they are derived; first- and second-order observation programs must be used to define representative collection sites;
- samples should be collected at the same locations as ground observation sites and should use ground observation maps to delineate sample collection sites;
- samples should be collected only at low tide;
- sample sites must adequately represent:
  - surface cover classes;
  - shore-zone morphology (sample principal across-shore components);
  - intertidal zonation (upper, middle, and lower intertidal zones);
- surface (0-2 cm) and subsurface (sample depth dependent on penetration of oil) samples are required to quantitatively define stranded oil volumes;
- sample compositing should be used to minimize numbers of samples (sample compositing consists of taking small subsamples from several locations and recombining them into a single sample);
- sample collection sites should be referenced to survey profiles;
- as many samples as possible should be collected; not all must be analysed;
- sample size for muddy or sandy sediments should be approximately 1 L (1.5 kg); for coarser sediments larger samples are required;
- collection techniques should be established in writing and adhered to in all subsequent collections;
- collection techniques and equipment should be scrutinized by a chemist familiar with analytical techniques to assure proper sampling, sample handling, and sample storage;

TABLE 3

Sample Collection Requirements (Continued)

- unambiguous sample labelling is essential;
- as a minimum it is recommended that samples be collected along three transects with three samples per transect; compositing of three or more subsamples is recommended (e.g., a minimum of 27 sample collection sites); and
- sediment size description for each sample should be provided.

EQUIPMENT (assumes ground observation site used for sampling)

- sample bags for total hydrocarbon samples;
- acid-washed jars for compositional analyses;
- acetone for cleaning sampling equipment;
- transport crates or cases;
- labelling tapes, markers;
- sample log sheets;
- sampling spatulas, trowels, etc.

SOURCES OF EXPERTISE

Coastal Processes: Atlantic Geoscience Centre
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia B2Y 4A2

Pacific Geoscience Centre
Institute of Ocean Sciences
P.O. Box 6000
Sidney, British Columbia V8L 4B2

TABLE 3

Sample Collection Requirements (Continued)

Chemical Sampling:	Regional offices of the Environmental Protection Service (Environment Canada)
	Ocean Chemistry Division Bedford Institute of Oceanography P.O. Box 1006 Dartmouth, Nova Scotia B2Y 4A2
	Ocean Chemistry Division Institute of Ocean Sciences P.O. Box 6000 Sidney, British Columbia V8L 4B2

ESTIMATED COSTS

Including above-listed equipment and two technicians per sampling crew. Estimated number of sample sites per day is 3-4:

Mobilization costs (less air fares): $1,500
Field survey costs: $1,050 per day per crew
Sample analyses: Total hydrocarbon - $50 per sample
Compositional - $200-500 per sample

DISCUSSION OF MONITORING PROGRAMS

Three levels, or orders, of monitoring surveys are outlined in the previous discussions:

- aerial surveys (first order)
- ground surveys (second order)
- sample collection surveys (third order).

General features of each monitoring program are summarized in Table 4. The important aspect is that a variety of approaches is available and that the scale of the spill will define the budget and determine which program is appropriate (i.e., establish the monitoring objective).

The main feature of the recommended approach to monitoring programs is that no single technique can be used to satisfy all monitoring program objectives; a hierarchy of survey programs is required to identify general information first and proceed to identify progressively more detailed levels of information. Given the typical high variability of shoreline contamination, such an approach is essential for conducting an efficient monitoring program. Higher order surveys (second or third order) can be designed more effectively once the general patterns are known.

Spills where there were demonstrated effects over several years were those spills where oil was incorporated into the sediment at the time of the spill (e.g., West Falmouth and METULA spills) emphasizing the need to establish sampling programs early in the history of the spill.

GUIDE TO MONITORING PROGRAM USAGE

Aerial Surveys

Aerial surveys should be conducted on all but the smallest spills (less than 1 km) to assess the extent (spatial coverage) and degree of contamination. Simple maps of oil distribution (as illustrated in Fig. 5) are useful both for operations and for scientific research. Daily or weekly comparison of such maps provides a guide to natural cleaning effectiveness and to the effectiveness of cleanup operations. The maps will also indicate the most appropriate areas for more detailed monitoring or for cleanup activities.

TABLE 4

Comparative Aspects of Shoreline Reconnaissance Surveys

Component	First-order Survey	Second-order Survey	Third-order Survey
Type of Survey:	aerial surveys	ground surveys	sample surveys
Objective:	regional overview	short-term or long-term monitoring	long-term monitoring or litigation
Level of Effort:	low	moderate	high
Cost:	$5,000-10,000	$10,000-20,000	>$50,000
Minimum Activities:	systematic visual observations, photography	systematic visual observations, survey profiles	systematic sampling and analysis
Products:	regional maps of oil distribution and levels of contamination	large-scale maps of oil distribution on representative shoreline types	quantitative documentation of oil distribution on shorelines
Possible Options:	video imagery, photographs, specialized sensors, studio image enhancement	specialized sensors, enhanced photographic imagery	scientific research on causal effect relationships; measurement of processes
Special Notes:	provides real-time data	provides real-time data if properly designed	does not provide real-time data unless field lab established

All maps should be archived and cross-referenced with either videotapes or photographs, which serve as verification for map interpretations. The maps provide a permanent record for possible use in legal proceedings, claims negotiations, and long-term monitoring. The set of maps illustrating contamination is of critical importance in that it will generally document the highest contamination levels and initial impact area.

Ground Surveys

Ground surveys, which represent a second-order survey, are recommended for spills of moderate size (greater than 10 km) and for spills where more detailed sampling (third-order) is anticipated. The purpose of the surveys is to document the accuracy of the aerial surveys and to provide a framework for more detailed sampling. In particular, ground surveys provide a comparatively inexpensive means of documenting effectiveness of cleanup operations at specific sites and also of documenting the cleaning effectiveness of natural processes.

Ground surveys represent an attractive alternative to detailed sampling in that (a) they provide real-time results and maps and (b) they are comparatively inexpensive. As such, ground surveys are potentially useful to operations personnel as well as for scientific studies. It is estimated that one field crew can produce maps for 500 m of shoreline per day, including establishing benchmarks and conducting topographic surveys. Given the 10% rule suggested in the previous section on ground surveys, this represents a sufficient sample size to characterize approximately 5 km of shoreline. As such, two field crews, at a combined cost of approximately $2,200 per day (exclusive of transportation costs), could characterize 10 km of coast per day, or 70 km per week ($15,400 per week). This approach is similar to that used in a monitoring program of the Puerto Rican oil spill off San Francisco in 1984. Twenty-five stations of approximately 100 m in length were used to characterize 220 km of shoreline (e.g., 8.9 km per ground survey site). In that particular survey, four teams of three individuals covered the entire area in three days, although ten separate biological sample stations were also included in the survey.

With simple approximations about the thickness of the oil cover, quantitative estimates of the volume of oil stranded can be made. Using information from the aerial survey maps, the total volume of stranded oil per kilometre of shoreline can also be estimated, to serve as a guide to cleanup operations (e.g., quantities of oil and/or sediment that may have to be recovered).

The maps of oil distribution should be archived so that they serve as a permanent reference for use in legal proceedings, claims negotiations and long-term monitoring. As with the aerial reconnaissance observations, initial survey maps are of critical importance in that they usually represent the time of highest contamination levels.

Sample Surveys

Sample surveys provide a means of "calibrating" observations from ground surveys and aerial surveys. Sample surveys are likely to be used when there is potential for litigation or when there are long-term research monitoring objectives. The sample analysis procedures provide the most quantitatively defensible data, although one must interpret the data with caution because even though the analyses can be conducted with considerable precision, if the samples are not representative then the analysis results may be misleading. The point is: for the sample analysis data to be useful, it is imperative that the samples be representative and that the sample-collection locations be representative (i.e., first- and second-order surveys must be conducted to ensure representivity of samples).

If the principal objective of the sampling program is to "calibrate" aerial and ground visual observations, then total hydrocarbon analyses ($50 per sample) will provide sufficient information for computing volumes of stranded oil. If, however, there is the additional objective to document compositional changes due to weathering or to document toxicity, then compositional analyses will be required. Costs for compositional analysis will vary significantly with level of detail required; abbreviated gas chromatograph (GC) analysis is comparatively inexpensive ($200 per sample) whereas combined GC mass spectrophotometer analysis can be comparatively expensive ($600 per sample). Because of the expense of compositional analyses (at least four times as expensive as total hydrocarbon analyses), the need for the analyses must be clearly defined. In many cases it may be useful to collect samples for compositional analysis but only analyze them if absolutely required; this procedure adds a small incremental cost to the collection program while maintaining the potential to conduct compositional analyses at a later date.

SUMMARY OF RECOMMENDED APPROACH

The selection of the monitoring approach must be determined by the monitoring objectives. These objectives will differ depending on whether the results are to be used for a guide in response operations, in litigation proceedings or in scientific research. **The monitoring objective must be defined early in the spill, or even prior to the spill, to define the appropriate funding level.**

Once the objective is established, a monitoring program can be designed. Three levels of monitoring programs are outlined in this report: systematic aerial reconnaissance, systematic ground observations, and systematic sampling. The programs represent an increasing level of detail and provide general to specific information on contamination levels. An important aspect about the use of these programs is that they are hierarchical and that data from a more general program are a prerequisite to design and implementation of more detailed programs. **The use of the reconnaissance-level data in the design of the detailed sampling programs vastly improves the sensitivity of those programs and provides an objective basis for selection of either sample sites or specific sample locations.**

APPENDIX 1
SAMPLE COLLECTION REQUIREMENTS FOR LEGAL SURVEYS

INTRODUCTION

This appendix provides a brief summary of sample handling procedures that are required for samples that may be used in court. Significant elements of the procedures include:

- samples must be rigorously identified as to origin;
- samples must be rigorously protected from substitution, alteration or tampering throughout your custody of them. They must be adequately sealed;
- notebooks of original and intermediate records must be available (as far as practical);
- records must be protected from confusion or loss;
- other items of evidence must be similarly identified and protected;
- documentary evidence must be maintained of every transfer of samples and records from one custodian to another.

This summary is extracted from a more general draft procedures manual currently under review by the Environmental Protection Service of Environment Canada. A summary of the U.S. Environmental Protection Agency guidelines is provided in Cox et al. (1980).

CONTINUITY

The 'continuity' of an exhibit is, more or less, the history of the exhibit from the time the investigator removes it from the scene of an offence until it is presented to the court as evidence. The courts require that two facts be established about any exhibit before it can be accepted as evidence:

(1) that the exhibit presented to the court is, in fact, the one the investigator obtained at the scene; and

(2) that the exhibits were not altered or adulterated before either the laboratory analysis or presentation to the court.

Each person who has possession of an exhibit at any time may be required to prove to the court that he or she had personal control of that exhibit for every minute of that time and that no other person could have touched the exhibit without his or her knowledge.

It is difficult to over-emphasize how much importance the courts place on continuity. Keep it in mind always!

To meet these criteria to the satisfaction of the courts the following rules must be adhered to when handling samples which may become exhibits.

SAMPLING PROCEDURES AND CONTINUITY OF EVIDENCE

Sample Containers

Be sure that the containers are new and clean. Ensure there are no labels or writing on the bottles or caps prior to collecting the samples. Plastic bottles are better than glass because they are less likely to rupture. Some chemical analyses require the sample be collected in a specific bottle size or type and some analyses require preservatives be added; for example, compositional analysis samples (to be analysed by GC) require collection in acid-rinsed bottles with special caps to prevent contamination and require immediate freezing to minimize biodegradation. If you are not certain, check with the laboratory personnel. If you do not have access to the correct bottle or preservative, collect the sample the best way possible and take it to the laboratory as soon as possible.

Sample Collection

If possible, contact the appropriate laboratory before collecting samples. Sample collection tools should be cleaned three times prior to prevent sample cross-contamination. This includes any device that comes in contact with the sample being collected. The sample should be collected in a way that minimizes the disturbance of the other material present. The sample collected should be representative (try to sample in the main flow of the deleterious material. Avoid sampling in the eddy currents, behind log jams, etc.).

Photographs of the sample sites, samplers collecting the samples and the samples themselves should be taken and supplemented by detailed field notes.

Sample Sites

Strategies for selecting sample sites are outlined in the Hierarchical Shoreline Monitoring Program section of the main text. Two or three replicates are recommended for each site.

Sample Identification and Sealing

As soon as the sample has been collected, the container should be labelled with a scriber and sealed. The area of the container where the label is to be inscribed should be marked with indelible felt pen to aid field personnel and the analyst in locating the label later. If more than one person is carrying out the sampling, only one should do the labelling to ensure that all sample containers are labelled in a consistent manner. The following information should be included:

(1) the sample site or location (this would include the source of the deleterious substance)
(2) the date and approximate time
(3) the initials of the sampler and the witness
(4) the analysis to be carried out may be included but is not essential.

e.g. North Vancouver Landfill
West Ditch Discharge to Lynn Creek
December 20, 1980 1300-1330 hrs.
G.T. O.E.L.
GC/MS

All openings of the container must be sealed with tape, wax or in some other manner so that the container cannot be opened without breaking the seal and if the seals are broken, the sampler or the analyst would be aware of it. The most common method is to wrap masking tape around each cap and then initial the seal with the initials overlapping the tape and the container. Although rather primitive, it is simple and it works.

Field Records

The identification, the container and all other pertinent information should be recorded in the inspector's field notes. The inspector should also include other observations such as substrate types, exact location of sample, surface oil concentration, depth of sampling and reference to the photograph numbers. The name of the analyst or other person to whom the samples are given, should be noted along with the time and if possible the sample analysis number.

Sample Transfer and Shipment

If the samples are to be stored overnight or prior to shipping, they should be kept in a locked location preferably with a single key in the hands of the sampler (in the trunk of a car, for an example).

If the samples are to be shipped by public transport (plane, bus, etc.) it is preferable that they be sent in a locked box in order to ensure that the containers are not lost or broken and to ensure that the seals are not accidentally broken. Coolers can be used allowing the samples to be shipped on ice.

It is preferable to have someone collect the samples from the terminal to minimize intermediate handling. A covering memo should be attached to the outside of the shipping box (enclosed in an envelope) so that the recipient does not need to open the boxes to determine the contents. The keys to the locked boxes should be sent to the analyst by registered mail, along with copies of the bills of lading and other shipping documents (you should also retain a set of these documents) in case the samples are lost in transit.

These rules are a summary of the procedures the courts have demanded in order to establish the continuity of the exhibits. Although they may seem to be excessively rigid, omitting a step may result in an exhibit being ruled inadmissible or the person presenting the evidence may be discredited. Either of these circumstances could result in the loss of the case.

SAMPLE PRESERVATION

Table A-1 is a condensation of collection and handling techniques. Analytical methods are constantly changing and techniques are also changing with the aim of improving efficiency. Check with the laboratory for up-to-date references on sample preservation.

The table column headings are:

1. Parameter - the item to be analysed.

2. Container - the most commonly used bottles are 2-L plastic, 200-ml plastic (acid-washed), 3-oz glass and 4-oz glass.

3. Sample size - this is the minimum size required for the analytical method. Some samples are analysed in duplicate. Where possible, the sample should be representative of a homogenous solution.

4. Preservation - the aim is to maintain the parameters in their original concentration. These techniques are successful to various extents, none are perfect. Old reagents may be worse than none at all - check with the lab.

5. Maximum holding period - some of these have been tested, others have been arrived at by trial and error. None are mandatory because there are great variations between samples and also because of interactions of the parameter in the sample with other constituents of the sample. The main rule is THE SOONER THE BETTER.

TABLE A-1

Sample Handling and Preservation Techniques

Parameter	Container	Sample Size	Preservation	Max. Hold
total hydrocarbon content	whirl pak bags	>1,000 g	freeze for longer storage	6 months for low concentrations
compositional analysis (GC-MS)	8 oz glass, baked at 350° C; solvent-cleaned Teflon lid-liner (best) or aluminium foil (for short-term storage only)	>200 g	quick freeze, keep frozen	approx. 1 to 2 years

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