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Marine Oil Accumulations

Based on methodology already employed, relatively accurate quantitative data on oil loss can be determined by remote-sensing methods combined with surface sampling techniques.

Abstract: *A methodology for the quantification of marine oil accumulations, utilizing coordinated surface sampling and remote-sensing techniques, was developed by the Geography Remote Sensing Unit of the University of California, Santa Barbara. The methodology relies on accurate temporal and spatial documentation of surface samples and the correlation of these data with vertical ultraviolet scanner imagery (0.23 −0.35 micrometer range). Implementation of this methodology, in a controlled soybean oil spill experiment, indicated only a 3.0 percent error in the calculation of the volume of oil spilled.*

Introduction

As a part of an effort to combat the ever-increasing number of marine oil pollution incidents, the United States Coast Guard has undertaken the task of developing a light-weight, air-deployable oil-containment barrier for use under moderate to high sea-state conditions. The prime contractor for the Coast Guard in this mission has been Johns-Manville Products Corporation, Manville, New Jersey. Following a period of intensive research and development, a full-scale prototype barrier was constructed for use in a series of open sea tests. The purpose of the testing program was to assess the barrier's oil containment efficiency, operational performance, and survival characteristics under a variety of sea-state conditions. Preliminary tests of the barrier conducted in 1971 proved inconclusive owing to excessively calm sea conditions.

Accordingly, an additional test was scheduled for early March 1972 in the Santa Barbara Channel (offshore from Point Conception, California), historically one of the roughest stretches of water in the United States. The Geography Remote Sensing Unit (GRSU) of the University of California, Santa Barbara, received a Coast Guard contract to utilize remote-sensing data in conjunction with surface-sampling data to evaluate the performance of the oil containment system during this test. The test also provided an excellent opportunity for the GRSU to investigate the utility of various remote-sensing systems for detecting and providing quantifiable data on oil spills.

The intent of this paper is to present the findings that resulted from the accomplishment of the Coast Guard and GRSU objectives. In order to obtain a needed perspective, a brief description of the background to the actual testing is provided. Following this is a section concerning the methodology used by GRSU for the test. A third section deals with the procedures used to analyze the remote sensing data and to prepare an oil loss budget. The fourth section involves a discussion of the results of the analysis. Finally, concluding remarks are made regarding the accomplishment of the various objectives of this testing program.

Description of Experiment

The test offshore from Point Conception called for the deployment of the 1000-ft. prototype barrier into which a known amount of biodegradable soybean oil (approximately 37,500 gallons) was pumped on two separate occasions, March 8 and March 10, 1972. The barrier was then towed by two vessels in a U-shaped configuration at various speeds, gap openings and directions with regard to prevailing winds and current (see Figure 1). Soybean oil was used in this test owing to environmentalist opposition to the use of petroleum base oils. To facilitate visual identification of the soybean oil by teams of scuba divers observing the function of the barrier from underwater, orange Beta-Carotene dye was added to the soybean oil.

Preliminary testing conducted by GRSU indicated that suitable film-filter combinations for the detection of soybean oil with Beta-Carotene dye on water were panchromatic black-and-white with a green (Wratten 61A) or a red (Wratten 25A) filter. Ektachrome color (no filter) and Ektachrome Infrared with a yellow (Wratten 15B) filter also proved effective for the detection of soybean oil.

In addition to the photographic mission to be flown by the GRSU, several other groups were to acquire imagery of the test. Of these other missions, the most useful data for evaluation were provided by ultraviolet scanner imagery (0.23 to 0.35 micrometer range), supplied by North American Rockwell (NAR), and near-vertical panchromatic black-and-white photography, supplied by the Coast Guard (USCG).

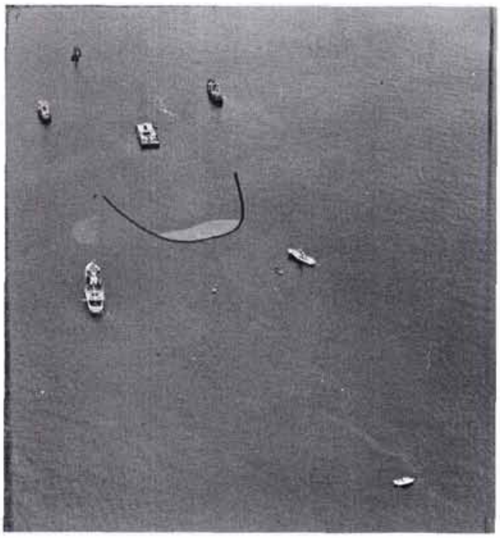

FIG. 1. Photo taken by the GRSU aircraft of the oil-containment system. The small boat in the lower right portion of the photo shows the U.C.S.B. sampling boat at the edge of the trailing slick.

METHODOLOGY

The primary objective in the analysis of the remote-sensing data to be collected during the test operations was the preparation of a time-dimensional budget for the soybean oil loss from the oil containment barrier. This time-dimensional oil loss budget could then be correlated with the different towing speeds and barrier gap openings to assess the operational efficiency of the containment system.

The use of remote sensing data for the assessment of the oil-containing efficiency of the barrier was based on three assumptions: (1) that oil which escaped from the barrier could be detected and its areal extent measured on imagery obtained by airborne sensors; (2) sea surface measurements of oil film thickness could be obtained and correlated with coincident imagery of the areal extent of the oil; and, (3) if the speed of the barrier were known throughout the experiment, oil losses for different speeds and towing modes could be computed.

An operational methodology based on the above three assumptions was devised in four parts. The first part concerned the collection of various types of imagery from airborne sensors; the second part dealt with the collection of surface samples of oil thickness; the third part involved the correlation of data obtained from surface sampling with the imagery from the airborne sensors; and the fourth part concerned the photogrammetric techniques used to develop a time-dimensional oil-loss budget.

The acquisition of imagery from airborne sensors was primarily accomplished by groups other than GRSU. A number of airborne sensor systems were used, including: side-looking, synthetic aperture radar (X-band) flown by Hughes Aircraft Co. (Culver City, California); differentially-polarized panchromatic photography flown by NASA Ames Research Center (Moffitt Field, California); panchromatic photography from a U.S.C.G. helicopter; and, nine-channel multispectral scanner imagery and separate U.V. scanner imagery flown by North American Rockwell (Downey, California). These types of imagery were analyzed to determine the most appropriate type for delineation of the areal extent of the oil slick. In addition, the GRSU obtained multispectral 35-mm photographs throughout the experiment.

A U.C.S.B. sea-surface sampling boat was stationed from 600 to 1,600 feet behind the oil containment barrier to sample the thickness of the oil which escaped the barrier. The methods of sample collection and thickness calculation were developed by Dr. P. G. Mikolaj of the Department of Chemical and Nuclear Engineering (U.C.S.B.) in conjunction with Dr. A. A. Allen of Marconsult Corp. (Santa Monica, California).*

In order to correlate the imagery supplied by the airborne sensors with the oil film thickness data acquired by the surface sampling vessel, the GRSU aircraft took photographs documenting the exact position of the sampling boat at the time of each sample. The GRSU aircraft was in constant radio contact with the sampling boat both to facilitate this photographic documentation of the sample location and to guide the boat to representative sampling locations within the oil slick.

The portion of the operational methodology dealing with the photogrammetric techniques is primarily concerned with the development of a time-dimensional oil-loss budget. In order to prepare the oil-loss budget several steps were required: (1) the areal extent of the oil slick trailing from the barrier was delineated; (2) utilizing data on the towing speeds at different times, the slick was divided into five-minute time-of-loss sections; (3) each of the five-minute sections of the slick was measured to determine its areal extent; (4) data on the thickness of oil, based on surface sampling data, were used to compute the volume of oil within each five-minute section; and, (5) the resultant time-dimensional oil loss budget was graphically displayed and correlated with the operational parameters of towing speed and barrier configuration.

The Test and Oil Loss Budget Preparation

Although two separate tests were conducted, one on March 8 and a second on March 10; only the first test will be discussed. Data for the second test was incomplete owing to scheduling changes. On March 8, approximately 25,000 gallons of soybean oil were pumped from a barge into the oil containment barrier under relatively calm sea conditions. The test lasted 4.5 hours during which time the barrier was towed at speeds ranging from 0.5 to 1.75 knots, and at gap openings of 250 and 450 feet. At the conclusion of the test, all 25,000 gallons of soybean oil had escaped from the barrier.

The following is a discussion of the procedures used and problems encountered in the actual application of the proposed methodology for the preparation of an oil loss budget.

Step 1

For the delineation of the areal extent of escaped oil, 14 vertical black-and-white ultraviolet (.23 – .35 micron range) scanner images, acquired by North American Rockwell (NAR), and 3 near-vertical black-and-white photos, acquired by the United States Coast Guard, were utilized. The 14 NAR images were most useful because: (1) the images were nearly vertical, thereby minimizing angular distortion; (2) the images covered the entire scene of the oil slick, including the surface sampling vessels; and, (3) image contrast ratios were low, enhancing the identification of subtle differences within the oil slick. Coast Guard photographs were used to cover time periods during which the North American Rockwell aircraft was refueling. The three Coast Guard photographs, which were utilized in

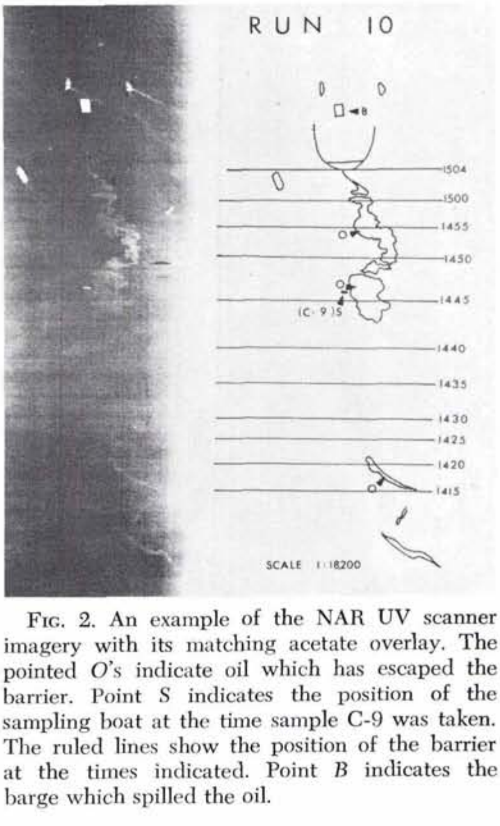

FIG. 2. An example of the NAR UV scanner imagery with its matching acetate overlay. The pointed *O*'s indicate oil which has escaped the barrier. Point *S* indicates the position of the sampling boat at the time sample C-9 was taken. The ruled lines show the position of the barrier at the times indicated. Point *B* indicates the barge which spilled the oil.

* The technique basically employs the use of a hydrophobicoleophylic material which attracts the oil. The oil is subsequently dissolved in glycerine and volumetric determinations are performed colorimetrically. For a more detailed discussion of the sampling and quantifying techniques, see Estes, Mikolaj and Thaman, 1972.

the evaluation, approached the quality of the imagery obtained by NAR.*

The areal extent of the oil was plotted by applying cellulose acetate overlays to each of the 17 photographs and then carefully delineating the oil slick. An example of a NAR image with its respective overlay can be seen in Figure 2.

STEP 2

Because the surface sampling boat from U.C.S.B. sampled the oil slick at a distance ranging from 600 to 1,600 feet behind the barrier, it was necessary to determine the temporal position of the vessel within the oil slick at the time of each sample. For example, if the oil sample was collected at 1,502 hours (as in the case of sample C-9), the oil in that sample was estimated to have escaped from the barrier during the five-minute interval between 12 and 17 minutes before that particular sample was taken (in this case between 1,445 hours and 1,450 hours).

In order to identify correctly the samples with reference to the approximate time of escape from the barrier, it was assumed that the major movement of oil away from the barrier was the result of the towing action of the ships. Although waves, current, wind, and the spreading effect of the oil is noticeable, the combined effect of these parameters on the total length of the slick was considered minor in comparison to towing speed. Therefore, measurements were based solely on the velocity of the barrier moving away from the escaped oil.

In order to divide the slick into five-minute time-of-loss sections, the image scale and the average towing speed for each five-minute interval were needed. To determine the scale of each image, the length of the 182-foot towing barge, visible on all of the NAR imagery, was measured. Other known lengths were used to determine the relative scales for the Coast Guard imagery. Data on the barrier velocity at five-minute intervals was supplied by Hydronautics, Inc. (Laurel, Maryland). The distance traveled by the barrier in each five-minute interval was then marked on the acetate overlays (see Figure 2), thus making possible the calculation of the approximate time of loss for any portion of the oil slick.

STEP 3

To measure the areal extent of the slick, the cellulose acetate overlays were optically enlarged approximately 2.5 times and projected onto graph paper. The new scale factor and resultant area equivalents for each square on the graph paper were then calculated, and the squares covered by the slick were counted for each five-minute section. Next, the number of squares, and the area represented by each, were multiplied to give the area of the oil slick for each five-minute section.

It should be pointed out here that, as many of the NAR runs contained essentially overlapping information, a choice of several images for the same five-minute section might occur. In these instances, the image showing the sections to be measured between 5 and 20 minutes behind the barrier were chosen for measurement. This choice was made for four reasons: (1) enough time was allowed for the oil that escaped under the barrier to reach the surface; (2) the 15-minute measuring period was short enough that the oil had not spread too thin to be accurately identified; (3) to provide relatively consistent measurements of the same temporal section of the slick; and (4) to use the section of the slick closest to the location of the majority of oil samples.

STEP 4

In order to calculate the volume of oil lost for each five-minute interval, an average thickness figure for the oil in each interval was needed. To evaluate properly each thickness measurement, the sample boat had to be located within a five-minute section and the relative position of the boat within the slick also had to be determined. The sample boat was visible on nearly all of the NAR imagery, and additional locational information consisted of some 800 hand-held aerial photographs taken during the experiment to document the position of the sample boat at the time of each sample. These aerial photographs were taken by the GRSU from a Cessna 172 aircraft assigned to a flight altitude of 1500 feet. Analysis of both the NAR imagery and GRSU photographs made it possible to determine accurately the relative position of the sampling boat within the slick so that each sample value could be evaluated as to whether it was representative of that particular portion of the slick (see Figure 2).

A problem arose when the sampling data were analyzed. Soybean oil on water tends to collect in discrete cells which are clearly visible from the surface. These cells introduced a potential sampling error according

* For a complete analysis of the other imagery obtained in this experiment, see Estes, Thaman, Ryerson, and Butler, 1972.

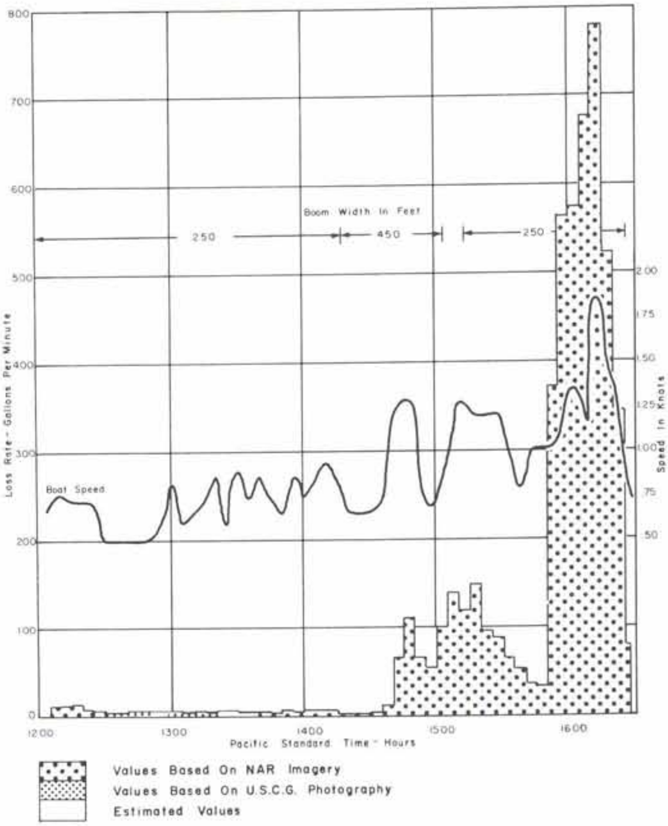

FIG. 3. Graphic display of a time-dimensional oil-loss budget showing barrier speed and width.

to whether the sample was taken in an oil cell or next to one. Therefore, in order to provide more consistent and representative sampling results, a purely subjective evaluation of slick thickness was also made at each sample location. This subjective evaluation was confined to three classes: thin films (T); moderate films (M); and heavy films (H). These three classes were assigned to each sample at the time of sample on the basis of a subjective evaluation. At the end of the experiment all sample values of a given class were averaged and a mean value for each thickness was determined. The resultant thickness values used for the computation of the volume of the escaped oil were: T = .025 mm; M = .130 mm; and, H = .830 mm.

STEP 5

The graphic display shown in the histogram in Figure 3 illustrates the computed oil loss values in gallons/minute as a function of time. The operational parameters of barrier speed and barrier mouth widths are included to allow visual comparison of these factors and oil loss.

The graphic comparison of oil loss versus barrier speed shows that there was a close correlation between the towing speed and oil loss. Although there was always some loss of oil from the barrier throughout the experiment, this loss was minimal if the towing speed was under 0.75 knots or even 1.00 knots. The loss rate if towing at speeds below 0.75 knots was very rarely over 10 gallons per minute. When speeds in excess of 1.00 knots were initiated around 1,420 hours, the loss rate increased dramatically to between 50 and 150 gallons per minute. When the towing speed was lowered to 1.00 knots (between 1,530 hours and 1,550 hours) the loss rate decreased to levels between 20 and 30 gallons per minute. When the towing speed was again increased at 1,555 hours to speeds of approximately 1.50 knots, oil loss began to reach the catastrophic proportions of 400 to 800 gallons per minute.

If the mouth width of the barrier and oil loss is correlated, there did not seem to be any significant difference in oil loss. Between 1,415 hours and 1,430 hours, where the barrier was being towed at a mouth-width of 450 feet, the loss of oil remained below 10 gallons per minute except where towing speeds approaching 1.00 knots began around 1,435 hours.

Evaluation of Methodology

In actual operation, the methodology proposed and used in this test proved to be both accurate and relatively easy to implement. The oil-loss budget presented in Figure 2 contained a cumulative error of only 3.0 percent (a value of 25,750 gallons computed from remote sensing data versus an estimated 25,000 gallons actually spilled), which can be considered quite accurate. As this represented only one test, further tests would be required to establish fully the accuracy of this methodology.

Several factors are important for a successful experiment. Possibly the most important of these is the acquisition of high-quality *vertical* imagery for the determination of the areal extent of the slick. Further testing may prove the utility of vertical photographs for three reasons. It is: (1) less expensive than imagery obtained using more sophisticated sensor systems; (2) more reliable; (3) easier to process; and (4) easier for an average person to interpret owing to familiarity with photographic signatures. From the results of this test and other research accomplished by GRSU personnel, scanner imagery, especially that acquired in the ultraviolet portion of the spectrum, seems to yield valuable data regardless of the oil type. Optimum image scales for the study and quantification of oil spill incidents, comparable to that of March 8 and 10, would be on the order of 1:5,000 to 1:10,000.

The surface sampling techniques employed by the U.C.S.B. sampling boat proved accurate and efficient in operation. However, there is a need to take a greater number of samples at a given point in time. A higher frequency of sampling would give more representative sampling results and obviate the need for making subjective evaluations (such as those leading to the choice of thin, moderate and heavy values for the oil thickness). In order to take more samples, it may be advisable to use more than one boat if the slick is large. An alternative possibility would be the use of as many as three or four sampling devices simultaneously from different stations on a single boat. Regardless of the number of samples or sampling craft, they must be monitored carefully from the air, with a photograph taken at the moment each sample is acquired. Samples taken without aerial documentation may be entirely useless because of the variable concentrations and rapidly changing appearance of oil on water. The use of two light planes might be advisable to avoid the hiatus in sample collection documentation resulting from the periodic necessity for planes to refuel.

Conclusion

Based on the methodology employed on March 8 we have shown that relatively accurate quantitative data on oil loss can be determined by remote-sensing methods combined with surface sampling techniques. With better coordination of operation, increased surface sampling frequency, and continuous high quality, large-scale vertical imagery, accuracy could possibly be improved. With further development of remote sensing techniques, the dependence on surface sampling could possibly be reduced.

References

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