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Standard Guide for Estimating Oil Spill Recovery System Effectiveness[1]

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1. Scope

1.1 This guide covers the key factors to consider in estimating the effectiveness of containment and recovery systems that may be used to assist in the control of oil spills on water.

1.2 The purpose of this guide is to provide the user with information on assessing the effective use of spill-cleanup equipment. It is intended for use by those involved in planning for and responding to oil spills.

1.3 Sections of this guide describe calculation procedures for estimating recovery system effectiveness. It should be understood that any such calculations cannot be expected to predict system performance, but are intended to provide a common basis for comparing system performance.

1.4 One of the main reasons that the calculation procedures cannot be used to predict system performance is that the analysis is sensitive to assumptions made on the properties of the oil slick, and particularly the changes in slick thickness and emulsification. It is emphasized that the purpose of this guide is not to provide a standard method for estimating slick property changes, but rather to provide a standard guide for using that information in comparing system performance.

2. Referenced Documents

2.1 *ASTM Standards:*

F 625 Practice for Classifying Water Bodies for Spill Control Systems[2]

F 631 Guide for Collecting Skimmer Performance Data in Controlled Environments[2]

F 808 Guide for Collecting Skimmer Performance Data in Uncontrolled Environments[3]

F 1523 Guide for Selection of Booms in Accordance with Water Body Classifications[2]

3. Terminology

3.1 *Definitions:*

3.1.1 *advancing skimmer*, *n*—a skimmer that is designed to be used to sweep out the spill area.

3.1.2 *Discussion*—The skimmer may be independent or may be attached to containment boom to increase sweep width. In some cases, the skimmer may not be attached to the boom but is positioned in the pocket of the boom for skimming. As long as the skimmer operates while moving, it is considered to be an advancing skimmer. Some skimmers are used in both an advancing and stationary mode. These are classified according to their application.

3.1.3 *contained spills*, *n*—a spill that is restricted from spreading by containment boom or natural means.

3.1.4 *oil slick encounter rate*, *n*—the volume of oil slick per unit time actively encountered by the oil spill recovery system, and therefore available for containment and recovery (m^3/h).

3.1.5 *oil spill recovery system*, *n*—a combination of devices that operate together to recover spilled oil; the system would include some or all of the following components: (*1*) containment boom, (*2*) skimmer, (*3*) support vessels to deploy and operate the boom and skimmer, (*4*) discharge/transfer pumps, (*5*) oil/water separator, (*6*) temporary storage devices, and (*7*) shore based storage/disposal.

3.1.6 *recovery system effectiveness*, *n*—the volume of oil that is removed from the environment by a given recovery system in a given recovery period.

3.1.7 *recovery period*, *n*—the time available for recovery systems to carry out cleanup operations.

3.1.8 *response time*, *n*—the time interval between the spill incident and the start of cleanup operations.

3.1.9 *stationary skimmer*, *n*—a skimmer that is intended to be used in a fixed location and is moved to new accumulations of oil as skimming progresses.

3.1.10 *Discussion*—Some stationary skimmers are used in a containment boom system that moves to collect oil, then pauses to permit the skimmer to recover the oil collected. Even though this system moves periodically, the skimmer is still ranked as a stationary skimmer because it operates when the system is at rest.

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[2] *Annual Book of ASTM Standards*, Vol 11.04.

[3] Discontinued; See 1998 *Annual Book of ASTM Standards*, Vol 11.04.

3.1.11 *uncontained spill, n*—a spill that continues to spread after the recovery effort begins.

4. Summary of Guide

4.1 In evaluating the effectiveness of containment and recovery systems used in response to oil spills, many factors need to be considered of which skimmer performance is but one. The objective of this guide is to describe a range of factors that must be considered in estimating recovery system effectiveness.

4.2 In order to evaluate a recovery system, there are two general types of information required, a set of information to describe the spill scenario against which the system will be measured, and a set of information to describe the performance characteristics of the recovery system.

4.3 Information on the spill is required to adequately define the problem and thereby provide a focus for the evaluation process. The spill should be defined in sufficient detail as to allow an unambiguous interpretation of its behavior in terms of the operating parameters of the countermeasures system. For certain purposes it may be desirable to develop a set of standard spill scenarios against which response system effectiveness would be measured in a quantifiable manner.

4.4 The performance characteristics must be identified for the recovery system and its various components. In general, the information requirements will include the rates or capacities, or both, the operating limitations, and the support requirements.

4.5 This guide covers equipment-related factors that will affect recovery-system effectiveness. Additional important factors that are not covered in this guide but should be considered as being critical to the success of a spill response include: contingency planning; communications plans; government approvals; logistics of supporting manpower and equipment in the field; and training and exercising of manpower.

5. Spill-related Information

5.1 *Spill Type*:

5.1.1 Response strategies will depend to some extent on the type of spill. The spill scenario should be defined as to whether it is an instantaneous or continuous release, whether or not the spill has ceased flowing, and whether the spill is contained or uncontained.

5.2 *Oil Slick Properties*—The following oil slick properties must be specified for the spill scenario. As some of these properties may vary with time, it may be desirable to use computer-based behavior models to produce spill property information for the time period of interest. For certain applications it may be useful to produce standard sets of spill property information that describe spills of interest as a function of time.

5.2.1 *Spill Volume*—The total volume of oil spilled should be specified (m^3). For spills that have not ceased, a spill rate (m^3/h) should also be specified.

5.2.2 *Spill Area*—The total spill area must be estimated in order to calculate estimates of slick thickness. For uncontained spills, the total spill area will increase over time; estimates can be made using computer-based behavior models. Alternatively, a simplified spreading model (Fig. 1: example spreading curves) can be used for first-order estimates.

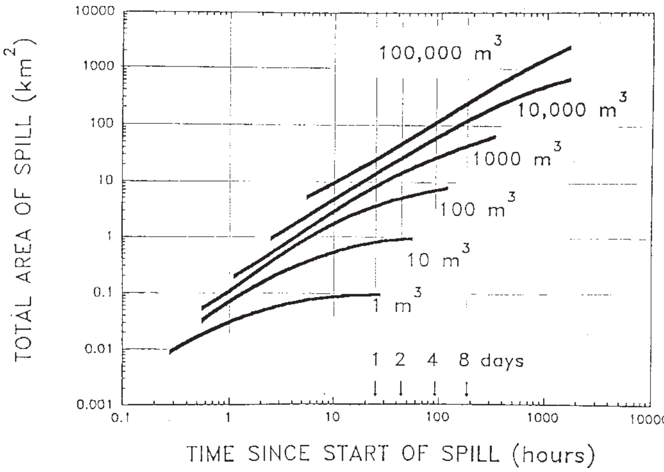

FIG. 1 Total Slick Area versus Time

5.2.3 *Slick Thickness*—Slick thickness is used in subsequent calculations of system encounter rate. Slick thickness is defined as the overall average thickness of the slick, and is estimated by dividing the spill volume by the total spill area at any given time. For this calculation, spill volume should take into account losses from the slick due to evaporation and natural dispersion, and increases to the slick volume due to emulsification. For uncontained spills, natural spreading forces will cause the slick thickness to decline steadily during recovery operations, and may result in a discontinuous slick composed of windows and patches separated by sheen or open water, or both. These factors should be considered in estimating an overall average slick thickness.

5.2.4 *Slick Viscosity*—The viscosity of the spilled product is used as a criteria to evaluate skimmer performance, as many skimming and pumping units will perform less effectively as viscosity increases. The viscosity of the spilled product will generally increase through the recovery period as the oil is subjected to weathering and emulsification processes. The viscosity should be specified as mm^2/s (cSt).

5.2.5 *Emulsification*—Emulsification is important as a spill process not only for its effect on oil viscosity but also because an emulsified oil represents a greater total volume of spill product that must be handled by skimming and pumping systems. Many crude oils and refined products will tend to emulsify over the life of the spill depending on the properties of the oil and the level of wave energy in the spill environment. The degree of emulsification should be specified as the emulsified water content expressed as a percentage.

5.2.5.1 It is recognized that emulsification rates for oil spilled in the marine environment will vary greatly depending on the oil properties, spill size, sea conditions, and temperature. As noted in 1.4, it is not the intent of this guide to provide standard rates of emulsification for a variety of oil products and environmental conditions. For the purposes of comparing system performance, the data in Table 1 is provided as an example of emulsification data for crude oil over a period of several days. Users of this guide are encouraged to use alternative data that suits their particular oils and environmental conditions.

TABLE 1 Example Data for Emulsified Water Content versus Time for Crude Oil

	12 h	1 day	2 days	3 days
% Water Content	30	50	65	75

5.3 *Spill Environment*:

5.3.1 *Temperature*—Water temperature is important as a parameter for estimating oil slick properties as well as the rate of change of those properties due to weathering and emulsification. (It is assumed that the temperature of the oil slick is the same as the water on which the oil is floating.) Water temperature is defined as the temperature of the upper surface layer and should be specified as °C.

5.3.1.1 Air temperature may be important as a parameter for modifying or limiting the performance of skimming and pumping equipment, and should be specified as °C.

5.3.2 *Wind/Waves*—The wind and wave environment is important to the analysis for two reasons; first, as a parameter in estimating the behavior changes of the oil slick, and second, as a limiting factor for recovery operations. For the first purpose, average wind speeds (km/h) should be specified. For the purpose of establishing criteria for limiting recovery operations, exceedance statistics (significant wave height) should be specified for the spill location. Exceedance criteria should be expressed as the percentage of time that conditions will allow recovery operations with reference to the equipment selected for the response and the environmental criteria listed in Practice F 625. For example, for spills in open water, wave exceedance data should be specified as the percentage of time that waves are less than or equal to 2 m, which would represent the percentage of time that equipment specified for open water use would be applicable.

5.3.3 *Current*—The presence of water currents may influence the selection of response strategies for a spill scenario, and may lead to a reduction in containment effectiveness in certain applications. The water currents, in m/s, should be specified for a given environment, with due regard to any local variations.

5.3.4 *Visibility*—Due to concerns with worker safety in poor visibility, as well as the inefficiencies related to the monitoring, tracking, and containment of oil slicks during periods of poor visibility, it is assumed in general that recovery operations are only possible when there is daylight and visibility of greater than 500 m (0.25 n.miles). Both of these factors should be expressed as the percentage of time that conditions exist that would allow effective operations.

5.3.4.1 It may be possible to effectively operate during periods of darkness and poor visibility if the recovery system includes adequate lighting equipment, remote sensing systems for assisting monitoring and containment efforts, or highly accurate navigation systems, or combination thereof. This may be particularly applicable to spills in nearshore and protected waters. In such cases a more liberal criteria for visibility limitations could be specified.

5.3.5 *Summary of Environmental Applicability Factors*—The wave exceedance, daylight, and visibility factors can be combined to produce an overall applicability factor that would represent the percentage of time that a given recovery system could be effectively used for a given spill scenario. For example, for an environment that has waves less than 2 m for 80 % of the time, receives 14 h of daylight, and has visibility greater than 500 m for 95 % of the time (note: all figures should be specified for the time of year of interest), the environmental applicability would be estimated as: $(0.80) \times (14/24) \times (0.95) = 44\ \%$.

5.4 *Spill Location*:

5.4.1 Spill location should be specified with respect to distance of response bases, in order to estimate transit times for the recovery systems, and with respect to shoreline, in order to estimate the time available to respond prior to shoreline oiling. Spill location may also be of importance when evaluating recovery systems that include the shuttling of recovered oil between the recovery site and temporary storage locations, in which case transit times may have to be deducted from the on-site availability of storage systems.

6. Recovery System Information

6.1 *Containment System Operating Factors*:

6.1.1 *Encounter Rate*—The encounter rate of the recovery system is a prime consideration in evaluating performance. The encounter rate is simply the rate (m^3/h) at which the system encounters the oil slick. The encounter rate includes three components: sweep width, encounter speed, and oil slick thickness.

6.1.1.1 The sweep width (or swath) is the width intercepted by a boom in collection mode, and is calculated by multiplying the boom length by the gap ratio. Where the gap ratio is not specified, a value of ⅓ should be used.

6.1.1.2 The encounter speed is the tow or current speed relative to the containment system. If not specified, a maximum encounter speed of 0.5 m/s (1 knot) should be used.

6.1.1.3 Encounter rate can be calculated as the product of these three factors, taking into account consistency of units. As well, simple nomograms (Fig. 2) can be used to estimate encounter rates for a range of conditions.

6.1.2 *Operating Limitations*—Containment equipment must be specified with regard to the environmental conditions of the given spill scenario. Guidance for selecting booms can be taken from Guide F 1523, which lists minimum requirements for boom dimensions and strength properties for calm, protected, and open bodies of water. Other limitations on the specified boom, such as minimum water depths and maximum tow speeds should also be listed.

6.1.2.1 The applicability of a boom to a given spill scenario should be considered as a constraint to containment operations. For example, a boom designated for calm water use (in accordance with Guide F 1523) will be satisfactory for containment operations in waves up to 0.3 m (1 ft). If the wave climate for a given area is such that 0.3 m waves are exceeded 25 % of the time then the boom could be considered to be applicable 75 % of the time.

6.1.2.2 Encounter speed is included as a factor in calculating the encounter rate. For most booms the maximum encounter speed will be in the range of 0.35 to 0.5 m/s (0.7 to 1 knot). It is recognized that certain containment systems have been designed to operate at higher encounter speeds: greater speeds than those noted above may be used if test data is available to

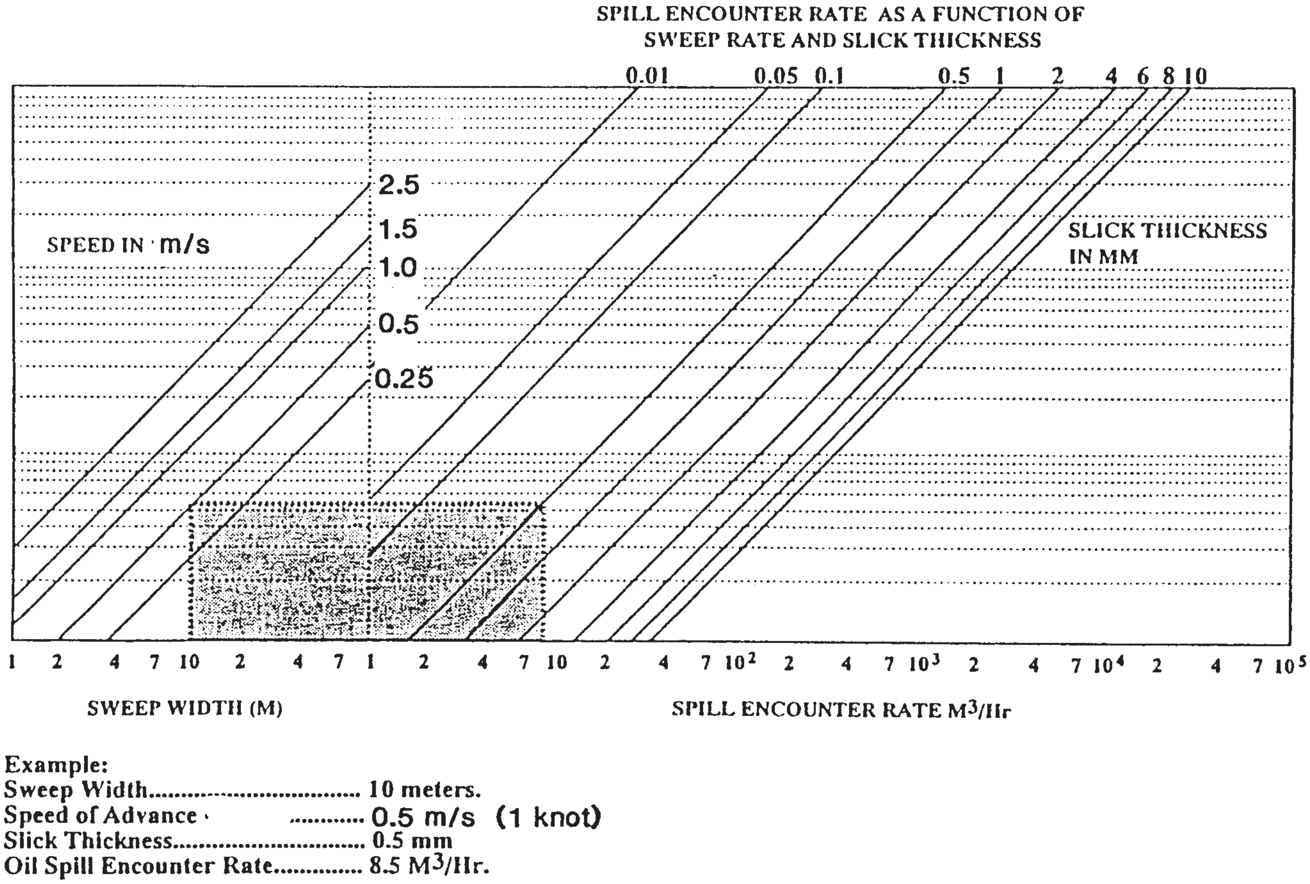

FIG. 2 Oil Spill Encounter Rate

support the selected encounter speed. For most booms, encounter speeds greater than 0.5 m/s should be used only with an accompanying reduction in the system's throughput efficiency to account for losses from the containment system.

6.1.3 *Support Requirements*—Support requirements for the listed containment equipment should be specified. Support requirements could include: transportation to deliver the boom to the spill site; equipment such as cranes or winches required to deploy, tow, and retrieve the boom; boom tackle such as tow lines, marker buoys, anchors, connectors; power or air requirements, or both, for boom deployment, operation, and retrieval; adequate manpower for deployment and retrieval; and vessels with adequate deck space for the required equipment, as well as adequate power and maneuverability for the specific situation. Any limitations on the specified support equipment should be specified; these could include: sea-state limits for vessel operation; draft limits on the vessels; minimum and maximum transit and tow speeds; and limits on vessel operation with respect to distance of shore.

6.2 *Recovery System Operating Factors*:

6.2.1 *Recovery Rate*—An appropriate recovery rate must be determined for the skimming unit based on the operating conditions specified in the spill scenario. The recovery rate should reflect realistic expectations of performance with regard to the slick thickness and viscosity as well as the specified environmental conditions, all of which may vary with time.

NOTE 1—The recovery rate used in the performance calculations cannot exceed the encounter rate estimated for the containment system.

6.2.1.1 The most desirable source of information for estimating a skimmer's recovery rate is experimental or field data collected for the particular skimmer of interest (Guides F 631 and F 808). As performance data is not available for many devices, a second alternative would be to examine experimental or field data from other comparable devices, and use it to estimate a realistic recovery rate for the spill conditions of interest. In the absence of any such data it may be necessary to use an estimate based on the skimmer's nameplate recovery rate. Report the source of the data and the method used to estimate the recovery rate.

6.2.2 *Recovery Efficiency*—A skimmer will generally recover free water along with the recovered oil. The amount of water recovered will affect the relative efficiency of a skimmer system because the total fluid volume must be handled by the transfer, storage, and disposal systems. In order to estimate the amount of total fluids that must be handled, the recovery efficiency of the skimming system must be known for the operating conditions expected. As with the recovery rate, the recovery efficiency may vary with the slick conditions and the environmental conditions, and should be estimated based on test data if available.

6.2.3 *Skimmer Operating Limitations*—Any limitations on the operation of the skimming unit should be specified. These could include: upper limits on the viscosity of the oil slick;

minimum slick thicknesses for effective operation; maximum sea states; and maximum hours of continuous operation.

6.2.4 *Support Requirements*—Support requirements for the listed skimming equipment should be specified. Support requirements could include: transportation to deliver the skimmer to the spill site; equipment such as cranes required to deploy and retrieve the skimmer; power requirements for skimmer deployment and operation; ancillary pumping systems; adequate manpower for deployment, operation, and retrieval; and vessels with adequate deck space for the required equipment. Any limitations on the specified support equipment should be specified; these could include: sea state limits for vessel operation; draft limits on the vessels; minimum and maximum transit and tow speeds; down-time for equipment maintenance; and limits on vessel operation with respect to distance of shore.

6.3 *Transfer and Storage Operating Factors*:

6.3.1 Storage capacity must be available to handle the estimated volume of total fluids (that is, recovered oil or emulsion and free water, or both). Sufficient temporary storage must be available at the spill site to handle fluids as they are recovered, and if applicable, additional storage must be available for the consolidation and storage of collected fluids awaiting disposal.

6.3.2 In general, it should be assumed that all collected fluids will require storage and eventual disposal. In some instances, however, it may be possible to reduce the total storage and disposal requirement through the use of oil/water separation and decanting of free water. This would require the specification of equipment and manpower dedicated to that task. Alternatively, the time required to carry out separation and decanting should be considered as a possible limiting factor which, in some instances, would reduce the amount of time available for skimming.

6.4 *Overall System Operating Factors*:

6.4.1 *Response Time*—The response time is defined as the time interval between the spill incident and the start of recovery operations. A response time should be estimated for the scenario taking into account an adequate time for the mobilization of recovery resources (that is, time to notify response teams and assemble the required equipment) as well as estimating a transit time of resources from the response base to the scene of the spill. In estimating transit times, unless otherwise justified, transit speeds of 10 km/h (5 knots) by water, 55 km/h (35 mph) by land, and 185 km/h (100 knots) by air should be assumed.

6.4.2 *Recovery Period*—The recovery period is defined as the time available for recovery operations. If appropriate to the analysis, the recovery period may be specified as including the response time; reporting should include a clear distinction between the two parameters. Users of this guide should select a recovery period appropriate to the circumstances of the spill scenario, and should consider the following factors, which may affect the period of time during which oil will be present on the water surface and available for recovery:

6.4.2.1 Proximity of the spill to shoreline or shallow water,

6.4.2.2 Type of oil and size of spill (re: rates of spreading and natural dissipation),

6.4.2.3 Hours of daylight, and

6.4.2.4 Weather conditions and sea state.

6.4.2.5 Alternatively, for the purposes of comparative analyses, an arbitrary recovery period may be specified.

7. Example Calculation

7.1 The following example calculation illustrates the methodology in estimating the effectiveness of a recovery system against a target spill. Through the example calculation, example values are given for slick thickness, emulsification, and recovery-system parameters. It is emphasized that these values are for illustrative purposes only. As well, for the purposes of this example, it is assumed that weather conditions do not hinder the response in any way; the implications of this assumption are discussed at the end of the example. A summary of the calculations is presented in a worksheet at the end of the example.

7.1.1 Consider a 1500 m^3 (9400 bbl) spill of crude oil. The spill occurs in open water, approximately 90 km from a response base. Estimate the effectiveness, over the first 24 h, of a recovery system that includes 250 m (820 ft) of containment boom, one skimmer with an estimated recovery rate of 25 m^3/hr (150 bbl/h), and a storage barge with a capacity of 200 m^3(1300 bbl).

7.1.2 The first requirement is to estimate a response time. For this example it is assumed that three hours are required for notification and mobilization of the equipment. Given the spill location, the transit time can be calculated as 90 km ÷ 10 km/h = 9 h, giving a total response time of 3 + 9 = 12 h.

7.1.3 Given that recovery operations will not begin until 12 h after the spill occurs, the slick conditions required in the analysis can be estimated. From the graph of slick area (Fig. 1), calculate the slick thickness as spill volume divided by total spill area (see Table 2).

7.1.4 The average slick thicknesses can now be used to estimate the encounter rate of the recovery system. Through the time period of interest, the slick thickness declines from 0.375 mm at 12 h, to 0.21 mm at 18 h (averaging 0.29 mm through that time period), and 0.15 mm at 24 h (and averaging 0.18 mm for the 18 to 24-h time period). Given the containment boom length of 250 m, and assuming a gap ratio of 0.33 and a maximum encounter speed of 0.5 m/s (1 knot), the encounter rate for the period of 12 to 18 h can be calculated as:

$$\begin{aligned}\text{encounter rate} &= \text{sweep width} \times \text{slick thickness} \times \text{encounter speed}\\ &= (0.33 \times 250\ \text{m}) \times (0.29\ \text{mm}) \times (0.5\ \text{m/s})\\ &= 43\ \text{m}^3/\text{h}\end{aligned}$$

7.1.5 Similarly, the encounter rate for the 18 to 24-h time period can be calculated as 27 m^3/h. In each time period, the encounter rate exceeds the recovery rate for the skimmer,

TABLE 2 Estimated Analysis of Slick Conditions

Time, h	Total Slick Area, km^2	Average Slick Thickness, mm
12	4	0.375
18	7	0.21
24	10	0.15
48	20	0.075
avg, 12 to 18	5.5	0.29
avg, 18 to 24	8.5	0.18

TABLE 3 Summary of Calculations

	Comments	No. 1	No. 2	Total
A. Time Period, h	No. 1: 12 to 18 h No. 2: 18 to 24 h	6	6	12
B. Slick Thickness, mm	scenario definition	0.29	0.18	
C. Encounter Rate, m^3/h	swath × speed × "B"	43	27	
D. Available Skimming Rate, m^3/h	specified in recovery system definition	25	25	
E. Actual Skimming Rate, m^3/h	lesser of "C"," D"	25	25	
F. Potential Volume Skimmed, m^3	"A" × "E"	150	150	300
G. Available Storage, m^3	specified in recovery system definition	200	50	
H. Actual Fluid Volume Stored, m^3	lesser of" F"," G"	150	50	200
I. Recovery Efficiency,%	scenario definition	75	75	75
J. Oil/Emulsion Stored, m^3	"H" × "I"	112.5	37.5	150
K. Emulsification, % water	scenario definition	20	20	20
L. Oil Stored, m^3	"J" × (1 − "K")	90	30	120
Total Volume of Oil Recovered	120 m^3	8 % of spill		

although it is clear that as the slick thickness continues to diminish, the encounter rate will soon be less than the "available" recovery rate and the recovery operation will be restricted by the encounter rate.

7.1.6 For the time period of interest, then, the oil slick recovery rate is the specified rate of 25 m^3/h, and the total potential volume of fluid recovered is (25 $m^3/h \times 12$ h) = 300 m^3. As this exceeds the available storage volume we are therefore restricted to a total fluid volume of 200 m^3, the volume of the storage barge. We must now determine the components of the recovered fluid. The selected skimmer has a specified oil recovery efficiency of 75 %; therefore 75 %, or 150 m^3 of the recovered fluids is oil and emulsion with 50 m^3 of free water. Secondly, the scenario definition states that the slick is expected to emulsify, with an estimated 10 % water content after 12 h and 30 % after 24 h. As a rough approximation, we can assume an average 20 % water content through the 12 to 24-h period. Therefore, the 150 m^3 of emulsion is in fact 120 m^3 of oil and 30 m^3 of emulsified water. (It should be noted that had the recovery system included a system for separating free water or breaking the emulsion, or both, and if discharge of separated water were permitted, then the storage limitation of 200 m^3 could have been applied to oil rather than total recovered fluids.)

7.1.7 Based on the preceding information it is estimated that a total of 120 m^3 of oil, or about 8 % of the total spill volume, could be collected in the first 24 h of the spill (see Table 3).

7.1.8 For the purposes of this example it was assumed that environmental conditions did not hinder the response in any way. There are a number of ways that weather factors could be used to modify the preceding methodology. As discussed in 5.3 of this guide, environmental data can be used to calculate an applicability factor. As well, sea conditions in the area of interest could be used to modify the recovery rate and recovery efficiency calculations, for example, for skimmers that are expected to have changes in performance with changes in wave height.