EDRC Project Final Report

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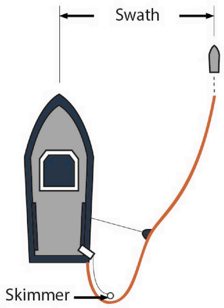

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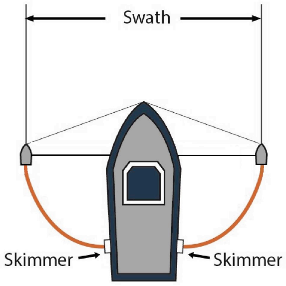

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Genwest Systems & Spiltec EDRC Project

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NOTE: The views, opinions, and/or findings contained in this report are those of the authors and shall not be construed as an official Government position, policy or decision, unless so designated by other documentation.

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The Genwest EDRC Project Team thanks those individuals from organizations listed in ***Appendix A. Contacts*** that participated during interviews for this project.

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- Ian Buist and Randy Belore of SL Ross (SLROSM).

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List of Acronyms

ANS	Alaska North Slope crude oil
API	American Petroleum Institute
ASTM	ASTM International, formerly known as the American Society for Testing & Materials
bbl	barrels
bpd	barrels per day
bph	barrels per hour
BSEE	Bureau of Safety and Environmental Enforcement
CFR	Code of Federal Regulations
DMP2	Dispersant Mission Planner 2
DNV	Det Norske Veritas
DWH	Deepwater Horizon
EBSP	Estimated Burn System Potential
EC	ERSP Caculator
EDRC	Effective Daily Recovery Capacity
EDSP	Estimated Dispersant System Potential
ER	Encounter Rate
ERR	Emulsion Recovery Rate
ERSP	Estimated Recovery System Potential
gpm	gallons per minute
IFO	Intermediate Fuel Oil
IPIECA	International Petroleum Industry Environmental Conservation Association
IR	Infrared
ISB	In-situ Burn Calculator
kts	Knots (Nautical miles per hour)
LLS	Light Louisiana Sweet crude oil
MEC	Mechanical Equipment Calculator
MES	Maximum Effective Swath
NCA	Norwegian Coastal Adminstration
NEBA	Net Environmental Benefit Analysis
NOAA	National Oceanic and Atmospheric Administration
NOFO	Norwegian Clean Seas Association for Operating Companies
NP	Nameplate
NOAA	National Oceanic and Atmospheric Administration

OLF	Norwegian Oil Industry Association
OPA 90	Oil Pollution Act of 1990
ORR	Oil Recovery Rate
OR&R	Office of Response and Restoration
OSRO	Oil Spill Removal Organization
OSRV	Oil Spill Response Vessel
PR	Pump Rate
PSV	Platform Supply Vessel
RE	Recovery Efficiency
ROC	Response Options Calculator
RSC	Response System Calculator
SFT	Formerly the Norwegian Pollution Control Administration
TE	Throughput Efficiency
TFRR	Total Fluid Recovery Rate
TSD	Temporary Storage Device
USCG	United States Coast Guard
VOO	Vessel of Oppotunity

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I. Executive Summary

In September 2011, the Genwest Project Team began a contract with the Bureau of Safety and Environmental Enforcement (BSEE) to conduct an objective and independent assessment of the existing Effective Daily Recovery Capacity (EDRC) planning standard. The EDRC is a measure used throughout the United States as a planning standard for estimating the volume of oil a skimmer could recover each day. In addition, the Project Team was to consider improvements that might be made to the EDRC approach and recommend new methods and guidelines to either enhance or replace that method of calculating a recovery system's daily potential for removing oil spilled on water.

The first phase of the project involved a review of relevant literature (see ***Section V. Bibliography***) and consulting with representatives from appropriate government agencies, oil companies, oil spill response cooperatives and contractors, research organizations, manufacturers, and oil spill specialists throughout the United States and abroad (see ***Appendix A: Contacts*** for a list of organizations contacted). The literature search, meetings, and attendance at several conferences and workshops in the United States and abroad provided opportunities to gather information and to meet with oil spill response experts, researchers, and regulators with a broad range of experience involving equipment testing and the development of planning standards. ***Section II Introduction*** and ***Section III.A Project Background*** give additional information on the objectives and approach used during this study.

Nearly all interviews conducted during this study (see ***Appendix A: Contacts***) included discussions about the current EDRC and related methodologies and technologies, and about potential policies or rules involving the creation of meaningful planning standards (i.e., standards that do not involve promises of performance). There were concerns expressed about the use of the term "Daily" in EDRC since "daily" suggests that a skimmer's recovery capacity would remain the same day after day. A more realistic measure would need to address a skimming system's ability to access oil that continues to spread and thin out with time. Individuals interviewed during this project expressed the importance of oil encounter rate to provide a better estimate of a system's recovery potential as compared with the use of a single-value EDRC involving a de-rated Nameplate (NP) recovery capability.

There was also strong opinion that the Nameplate recovery capability of a skimmer, often provided by the manufacturer, should be determined through a controlled and standardized set of test protocols carried out by an unbiased third-party group at an approved facility such as the Ohmsett Test Facility in Leonardo, New Jersey. A strong and consistent theme identified by participants, was the limitations of the current EDRC and the need for an encounter-rate, performance-based measure of daily recovery potential for skimming systems. These insights provided the incentive for the development of a new and improved measure of total "system" recovery potential. Such a measure would be flexible to accommodate different types of skimming systems, easy to use, and yet comprehensive in its ability to handle multiple operational parameters. While performance-based, the final tool would facilitate a "Planning Standard", distinguishable from a "performance standard".

A search for a performance-based tool or computer model with the ability to address oil encounter rate to support a planning standard involved nearly all the organizations in the contact list (***Appendix A***). Numerous return visits and calls were conducted to explore such an approach or to find something better for the estimation of a daily, but changing, skimming system recovery capability. Several concepts were explored during interviews with both domestic and foreign groups (***Section III.B Candidate Concepts***). Knowledge gained from computer simulations previously developed by Genwest, including the Mechanical Equipment Calculator (MEC) and the Response Options Calculator (ROC), provided insights into a potential solution. However, these models are either too restrictive (the MEC, using a single-valued oil thickness over the full simulation period) or overly specific (the ROC, calculating hourly thickness values based on defined oil / environmental conditions).

Through ongoing meetings with computer modeling specialists, personnel with equipment test facilities, and bi-weekly teleconference meetings with the project's sponsors, it was decided that recovery system operations could be simulated using recovery system parameters and algorithms drawn from portions of the ROC calculator. It was also decided that the ROC oil spreading equations could be used separately with a broad range of oil types and environmental conditions to identify meaningful average oil thicknesses for each of three days following a significant spill (typically hundreds to thousands of barrels).

To derive and confirm these three average oil thicknesses, a thickness analysis was conducted using the ROC model and the results were compared with oil thickness predictions from three commonly used and respected models (Applied Science Associates' SIMAP model, SINTEF's OSCAR model, and SL Ross oil spill model SLROSM). Based on this analysis (***Section III.C. Analysis of Oil Thickness***) and direct spill response experience, three nominal average oil thickness values were selected: 0.1 inch (12-hour exposure), 0.05 inch (36-hour exposure), and 0.025 inch (60-hour exposure) following a batch release of oil. The lowest value (60-hour exposure at midpoint of Day 3) approaches a few tenths of a millimeter. These values do not reflect the variability of oil thicknesses and conditions possible in an ocean environment (e.g., patches, streamers, windrows, etc.). They do, however, represent reasonable "nominal" average thickness values for use in developing "planning standards".

The selection of nominal average oil thicknesses facilitates the calculation of recovery system potential based on oil encounter rate. However, the selection of actual values used for a planning standard could vary depending upon the nature and magnitude of spills anticipated for a given location. The average oil thicknesses identified as "nominal" values for recovery during Days 1, 2, and 3 reflect the Project Team's best estimates for developing a recovery system assessment model. Further analysis may reveal a different set of nominal thicknesses.

The nominal average oil thicknesses selected for this study are based on relatively short-period releases of oil (i.e., "batch spills"). ***Section III.C, Analysis of Oil Thickness***, addresses the reason for selecting such batch releases and how the results can be used for continuous releases (e.g. blowouts) as well.

The new model developed in this project accounts for the performance of a skimming system as it accesses and contains oil, recovers and stores oil, and then transits to a backup vessel, barge or facility to offload its recovered fluids (Figure III.B-1). The model allows for the calculation of an Estimated Recovery System Potential (ERSP) based on nominal average oil thicknesses for each of the first three days following the release of a significant oil spill, typically involving hundreds to thousands of barrels. ERSP parameters are defined and their algorithms provided in ***Appendix B. ERSP Calculator User's Guide.***

The selection of three nominal oil thickness values for recovery during the first few days following a spill enables the calculation of three nominal average oil encounter rates for a given skimming system. A recovery system's operating swath and speed with respect to the slick while moving through a given average oil thickness is sufficient to develop a fully integrated set of parameters for any recovery system (large or small, nearshore, or offshore). Additional characteristics would include: the recovery system's onboard storage capacity; Nameplate recovery rate; Recovery Efficiency (RE); Throughput Efficiency (TE); discharge pump rate; etc. These and other operational parameters would need to be validated through controlled field / tank trials. Parameters are defined and their algorithms provided in ***Appendix B. ERSP Calculator User's Guide***.

Representative skimming configurations are described involving large, medium, and small Oil Spill Response Vessels (OSRVs) with a variety of skimming capabilities, onboard storage capacities, skimming speeds, etc. Diagrams and system descriptions for these configurations are provided to illustrate how certain parameters should be used and possibly modified for maximum performance using the ERSP Calculator. Several of the generic skimming configurations are used to define specific skimming systems and the input values associated with each system. The ERSP Calculator is used to reveal important strengths and weaknesses of each system; it allows one to explore ways to overcome system configuration weaknesses by modifying system components and other operational variables. One representative improvement involves the use of a Maximum Effective Swath (MES), which for a given recovery system is achieved when its Total Fluid Recovery Rate (TFRR) (including oil/emulsion and free water) matches its full Nameplate recovery potential. The operation of a skimming system with marginal recovery potential in its standard configuration might easily double or triple its daily recovery potential if operated downstream of an open-apex U-boom deflection system. Such a system could provide the additional swath needed to achieve the MES.

The ERSP Calculator is used to explore the sensitivity of the system configuration parameters that influence daily recovery potential. The selection of a number of representative skimming systems and the simulation of ways to optimize their daily recovery potential reveals the benefits of a planning standard based on oil encounter rate and other operational parameters. Such analyses show that enhancements can be identified and their benefit determined by modifying key operational parameters. The ERSP Calculator gives immediate feedback on system performance changes resulting from modifications of any of the input parameters. The calculator provides graphic representation of recovery operations including timelines of the number and duration of skimming periods for a complete fill of onboard storage, as well as the number and duration of transits and offload cycles.

In addition to the potential volumes recoverable over a 3-day period, the calculator gives possible areal coverage rates. For a given skimming configuration, the total area that could be swept over a 12-hour operating period is provided, typically on the order of a square mile for most large skimming systems. The impact of a spreading and thinning oil slick upon any recovery system should be considered as it affects both the volume recovery potential and areal coverage capability for that system. The importance of system swath and speed, Nameplate recovery rate, onboard storage, and areal coverage rate is discussed in ***Section III.F. Summary Observations***.

Other factors are considered with respect to their influence upon the amount of oil that could be removed from open water with various types of skimming systems. Consideration is given, in ***Section III.G. Other Factors Affecting Response*** for example, to the importance of surveillance and spotting capabilities, staging and response time, vessels-of-opportunity, human factors, night operations, offshore versus nearshore operations, cold-climate conditions, and the interaction of mechanical recovery operations with the use of controlled burning and the application of chemical dispersants.

The importance of these activities cannot be overemphasized. Vessel and equipment staging is one of the most important aspects of oil spill preparedness and response, as it includes not only the type and amount of response resources, but the time required to arrive on scene upon notification of a spill. The nature and amount of spillage possible, the distance of possible spill sources offshore, etc., are used by Oil Spill Removal Organizations (OSROs) to plan for and provide the right balance of shore-based facilities and offshore, centrally-located vessels, barges, and support platforms. Multi-purpose vessels such as those currently used as Platform Supply Vessels (PSVs) in the Gulf of Mexico can provide significant improvements for rapid and effective response (MSRC, 2011). Future planning standards could include the ERSP-type of recovery potential estimate; however, it will also be necessary to plan for and demonstrate that suitable types and amounts of response resources can arrive on location within a specified period of time.

Another factor not included in the ERSP calculation but of great importance is the provision of surveillance and spotting capability within hours of spill notification. This type of support is essential so that recovery systems can be directed to the heaviest concentrations of oil as quickly as possible. Once it is determined that it is safe to operate in a given area, qualified aerial observers are needed to direct skimmers into the heaviest concentrations of oil, and to keep them redirected as necessary.

Controlled burning and the application of chemical dispersants were not included in this study as options for which an Estimated Burn or Dispersant System Potential could be considered. The importance of these options, however, is addressed in ***Section III.G Other Factors Affecting Response*** of the report, and representative activities for each are shown in Figure III.G-1. These options become increasingly important when considering the volume recovery potential of mechanical removal systems alone, and the wind and sea conditions that can preclude the effective use of boom and skimming systems. The mechanical removal of spilled oil at sea, even in relatively calm or protected nearshore waters, may involve conditions that result in oil recovery volumes that are considerably lower than the estimated recovery potentials associated with a given ERSP. The overall volumes of oil recovered by skimming operations following the Exxon Valdez Spill in 1989 (USCG, 1993, Volume I), and the Deepwater Horizon Spill in 2010 (The Federal Interagency Solutions Group, 2010) serve as reminders of just how difficult it can be to recover spilled oil.

Every response option should be considered and used wherever it is safe and environmentally acceptable to do so. The oil spill response community needs to have every oil removal and elimination tool available for immediate response as needed, where it is safe and effective to use that response tool. The environmental tradeoffs of skimming, burning, and dispersing have been studied for decades, and industry's operators and plan holders should have clear authorization guidelines and response credits in place to stimulate the preparations for, and the implementation of, all available options.

II. Introduction

A primary objective of this study was to recommend improvements to the current use of the Effective Daily Recovery Capacity (EDRC) formulation as a measure of a skimmer's ability to recover oil on open water and to scientifically validate these recommendations. To prepare an objective and independent assessment, the Project Team met with spill response organizations, petroleum handlers, contractors, manufacturers, researchers, regulators and environmental groups to discuss the existing EDRC approach and to explore ways to improve the estimation of a recovery system's potential using performance-based operational parameters. These parameters need to include the changing properties of spilled oil with time, and the characteristics of a full recovery "system" that influences the ability to encounter, contain and recover oil. The assessment of a recovery system should include its ability to store and process / decant recovered fluids, and to transit and offload recovered fluids to backup storage vessels, barges or facilities. Figure II.1 is a diagram of this planning standard approach.

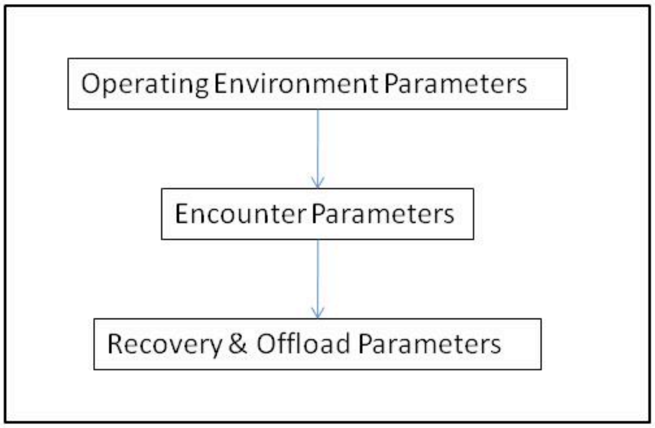


Figure II.1 Planning standard development using performance-based operational parameters.

Specific project objectives and tasks as outlined in the contract statement of work are provided below. These directives, provided by BSEE and the USCG, were used throughout this project to guide the gathering and evaluation of information and to explore options for an improved measure of skimming system recovery potential. They also guided the design and development of a computer-based methodology to calculate the recovery potential for skimming systems on water, as detailed in this report.

II.A. Objectives

A. *Prepare an objective and independent assessment to scientifically validate the most appropriate methodologies for estimating the effective daily recovery capacity (EDRC) of oil skimming systems;*

B. *Provide recommendations for EDRC improvements to inform oil spill planning and preparedness; and*

C. *Make recommendations for new EDRC methodologies and guidelines for response systems deployed in nearshore and offshore operating environments.*

II.B. Summary of Tasks

A. *Evaluate existing EDRC methodologies and technologies.*

B. *Research skimmer (or pump) de-rating factors and other planning standards used by other oil producing countries.*

C. *Compile skimmer efficiency data from actual usage in different operating environments (nearshore and offshore).*

D. *Examine the influence of other variables on recovery rates. Interaction of mechanical, dispersants and/or in-situ burning.*

E. *Recommend factors for predicting recovery rates reflecting how the system will operate in nearshore and offshore environments.*

F. *Develop a user-friendly computer based methodology for EDRC.*

G. *Formalize the findings and recommendations from the project into a reviewed and approved Final Report and present these findings to the BSEE & USCG.*

II.C. Project Design

The tasks above were addressed through extensive interviews, literature searches, data analyses, recovery system comparisons, and parameter sensitivity evaluations. As these efforts progressed, there were ongoing interviews with oil spill response experts, researchers, manufacturers, and agencies to gather additional information for the test and evaluation of concepts that could best define a recovery "system" and the parameters needed to characterize it.

A document relevant to the origins of the existing EDRC was found in the **Proceedings of the 1993 International Oil Spill Conference** (Lees, 1993). In this paper the author lists a number of environmental, oil and recovery system descriptors, stating that the database for all these factors is too limited to specify or evaluate each one. The primary factors needed to determine recovery system potential were identified in the report. Those factors have not changed, and are used in this project to evaluate a recovery system's potential.

The interviews and subsequent analyses focused on quantifiable parameters, such as system swath, speed, Nameplate recovery rate, etc. These operational parameters, identified by Lees in 1993, are still needed in order to create a computerized model for the estimation of a skimming system's recovery potential.

It was also evident that other non-quantifiable factors would need to be considered. These include the staging of equipment, the provision of surveillance and spotting capabilities, night operations, etc. These factors play an important role in the provision of a fully integrated response capability. They involve preparations, equipment, personnel, and procedures without which it would be nearly impossible to implement and carry out actual field operations. It was the blending of the physical operational parameters, those needed to "calculate" a skimming system's recovery potential, and the more subjective factors essential for effective recovery operations, that drove the project design.

Once most of the project interviews had been completed and data was analyzed regarding recovery system performance from field trials, tank tests and actual spills, the findings were used to assess how others (both national and foreign) have used, or are planning to use, similar data to create planning standards. These findings are presented in ***Section IIIB. Candidate Concepts***.

The Project Team made every effort to contact and interview key individuals that were especially familiar with oil spill response prevention, planning and procedures. These efforts focused on guidelines and regulations, including the current EDRC approach to the calculation of daily recovery capacity. Organizations contacted during this study (***Appendix A: Contacts***) include: the American Petroleum Institute (API), Aramco Services, Det Norske Veritas (DNV), the International Petroleum Industry Environmental Conservation Association (IPIECA), Ohmsett, Norwegian Clean Seas Association for Operating Companies (NOFO), and several individual oil companies, OSRO's and other industry experts in the U.S. and abroad. Meetings with individuals from these and other groups were conducted with the understanding that specific concerns and opinions would not be revealed, and that general observations and suggestions would be used only to help clarify and refine an understanding of past, current and future aspects of recovery system assessment and related planning standards.

The results of these meetings and telephone interviews, combined with an extensive search of conference proceedings, ASTM International standards (formerly known as the American Society for Testing & Materials), government regulations, and industry technical reports (***Section V. Bibliography***), led to the conclusion that the current EDRC formulation would need significant changes. The Project Team realized that no other existing concept seemed to fit the objectives of a fully integrated recovery system approach that could address the changing properties of oil and the full range of operational variables needed to define a response "system". The Project Team focused on the kinds of system-performance-based calculations that have been used in other modeling efforts conducted by Genwest, such as the Mechanical Equipment Calculator (MEC) and the Response Options Calculator (ROC).

The Mechanical Equipment Calculator is a part of the National Oceanic and Atmospheric Administration's (NOAA) Spill Tools^{TM} suite of programs, which were developed for NOAA by the Project Team in the 1990s. The Spill Tools^{TM} program provides encounter-rate based methods to evaluate the capacity of local resources to reduce the impact of spills.
Figure II.C-1 graphically depicts the contrast between the simple one-parameter computation required for the basic EDRC planning standard against the more technically robust and operational "systems" approach taken here. The new recommended evaluation tool, the

Estimated Recovery System Potential (ERSP) Calculator, reflects both the multiple parameters and the full recovery cycle associated with on-water oil spill skimming systems.

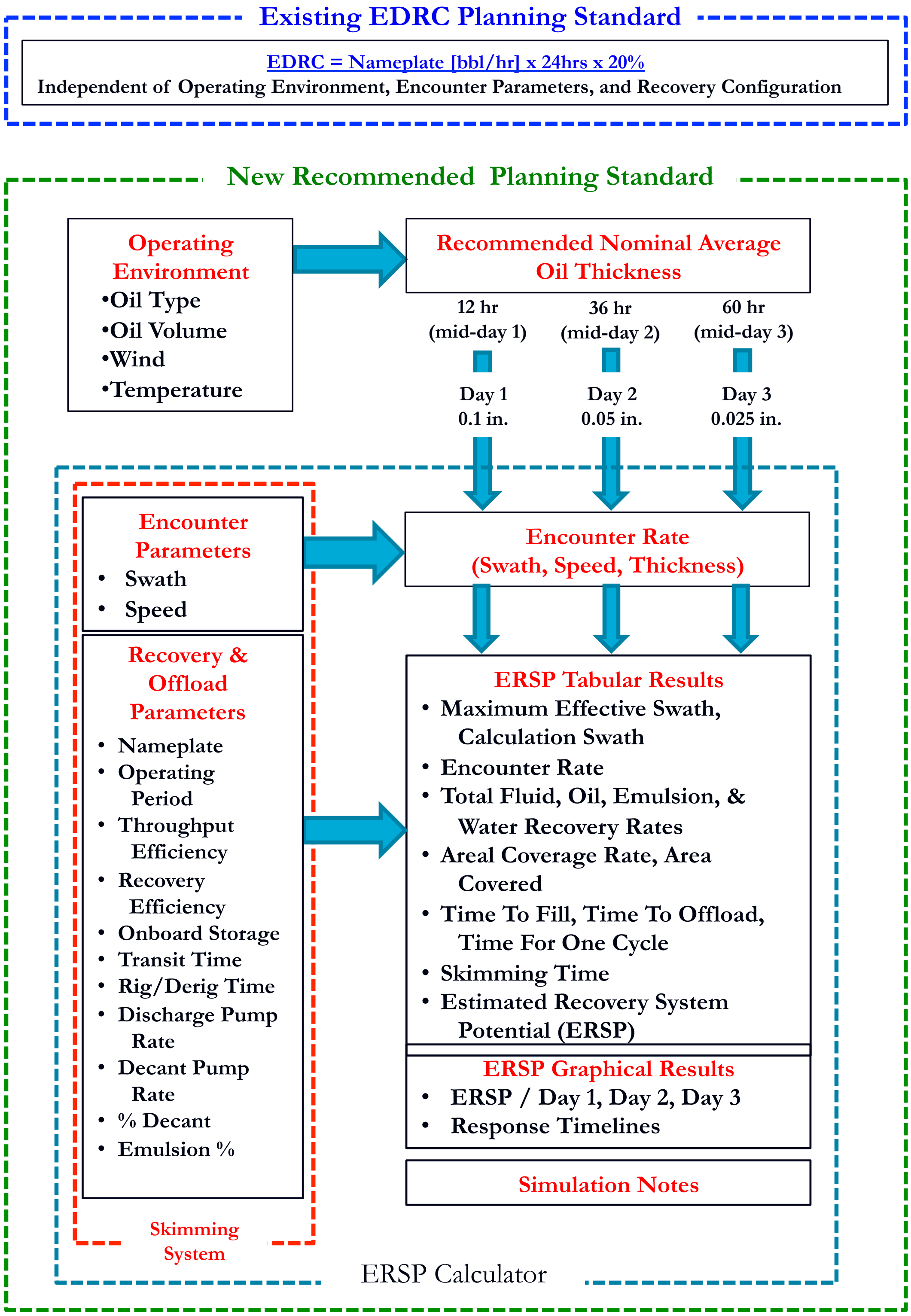
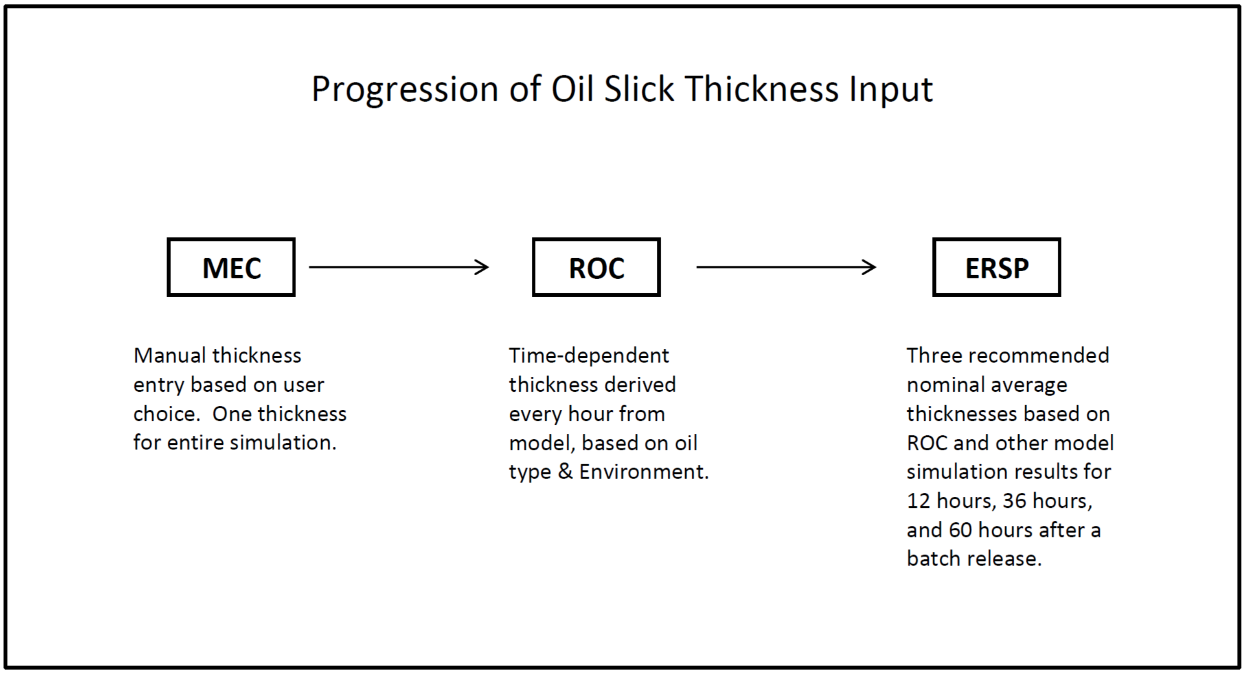


Figure II.C-1: EDRC Project Technical Approach and ERSP Framework.

To facilitate the evaluation and comparison of different skimming systems and configurations, it was determined that the inherent variability of environmental and oil characteristics data would best be minimalized in these computations. The variations of oil types and site-specific environmental conditions impact the oil thickness being used to compute encounter rate. Based on this, hundreds of simulations were run to aid in the identification of three nominal average thickness values to be used for computing recovery system potential described in this report.

The following diagram illustrates the progression of methods used for thickness entry in models the Project Team has developed (Figure II.C-2). The importance of oil slick thickness cannot be overemphasized. It is the most difficult factor to assess in determining the encounter rate and is one of the most important parameters upon which the assessments of all response options depend.



Manual thickness entry based on user choice. One thickness for entire simulation.

Time-dependent thickness derived every hour from model, based on oil type & Environment.

Three recommended nominal average thicknesses based on ROC and other model simulation results for 12 hours, 36 hours, and 60 hours after a batch release.

Figure II.C-2: Progression of methods used for modeling of oil thickness.

While the MEC and ROC models provide useful peer-reviewed algorithms for system performance, their formulations and use of oil slick thickness would need to be modified to align with the objectives of this project. It was also apparent that the changes a slick can go through with time would need to be examined and simplified to accommodate the development of a planning standard to replace the EDRC.

The design of a new and improved method to assess skimming system recovery potential on a daily basis would normally address spatial and temporal aspects of oil spreading, emulsification and degradation. Such changes are addressed in the ROC and other oil spill models. However, the creation of a relatively easy-to-use, performance-based formulation for daily recovery potential would need to involve an acceptable simplified representation of such processes. A recovery system's ability to access, contain and recover floating oil would need to account for the changing thickness of oil with time and the resulting reduction in oil encounter rate.

In the sections that follow, an approach is described that involves an approximation of oil thickness after spreading for 12 hours, 36 hours and 60 hours. These are values that could represent the mid-day times of each of three days following a spill released at midnight. This representation of time following spillage is one way of examining the range of thicknesses associated with a number of oil types and volumes released under a broad range of spill conditions. This approach also allows one to examine the results for sudden "batch" releases of oil, and to then consider how such results influence the accessing of oil downstream of a continuous release.

The effort to simplify and consolidate otherwise complex oil spreading and degradation processes targets the possible identification of reasonable standardized thickness values to facilitate the creation of a planning standard. As discussed further in ***Section III.C. Analysis of Oil Thickness***, the "nominal average" oil thicknesses for each of three days following spillage are provided as reasonable thicknesses for consideration. These thickness values are then used to facilitate representative recovery system calculations and comparisons of various response systems.

During the course of this study, a 3-day assessment of slick thickness reductions led to a modeling scheme that proved helpful in simulating the performance of a number of representative skimming systems. Those efforts, described in ***Section III.D*** and ***Section III.E***, confirmed the efficacy of modeling recovery system parameters and revealed a number of important operational findings that could significantly enhance any recovery system operation. The unfolding of a useful set of algorithms to assess daily recovery potential led to the creation of what became the ERSP Calculator. It serves as a relatively simple stand-alone computer model that could be used as a performance-based “measure” of a skimming system’s 3-day recovery potential; a vital part of a new and improved planning standard.

The ERSP Calculator made it possible to address many of the objectives of this study while also providing a model with which important recovery system parameters could be studied and compared. The project was designed so that any possible enhancement or replacement of the EDRC formulation would address changing oil encounter rates and other important operational parameters. The proposed replacement of EDRC with an improved, operationally-based ERSP has made it possible to estimate daily recovery potentials for nearly any skimming configuration (i.e., large or small, offshore or nearshore) while also allowing for the optimization of system components to maximize recovery capability.

III. Analysis & Recommendations

III.A. Project Background

The existing regulatory standard for quantifying oil spill surface recovery capacity is the EDRC. It has served the regulatory and response community for many years as a relatively simple standard for evaluating the possible recovery capability of a given skimmer. One of the shortcomings of the EDRC formulation involves the de-rating of a skimmer's performance to 20 % of its Nameplate recovery capacity to estimate the volume of oil that can be recovered in 24 hours (33 CFR 154 App. C and 30 CFR 254.45 b and c). This simple percentage approach, adopted after the passage of the Oil Pollution Act of 1990 (OPA 90), is based on a best estimate that tried to account for downtime due to darkness, viscosity, oil / water separation, the presence of debris, etc. (Lees, 1993).

According to Lees (1993), the EDRC was already recognized for its limitations. A more realistic approach would involve consistent, standardized test data for recovery potential and that a full spill recovery "system" should be identified and used to calculate a meaningful estimate of a system's recovery potential. Such a system should include, if possible, the full range of factors that affect a skimming system's oil encounter rate, its ability to contain and recover oil or emulsion, and the quantities of fluid that can be stored onboard. A systematic approach should also include the time required to offload recovered fluids and return for continued skimming within an established operating period.

During the completion of Tasks A, B and C, the Project Team met with individuals representing petroleum companies, federal and state regulatory agencies and oversight groups, oil spill response organizations (OSROs), environmental and citizen advisory groups, equipment manufacturers, and spill response specialists throughout the United States and abroad (***Appendix A. Contacts***). The review of international standards and related petroleum activity involving planning and preparedness (Task B), and the gathering of data on recovery system evaluation procedures and results (Task C), provided valuable input for this study. The ideas and experiences of those interviewed helped build a strong foundation for the analysis and a recommendation of an improved method to estimate mechanical recovery rates and efficiencies both nearshore and offshore. One goal was to study other efforts involving the assessment of recovery systems and identify a reliable method or "tool" that could be used to measure system recovery potential under a broad range of oil and environmental conditions. The ultimate goal is to develop a new "Planning Standard" for the mechanical removal of oil on open water.

III.B. Candidate Concepts

The identification and analysis of candidate concepts to assist with the development of a planning standard focused on several key objectives:

- To find a consistent and reliable means of analyzing the full range of parameters that describe a mechanical recovery system's ability to remove oil from the sea surface. The parameters should include all quantifiable and verifiable factors that influence a recovery system's activities including the access of oil on the surface, the collection and containment of that oil, the skimming of the oil from the surface, the storage and possible treatment or decanting of water from recovered fluids, and the offloading of recovered oil to backup storage.
- To recognize that any new and improved way to characterize and assess a skimming system's capability would have to involve a period of time over which the release and spreading of oil could strongly affect any estimate of recovery potential. This objective, and the known rapid spreading rate of most oil spills, emphasized the need to account for a skimming system's changing oil encounter rate with time.
- To find the right balance between simplification and sophistication to support an easy-to-use model or spread sheet, while adequately addressing the operational variables that influence recovery rates and efficiencies, areas of coverage, etc. A goal was to include those parameters that most influence the volume of oil that could be recovered within a given operating period/day for a representative or nominal average oil thickness within that period.

Four candidate concepts were considered during the course of this project to meet the objectives defined above. It is important to note that for each concept, the goal was to identify a more realistic formula, spread sheet, or computer model that could replace or enhance the current EDRC formulation. The outcome of this effort was not to address the calculation of Worst Case Discharge Planning Volumes, or show how an improvement or replacement of the existing

EDRC would be used by regulators to determine the response resources needed for specific spill scenarios. The following concepts were examined in order to find a suitable method of calculating the recovery potential of a skimming system in barrels per day (bpd), or better yet, barrels per operating period:

1. Modification of Current EDRC
2. Norwegian Risk-Based Approach
3. Partial Use of the Response Options Calculator (ROC)
4. Development of a Full-System, Encounter Rate-Based System

III.B.1 Modification of Current EDRC

Interviews were conducted during the course of this project to determine the supporting logic for the existing EDRC 20% de-rating factor, and to get clarification on the logic, variables, or policies used in determining the EDRC. One of the best sources of information on the origin of EDRC (Lees, 1993) addresses the enactment of the Oil Pollution Act of 1990(OPA 90) and how this regulation affected oil spill planning requirements, the rule-making process for implementing these requirements, and key issues that would affect oil spill response throughout the United States.

The following statements are taken from Lees (1993) paper "**Contingency Planning, Contractor Requirements, and Oil Pollution Act of 1990 Implementation**" as they help to explain how the EDRC approach was created and how the de-rating factor of 20% was selected for the EDRC calculation:

> *"The Coast Guard also realized that several issues required intensive technical input; consequently, it formed the Oil Spill Response Plan Negotiated Rule-Making Committee. The committee included participants from various interests affected by this rule making, including representatives of domestic and foreign vessel and facility owners and operators, environmental groups, response contractors, local and public interest groups, labor unions, the Coast Guard, and states in the various USCG geographical regions."*

> *"Effective skimming capacity depends on, among other things, the encounter rate of the*

> *skimmer with the oil, the efficiency of the oil/water separation process in the skimmer, the viscosity of the oil, and the presence of debris. It also depends on weather, visibility (night or fog), and the skill of the operator. The database for all these factors is too limited to specify or evaluate each one. As a result, the committee - following an approach similar to that adopted by the State of Washington in its response plan rules - recommended, and the Coast Guard proposed to use, the following factor:"*

Effective Skimming Rate (bbl/day) = Manufacturer's Nameplate capacity (bbl/hr) x 24 (hrs./day) x 20%

> *"The de-rating factor attempts to capture all the variables, including the number of hours per day of skimming and the skimmer efficiency. Applicants may apply for additional credit if they can demonstrate that any of the factors justifies more credit."*

The information in Lees' document (1993) shows how the existing EDRC standard was adopted by the USCG as recommended by the Oil Spill Response Plan Negotiated Rule-Making Committee. The recommendation was based on the limited availability of data at the time, and upon a similar approach that was being taken by the State of Washington. The Minerals Management Service (MMS) also adopted this standard in 1997 regulations.

The EDRC approach has survived since its implementation following the enactment of OPA 90. The EDRC involves a simple calculation where the Nameplate recovery capacity or throughput of a skimmer (in barrels per hour) is multiplied by 24 hours/day, and then by an efficiency factor of 20% (unless approved at a different percentage by the USCG or BSEE). If a skimmer involves a pump that determines the throughput of recovered fluids, then the pump capacity is used. There are minor variations of this calculation depending upon the type of skimmer (e.g., with belt and mop type skimmers), and where an owner/operator or plan holder can document and have approved an actual average oil recovery rate in barrels per hour which is then multiplied by the number of hours that the skimmer can actually be operated each day. Again, the use of a given oil recovery rate must be validated using ASTM protocols, and the proposed hours of actual use must be documented and approved by the USCG or BSEE.

Federal regulations[1] address specific requirements for the calculation of EDRC for skimmers. The 30 CFR 254.44b allows an operator to use a different efficiency factor for a skimmer; BSEE also has specific requirements and test criteria for boom and skimmer evaluations (30 CFR 254.45 b and c).

The EDRC 20% efficiency factor formulation (or any adjustment approved by the USCG) is supposed to account for limitations imposed by available daylight, weather, sea state, etc. Even with an approved alternative calculation for efficiency and actual hours of expected use each day, the EDRC formulation calculates a "daily" recovery capacity. This implies that the EDRC would not change from one day to the next. In other words, a calculated recovery capacity for a certain skimmer on Day 1 would be the same on Day 2, Day 3, etc., even though the spreading of oil would reduce the average oil thickness over time and the corresponding encounter rate for that skimmer.

The existing EDRC formulation does not account for changing oil thickness with time; it also does not account for the matching of nameplate recovery capacity to the rate at which oil is being intercepted (i.e., oil encounter rate). This shortcoming occurs because the EDRC does not include actual system characteristics, such as swath, speed, recovery efficiency, throughput efficiency, onboard storage, etc. These operating characteristics are required in order to estimate the potential recovery capability of a skimming system each day. The EDRC calculation is further limited by the absence of any consideration of the time to fill onboard storage and the time to transit to a backup storage vessel, barge or facility to offload its recovered fluids.

The shortcomings associated with EDRC cannot be fixed with modifications to its existing formulation. The refinement of EDRC to meet the objectives of an encounter rate-based system with allowance for oil access, containment, recovery, storage, and transfer must involve a complete reformulation with parameters that permit the quantification of those processes.

III.B.2 Norwegian Risk-Based Approach

Members of the Project Team have worked on oil spills, research projects, training exercises,

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[1] Examples given include: 30 CFR 254; 33 CFR 154 App. C; 33 CFR 155 App. B; and 40 CFR 112 App. E.

and contingency plans throughout the world. These exposures to industry, academia, and regulatory groups, together with the interviews conducted during this study, have revealed that few countries, if any, have developed the kind of recovery system assessment tool needed here for a planning standard. Norway has conducted numerous studies, research projects, field trials, and equipment development programs to improve oil spill response technology and model the many processes of oil fate and behavior, equipment performance, and the impacts of oil upon the environment. In recent years this community, working with some of the most dynamic and challenging conditions of the North Sea, has contributed significantly to the study and analysis of topics closely related to the objectives of this project.

Organizations such as the Climate and Pollution Agency (Klif)[2], the Norwegian Oil Industry Association (OLF), and others have established various guidelines for addressing spills of different sizes off the coast of Norway. This includes specific regulations covering response time requirements for boom and skimmers, oil recovery rates, and "sweeping capacity" (our areal coverage rate). The Norwegian Coastal Administration (NCA) is still another government agency with the responsibility of organizing and maintaining governmental, municipal, and industry oil spill preparedness. Oil spill contingency plans for Norwegian operators are set with 4 "barriers": 1) respond immediately at the point of discharge; 2) respond along the predicted trajectory of the spill; 3) respond near the coastline; and 4) respond to oil at the shoreline and in the intertidal zone.

Plans include an assessment of the size and risk of discharge as well as the most promising response method to be used (i.e., recovery, dispersants, or burning). Dispersants and mechanical recovery are clearly the preferred options. At the current time there are no specific guidelines or regulations pertaining to the use of burning. Decisions regarding the type and size of response are made on a site-specific basis with the most realistic spill scenarios possible. The scale of a response is planned in proportion to the perceived risk, with the deployment of equipment as effective as possible within the constraints of available resources.

As indicated above, most of the documentation found on Norwegian guidelines and

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[2] Formerly the Norwegian Pollution Control Administration (SFT)

regulations deal with functional, rather than technical, requirements. It is when plans involve groups such as NOFO (the Norwegian Clean Seas Organization), the Norwegian Coast Guard, and the Armed Forces that more specific guidelines and standards come into play and specific requirements are put forth regarding oil recovery vessels, equipment, dispersant application, etc. NOFO, together with organizations like DNV and SINTEF, strive to include such requirements in their assessments of alternative spill response strategies. SINTEF, for example, has developed the Oil Spill Contingency And Response (OSCAR) model that includes site-specific information on the probability of a spill, probable release conditions, oil type, and environmental conditions. While the OSCAR model is a comprehensive and sophisticated tool for examining oil fate and behavior, trajectories, response options, and environmental impact, it does not satisfy the requirement of this study for a simple measure of a recovery system's potential based on oil encounter rate, Throughput and Recovery Efficiencies, storage, decant, and offload capabilities. The OSCAR model is also privately owned, not freely available to the general public, and it requires a considerable amount of training to use it effectively.

Norway's current reliance upon nominal recovery (or pumping) capacities in the contingency plans of offshore operators, adjusted for weather conditions and resulting downtime, has been accepted by the authorities of that country. They are currently looking for improvements, and are in the process of developing a new standard for the estimation of recovery capacity. Their risk-based assessments of spill probabilities and the risk of impact on birds, fish and mammals are commendable and of great help when dealing with Net Environmental Benefit Analyses (NEBAs) and issues of response resource needs for a given level of protection. However, this planning and response assessment technique, together with the modeling limitations described above, suggests that the Norwegian risk-based approach, as currently used, would not meet the project's needs.

III.B.3 Partial Use of the Response Options Calculator (ROC)

The ROC was given serious consideration as a possible means of meeting the objectives of this study. The ROC already uses many of the algorithms that allow a calculation of a recovery system's potential for accessing, containing, skimming, storing, and offloading oil from an open-water environment. The ROC has been peer-reviewed and beta tested, and can handle both batch releases and continuous spills under a broad range of environmental conditions.

The ROC was designed as a scientifically advanced model to handle a broad range of oil types, predicting the hourly thickness of an oil spill using a combination of calculations involving the oil characteristics and environmental conditions selected by the user. One can also select a constant thickness for a set of conditions over a specified period of time. The calculator performs its calculations by allowing for the weathering and spreading of a spill, or by using a constant oil thickness. It performs its calculations over intervals of one hour, providing detailed results of system performance for mechanical recovery systems, chemical dispersant application systems, and for vessels deployed to conduct controlled in-situ burns.

It takes a fair amount of preparation and practice to operate the ROC, as there are many scenario descriptors that must be understood and used to move through the set-up of each computer simulation. These may include such settings as the simulation time zone, date and time of simulation start, type and volume of oil spilled, rate of release, water temperature, wind speed, etc. These and many other specific input parameters must be used in order to run a single calculation of system performance. The model does what it was designed to do well; however, it was not designed to provide an estimate of recovery system potential for designated operating periods on each of three days following a spill. The model's extensive algorithms involving the weathering and spreading of oil, together with its sophistication in simulating the application of dispersants and the burning of oil, make it too complex for this application. The replacement or enhancement of the existing EDRC formulation should be an easy-to-use tool that can simply give the expected recovery potential of a skimming system over the first few days of a spill. It should also produce results in a convenient format for any recovery configuration to facilitate the use of a Planning Standard.

III.B.4 Development of a Full-System, Encounter Rate-Based System

A review of the three previous approaches reveals that the best way to improve the existing EDRC formulation is to build upon the experience gained while developing previous oil spill response models. The Project Team has developed several models including the MEC, In-Situ Burn Calculator (ISB Calculator), Dispersant Mission Planner 2 (DMP2) (NOAA OR&R, 2012), and the ROC. These models, or the logic in them, have been used in other models and response capability assessments (Konkel and McCay, 2008; Censum, 2008; and Washington Oil Spill Advisory Council, 2009). Some of the basic algorithms from these models were reviewed with regulators, responders and plan holders that currently use the existing EDRC. The lessons learned while developing those models, together with the suggestions received from individuals who have used them, provided confirmation that a meaningful assessment of recovery potential should include an oil encounter rate-based approach (Gregory, et al., 1999). This research confirmed that at least three days of estimated recovery potential would be needed to address the important, early phase of a response when oil is at its thickest (Day 1), and when there is sufficient time for the cascading of additional resources during Days 2 and 3.

Figure III.B-1 provides an example of the steps involved when planning for and responding to an offshore oil spill. It begins with the pre-spill staging of response resources, moves through the activities of finding, accessing, recovering, storing, and offloading recovered oil to backup storage, and then shows the cleaning (or "decon") of vessels/equipment and the disposal of recovered fluids. These activities would normally be addressed by the owners or operators of vessels and offshore facilities in their response plans. Regulators examine these plans to ensure that the operator or plan holder has identified the resources and trained personnel necessary to conduct each activity. Inspections and exercises are conducted to verify that the operators can deploy and operate the equipment safely and effectively.

Figure III.B-1 illustrates the activities that should be included in the model – from the time oil is first accessed through the transfer of recovered fluids to backup storage and the return of a skimmer to the spill for continued recovery. The parameters for each of these four primary operational activities need to be specified for a given skimming system. These parameters will be used to create algorithms that account for oil slick thickness and water content, skimming system configuration and efficiency (i.e., swath, speed, recovery efficiency, etc.), system storage and decant capabilities, and factors that affect the times to transit and offload recovered fluids.

One of the most important parameters needed to assess a skimming system's potential recovery capability is the average oil or emulsion thickness being accessed. The oily fluids encountered by a skimming system will often contain some water as a water-in-oil emulsion. The terms "oil thickness" or "oil / emulsion thickness" are used interchangeably in this report as the thickness of the oily material encountered by a skimming system.

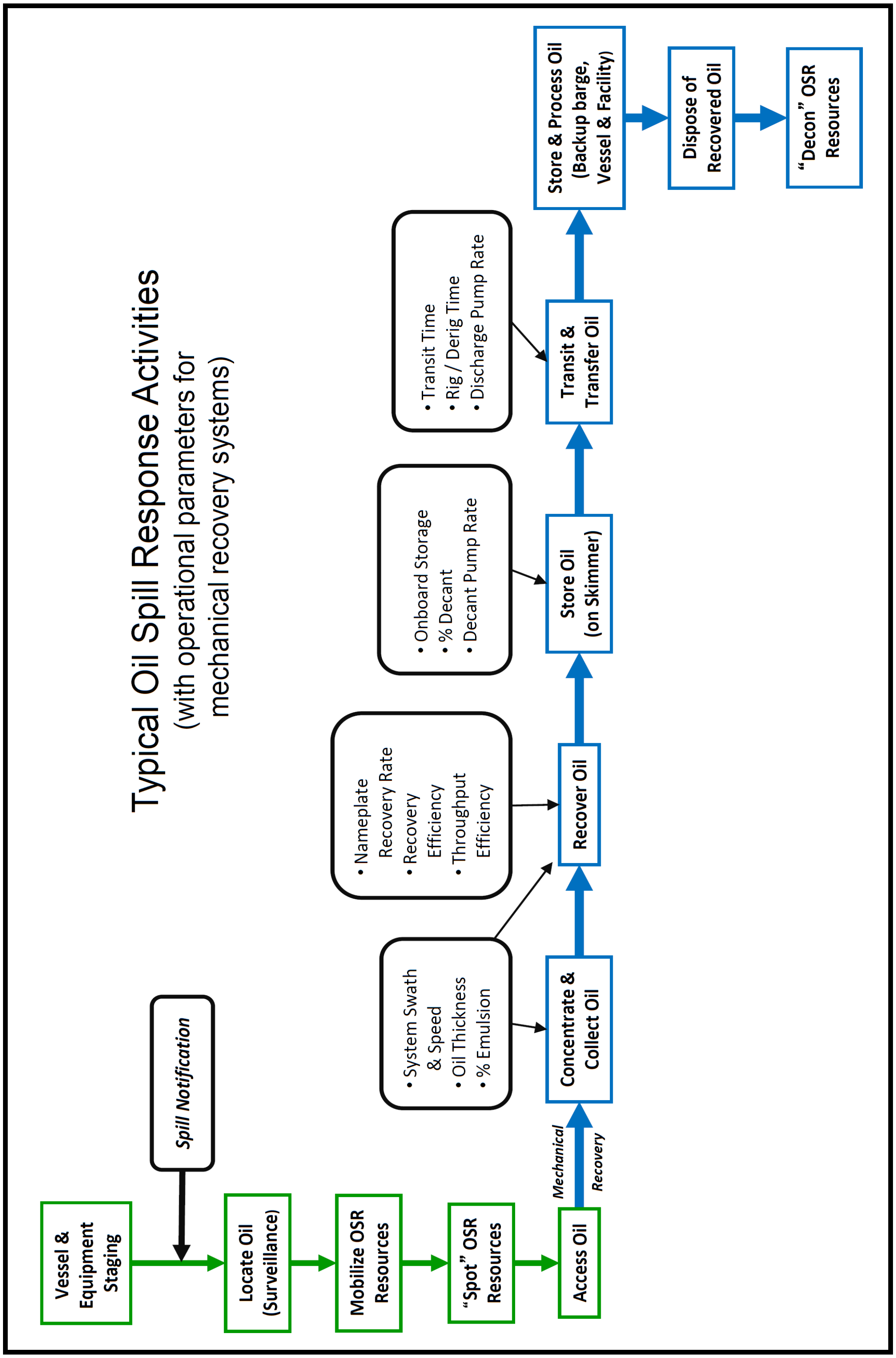

Figure III.B-1: Typical oil spill response activities.

III.C. Analysis of Oil Thickness

III.C.1 Oil Thickness Dynamics

Rarely does an oil slick have a single thickness even within a relatively small area. Slicks often have a range of thicknesses spanning several orders of magnitude. An average oil slick thickness, however, can be used as a measure of the amount of oil available to be recovered and is one of the three components of oil encounter rate. Thickness is commonly expressed in millimeters or inches but can also be reported as a concentration or volume per unit area (e.g., barrels of oil per acre). Thickness is very difficult to measure directly. Infrared (IR) sensors can detect the presence of oil slicks but generally provide relative thickness only. Oil slicks are not only variable in thickness; they often have very complex structures (patches, streamers, etc.). An “average” oil thickness is used in this report to represent the total volume of oil contained in a given area. The following graphic (Figure III.C-1) was modified from the NOAA DMP2 that was developed by members of our Project Team.

This graphic illustrates the relationship between average oil thickness and equivalent volumes of oil per unit area, or “concentration”. Any line drawn vertically through the selected average oil thickness in the figure would yield the corresponding volume of oil per unit area at that average thickness. Along the top of the figure are color descriptions (Sheen, Rainbow, Metallic, etc.) corresponding to oil thickness values that are generally used within the oil spill response community. There is still some controversy over the precise thickness range that should be assigned to a given color category, as well as the number and description of those categories. However, the five categories shown and their corresponding thickness values are consistent with recent studies (Bonn Agreement, 2007) and are commonly used by NOAA (NOAA OR&R, 2007) and other spill response organizations.

The stars shown within each color category in Figure III.C-1 are provided as near-mid-range values for each of the color categories. These are useful for the selection and possible use of “nominal” or “order-of-magnitude” values for oil thickness and concentration associated with each color category.

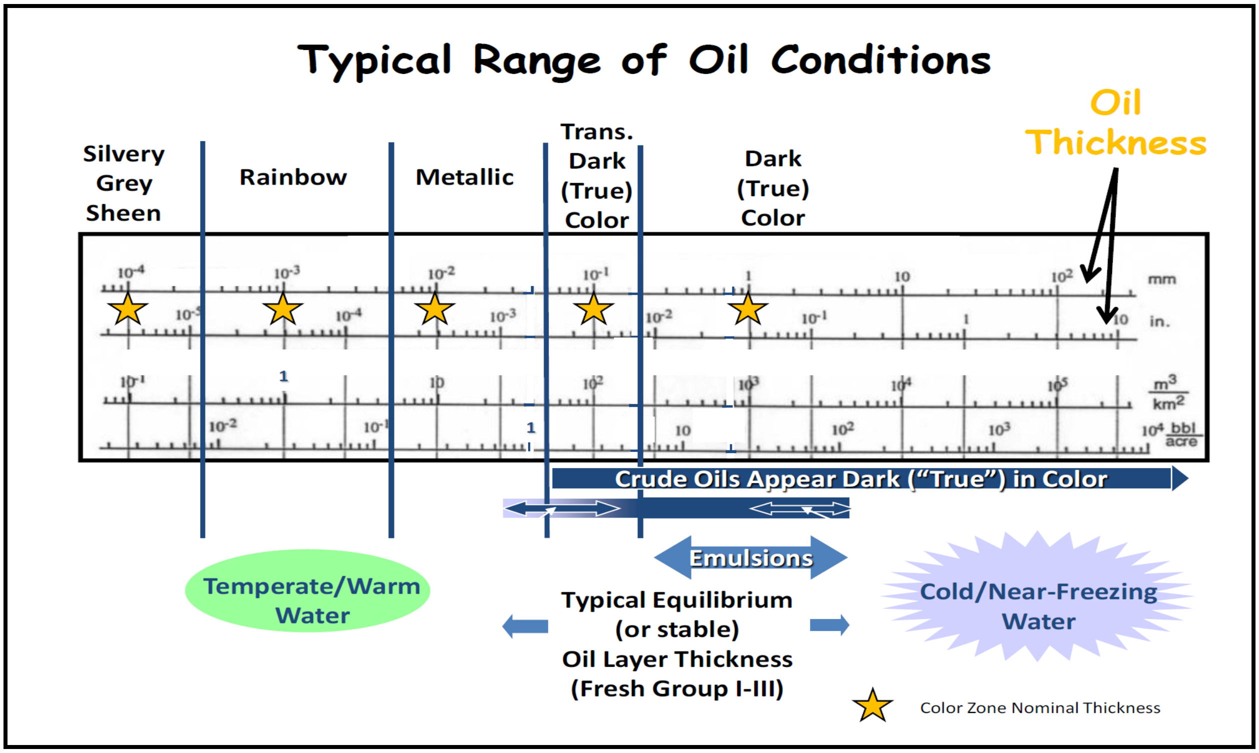

Figure III.C-1: Oil thickness and concentrations for various oil conditions. From Spiltec & Genwest Systems, Inc.

As an example, if oil is observed within the transitional dark category, a nominal average oil thickness might be represented as 0.1 mm (a few thousandths of an inch). This order-of-magnitude estimate would correspond to a nominal concentration of 100 cubic meters of oil per square kilometer (~2 ½ bbl/acre), or ~ 100 gallons/acre. Horizontal bars at the bottom of the figure serve as reminders of the range of oil conditions that one could associate with oil slicks that have undergone spreading, influenced strongly by gravity and the viscosity of the oil.

When spreading oil reaches a relatively stable condition where additional spreading is reduced considerably (sometimes referred to as "equilibrium" condition), average oil thicknesses may range from a few hundredths of a millimeter to a few tenths of a millimeter. Thin rainbow to silvery sheen films will normally exist around the perimeter of these slicks, taking on a greater percentage of the entire spill area as currents, wind and sea conditions continue to spread the oil.

Emulsions, viscous oils, and even light-to-medium-weight crude oils spilled into very cold waters will often achieve a thicker stable "equilibrium" condition that may be nearly one to several millimeters in average thickness. These so-called "stable" thicknesses may not last long depending on the wind and sea conditions and on the oil's tendency to spread, emulsify, evaporate, and degrade. The important point is that crude oils, especially dark crude oils, will typically appear dark (or "true" in color) at these stable thicknesses and thicker. Unless bounded or herded by boom, winds, convergence zones, shorelines, etc., these dark layers will likely fall within the "transitional" to continuous "dark" categories, representing at least 1 to 100 barrels of oil per acre (Figure III.C-1).

III.C.2 Modeling of Oil Thickness

When oil slicks are dark in color and are not free to spread (e.g., when contained or herded), it is impossible to estimate oil thickness by appearance alone. Because of the difficulty of measuring the thickness of oil slicks directly it has become common to model the processes involved in the spreading of oil spilled onto the surface of the sea. One such model is the ROC.[3] The ROC incorporates weathering (Galt, 2011) and spreading (Galt and Overstreet, 2011) of oil slicks for user-defined scenarios involving spill type and volume, oil characteristics, and environmental conditions. Response countermeasures are appropriately assigned by the user to build intuition on potential response system performance. The ROC was used in this study in two ways – first, to examine representative oil slick thicknesses for a variety of oils allowed to spread under a range of environmental conditions; and second, for the adaptation of the algorithms involving mechanical recovery for possible use in creating a replacement for, or enhancement of, the existing EDRC Calculation.

The ROC model was helpful while exploring the idea of a "nominal" average oil thickness for each of the first three days for various oil types and spill scenarios with a broad range of spill volumes and wind conditions. The ROC was used to calculate oil thickness for the heaviest concentrations of oil, regions where skimming systems would normally be directed to operate. In Figure III.C-2, Alaska North Slope Crude (ANS) and Light Louisiana Sweet (LLS) crude oils

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[3] Available from www.genwest.com/roc.

were used for a ROC model simulation. Temperatures included 0, 10, and 15 degrees° C (or 32, 50 and 59° F); wind speed inputs were 0, 5, 10, and 15 knots. The vertical bars display the range of thickness values after 12 hours of weathering and spreading for each spill volume. Each vertical bar represents twelve ROC simulations.

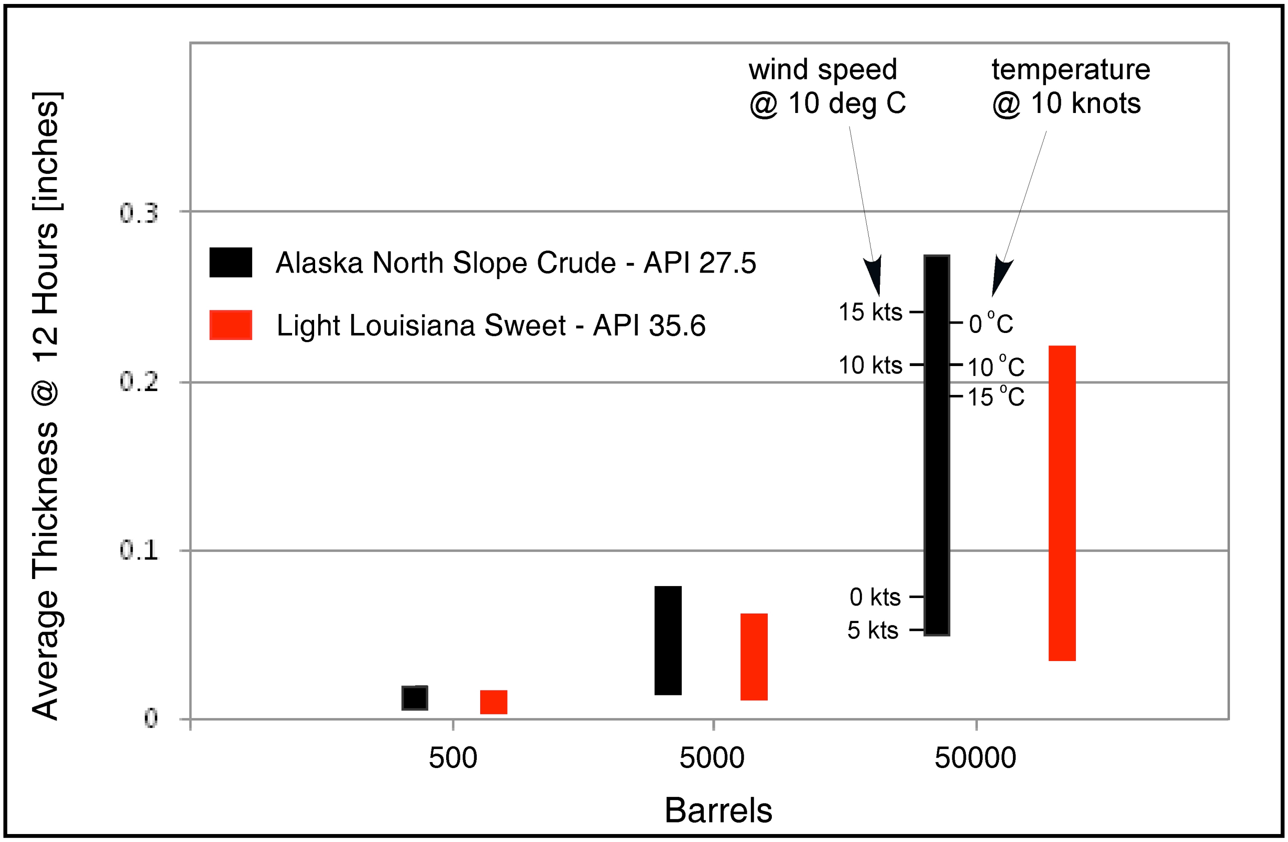

Figure III.C-2: Average Oil Thickness for ANS and Louisiana Sweet Crude oils over a range of spill volumes and wind conditions.

Oil slick thicknesses modeled by the ROC are influenced more by wind speed than by temperature. Note the relatively wide range of thicknesses possible in the chart for a 50,000-barrel release. At low wind speeds, the nearly uniform spreading of oil is governed more by the early gravity-viscous forces, allowing the oil to thin down with time. This is illustrated in the diagram where the thickness at 5 knots is less than the thickness at 0 knots. As winds begin to build to 5 knots, there is an increasing role of the wind to pile up oil at the downwind leading portions of the slick. The result is a thickening of the oil in that region, an actual reduction in the overall areal growth rate, and therefore a modest increase in the slick's overall average thickness. This process is depicted in the following schematic diagram (Figure III.C-3).

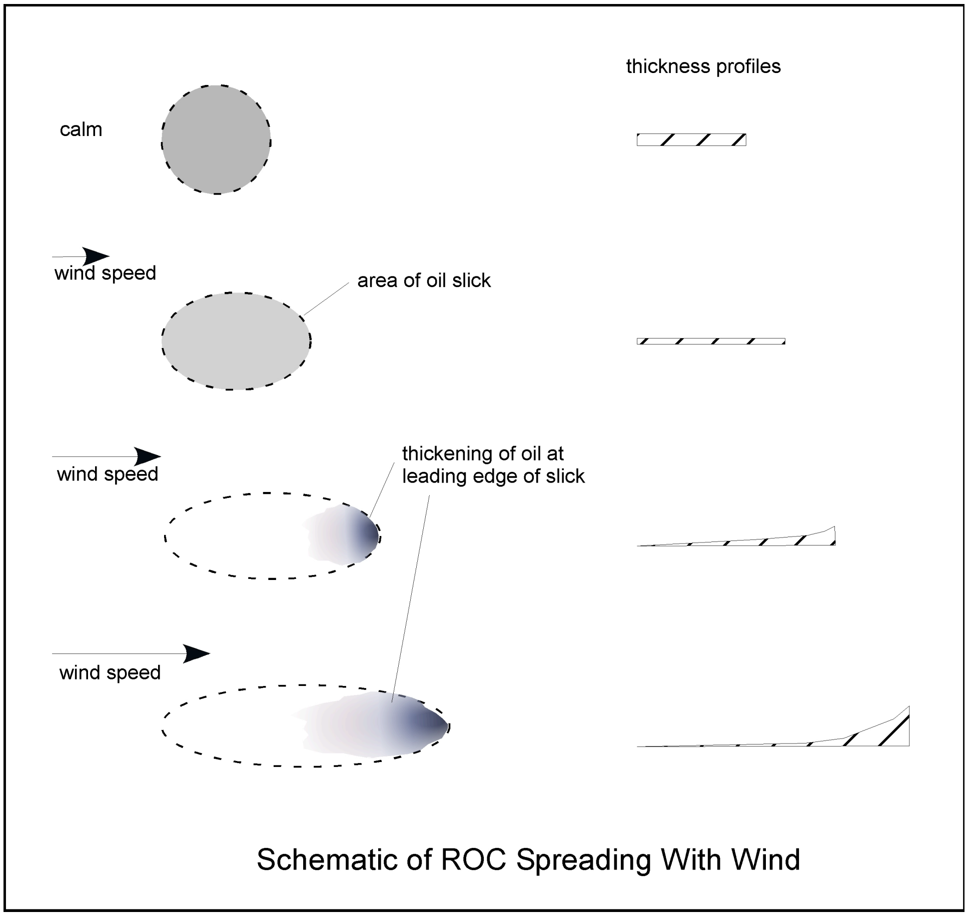

Figure III.C-3: Oil spreading with increasing wind in the ROC Calculator.

As previously stated, the ROC was used in this study to examine weathering, spreading, emulsification, and how resultant oil slick thickness varies with time. As an example, Figure III.C-4 shows a ROC time-dependent oil slick thickness output for a batch release of 5,000 barrels of ANS crude at 10°C and a wind speed of 10 knots. Note the calculated thicknesses of 0.06, 0.03, and 0.02 inch representing the 12-hour, 36-hour, and 60-hour spreading periods in this example. Also note that changes of oil thickness (slope of the thickness line) beyond 60 hours are very small, and the oil available for recovery beyond 60 hours becomes marginal. The ROC suspends weathering and spreading at an average thickness of 0.001 inch. The specification of nominal average thicknesses for the first three days of a batch release captures the most significant changes in oil slick thickness, directly relating to the most significant changes in encounter rate.

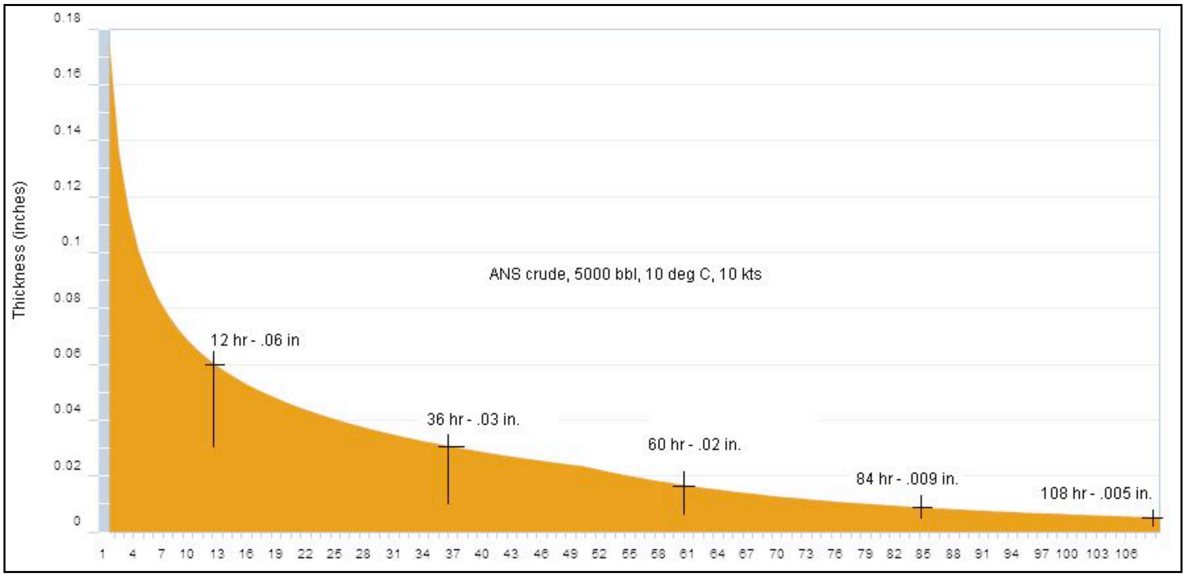

Figure III.C-4: Results of the ROC simulation involving ANS Crude with 10-knot wind at 10°C.

Model thickness analyses involved oil type, spill volume, wind, and temperature conditions that affect spreading and average oil thickness over time. The computer runs explored the range of oil thicknesses that support the use of a “nominal” average oil thickness for each of Days 1, 2, and 3 following a spill. These nominal values were identified as reasonable approximations of thickness for the mid-point of each day (i.e., 12, 36, and 60 hours of spreading); the use of these nominal average thicknesses for a given operating period (i.e., 10-12 hours per day) could facilitate and simplify the calculation of oil encounter rate for each period. This approach, with an encounter rate based on a fixed thickness for each day’s operating period provide a convenient standardized method as a “planning tool” to assess a skimming system’s potential recovery each day.

The calculation of these "nominal" average oil thicknesses after 12 hours, 36 hours, and 60 hours of spreading involved the following input:

- **Oil Type**:

  Light Louisiana Sweet (LLS - Group II[4]),

  Alaska North Slope Crude (ANS - Group III), and

  IFO300 (Group IV) (ITOPF, 2010).
- **Spill Volumes**: 500 bbl, 5,000 bbl, 50,000 bbl, and 500,000 bbl.
- **Temperatures**: 0°C, 10°C, and 15°C. (32°C, 50°C, and 59°F)
- **Wind Speeds**: 0, 5, 10, and 15 knots.

Figure III.C-5 displays the results of 432 individual ROC simulations involving all volumes, temperatures, and wind speeds.[5]These data are displayed as a scatter diagram with an Excel exponential best-fit trend line for Days 1, 2, and 3. The vertical axis is thickness in inches on a log base 10 scale.

A subset of ROC thicknesses was compared with several other models including the Applied Science Associates (SIMAP) model (Konkel, et. al., 2008), the SINTEF OSCAR model (Aamo, et.al., 1997) and the SL Ross Oil Spill Model - SLROSM (Belore, 2007). Data for Alaska North Slope Crude (ANS) was used for the comparison because its properties are in the databases of all the models. Simulated releases of 5,000 and 50,000 barrels at wind speeds of 5 and 15 knots were modeled. All runs were at 15°C. The results are displayed in Figure III.C-6.

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[4] The categorization used here (Persistent oils — Group II through IV) is based on a petroleum-based oil that does not meet the distillation criteria for a non-persistent oil as defined in 33 CFR Part 154.1020 or 33 CFR Part 155.1020. Persistent oils are further classified in these Codes based on an oil's specific gravity:

(1) Group II—specific gravity of less than .85.
(2) Group III—specific gravity equal to or greater than .85 and less than .95.
(3) Group IV—specific gravity equal to or greater than .95 and less than or equal to 1.0.
(4) Group V—specific gravity greater than 1.0.

[5] Refer to ***Appendix D. ROC Thickness Data*** for more information on these ROC simulation inputs.

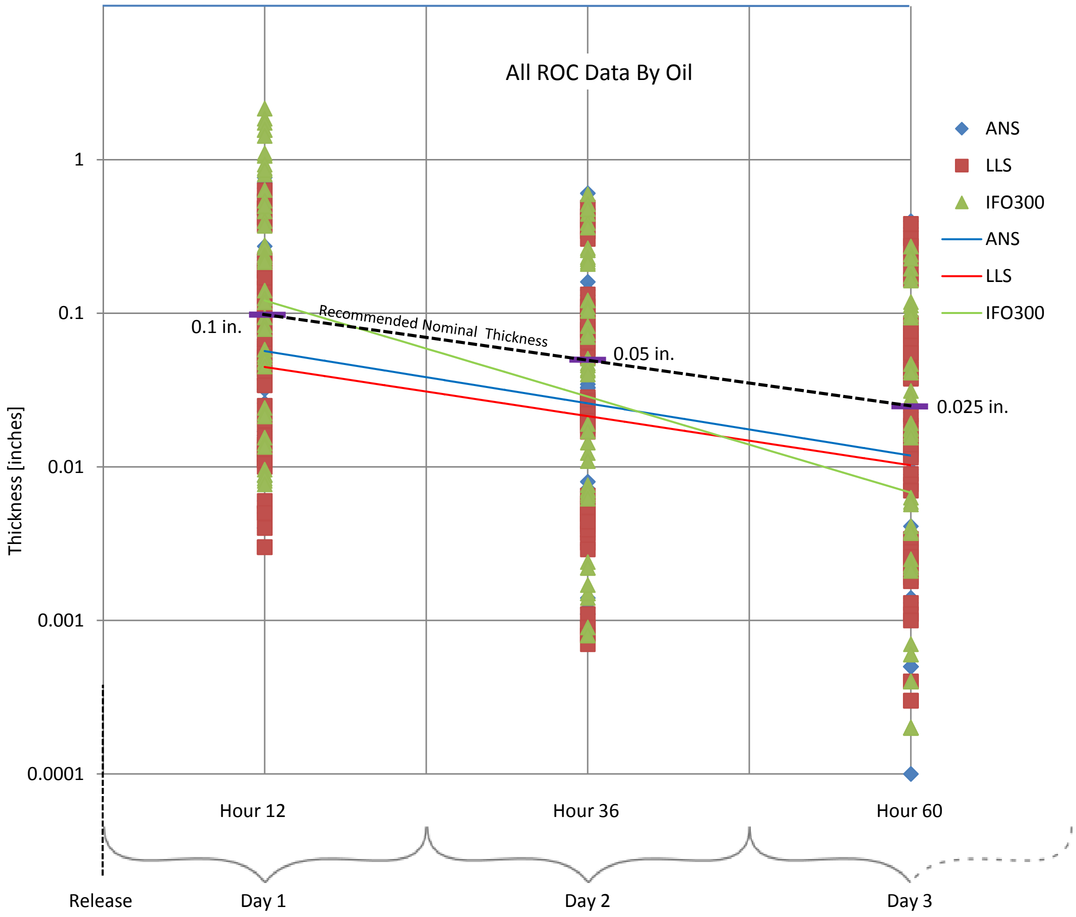

Figure III.C-5: Scatter diagram for 432 ROC simulations involving ANS, LLS, and IFO300 oils.

All of the models used in this analysis except the ROC are proprietary and, as a result, the algorithms used for spreading and weathering could not be accessed or described here. Model results involved values for the thickest oil at 12 hours, 36 hours, and 60 hours after a batch release.

Note that the data for all models plotted in Figure III.C-6 reflect the results of simulations for 5,000 and 50,000 barrels at wind speeds of 5 and 15 knots at 15°C.

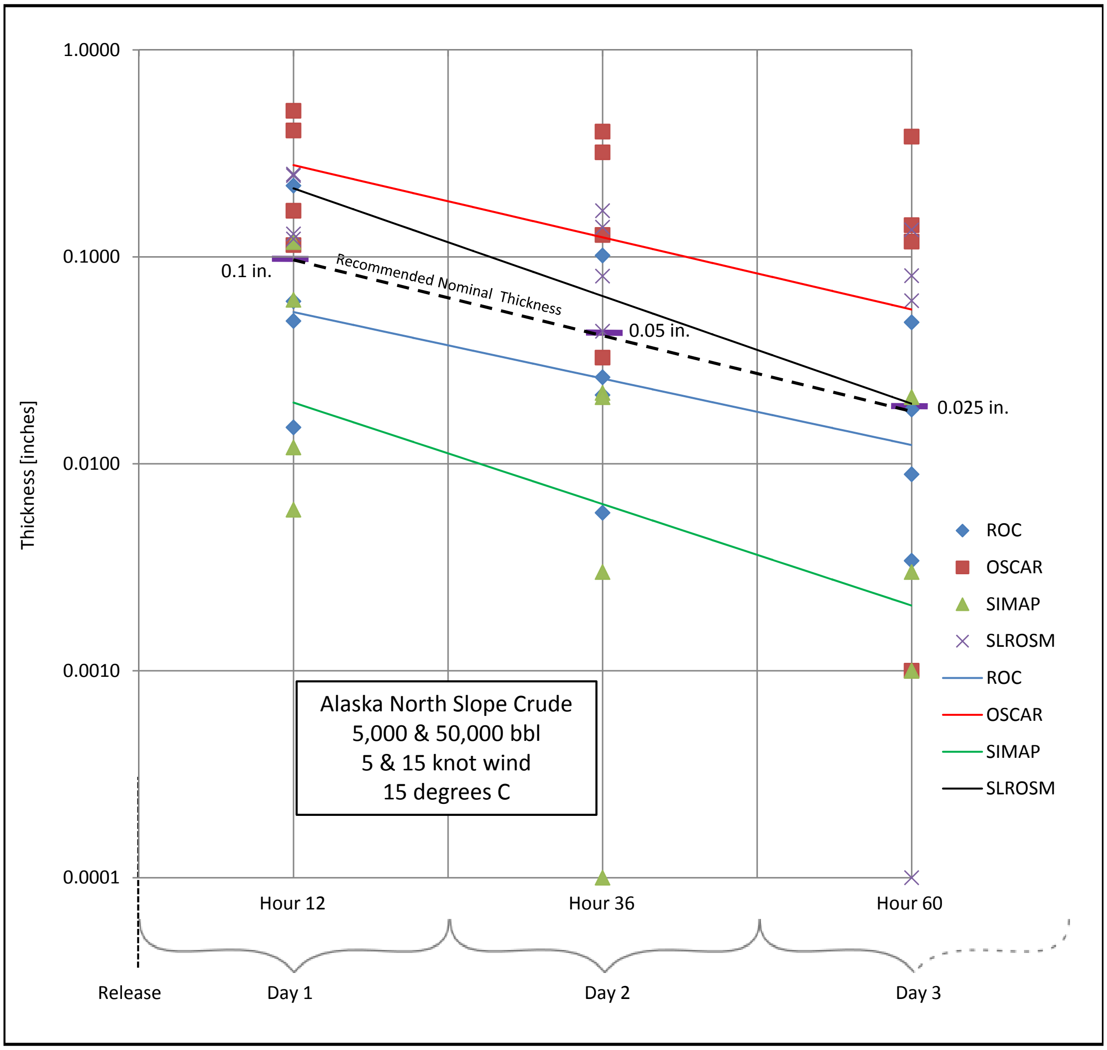

Figure III.C-6: Identification of recommended nominal average oil thicknesses for Days 1, 2, and 3.

These data do not reveal how much oil is available for mechanical recovery at a given thickness at each time step; however, the various thickness trend lines are within an order of magnitude of the average oil thicknesses being sought for this part of the study. Based on these data, the Project Team recommends that the values of 0.1 inch, 0.05 inch, and 0.025 inch be used as the nominal average oil thicknesses for Days 1, 2, and 3 of respectively.

The entire computer modeling effort discussed in this section was based on sudden, one-time release, or "batch" type spills. The selection of the nominal average oil thicknesses for the mid-day (or daylight) operating periods for Days 1, 2, and 3 are therefore based on the spread of oil as a one-time release at time zero.

It is important to note that the suggested nominal oil thickness values would also be appropriate as nominal thicknesses for the thickest portion of a **continuous** release as well. This suggestion is based upon the following observations:

- The assessment of oil recovery potential for a continuous release could involve the Day1 nominal average oil thickness for a batch spill as if Day1 repeats for each consecutive day (a simulated continuous release with multiple, individual batch releases).
- Any oil that escapes recovery or elimination on Day-1 from a continuous release would continue spreading and thinning out during subsequent days, so the batch release thickness values for Days 2 and 3 could still be used for skimming systems working on those days of a continuous release.
- The continuous release of oil, say from a blowout or sunken vessel, could involve a wide range of possible distributions on the surface. The depth of the source, combined with variations in surface and subsurface currents, make the simulation of oil distribution and slick thickness for a range of oil types and flow rates difficult to predict (recall the Deepwater Horizon [DWH] event in the Gulf of Mexico).

The calculation of a skimming system's potential daily recovery using both batch and continuous releases is discussed in the following ***Section III.D.2 Use of ERSP Calculator*** and in ***Appendix B: ERSP Calculator User's Guide***.

III.D. Recommended Option: 3-day Estimated Recovery System Potential (ERSP)

A 3-Day ERSP approach is favored over all other attempts to identify a quantitative measure of a skimming system's potential to recover oil from the ocean surface. The goal is to provide a computer model, referred to here as the ERSP Calculator, which uses all primary components of a full response system. These components include a skimming system's operating swath and speed, oil recovery rate, onboard storage, decanting capability, recovery efficiency, etc. There are other factors such as the time needed to get on location and the provision of surveillance and spotting support that also impact response preparedness; however, the ERSP Calculator is intended as a tool that can provide an estimate of a specific recovery system's ability to access, recover, store, and transfer spilled oil. The calculator is designed so that a meaningful "Planning Standard" can be developed based on realistic operational considerations.

The most important operational consideration involves the amount of oil that can be accessed by a given skimming system, normally referred to as the system's oil encounter rate. This rate is dependent upon three parameters: the skimming system's swath and speed; and the average oil thickness encountered within that swath. The average oil thickness is a highly variable characteristic, constantly changing with time, and dependent upon many environmental conditions. The type of oil spilled and the nature of its release (e.g., batch, continuous, surface, subsurface, etc.), together with water temperature, wind and sea conditions, all suggest that a skimming system will be exposed to a broad range of continually changing oil encounter rates. A "Planning Standard," however, need not reflect such specificity if a nominal average oil thicknesses can be identified and held constant for a relatively short operating period each day (e.g., 12 hours). The creation of a planning standard based on nominal average oil thicknesses can provide a simple and consistent way to calculate nominal average oil encounter rates for an operating period within each day. These encounter rates can be used to establish a given recovery system's ability to access and recover oil in a consistent way for comparison with other skimming systems.

In the previous Section (***III.C. Analysis of Oil Thickness***), it was determined that the recommended Nominal Average Oil Thicknesses of 0.1 inch (2.54 mm) for Day 1; 0.05 inch (1.27 mm) for Day 2; and 0.025 inch (0.64 mm) for Day 3 could be used to reflect a broad range of spill types and conditions for batch releases at the surface on open water. For planning purposes, these average oil thicknesses were selected based on spreading for 12 hours (to the middle of middle of Day 1), 36 hours (to the middle of Day 2), and 60 hours (to the middle of Day 3). These nominal thickness values are used in the ERSP Calculator to determine the estimated volume of oil that can be recovered by a specific skimming system over a defined Operating Period.

For simplicity of use and standardization of recovery potential over the first three days following large spills (i.e., 1,000s to tens of 1,000s barrels), the ERSP Calculator developed in this study uses the above nominal average thicknesses. However, the ERSP Calculator code could be modified to use different nominal thickness values to reflect specific oil type and spill location.

III.D.1 Parameter Selection

The ERSP Calculator model uses algorithms that are similar to those used in the MEC and ROC models, which were developed by the same team at Genwest Systems. The parameters that characterize a skimming system were selected and examined during this study to:

1. Establish which operating characteristics have the greatest influence on a skimming system's performance;
2. Identify and compare the effects of those characteristics with the greatest influence; and
3. Determine the extent to which certain parameters or related operational procedures could be modified to enhance a given system's performance.

Efforts were made to simplify the calculation of a skimming system's recovery potential (given in barrels per operating period). For example, it is important to account for the volume of "free" water collected for a given Recovery Efficiency (RE) and retained onboard. While the model may address the water content or emulsion of the encountered oil layer, it does not account for any additional emulsification that may be caused by the skimmer or agitation occurring during storage and transfer. There are too many variables (type & age of oil, wind & sea conditions, type of skimmer, settling time before product transfer to backup storage, etc.) that could influence the percentage of water in an emulsion as the spilled oil moves from initial recovery to final storage. Skimmer-induced emulsification could be measured during controlled system performance field trials and/or tank tests.

It is important to note that the "Emulsion %" (i.e., water content of oil encountered) as an input value in the ERSP Calculator provides important flexibility in the use of the model now and into the future. It would be difficult for users of the ERSP Calculator to anticipate and identify appropriate emulsion percentage values for input; current ASTM Standards[6] and standards under review acknowledge the importance of water content in both the oil emulsion

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[6] ASTM Standards F631-99; and F2709-08.

encountered, and in the emulsion influenced by the recovery process itself. These factors enter into the calculation of a Nameplate recovery rate for a given skimming system, a parameter that is essential in both the current EDRC calculation and the proposed ERSP Calculator.

While the ERSP Calculator provides for the possible input of an Emulsion % value, it is suggested that the default value of zero be used for the water content of the encountered oil. The Emulsion % value can be modified to accommodate any future planning standard guidelines that influence a skimming system's recovery potential.

The **input parameters** used by the ERSP Calculator include:

- **Name of System**- the identification of the system being evaluated.
- **Operating Period**- number of hours the named skimming system is available each day.
- **Emulsion %**- the percentage of water in the emulsion being encountered.
- **Speed (**relative to the oil slick**)**– during skimming.
- **% Decant**- percentage of "free" water decanted from onboard storage during skimming.
- **Swath**- total width of the skimming system while operating.
- **On-board Storage**- total volume of on-board storage tank(s) for recovered fluids.
- **Nameplate Recovery/ Pump Rate**- skimmer's proven recovery rate.
- **Decant Pump Rate**- rate of removal of "free" water by decanting onboard storage tanks.
- **Discharge Pump Rate**- rate at which oil/emulsion can be offloaded from onboard storage to backup storage.
- **Transit Time**- time to travel one-way from skimming area to backup storage vessel/barge/facility.**Note**: this time is doubled for a complete offload cycle.
- **Rig / De-rig Time**- time to handle lines/hoses/paperwork prior to and following the offload operation.
- **Throughput Efficiency** (TE) - percentage of oil/emulsion taken onboard from the volume encountered.
- **Recovery Efficiency** (RE) - percentage of oil/emulsion in total fluid recovered aboard the skimmer.

III.D.2 Use of ERSP Calculator

The primary output from the ERSP Calculator for the designated skimming system configuration, is the ERSP (in barrels per operating period), which is computed for each of the first three days following a "batch" release. Nominal average oil thicknesses for each of these days are based on a batch release of oil at the surface. The sudden batch release of a large volume of oil presents a unique challenge for responders, as they must address a greater volume of oil during the early hours of the response.

During a large, continuous spill (e.g., a well blowout), portions of the oil discharged would have avoided initial recovery efforts and would continue to weather and spread over time. The thickest, more concentrated oil would be located near the source.

The ERSP Calculator provides an estimate of a skimming system's recovery potential for the first three days following a major batch spill based on recommended nominal average oil thicknesses for each day. Determining a recovery system's Day-1 ERSP value could represent that system's capability to handle the near-source average oil thickness each day for a continuous spill for as long as that oil continued to be released.

Note that the ERSP calculator does not distinguish between skimming while concentrating oil versus skimming after oil has been concentrated to build a thicker layer around a skimmer. It is assumed that personnel operating the skimming system are using best industry practices, and that they are trained to operate the vessels and equipment to maximize Throughput and Recovery Efficiencies (TE and RE).

Representative skimming configurations are described in the following section as examples of typical recovery systems. Following those examples, ***Section III.E. Selected System Comparisons and Analysis*** provides detailed ERSP Calculator results for four representative recovery systems. The twenty-one **output parameters** for each of these systems include:

- Maximum Effective Swath (MES)
- Swath Used For Calculation (may differ from the "input" swath if > MES)

- Encounter Rate (ER)
- Areal Coverage Rate
- Total Fluid Recovery Rate
- Emulsion Recovery Rate
- Oil Recovery Rate
- Rate Free Water Taken Onboard
- Water Retained Rate
- Decant Rate
- Time to Fill Onboard Storage
- Time to Offload Full Tank(s)
- Time for 1 Full Cycle (includes fill of onboard storage, offload & 2 transits)
- Skimming Time in Operating Period
- Skimming Time in Operating Period (as a %)
- Area Covered (acres) in Operating Period
- Area Covered (sq. mi.) in Operating Period
- Total Volume of Oil / Emulsion + Free Water Recovered/Operating Period
- Total Volume of Oil / Emulsion Recovered / Operating Period
- Total # of Fills / Operating Period
- ERSP (Total Volume of Oil Recovered / Operating Period)

In its current form the ERSP Calculator is programmed to use the nominal average oil thickness values described above. However, the calculator could be modified to reflect different thickness values depending on the degree to which the user might want to reflect specific oil types, spill locations, and wind / sea conditions. If different nominal average oil thickness values are desired, the ROC or other recognized model could be used to derive alternate thickness inputs.

The Project Team developed a separate calculator called the Response System Calculator (RSC), to facilitate the evaluation of system potential using alternate oil thicknesses. The RSC is similar to the ERSP; however, it allows the user to input oil thicknesses encountered by a skimming system as well as the usual operating parameters for that system. One of the unique features of the RSC is its ability to calculate all standard outputs from the ERSP Calculator for a selected range of input values on any one of a skimming system's operating parameters. The user can select a parameter (e.g., system Speed) and set the number of iterations and the size of increments to be used for that parameter). For example, if the user entered a starting Speed value of 1 knot, with six iterations at 0.5-knot increments, the RSC would yield all twenty-one system performance values listed above for 1.0, 1.5, 2.0, 2.5, 3.0, and 3.5 knots.

The RSC was used as an evaluation tool during the early development of the ERSP Calculator so that the degree of influence and relative sensitivity of each parameter could be examined.

The ERSP Calculator or the RSC could be modified if deemed necessary by regulators, responders or plan holders. For example, some skimmer manufacturers have used their own test methods to arrive at a Nameplate recovery rate (NP) for their products. Other manufacturers have put their skimmers through the latest approved ASTM Standard[7] protocols to determine an approved Nameplate recovery rate and Recovery Efficiency (RE). Not all skimming systems have been tested and validated for their actual Nameplate and RE values. In the absence of test data for a particular skimming system, regulators might use available test results for a similar skimming system or they might use information derived from the ROC Model. The ROC provides suggested RE values for three different classifications of skimming systems. The RE values depend on the type and condition of the oil being skimmed, and the wind/sea conditions during skimming operations. ***Appendix C, Skimmer Recovery Efficiency Estimates*** contains a consolidation of RE data from a literature search and meetings with response experts (Dale, et al., 2011) conducted during the development of the ROC.

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[7] ASTM Standards F631-99;F1780-97, and F2709-08.

The ERSP Calculator can be used to estimate the daily recovery potential of nearly any configuration of a given skimming system. These systems might include large open-ocean systems with built-in or umbilically-connected high-volume recovery skimmers or medium sized skimming vessels with built-in or over-the-side skimmers. The calculator could simulate the recovery potential of small skimming vessels with outriggers on either side (or both sides), and even towed or pushed barges with skimming units off the side or towed behind. Sketches are provided in the following section, along with descriptions of how their configurations could be entered into the ERSP Calculator.

The calculator can also be used for nearshore and inland skimming systems since smaller, possibly shallow-draft systems can be evaluated based on the same input parameters used for open-ocean recovery systems. The ERSP Calculator can accommodate open-water or nearshore systems; self-propelled, pushed or pulled systems; and skimmers that can operate in warm or very cold climates. The estimation of recovery potential can be determined for nearly any floating skimming system (even in very cold and light ice cover) as long as it is advancing relative to the oil and its Nameplate recovery rate, TE & RE, and other inputs can be provided as described above.

III.D.3 Representative Skimming Configurations

Seven representative systems are provided in this section to illustrate how the various encounter and recovery configurations could be used with the ERSP Calculator. Four of these skimming configurations are used in ***Section III.E. Selected System Comparisons and Analysis*** to demonstrate the use of the ERSP Calculator. The results of these calculations reveal important operational characteristics along with the estimated recovery potential for each system.

System "A"

Figure III.D-1 is an example of a large Oil Spill Response Vessel (OSRV) with an over-the-side, umbilically-deployed skimmer positioned at the apex of a bridled J-boom configuration. The swath of the system (several hundred feet or more) is from the bow of the OSRV to the bow of the small boom-tending boat.

The skimming speed of a configuration of this kind would normally be between ½ knot and ¾ knot; however, as shown in the next configuration, special "Buster"-type boom and/or V-sweeps might be used to increase the skimming speed without excessive entrainment or splash-over. Typical onboard storage for large skimming systems is a few thousand barrels, while some of the largest OSRVs might have 10,000 to 20,000 barrels of onboard storage.

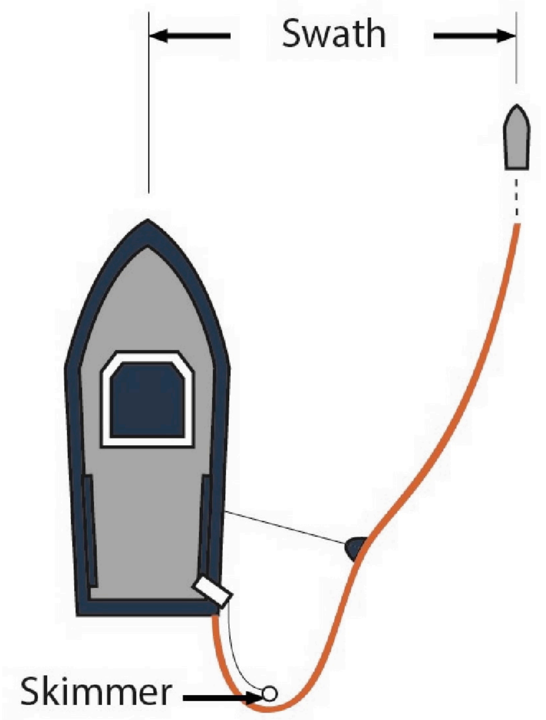


Figure III.D-1: System A: Large OSRV with bridled J-boom and over-the-side skimmer.

System "B"

Figure III.D-2 is an example of skimming system with the swath for calculation purposes being between the bows of the OSRV and the boom-tending boat. With speeds approaching 2 to 3 knots, swaths of a few hundred feet, and onboard storage representing several thousand barrels, this configuration has the potential for high oil encounter and recovery rates as well as high areal coverage rates.

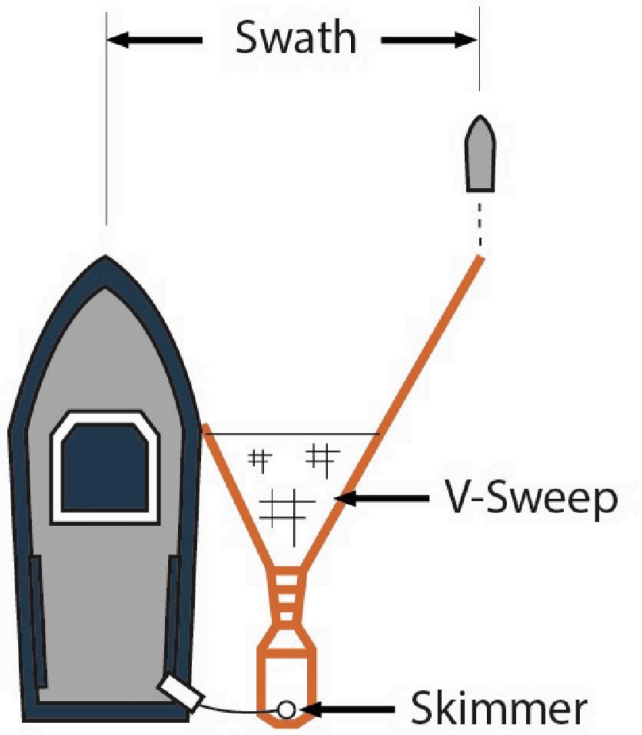


Figure III.D-2: System B: Large OSRV with V-sweep and high-speed recovery system.

System "C"

Figure III.D-3 is an example of a large skimming system with two barge-mounted, umbilically positioned skimmers in the apex of a very large U-boom configuration. The swath of such a system could approach what is often thought of as a "Maximum Achievable Swath" of approximately 1,000 feet. The swath is measured as the distance between the bows of the two boom-tending boats. Storage could include volumes up to 100,000 barrels or more; and the Nameplate recovery rates for both skimmers would be added in a single calculation.

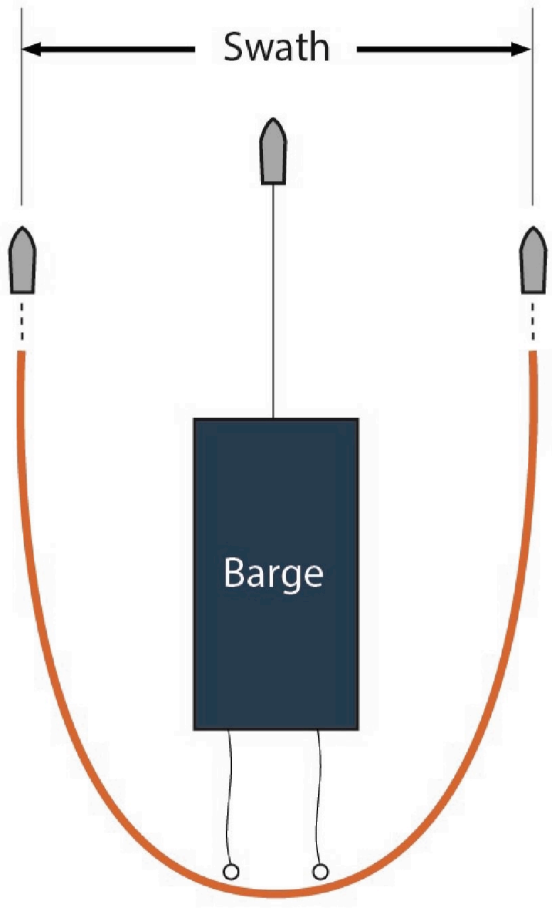


Figure III.D-3: System C: Large barge-mounted skimming system within U-configuration and two high-volume skimmers.

System “D”

Figure III.D-4 is an example of a relatively large skimming system employing a V-sweep deflection boom, held open by a boom vane. This system could include a high-volume recovery skimmer with a significant RE (e.g., grooved- or fuzzy-disc skimmer) at the apex of the “V”. The swath, typically between 50 and 100 feet, would be from the bow of the OSRV to the outboard, leading end of the V-sweep. A large OSRV could provide several thousand barrels of storage.

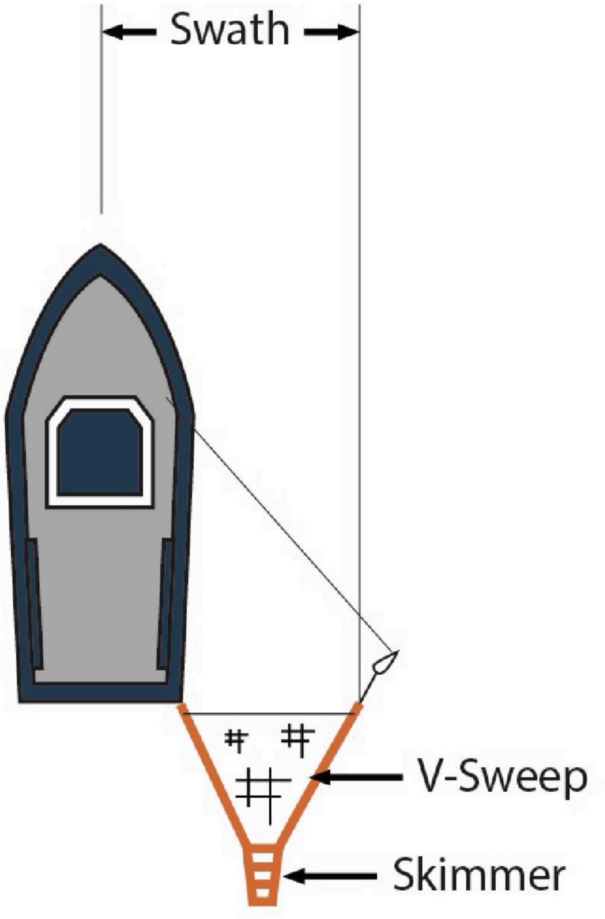


Figure III.D-4: System D: OSRV with V-sweep and boom vane using an efficient oleophilic skimmer.

System “E”

Figure III.D-5 is a skimming system that can provide large onboard storage (several thousand barrels) while retaining a relatively small draft. A barge could be towed by two boom-tending vessels, or possibly pushed with a tug boat (not shown). This configuration combines a large swath potential (several hundred feet) to achieve a high encounter rate with speeds in excess of 1 knot. Multiple oleophilic skimmers built into the barge with good oil/water separation capability provides a unique package for offshore and nearshore operations.

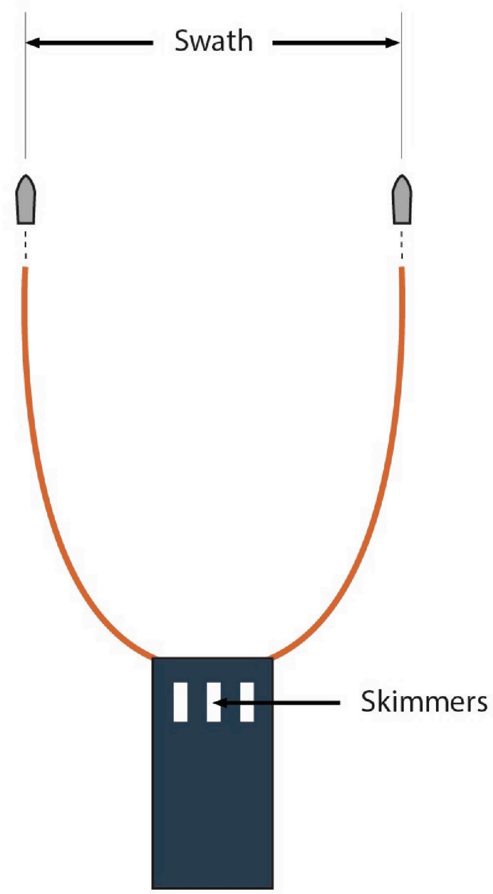


Figure III.D-5: System E: Barge with built-in oleophilic skimmers and two forward deflection booms.

System "F"

Figure III.D-6 depicts a relatively small, but highly maneuverable skimming system (between 40 to 80 feet in length) with typical onboard storage of between 50 to 250 barrels. In this configuration, outriggers are deployed on each side of the skimming vessel to hold deflection booms open, funneling oil toward the skimmers (either built-in or positioned over the side of the boat). Each skimmer will commonly have the capability to recover 100 to 250 gallons per minute. This configuration will typically have a 50 to 80 foot swath. Besides great maneuverability, a skimming package of this type can usually move at fairly high speed (with outriggers up) to backup storage.

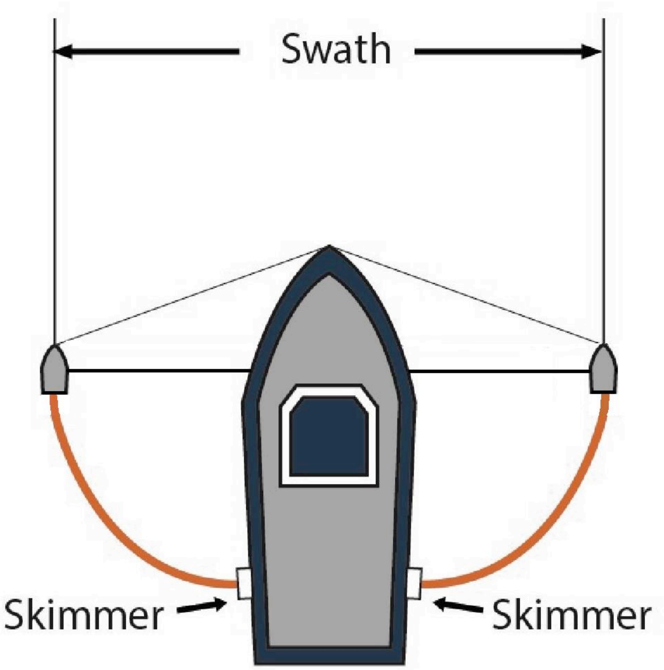


Figure III.D-6: System F: Relatively small, fast and maneuverable OSRV with two built-in skimmers and outriggers on each side of the vessel.

System "G"

Figure III.D-7 depicts a small skimming system with a 10 to 20 foot swath and little onboard storage (50 to 75 barrels or less). However, these recovery units can be highly maneuverable, have a small draft for working in shallow nearshore or inland waters, and able to move easily to backup storage (small barges or onshore facilities). This type of skimming system often works with a mother ship with heavy-lift capability, if operating far offshore; otherwise, these systems tend to be utilized in close proximity to shore or other safe haven.

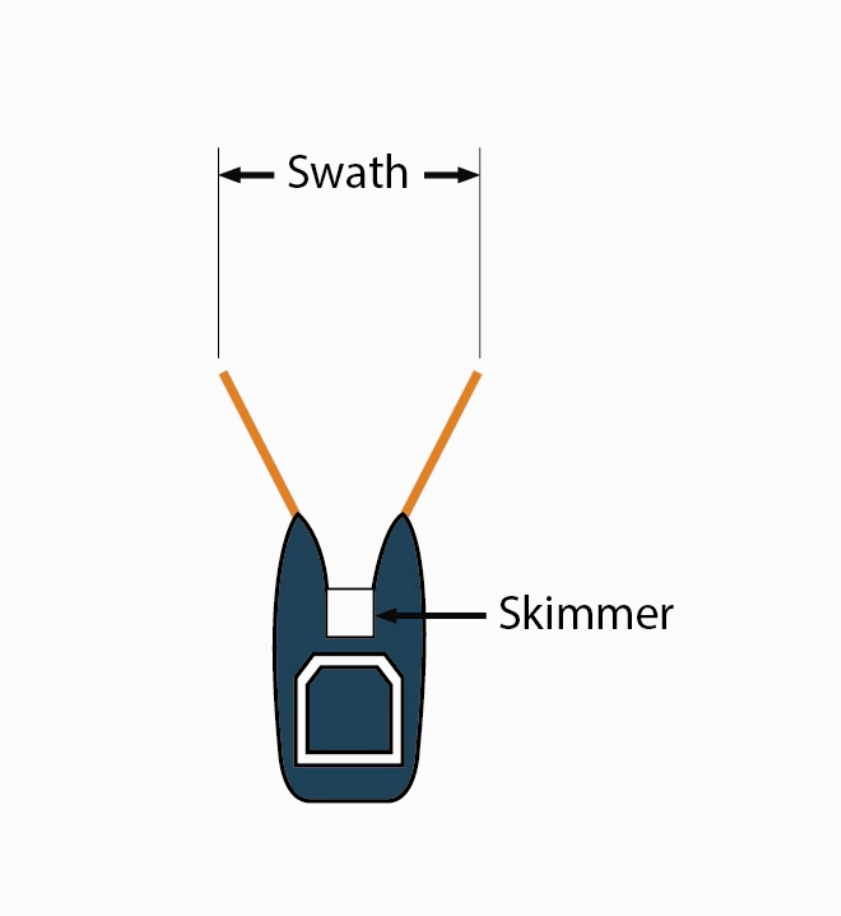


Figure III.D-7: System G: Small, highly maneuverable skimming system with built-in oleophilic skimmer and narrow swath.

Each of the skimming systems presented above could operate in modes that might substantially improve its overall oil recovery potential. Changes may involve: providing additional storage by working alongside or towing small barges, bladders or other towable Temporary Storage Devices (TSDs); manifolding discharge lines from onboard storage tanks and increasing discharge pump rates thereby reducing the time to offload recovered oil to backup storage. As shown in the ERSP Calculator output timelines, these types of configuration changes may allow for one or more additional fill cycles before ceasing operations for the day.

There are additional steps that can enhance the recovery potential of nearly any system, including the use of trained surveillance and spotting and the use of radar/infrared systems to extend the operating period under conditions of reduced visibility. Of all the tools and techniques available, there is one that stands out as a major enhancement for improving the amount of oil that any recovery system might access. It is the use of an “open-apex” U-boom configuration that can be towed with a wide (500- to 1,000-foot) leading swath. The swaths and speeds of these systems depend on the type of boom used, the horsepower of the boom-tending boats, and the ambient sea conditions. As shown in Figure III.D-8, under the right conditions a large oil deflection system can be used to concentrate oil through its downstream “open apex”, typically 25 to 50 feet wide. A 500-foot leading swath configuration of this type with a 25-foot open apex could increase the average oil layer thickness entering the system by a factor of twenty at its exit.

III.D.4 ERSP Output

Specific output parameters described earlier in ***Section III.D.2 Use of ERSP Calculator*** provide a summary of the results from calculations involving a recovery system’s ability to access, recover, decant, store, and transfer oil or emulsion encountered by that system. The user input section is provided at the top of the ERSP calculation page. Directly below the input section, the results of calculations provide estimates of the recovery system’s performance during each of Days 1, 2, and 3 following an oil spill on open water. These ERSP Calculator results, while based on nominal average oil thicknesses for batch releases, are still representative of what may be estimated for a response to a continuous release (see ***Section III.D.2 Use of ERSP Calculator***).

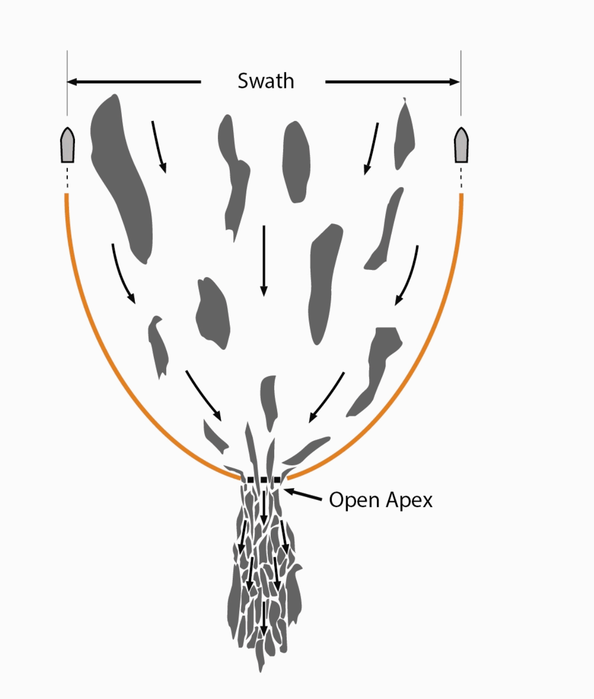


Figure III.D-8: Large, towed, open-apex, U-boom deflection system for concentrating oil to a narrow opening downstream.

At the bottom of the results column is the Estimated Recovery System Potential (ERSP) for each of the modeled three days. In addition to the numerical values for each day, there are graphics representing the ERSP values and the response timelines illustrating the times spent skimming, transiting to and from backup storage, and offloading recovered fluids each day.

Appendix B. ERSP Calculator User's Guide contains definitions of input and output parameters as well as the algorithms used in the ERSP Calculator. One of the most important parameters calculated involves a recovery system's Maximum Effective Swath (MES). This is the swath of a response system that results in the collection of oil/emulsion and free water that matches the system's ability to handle that volume of recovered fluids. In other words, when a recovery system is operating at its MES, the total amount of fluid encountered and taken onboard (oil/emulsion and free water) matches the skimming system's ability to move that much fluid to its onboard storage tanks. The Recovery Efficiency (RE) of a skimming system is determined by the amount of free water picked up during recovery; and the system's Throughput Efficiency (TE) is determined by the amount of oil/emulsion being picked up as a percentage of the amount encountered.

At times a given system's operating swath may be smaller or greater than its MES. If, at its standard operating swath, the Nameplate recovery rate (or pump rate) cannot handle the total volume of fluids being taken onboard, oil could pile up in front of the skimmer over time and be entrained or lost from the collection area. This would result in a reduction of the skimming system's TE. Such potential losses depend on the actual vessel/skimmer/boom configuration in use, sea conditions, whether skimming is continuous or intermittent (i.e. done in short bursts after periods of collection), etc. The results from the ERSP Calculator include both the MES and the Swath Used For Calculation. If the input swath is equal to or less than the calculated MES, the input swath is used for the calculations. If the input swath exceeds the MES, then the computation of the ERSP and all related calculations are performed using the MES.

Note that every recovery system also has a Maximum "Achievable" Swath, even when operating with an Open-Apex U-Boom Deflection System. Oil collection swaths, even with open-apex deflection systems, become difficult to operate and ineffective as swaths increase beyond 750 feet to at most, approximately 1,000 feet. With this empirical limitation in mind, only swaths and related recovery calculations that are achievable within acknowledged operational and environmental constraints should be considered. The ERSP Calculator has a number of alerts ("Simulation Notes") for the user, including one about "achievable" swaths. If a simulation is attempted with a swath that is greater than 1,000 feet, the user is alerted that the swath used for "calculation" may not be achievable.

Figures III.D-9, III.D-10, and III.D-11 are provided as examples of how a recovery system's MES varies with different skimming speeds and Nameplate recovery rate for each of the nominal average oil thicknesses for Days 1, 2 and 3.The calculation of MES for any recovery system also includes the TE and RE values for that system. The equation for MES is provided below. Note that if the RE and TE values are equal, those values cancel each other in this equation.

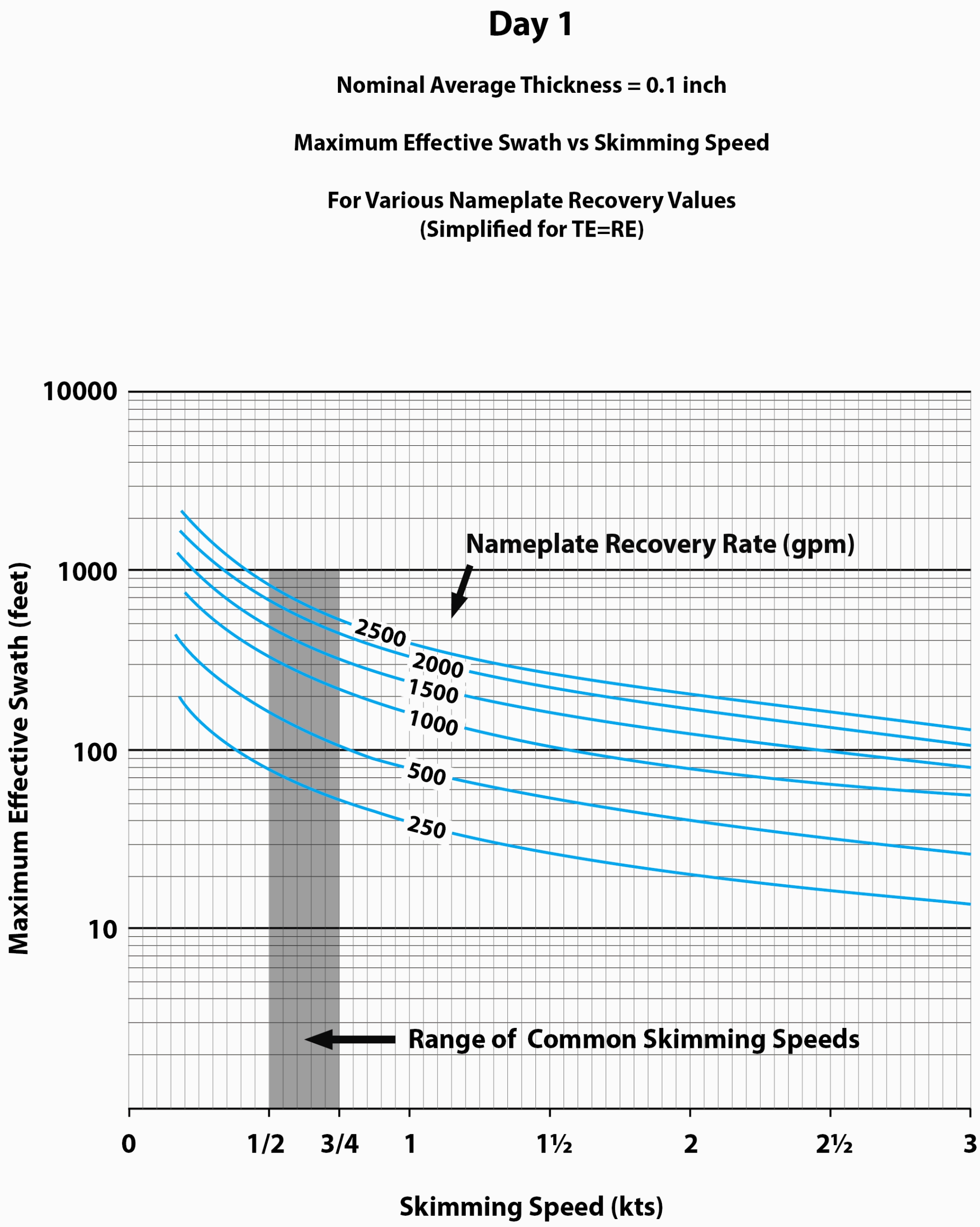


Figure III.D-9: Maximum Effective Swath versus Skimming Speed for Day 1.

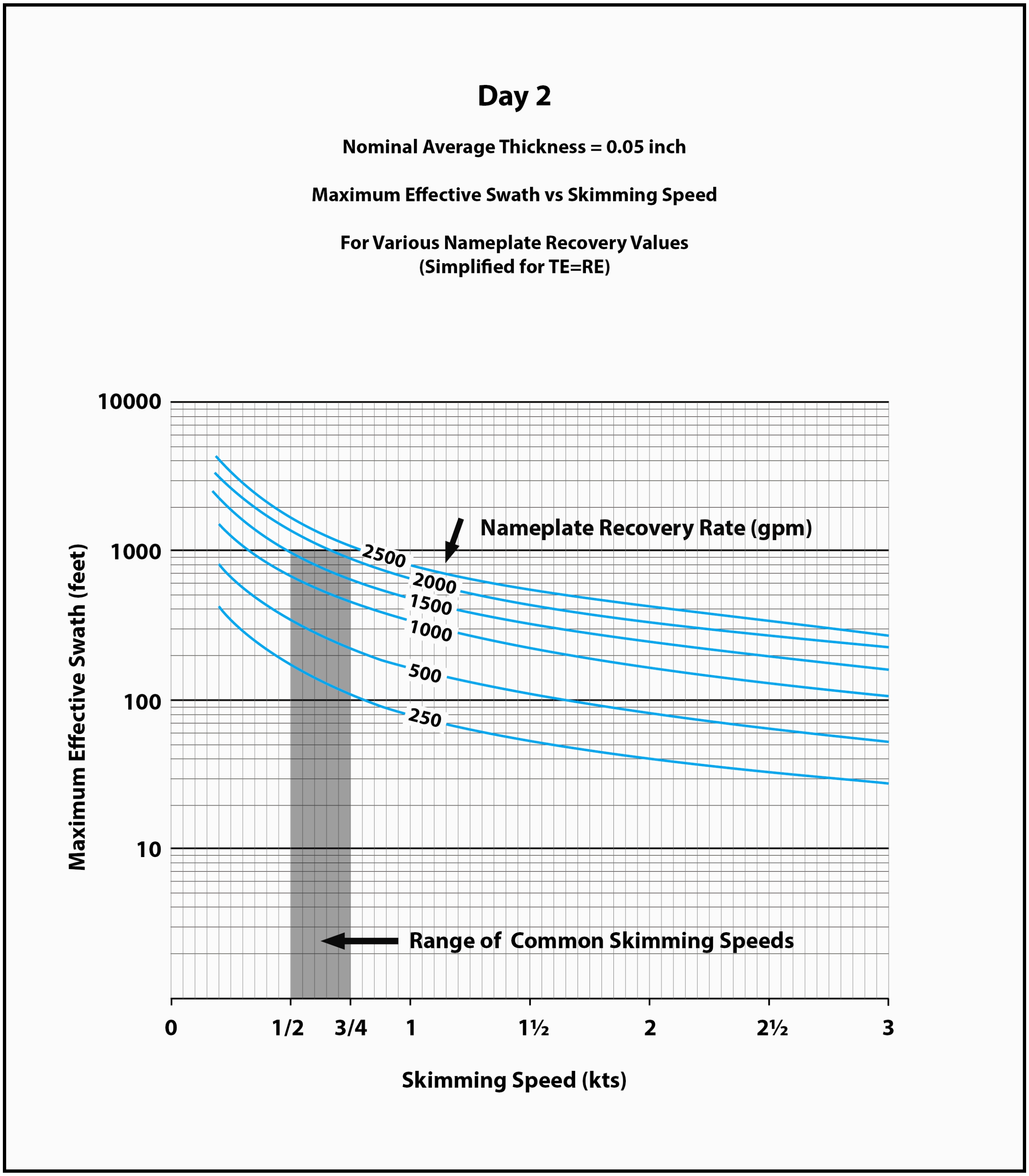


Figure III.D-10: Maximum Effective Swath versus Skimming Speed for Day 2.

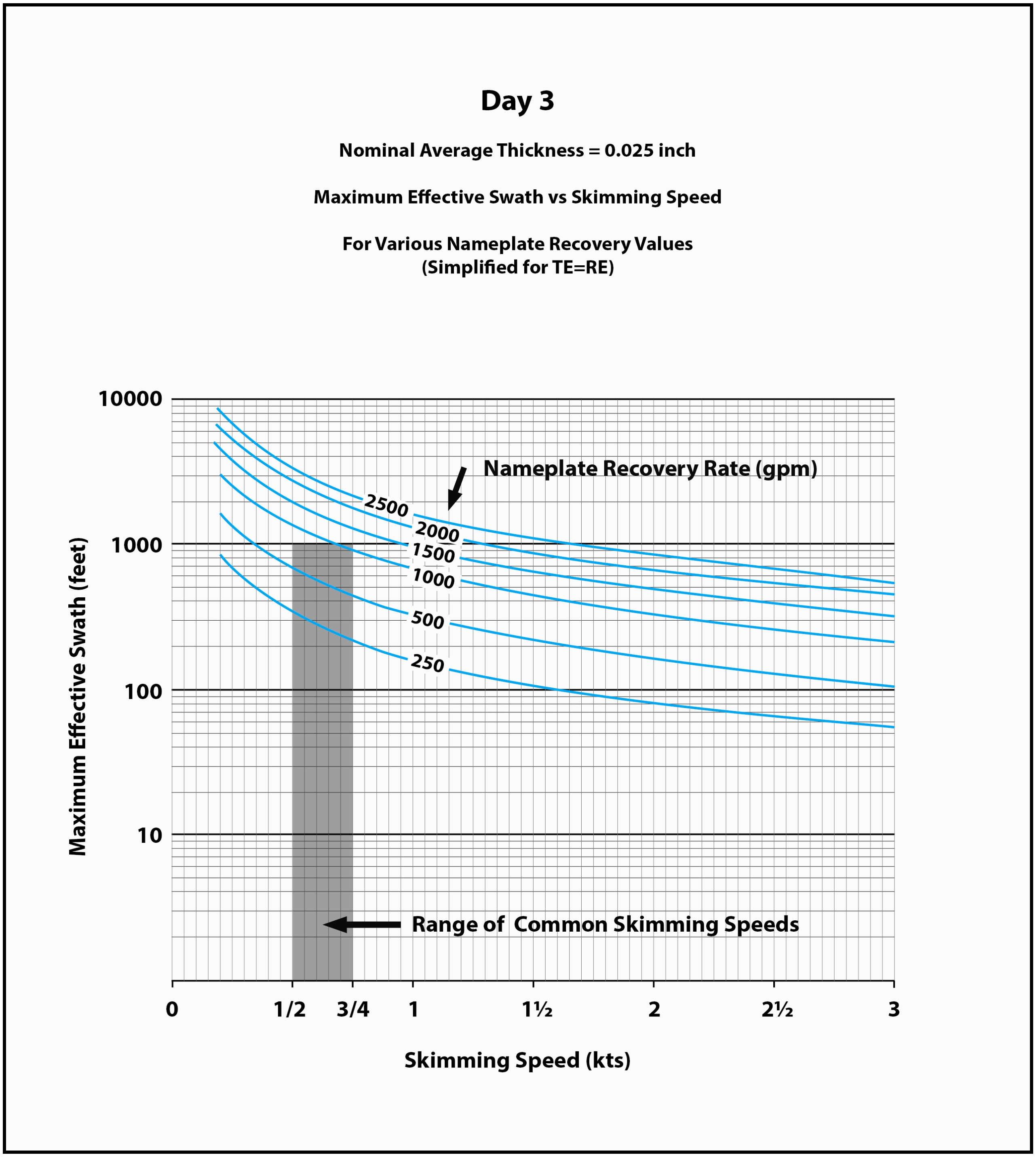


Figure III.D-11: Maximum Effective Swath versus Skimming Speed for Day 3.

Maximum Effective Swath (feet) = ***NP x RE / (63.13 x V x t x TE)***

Where:

NP = ***Nameplate Recovery Rate of skimmer (gpm)***

RE = ***Recovery Efficiency (as a %)***

V = ***Skimming Speed (knots)***

t = ***Thickness of the oil/emulsion encountered (inches)***

TE = ***Throughput Efficiency (as a %)***

63.13 = ***Conversion Factor [used to convert swath (feet), speed (knots) and thickness (inches) to gallons/minute]***

Whenever RE = TE, every gallon of oil/emulsion that is lost (not recovered) from the volume encountered, is matched by a gallon of free water picked up. That is, the total fluid recovery rate (which is equal to Encounter Rate times the ratio of TE to RE) equals the oil/emulsion encounter rate. Figures III.D-9, III.D-10, and III.D-11, for cases where TE = RE, need only account for the influences of Nameplate recovery rate, skimming speed, and oil thickness on a system's Maximum Effective Swath.

These figures illustrate how the Maximum Effective Swath remains well below the suggested maximum achievable swaths of 750 to 1,000 feet for Nameplate recovery rates as high as 2,500 gpm at skimming speeds of ½ to ¾ knot for a Day-1 nominal average oil/emulsion thickness of 0.1 inch (2.54 mm). As the oil/emulsion thicknesses drop down to hundredths of an inch over the next two days (Figures III.D-10 and III.D-11), then systems with higher nameplate recovery rates could, in theory, handle much wider swaths. For example, many open-water skimming systems with nameplate recovery capabilities of hundreds to approximately a thousand gallons per minute could easily work at skimming speeds of ½ to ¾ knot and still operate within their Maximum Effective Swaths of a few hundred feet well into Day 3. The figures also show how quickly maximum effective swaths are reduced for skimming systems that are capable of operating at speeds of 1 to 2 knots or higher.

Following the swath and encounter rate calculations the output includes:

- the rate at which an area is covered by the skimming system;
- the rate at which all fluids are recovered;
- the rates at which oil and water are taken onboard, retained or decanted;
- the time to complete the filling of onboard storage;
- the time to offload recovered oil;
- the time for a full skimming cycle (i.e. fill, offload and transits to/from backup storage);
- the total time spent skimming (in hours and as a percent of the operating period).

In addition to these times for completion of various activities, the calculator provides the area covered by the skimming system throughout the operating period, and the total volumes of oil/emulsion and water recovered. The last two output results include the number of times the onboard storage tank(s) are filled and the ERSP (in barrels) for the entire operating period.

Graphics, including the ERSP bar chart and Response Timelines described earlier, are presented for each of the 3 days below the tabular results column.

The analysis of MES shown in the graphics above demonstrates the importance of system performance parameters that most influence the operational capabilities of a mechanical recovery system. The analyses and recommendations described in this section are focused on the sensitivity of such parameters, using the ERSP Calculator as a tool to accomplish that goal.

The analysis of a possible replacement and/or enhancement of the EDRC approach would have to include a recovery system's ability to encounter, recover, store, and possibly "process" its recovered oil or emulsion. The analysis would also have to include response activities such as the transiting of the recovery system to and from its skimming location, and the time to conduct a transfer of its onboard oil to backup storage.

The ERSP Calculator is designed so that skimming system characteristics used in either nearshore or offshore areas can be used as input. The factors that typically distinguish offshore systems from those that might be used closer to shore or even inland usually involve the size and storage capacity of the system, the system's recovery capability, the ability to decant free water, the rate at which recovered oil can be offloaded to backup storage, etc. All of these factors can be simulated with the ERSP Calculator.

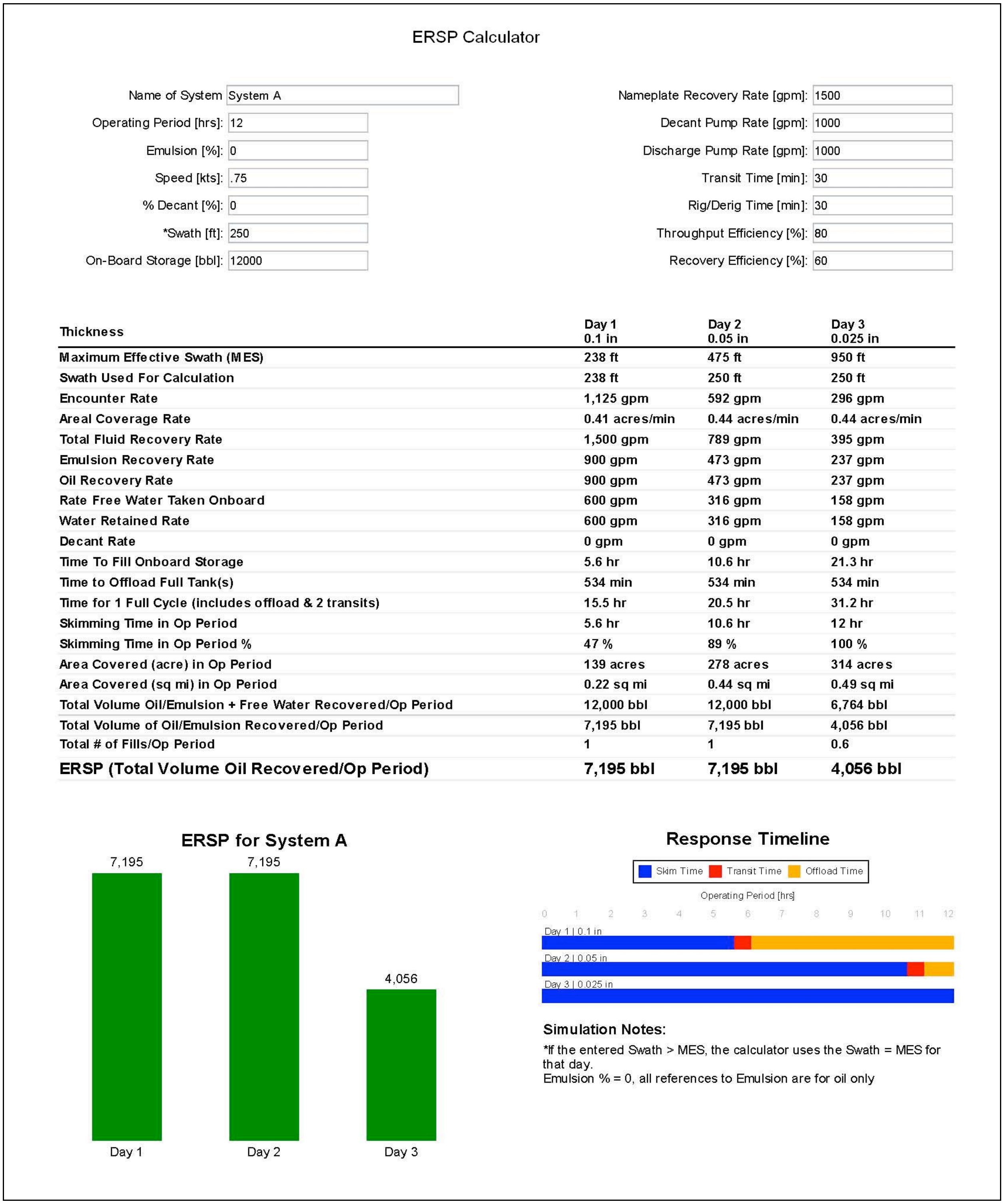
III.E. Selected System Comparisons and Analysis

In order to demonstrate the use of the ERSP Calculator and highlight important parameter sensitivities, four recovery system configurations have been selected from the seven representative skimming systems described in ***Section III.D***. They are:

- System "A" (Figure III.D-1) – a large self-propelled OSRV with onboard storage of 12,000 barrels; a single over-the-side skimmer positioned within a bridled J-boom configuration with umbilical discharge and hydraulic lines; moderate-volume decant and discharge capability; a single boom-tending vessel creating a swath of 250 feet; and a skimming speed of ¾ knot.
- System "C" (Figure III.D-3) – a very large towed barge with onboard storage of 100,000 barrels; two large weir skimmers operated from its stern; high-volume decant and discharge capability; a system swath of 500 feet, normally provided by two boom-tending vessels holding a U-configuration within which the barge and skimmers are positioned; and a skimming speed of ¾ knot.
- System "D" (Figure III.D-4) – a self-propelled OSRV with onboard storage of 4,000 barrels; a single oleophilic skimmer with good Throughput and Recovery Efficiencies (TE and RE) positioned at the downstream end of a V-sweep configuration held to an average swath of 60 feet with a boom vane; and a specified (though higher potential) skimming speed of 1 knot.
- System "F" (Figure III.D-6) – a relatively small self-propelled OSRV with 200 barrels of onboard storage; two built-in recovery-efficient brush skimmers on each side of the vessel with outriggers providing an overall swath of 70 feet; and a specified (though higher potential) skimming speed of 1 knot.

III.E.1 System “A”

A sample ERSP calculation page is provided in Figure III.E-1 for the System “A” standard configuration. The input data are shown at the top of the page, with the results of all system potential performance provided below the input data for Days 1, 2, and 3.



ERSP Calculator

Name of System: System A
Operating Period [hrs]: 12
Emulsion [%]: 0
Speed [kts]: .75
% Decant [%]: 0
*Swath [ft]: 250
On-Board Storage [bbl]: 12000

Nameplate Recovery Rate [gpm]: 1500
Decant Pump Rate [gpm]: 1000
Discharge Pump Rate [gpm]: 1000
Transit Time [min]: 30
Rig/Derig Time [min]: 30
Throughput Efficiency [%]: 80
Recovery Efficiency [%]: 60

Thickness	Day 1 0.1 in	Day 2 0.05 in	Day 3 0.025 in
Maximum Effective Swath (MES)	238 ft	475 ft	950 ft
Swath Used For Calculation	238 ft	250 ft	250 ft
Encounter Rate	1,125 gpm	592 gpm	296 gpm
Areal Coverage Rate	0.41 acres/min	0.44 acres/min	0.44 acres/min
Total Fluid Recovery Rate	1,500 gpm	789 gpm	395 gpm
Emulsion Recovery Rate	900 gpm	473 gpm	237 gpm
Oil Recovery Rate	900 gpm	473 gpm	237 gpm
Rate Free Water Taken Onboard	600 gpm	316 gpm	158 gpm
Water Retained Rate	600 gpm	316 gpm	158 gpm
Decant Rate	0 gpm	0 gpm	0 gpm
Time To Fill Onboard Storage	5.6 hr	10.6 hr	21.3 hr
Time to Offload Full Tank(s)	534 min	534 min	534 min
Time for 1 Full Cycle (includes offload & 2 transits)	15.5 hr	20.5 hr	31.2 hr
Skimming Time in Op Period	5.6 hr	10.6 hr	12 hr
Skimming Time in Op Period %	47 %	89 %	100 %
Area Covered (acre) in Op Period	139 acres	278 acres	314 acres
Area Covered (sq mi) in Op Period	0.22 sq mi	0.44 sq mi	0.49 sq mi
Total Volume Oil/Emulsion + Free Water Recovered/Op Period	12,000 bbl	12,000 bbl	6,764 bbl
Total Volume of Oil/Emulsion Recovered/Op Period	7,195 bbl	7,195 bbl	4,056 bbl
Total # of Fills/Op Period	1	1	0.6
ERSP (Total Volume Oil Recovered/Op Period)	**7,195 bbl**	**7,195 bbl**	**4,056 bbl**

Simulation Notes:

*If the entered Swath > MES, the calculator uses the Swath = MES for that day.
Emulsion % = 0, all references to Emulsion are for oil only

Figure III.E-1: System A with ERSP calculations for its standard configuration.

The Operating Period can be selected as desired; however, for this and all subsequent system comparisons, a 12-hour operational period is assumed. Nominal average oil thicknesses were selected for each of the three days based on the spreading model runs (described in ***Section III.C. Analysis of Oil Thickness***) for 12 hours of exposure (oil weathering) on Day 1, 36 hours of exposure to the middle of Day 2, and 60 hours of exposure to the middle of Day 3. An Operating Period of 12 hours each day is assumed to involve constant nominal average oil or emulsion thickness for that period and the Emulsion % input is kept at 0 % for all of the system comparisons. In order to simulate the encounter of an emulsion (e.g., a 30% water-in-oil emulsion), a 30% input value could be added. The calculated ERSP would account for the amount of water (30% in this example) within the total oil/emulsion recovered and give only the volume of “oil” recovered over the operating period.

The ERSP calculation page for System “A” (Figure III.E-1) shows that the standard configuration system would not be able to accommodate the volume of oil encountered (based on the given swath width, system speed on Day 1,and nominal average oil thickness of 0.1 inch, or about 2 ½ mm input parameters). The MES of 238 feet on Day 1 is close to, but slightly less than, the selected system swath of 250 feet. Working with that MES value, the Areal Coverage Rate, which is simply a function of swath and speed, is 0.41 acres / min.

By operating at the actual MES on Days 2 and 3, a reasonable improvement for the amount of oil recovered (i.e., ERSP) could be expected. However, the doubling of MES each day is attributable to a 50% reduction in the nominal average oil thickness each of Days 1 through 3. These effects offset each other. When operating any system at MES (assuming that the swath is achievable and all other parameters remain the same), the resulting ERSP remains constant since the decrease in average oil thickness causes a corresponding opposite change in MES.

The oil ER for each of the three days with this removal system is a function of three parameters: skimming speed; operating swath; and the average oil thickness entering the system’s swath. Equations used in the ERSP Calculator are provided in ***Appendix B***. Notice that for Days 1, 2, and 3, the swath used in the calculation stays nearly the same, with only a slight reduction on Day 1. The reduction occurs when the MES is slightly less than the system’s normal swath of 250 feet. With nearly equal swaths and skimming speed unchanged, the oil ER drops off in proportion to the changing average oil thickness.

Each output in this example could be verified by reviewing the formulations in ***Appendix B. ERSP Calculator User's Guide***; additional discussion is provided with this first sample calculation page (Figure III.E-1) to facilitate the use and interpretation of key parameters. Using the definition of Throughput Efficiency (TE) as the percentage of oil encountered that is actually brought onboard the system, the product of ER multiplied by TE should equal the skimmer's ORR. Referring to the Day 1 results, a check shows that the ER (1,125 gpm) times the TE (80%) does give 900 gpm for the skimmer's Oil Recovery Rate. This is the same value shown for the Emulsion Recovery Rate. However, had the calculation included an emulsion (i.e., % water-in-oil) to begin with, then the Emulsion Recovery Rate would have been reduced by that percentage of water to give the quantity of "oil only" in the "Oil" Recovery Rate.

Another important parameter is the Total Fluid Recovery Rate (TFRR), which is equal to the oil Encounter Rate (ER) multiplied by the ratio of TE to RE. On Day 1, the TFRR would be calculated by multiplying 1,125 x 80/60 to yield 1,500 gpm, as shown. Another calculation involves the Time to Fill Onboard Storage; this is calculating by dividing the onboard storage (in barrels) by the rate at which it is filled in barrels/hour. In this example, the onboard storage of 12,000 barrels is divided by the TFRR (of 1,500 gpm converted to 2,145 barrels/hour) resulting in a 5.594 hours (rounded to 5.6 hours) Time to Fill Onboard Storage value as shown in the results for Day 1 (Figure III.E-1).

Another useful calculation involves the Time for 1 Full Cycle value. This is the time to complete a fill of the onboard storage, to transit to a backup storage vessel or facility, to offload recovered fluids, and transit back to the oiled area to continue skimming. The offload time is determined by dividing the onboard storage volume by the discharge pump rate, and adding rig/de-rig times for line and hose handling. Transit times and rig/de-rig times are input values provided by the user.

System calculation results (e.g., skim time, offload time, transit time, and the number of fills per operating period) are illustrated in Response Timelines provided in the lower right corner of the ERSP results page (Figure III.E-1). The operating period for each day is shown in hours (1 through 12) above the timelines, along with the nominal average oil thickness for each day. The timelines provide a quick summary of the operational skimming times as well as time spent offloading and transiting each day for this system configuration.

The time for System “A” to complete a full cycle on Day 1 is given as 15.5 hours, with the skimming time taking 5.6 hours. The time line shows the 5.6 hours of skimming in blue, the transit to offload in red (30-minute input value), and the incomplete offload of recovered oil (534 minutes, or 8.9 hours) in orange. The completion of the offload and possibly the transit back to the recovery area might take place during periods of darkness or limited visibility following the 12-hour Operating Period.

On Day 2, this system is using a swath of 250 feet (i.e., the input value is less than the calculated MES) and is encountering less oil than it could if it operated at its MES. With the reduced encounter rate, it takes longer (now 10.6 hours) to fill its onboard storage tank. Under these conditions, and with the assumption that oil could be continually intercepted at the Day 2 average oil thickness, System “A” would skim for 10.6 hours (89% of the Operating Period), spending only a short portion of the day transiting to backup storage and beginning its offload operation. Taking longer to fill its onboard storage on Day 2, it still completes a single fill of its onboard storage within 12 hours, still recovering about 7,195 barrels (its ERSP) for Day 2.

Because of the ease with which input parameters can be changed and the estimated recovery potential results can be examined, the ERSP Calculator facilitates a rapid assessment of how the different recovery system characteristics influence a skimmer’s full recovery potential over a given operating period. Figure III.E-2is an example of an ERSP calculation page where System “A” is operated each day at its MES.

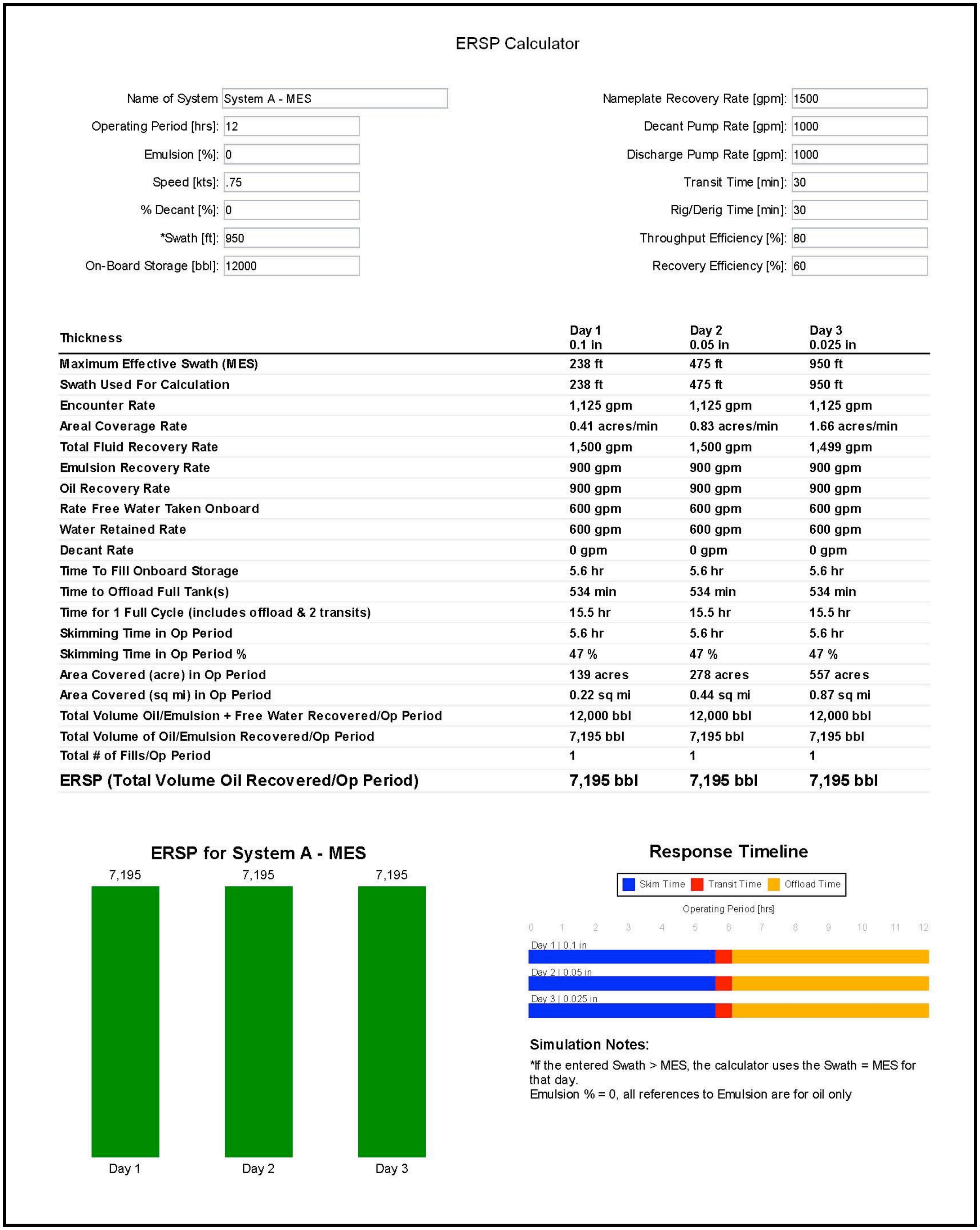
If a recovery system swath value that equals or exceeds the MES for Days 1, 2, or 3 (950 feet in this example) is entered into the calculator, the results for each day will be calculated using the calculated MES. Using these optimized swaths, the recovery system Encounter Rate changes to match the system’s ability to its Total Fluid Recovery Rate. The rates at which oil can be encountered on Days 2 and 3 now increase to match the rate on Day 1.

Figure III.E-2 shows that the ERSP values, now based on MES calculations, remain at the same level (i.e., 7,195 barrels) as calculated in the standard configuration mode (Figure III.E-1), except for the improvement on Day 3. On Day 3, the ERSP goes from 4,056 barrels to 7,195 barrels because a greater swath and ER enable a complete fill of its onboard storage within the operating period. The higher ER at the same level for all three days in the MES mode enables a complete fill in 5.6 hours each day. As the slicks continue to spread, the MES remains within a maximum <u>achievable</u> swath, giving the recovery system time to conduct a complete fill of onboard storage.

The importance of operating at or near a system's MES is evident from the example above. The ERSP Calculator has been helpful in answering other questions as well. For example:

- How would the ERSP values change each day if in addition to operating at MES the skimming system could also decant free water as it conducts its recovery operations?
- If the skimming system could operate at a higher RE, to what extent could the ERSP be improved?
- To what degree would the ERSPs be improved if the time to discharge recovered oil to backup storage could be reduced by increasing the Discharge Pump Rate?

Figure III.E-3 contains the results of an ERSP Calculator run where System "A" is operated at MES and decanting is simulated at its maximum value of 100%. Decanting would be difficult and less efficient during actual skimming operations especially as wind and waves cause sloshing of recovered fluids onboard. By setting the decant input at 100%, the resulting maximum benefit of decanting can be approximated. The benefit of decanting is evident in Figure III.E-3 as the ERSP of 7,200 barrels without decanting increases to 12,000 barrels with the removal of free water. Since the MES values for all three days are achievable, sufficient oil is made available to keep the ERSP estimate at 12,000 barrels. The Timeline diagram (bottom right corner of Figure III.E-3) drives home the benefit of decanting, as more than 9 hours out of the 12-hour operating period are spent skimming. This allows the OSRV to transit to its backup storage location and initiate offloading operations toward the end of the day, making maximum use of the operating period.



ERSP Calculator

Name of System	System A - MES	Nameplate Recovery Rate [gpm]:	1500
Operating Period [hrs]:	12	Decant Pump Rate [gpm]:	1000
Emulsion [%]:	0	Discharge Pump Rate [gpm]:	1000
Speed [kts]:	.75	Transit Time [min]:	30
% Decant [%]:	0	Rig/Derig Time [min]:	30
*Swath [ft]:	950	Throughput Efficiency [%]:	80
On-Board Storage [bbl]:	12000	Recovery Efficiency [%]:	60

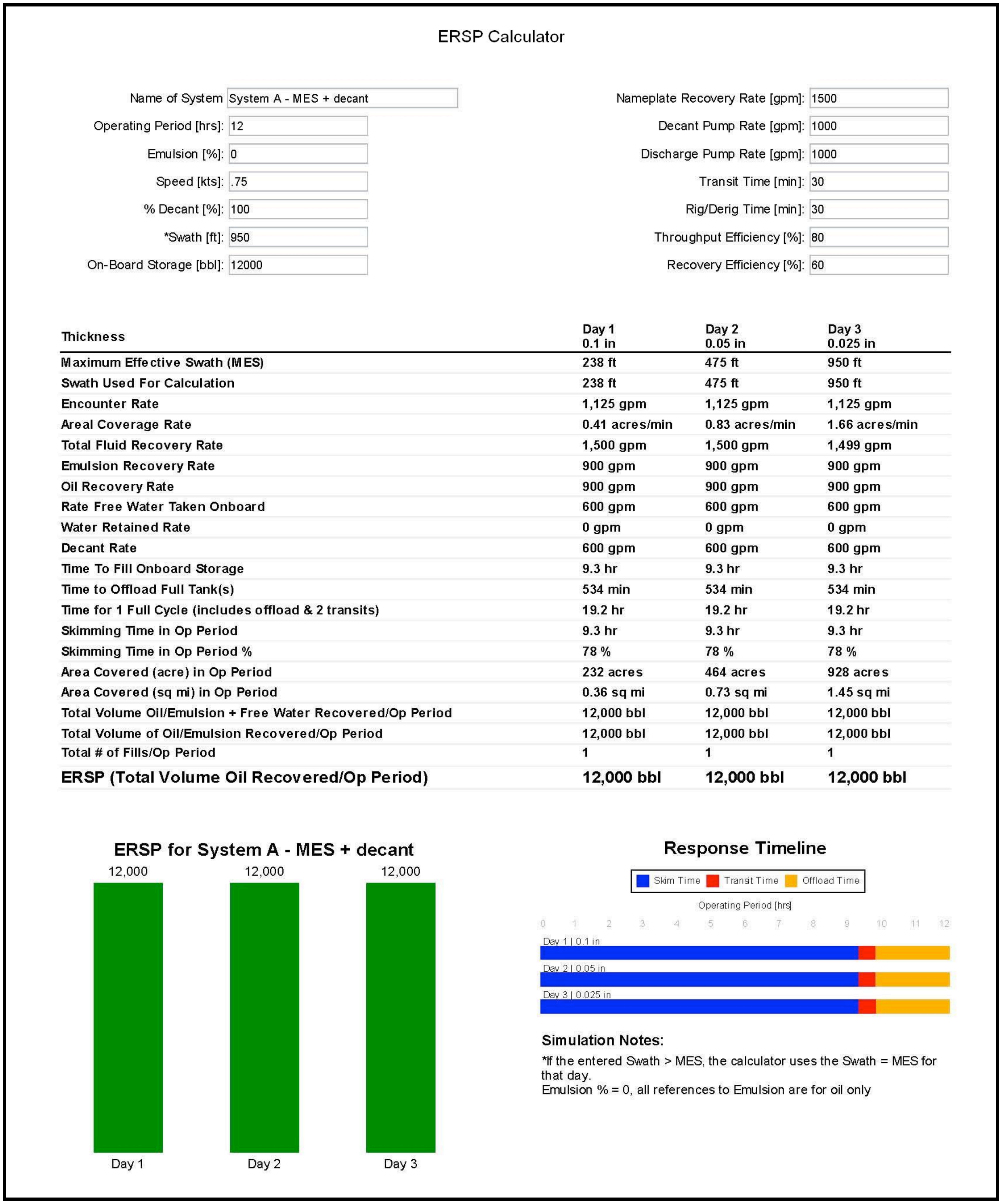
Thickness	Day 1 0.1 in	Day 2 0.05 in	Day 3 0.025 in
Maximum Effective Swath (MES)	238 ft	475 ft	950 ft
Swath Used For Calculation	238 ft	475 ft	950 ft
Encounter Rate	1,125 gpm	1,125 gpm	1,125 gpm
Areal Coverage Rate	0.41 acres/min	0.83 acres/min	1.66 acres/min
Total Fluid Recovery Rate	1,500 gpm	1,500 gpm	1,499 gpm
Emulsion Recovery Rate	900 gpm	900 gpm	900 gpm
Oil Recovery Rate	900 gpm	900 gpm	900 gpm
Rate Free Water Taken Onboard	600 gpm	600 gpm	600 gpm
Water Retained Rate	600 gpm	600 gpm	600 gpm
Decant Rate	0 gpm	0 gpm	0 gpm
Time To Fill Onboard Storage	5.6 hr	5.6 hr	5.6 hr
Time to Offload Full Tank(s)	534 min	534 min	534 min
Time for 1 Full Cycle (includes offload & 2 transits)	15.5 hr	15.5 hr	15.5 hr
Skimming Time in Op Period	5.6 hr	5.6 hr	5.6 hr
Skimming Time in Op Period %	47 %	47 %	47 %
Area Covered (acre) in Op Period	139 acres	278 acres	557 acres
Area Covered (sq mi) in Op Period	0.22 sq mi	0.44 sq mi	0.87 sq mi
Total Volume Oil/Emulsion + Free Water Recovered/Op Period	12,000 bbl	12,000 bbl	12,000 bbl
Total Volume of Oil/Emulsion Recovered/Op Period	7,195 bbl	7,195 bbl	7,195 bbl
Total # of Fills/Op Period	1	1	1
ERSP (Total Volume Oil Recovered/Op Period)	**7,195 bbl**	**7,195 bbl**	**7,195 bbl**

Simulation Notes:

*If the entered Swath > MES, the calculator uses the Swath = MES for that day.

Emulsion % = 0, all references to Emulsion are for oil only

Figure III.E-2: System A with ERSP calculations when operated at its Maximum Effective Swath.



ERSP Calculator

Name of System: System A - MES + decant
Operating Period [hrs]: 12
Emulsion [%]: 0
Speed [kts]: .75
% Decant [%]: 100
*Swath [ft]: 950
On-Board Storage [bbl]: 12000

Nameplate Recovery Rate [gpm]: 1500
Decant Pump Rate [gpm]: 1000
Discharge Pump Rate [gpm]: 1000
Transit Time [min]: 30
Rig/Derig Time [min]: 30
Throughput Efficiency [%]: 80
Recovery Efficiency [%]: 60

Thickness	Day 1 0.1 in	Day 2 0.05 in	Day 3 0.025 in
Maximum Effective Swath (MES)	238 ft	475 ft	950 ft
Swath Used For Calculation	238 ft	475 ft	950 ft
Encounter Rate	1,125 gpm	1,125 gpm	1,125 gpm
Areal Coverage Rate	0.41 acres/min	0.83 acres/min	1.66 acres/min
Total Fluid Recovery Rate	1,500 gpm	1,500 gpm	1,499 gpm
Emulsion Recovery Rate	900 gpm	900 gpm	900 gpm
Oil Recovery Rate	900 gpm	900 gpm	900 gpm
Rate Free Water Taken Onboard	600 gpm	600 gpm	600 gpm
Water Retained Rate	0 gpm	0 gpm	0 gpm
Decant Rate	600 gpm	600 gpm	600 gpm
Time To Fill Onboard Storage	9.3 hr	9.3 hr	9.3 hr
Time to Offload Full Tank(s)	534 min	534 min	534 min
Time for 1 Full Cycle (includes offload & 2 transits)	19.2 hr	19.2 hr	19.2 hr
Skimming Time in Op Period	9.3 hr	9.3 hr	9.3 hr
Skimming Time in Op Period %	78 %	78 %	78 %
Area Covered (acre) in Op Period	232 acres	464 acres	928 acres
Area Covered (sq mi) in Op Period	0.36 sq mi	0.73 sq mi	1.45 sq mi
Total Volume Oil/Emulsion + Free Water Recovered/Op Period	12,000 bbl	12,000 bbl	12,000 bbl
Total Volume of Oil/Emulsion Recovered/Op Period	12,000 bbl	12,000 bbl	12,000 bbl
Total # of Fills/Op Period	1	1	1
ERSP (Total Volume Oil Recovered/Op Period)	**12,000 bbl**	**12,000 bbl**	**12,000 bbl**

Simulation Notes:

*If the entered Swath > MES, the calculator uses the Swath = MES for that day.
Emulsion % = 0, all references to Emulsion are for oil only

Figure III.E-3: System “A” with ERSP calculations for Maximum Effective Swath and 100% decant.

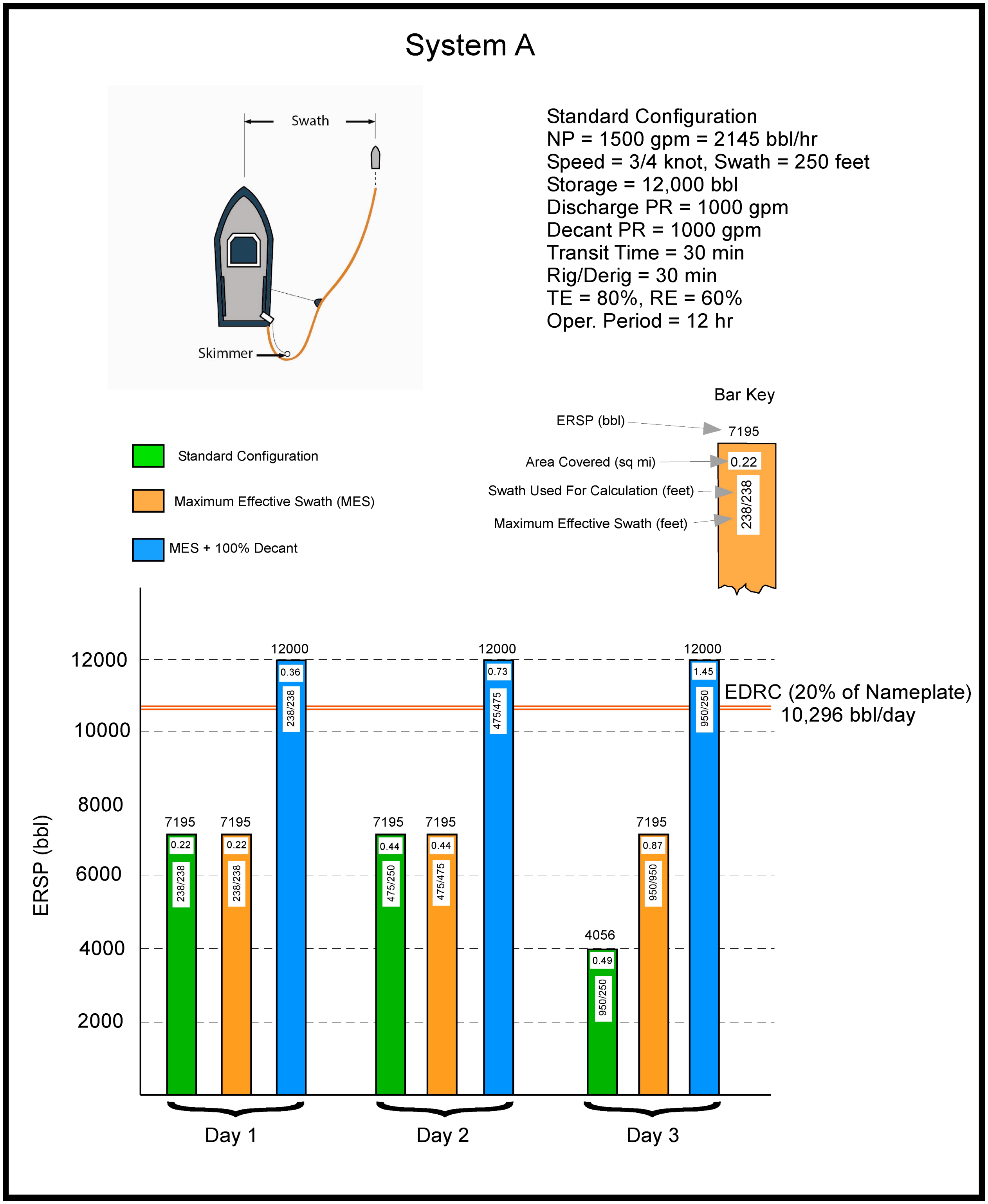


Figure III.E-4: Summary of System "A" ERSP calculations for Standard, MES, and MES + 100% decant configurations.

Figure III.E-4 is a summary of the calculations discussed so far for System "A". It shows a plot of the ERSP values for each of the three days where the vertical bars represent the standard configuration (in green), the use of MES (in orange), and the MES plus a 100% decant of the free water (in blue). Note that the ERSP estimates with MES + 100% decant are greater than the EDRC for System "A" on all three days.

Additional simulations have been examined for System "A" involving the effects of increasing RE and reducing the amount of time needed to offload from the OSRV to backup storage. The ERSP Calculator page for these simulations is not shown here; however, the results can be summarized as follows:

- If the RE of 60% assigned to this system in its standard configuration is increased to 80% or even 100%, the ERSP remains at 12,000 barrels even though the onboard storage can be filled more efficiently with less free water taken onboard.
- The time needed to fill the storage tanks is reduced; however, because of the time needed to transit and offload recovered oil, the system is still limited to one complete fill per day.

This is a good example of how a seemingly important improvement such as higher RE may not result in a significant change to the recovery potential of a given skimming system. The overall benefit of any improvement must be examined in light of its impact upon the entire "system", including the time available to benefit from the improvement (a 12-hour Operating Period in this example), the proximity to backup storage units, the ability to reduce offload time with additional discharge pumps, etc.

In this case, if the discharge pump rate could be doubled from 1,000 gpm to 2,000 gpm, the time needed to offload oil would be reduced on Days 1 and 2 to allow for the start of a second skimming period. While there would be insufficient time for a total second fill, System "A" could recover nearly 1,500 additional barrels of oil, increasing the ERSP on Days 1 and 2 to approximately 13,500 barrels. On Day 3, the ERSP remains at 12,000 barrels because the swath used for calculation purposes is held to an assumed maximum achievable swath of 1,000 feet, far less than the MES of 1,584 feet for the system as described (i.e., maximum decant, RE, and discharge improvements).

The importance of system parameters beyond those examined here becomes evident as one applies the same kind of analysis used for System "A" to three other systems ("C", "D" and "F", from ***Section III.D.3 Representative Skimming Configurations***). Examination of these systems shows how important onboard storage, skimming speed, and Nameplate recovery rate are to the computed ESRP for a given skimming system. In the following section, the ERSP calculation page, summary diagram and a brief discussion of results are provided for each skimming system.

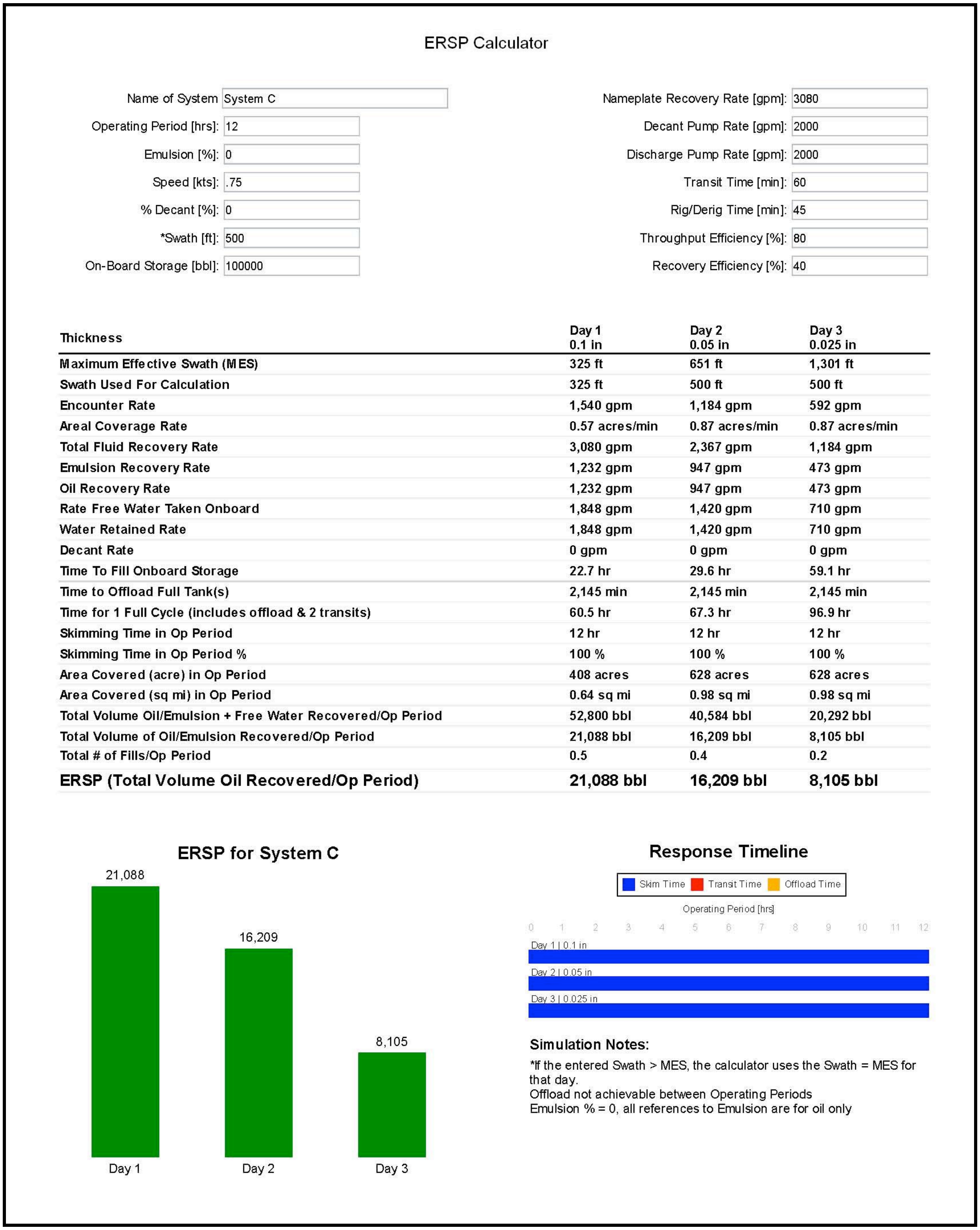
III.E.2 System "C"

The ERSP calculation page for System "C" (Figure III.E-5) contains the input characteristics for this skimming system along with the results of a 3-day response as before. This is an example of a large open-ocean system with two equally large oil skimmers working simultaneously from a barge with a storage capacity of 100,000 barrels. Even with systems with a total Nameplate recovery rate of 3,080 gpm and an estimated 40% RE, taking on 60% water and 40% oil, the system is not expected to fill in a single 12-hour operating period.

The Timelines at the bottom of the ERSP calculation page confirm that this system would be able to skim throughout the operating period as long as there was sufficient oil entering the system at the nominal average oil thickness. The results show that the Total # of Fills/Operating Period vary from 0.5 on Day1 to 0.2 on Day 3. Note, however, that even this "Standard" configuration of System "C" can achieve an ERSP of 21,088 barrels of oil on Day 1. This could be of great significance should this, or a comparable system, be available to respond to a large "batch" or ongoing "continuous" release of oil.

It is interesting to note that even with such high Nameplate recovery capabilities, the MES are still reasonably achievable for Days 1 and 2 (325 to 651 feet). The standard configuration for this system on Day 2 with its 500-ft swath would still generate an ERSP of 16,209 barrels. By Day 3, the MES is likely beyond any easily achieved swath; even with the 500-ft swath on Day 3, the ERSP is well over 8,000 barrels.

In order to illustrate how Response System "C" compares with System "A", Figure III.E-6 is provided with the same input parameter variations involving a "Standard" configuration, one where the MES is used (if possible), and where the MES is used along with a 100% decant. The ERSP for each mode of operation is given for Days 1, 2, and 3, along with data on the area covered, the MES, and the actual swath used for the calculation of ERSP.



ERSP Calculator

Name of System: System C
Operating Period [hrs]: 12
Emulsion [%]: 0
Speed [kts]: .75
% Decant [%]: 0
*Swath [ft]: 500
On-Board Storage [bbl]: 100000

Nameplate Recovery Rate [gpm]: 3080
Decant Pump Rate [gpm]: 2000
Discharge Pump Rate [gpm]: 2000
Transit Time [min]: 60
Rig/Derig Time [min]: 45
Throughput Efficiency [%]: 80
Recovery Efficiency [%]: 40

Thickness	Day 1 0.1 in	Day 2 0.05 in	Day 3 0.025 in
Maximum Effective Swath (MES)	325 ft	651 ft	1,301 ft
Swath Used For Calculation	325 ft	500 ft	500 ft
Encounter Rate	1,540 gpm	1,184 gpm	592 gpm
Areal Coverage Rate	0.57 acres/min	0.87 acres/min	0.87 acres/min
Total Fluid Recovery Rate	3,080 gpm	2,367 gpm	1,184 gpm
Emulsion Recovery Rate	1,232 gpm	947 gpm	473 gpm
Oil Recovery Rate	1,232 gpm	947 gpm	473 gpm
Rate Free Water Taken Onboard	1,848 gpm	1,420 gpm	710 gpm
Water Retained Rate	1,848 gpm	1,420 gpm	710 gpm
Decant Rate	0 gpm	0 gpm	0 gpm
Time To Fill Onboard Storage	22.7 hr	29.6 hr	59.1 hr
Time to Offload Full Tank(s)	2,145 min	2,145 min	2,145 min
Time for 1 Full Cycle (includes offload & 2 transits)	60.5 hr	67.3 hr	96.9 hr
Skimming Time in Op Period	12 hr	12 hr	12 hr
Skimming Time in Op Period %	100 %	100 %	100 %
Area Covered (acre) in Op Period	408 acres	628 acres	628 acres
Area Covered (sq mi) in Op Period	0.64 sq mi	0.98 sq mi	0.98 sq mi
Total Volume Oil/Emulsion + Free Water Recovered/Op Period	52,800 bbl	40,584 bbl	20,292 bbl
Total Volume of Oil/Emulsion Recovered/Op Period	21,088 bbl	16,209 bbl	8,105 bbl
Total # of Fills/Op Period	0.5	0.4	0.2
ERSP (Total Volume Oil Recovered/Op Period)	**21,088 bbl**	**16,209 bbl**	**8,105 bbl**

Simulation Notes:

*If the entered Swath > MES, the calculator uses the Swath = MES for that day.
Offload not achievable between Operating Periods
Emulsion % = 0, all references to Emulsion are for oil only

Figure III.E-5: System "C" with ERSP calculations for its standard configuration.

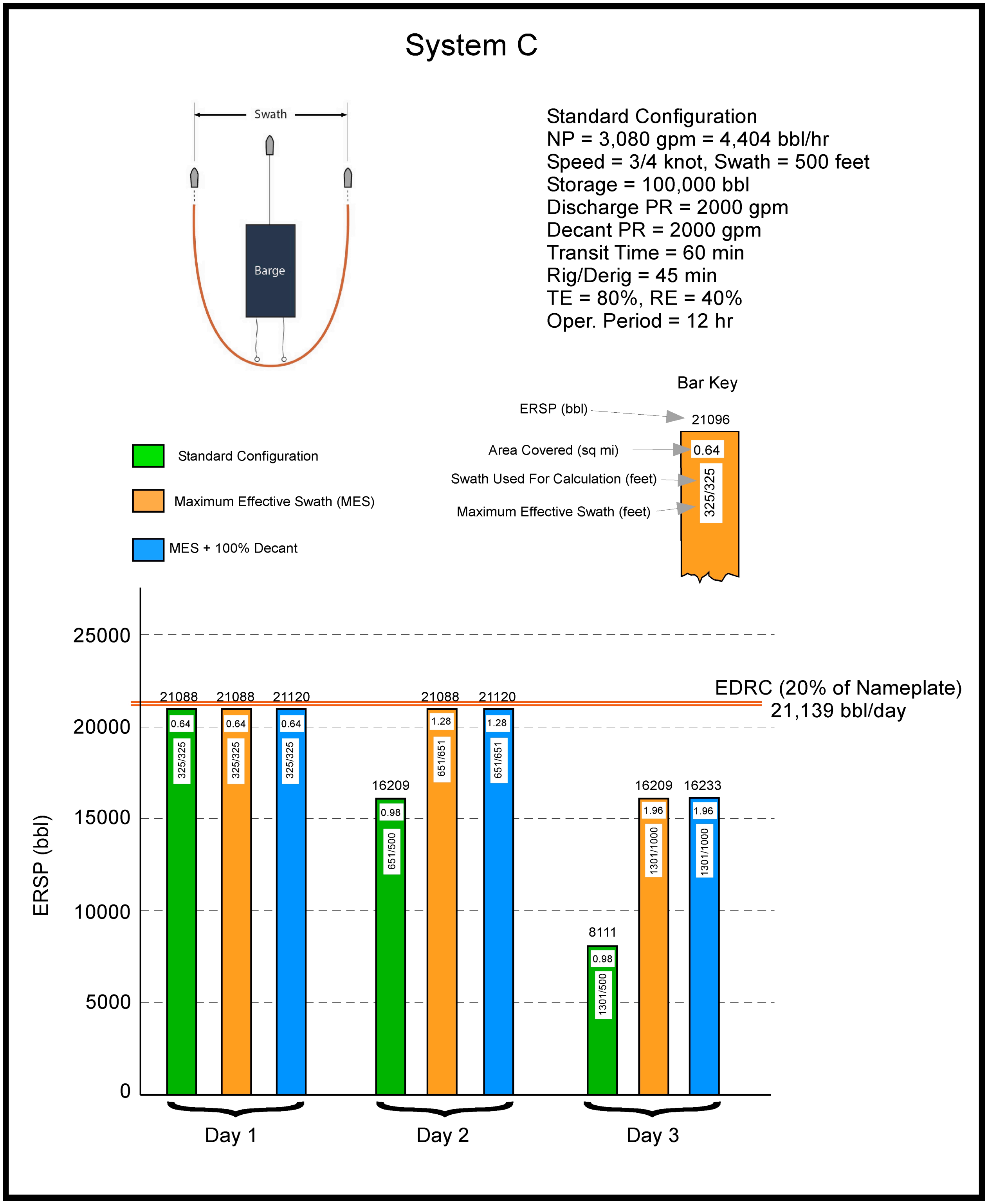


Figure III.E-6: Summary of System "C" ERSP calculations for Standard, MES, and MES + 100% decant configurations.

It is not surprising, given the large onboard storage and twin, high-volume skimming systems used, to see the ERSP values soar to more than 21,000 barrels during Days 1 and 2. As with System “A” (Figure III.E-4), it is when the system’s configuration and input data allow the calculation swath to match the MES that we see high ERSP values, surpassed only with System “A” and not with System “C” when decanting is introduced.

As shown in Figure III.E-6, System “C” remains at approximately 21,120 barrels for its ERSP on Days 1 and 2, even when decanting at 100%. It doesn’t matter whether decanting takes place or not, as there is ample room for both the water recovered (RE at 40%) and the oil. The skimming system is able to recover oil continuously throughout the 12-hour operating period.

Only the standard configuration (green bar) on Day 2 for System “C” and all response modes on Day 3 fall short of the simulated maximum ERSP values in excess of 21,000 barrels. Under all other conditions on Days 1 and 2, System “C” can achieve ERSP values that are nearly identical to the system’s EDRC of 21,139 bbl/day. Much higher recovery potentials for this system could be achieved by improving the RE for its two skimmers from 40% to 60%.

For example, with a RE of 60%:

- The MES increases because of the lower volumes of water that would be recovered with the oil,
- The greater achievable swaths for System “C” could increase the ERSP to more than 31,000 barrels on Day 1 and Day 2, and more than 16,000 barrels on Day 3.
- Decanting would not be necessary to achieve these higher ERSP values; but decanting would reduce the time needed to offload recovered fluids during hours beyond the system’s operating period.

The calculation of the time to offload recovered oil and water is important, especially for a skimming system of this size. For such large potential volumes recovered, the discharge pump rates need to be considered in light of the time available to offload and get back on location to resume skimming.

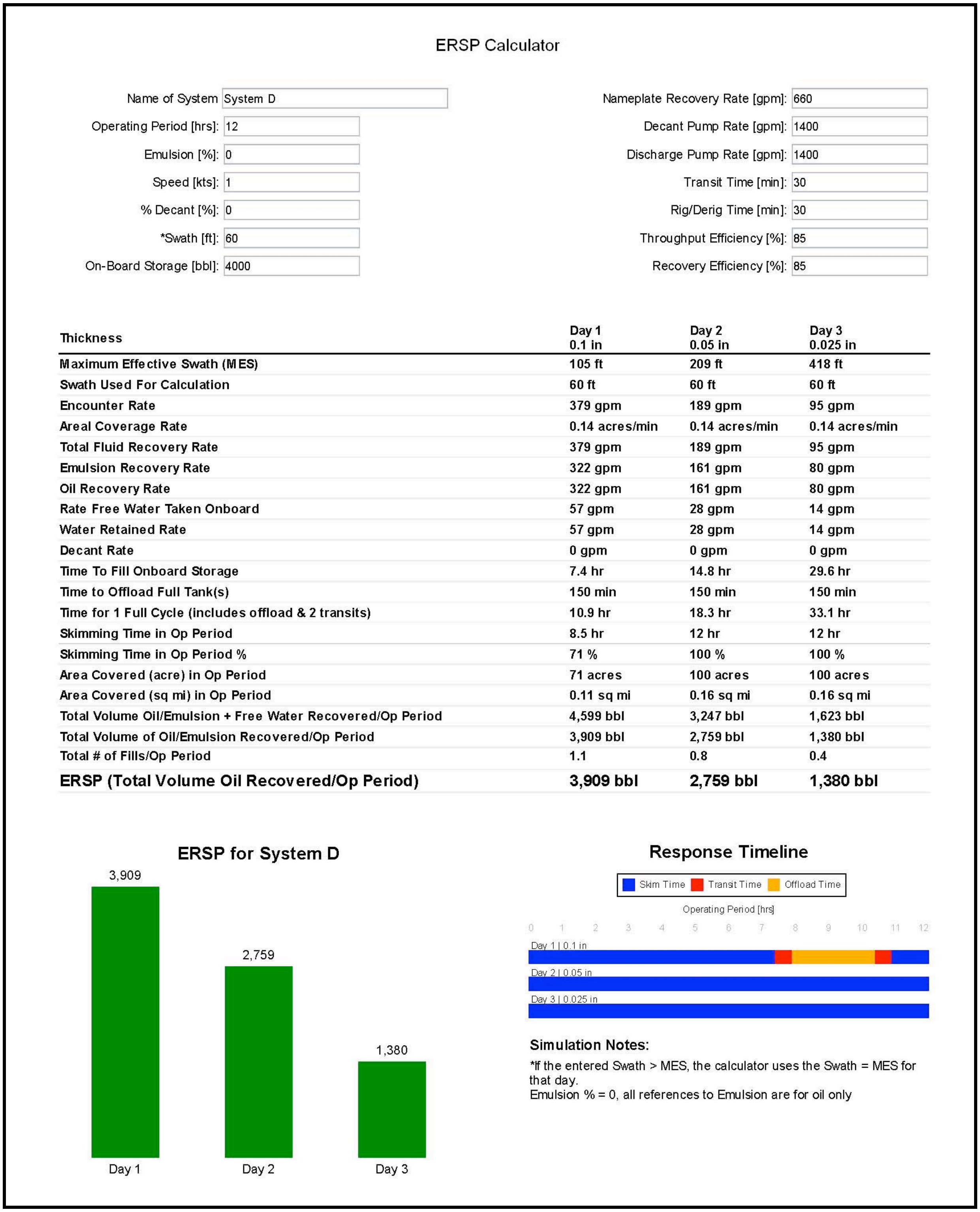
For this System "C", for example, a full onboard storage of 100,000 barrels with a discharge pump rate of 2,000 gpm (2,860 barrels/hour) would require about 35 hours just to transfer the fluids. This does not include the time for transit to and from backup storage, the time for line and hose handling, etc. A much more robust discharge system with larger pumps and the ability to empty multiple tanks or switch between tanks quickly would maximize the time spent actively skimming in each operating period.

III.E.3 System "D"

System "D" is different than the two previous systems as its skimmer has a lower Nameplate recovery rate. However, the skimmer is more efficient with both its TE and RE equal to 85%. With a Nameplate recovery rate of 660 gpm (944 barrels/hour), the system is positioned at the downstream apex of a V-sweep boom configuration that is held in place with a boom vane. The entire skimming assembly is attached at the stern of a large OSRV with an onboard storage capacity of 4,000 barrels. This system's decant and discharge pumps are rated at 1,400 gpm (~2,000 barrels/hour), and its "Standard" configuration produces a swath of 60 feet. The system is assumed to require 30 minutes for transit to backup storage, and it is estimated that line/hose handling (i.e., Rig & De-rig) would require approximately 30 minutes as well for each offload of recovered fluids.

The ERSP calculation page for System "D" (Figure III.E-7) reveals that the system's 60-foot swath is considerably smaller than the calculated MES of 105, 209, and 418 feet for Days 1, 2, and 3. The system's standard configuration results in ERSP values that are about one half of what the value would be if operated at MES. The improvement by working at MES is illustrated in Figure III.E-8 where ERSP is provided for Days 1, 2, and 3. The second bar (in orange) for each day shows significant ERSP improvement over the system's standard configuration capability (in green). By operating at the system's MES, there is a two to five-fold increase in the ERSP from Day 1 to Day 3.

The ERSP value of 6,799 barrels for each of the three days is significantly higher than the system's EDRC of 4,530 barrels/day. This is apparent from the results shown on the ERSP calculation page (Figure III.E-7). Even though the "D" system has a high RE, the ER for the system in the standard configuration is a small fraction of the Nameplate recovery rate.



ERSP Calculator

Name of System	System D	Nameplate Recovery Rate [gpm]:	660
Operating Period [hrs]:	12	Decant Pump Rate [gpm]:	1400
Emulsion [%]:	0	Discharge Pump Rate [gpm]:	1400
Speed [kts]:	1	Transit Time [min]:	30
% Decant [%]:	0	Rig/Derig Time [min]:	30
*Swath [ft]:	60	Throughput Efficiency [%]:	85
On-Board Storage [bbl]:	4000	Recovery Efficiency [%]:	85

Thickness	Day 1 0.1 in	Day 2 0.05 in	Day 3 0.025 in
Maximum Effective Swath (MES)	105 ft	209 ft	418 ft
Swath Used For Calculation	60 ft	60 ft	60 ft
Encounter Rate	379 gpm	189 gpm	95 gpm
Areal Coverage Rate	0.14 acres/min	0.14 acres/min	0.14 acres/min
Total Fluid Recovery Rate	379 gpm	189 gpm	95 gpm
Emulsion Recovery Rate	322 gpm	161 gpm	80 gpm
Oil Recovery Rate	322 gpm	161 gpm	80 gpm
Rate Free Water Taken Onboard	57 gpm	28 gpm	14 gpm
Water Retained Rate	57 gpm	28 gpm	14 gpm
Decant Rate	0 gpm	0 gpm	0 gpm
Time To Fill Onboard Storage	7.4 hr	14.8 hr	29.6 hr
Time to Offload Full Tank(s)	150 min	150 min	150 min
Time for 1 Full Cycle (includes offload & 2 transits)	10.9 hr	18.3 hr	33.1 hr
Skimming Time in Op Period	8.5 hr	12 hr	12 hr
Skimming Time in Op Period %	71 %	100 %	100 %
Area Covered (acre) in Op Period	71 acres	100 acres	100 acres
Area Covered (sq mi) in Op Period	0.11 sq mi	0.16 sq mi	0.16 sq mi
Total Volume Oil/Emulsion + Free Water Recovered/Op Period	4,599 bbl	3,247 bbl	1,623 bbl
Total Volume of Oil/Emulsion Recovered/Op Period	3,909 bbl	2,759 bbl	1,380 bbl
Total # of Fills/Op Period	1.1	0.8	0.4
ERSP (Total Volume Oil Recovered/Op Period)	**3,909 bbl**	**2,759 bbl**	**1,380 bbl**

Simulation Notes:

*If the entered Swath > MES, the calculator uses the Swath = MES for that day.
Emulsion % = 0, all references to Emulsion are for oil only

Figure III.E-7: System “D” with ERSP calculations for its Standard configuration.

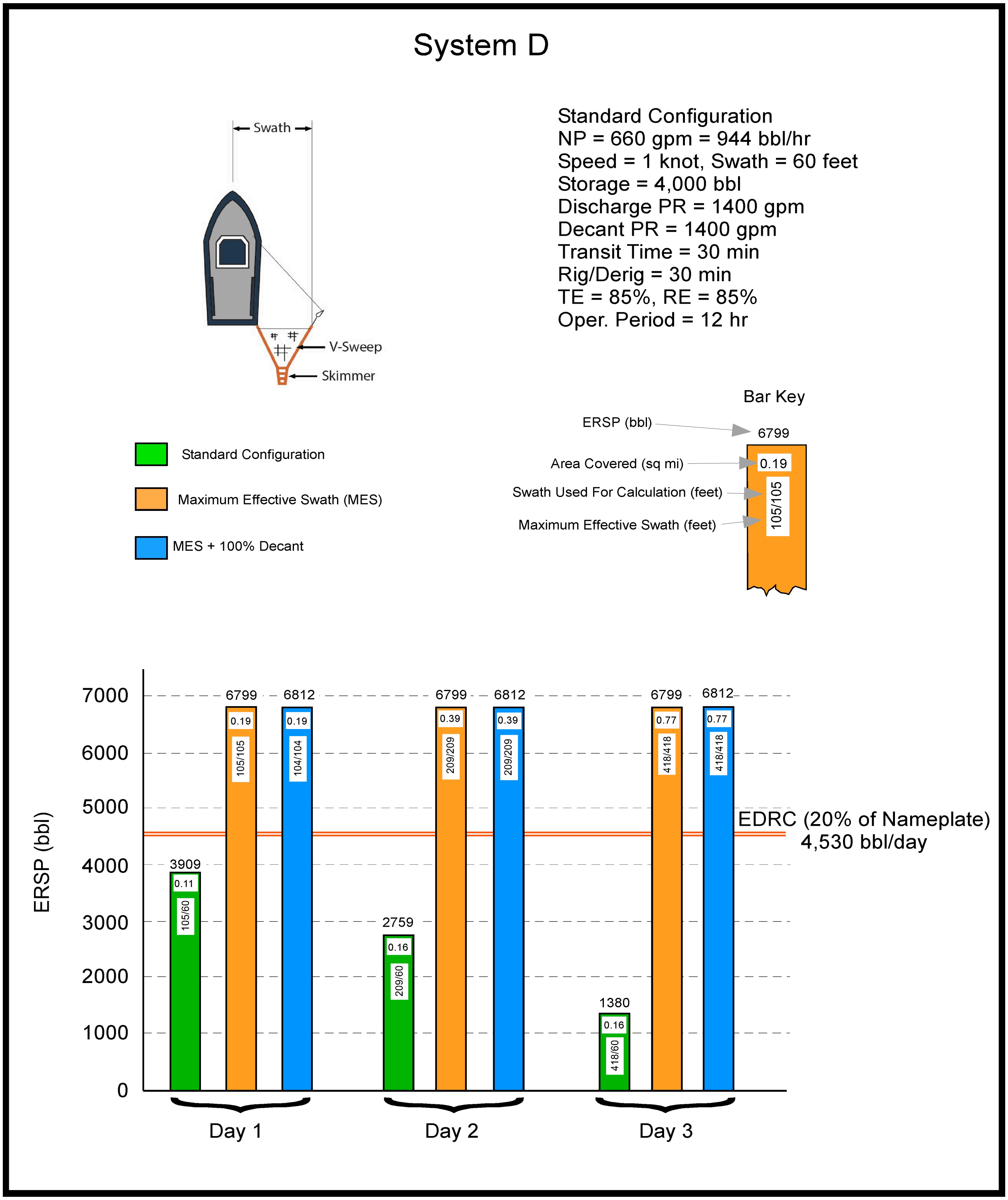


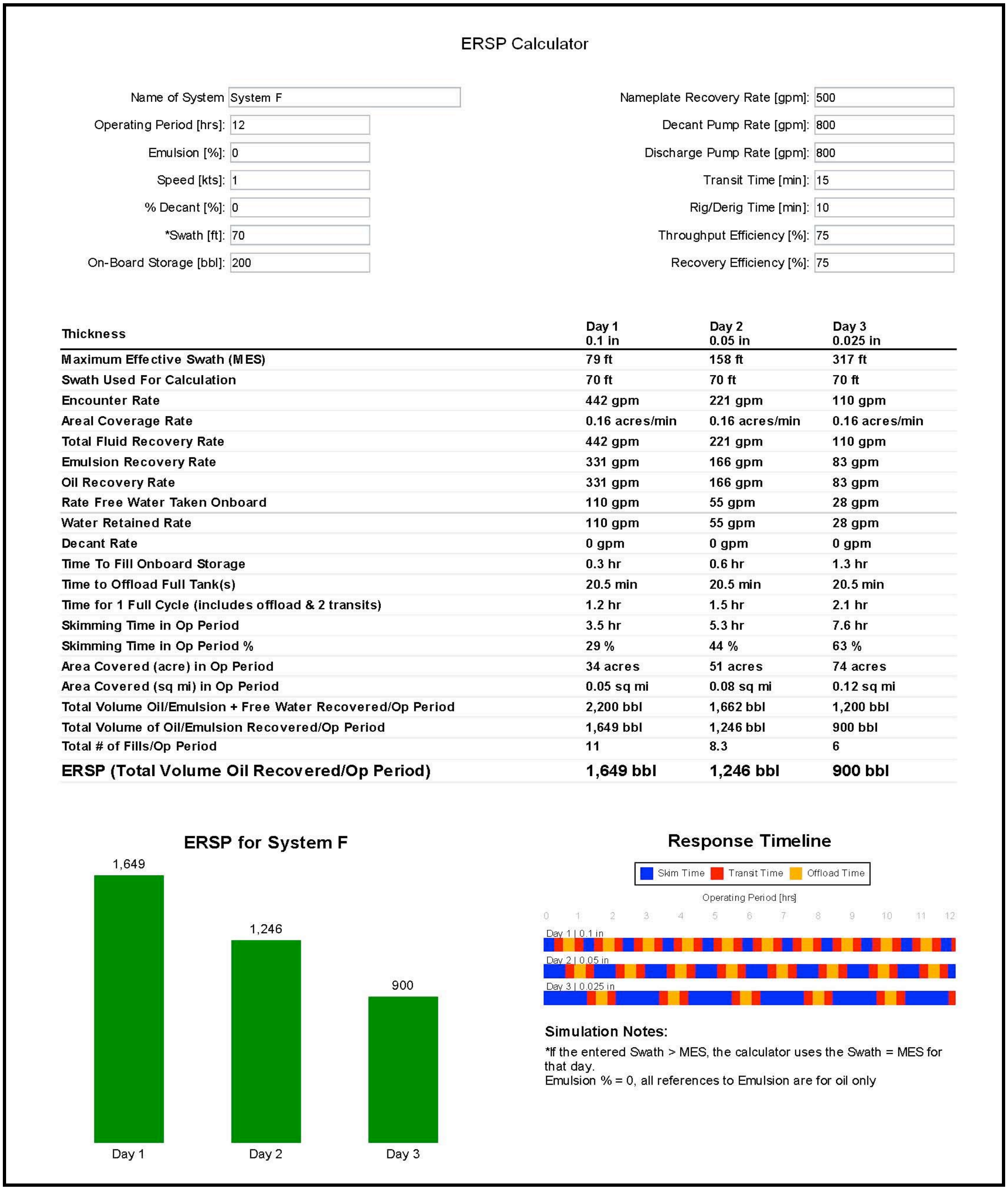
Figure III.E-8: Summary of System "D" ERSP calculations for Standard, MES, and MES + 100% decant configurations.

If the ERSP Calculator is run for System "D" at its MES, the Total Number of Fills/Operating Period increases from 0.4 to 1.1 in the standard configuration (60-foot swath) to allow two complete fills on Days 1,2, and 3. To accomplish these swath increases to as much as 418 feet on Day 3, one might operate the entire recovery system immediately downstream of an open-apex U-boom deflection system or consider the use of additional deflection boom and a boom-tending vessel connected to the outboard leading end of the V-sweep.

Analyses of this system with the ERSP Calculator included several variations of input, including a number of decant and discharge rates over a 12-hour operating period. As shown in Figure III.E-8, there is no improvement in the ERSP value by conducting a 100% decant of all free water. Since no water would be retained per fill with a 100% decant, the time to fill with only oil would increase, as would the volume of oil per fill. These are desirable improvements. However, the volume of oil recovered per 12-hour operating period would unfortunately remain the same since the fraction of a second fill in the 12-hour period would actually be less than what could be recovered in a second fill without decanting. The Total # of Fills / Operating Period is 1.7 with decanting versus 2.0 without decanting.

III.E.4 System "F"

The fourth system selected from the representative skimming configurations involves a relatively small OSRV with an onboard storage of 200 barrels. The OSRV has two built-in brush skimmers with Nameplate recovery rates of 250 gpm each, for a combined system Nameplate recovery rate of 500 gpm (715 barrels/hour). Using the 20% of Nameplate recovery rate over 24 hours yields an EDRC value of 3,432 barrels/day. The Discharge and Decant pump rates have been input at 800 gpm (1,144 barrels/hour) and the TE and RE have been set at 75% each. This System "F" configuration has been given a skimming speed of 1 knot and a total swath of 70 feet. Because of the size and likely transit speed of this system, it has been given a Transit Time of 15 minutes and a Rig/De-rig time of 10 minutes. As with the previous 3 skimming systems, a print out of the ERSP calculation page is provided (Figure III.E-9) along with a comparison of ERSP values (Figure III.E-10). These figures show how the system performs with its "standard" configuration, with MES, and when a full 100% decant is added to the MES mode of operation.



ERSP Calculator

Name of System: System F
Operating Period [hrs]: 12
Emulsion [%]: 0
Speed [kts]: 1
% Decant [%]: 0
*Swath [ft]: 70
On-Board Storage [bbl]: 200

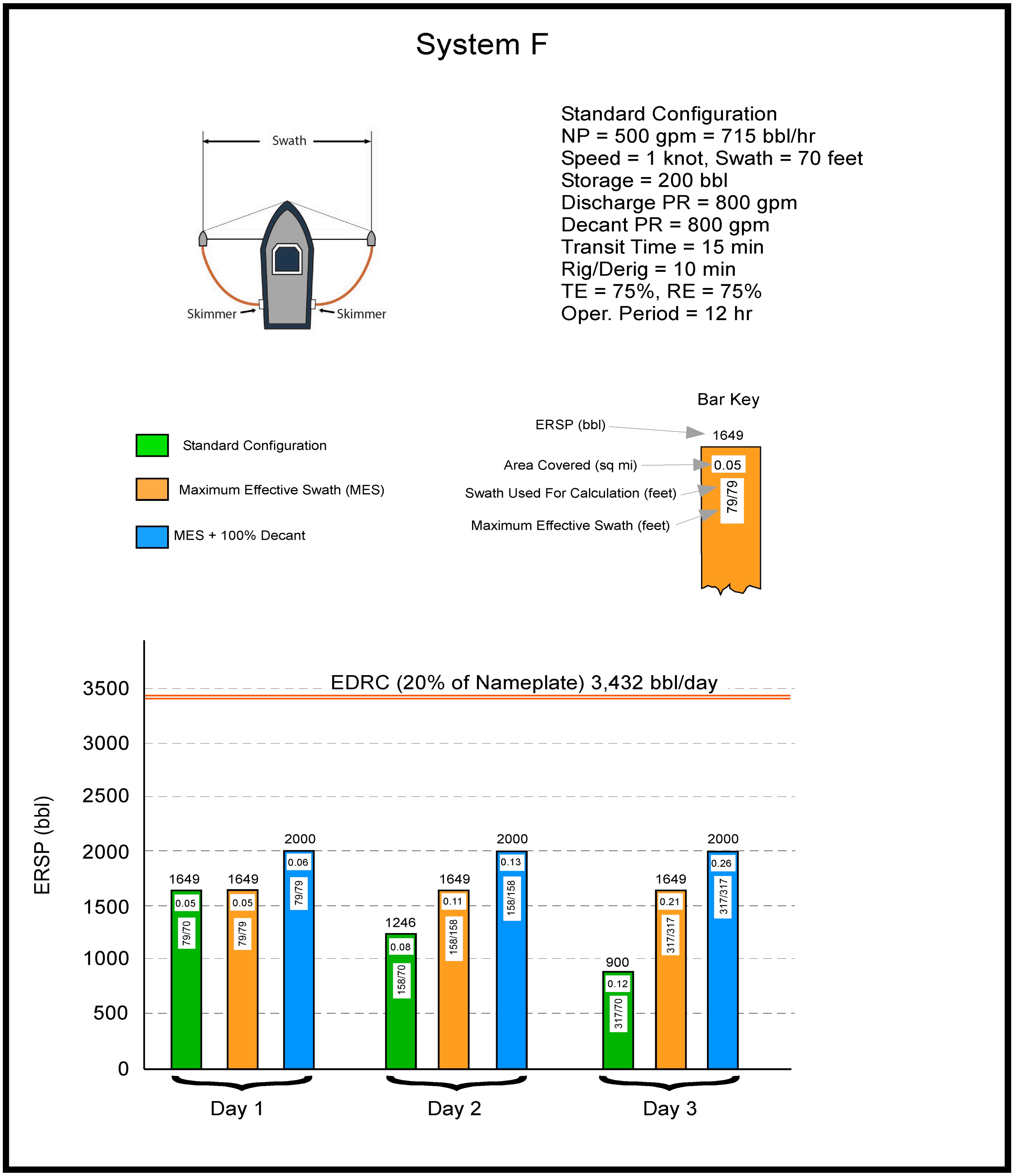
Nameplate Recovery Rate [gpm]: 500
Decant Pump Rate [gpm]: 800
Discharge Pump Rate [gpm]: 800
Transit Time [min]: 15
Rig/Derig Time [min]: 10
Throughput Efficiency [%]: 75
Recovery Efficiency [%]: 75

Thickness	Day 1 0.1 in	Day 2 0.05 in	Day 3 0.025 in
Maximum Effective Swath (MES)	79 ft	158 ft	317 ft
Swath Used For Calculation	70 ft	70 ft	70 ft
Encounter Rate	442 gpm	221 gpm	110 gpm
Areal Coverage Rate	0.16 acres/min	0.16 acres/min	0.16 acres/min
Total Fluid Recovery Rate	442 gpm	221 gpm	110 gpm
Emulsion Recovery Rate	331 gpm	166 gpm	83 gpm
Oil Recovery Rate	331 gpm	166 gpm	83 gpm
Rate Free Water Taken Onboard	110 gpm	55 gpm	28 gpm
Water Retained Rate	110 gpm	55 gpm	28 gpm
Decant Rate	0 gpm	0 gpm	0 gpm
Time To Fill Onboard Storage	0.3 hr	0.6 hr	1.3 hr
Time to Offload Full Tank(s)	20.5 min	20.5 min	20.5 min
Time for 1 Full Cycle (includes offload & 2 transits)	1.2 hr	1.5 hr	2.1 hr
Skimming Time in Op Period	3.5 hr	5.3 hr	7.6 hr
Skimming Time in Op Period %	29 %	44 %	63 %
Area Covered (acre) in Op Period	34 acres	51 acres	74 acres
Area Covered (sq mi) in Op Period	0.05 sq mi	0.08 sq mi	0.12 sq mi
Total Volume Oil/Emulsion + Free Water Recovered/Op Period	2,200 bbl	1,662 bbl	1,200 bbl
Total Volume of Oil/Emulsion Recovered/Op Period	1,649 bbl	1,246 bbl	900 bbl
Total # of Fills/Op Period	11	8.3	6
ERSP (Total Volume Oil Recovered/Op Period)	**1,649 bbl**	**1,246 bbl**	**900 bbl**

Simulation Notes:

*If the entered Swath > MES, the calculator uses the Swath = MES for that day.
Emulsion % = 0, all references to Emulsion are for oil only

Figure III.E-9: System “F” with ERSP calculations for its Standard configuration.



System F

Standard Configuration
NP = 500 gpm = 715 bbl/hr
Speed = 1 knot, Swath = 70 feet
Storage = 200 bbl
Discharge PR = 800 gpm
Decant PR = 800 gpm
Transit Time = 15 min
Rig/Derig = 10 min
TE = 75%, RE = 75%
Oper. Period = 12 hr

Figure III.E-10: Summary of System "F" ERSP calculations for Standard, MES, and MES + 100% decant configurations.

The usual enhancement of ERSP occurs on Days 2 and 3 when this system is operated at its MES. The ERSP values improve from 1,246 barrels and 900 barrels on Days 2 and 3 to approximately 1,649 barrels, matching the ERSP of Day 1. Since the MES values of 158 feet and 317 feet for Days 2 and 3 are much wider than the system's standard configuration, System "F" would have to work downstream of an open-apex U-boom deflection system to provide the necessary oil encounter rate to match its Total Fluid Recovery Rate (TFRR). The encounter rate and the TFRR are the same (considering slight differences due to rounding in the calculator) whenever a system's TE and RE are equal and a MES is used.

There is an additional increase in the calculated ERSP to 2,000 barrels for all three days when the free water collected is fully decanted (i.e., % Decant = 100). Note that even with the MES and maximum decant settings, the ERSP values for this relatively small OSRV do not compare well with the 20% de-rated Nameplate recovery rate (i.e., EDRC) of 3,432 barrels/day. Even if the RE for this system could be improved from 75% to 100%, the ERSP would only increase to 2,200 bpd. These calculations illustrate the importance of onboard storage, even for a system with a relatively high Nameplate recovery rate and high RE.

If this system operates at its MES with full decant capability with both the TE and RE values at 75%, a doubling of the storage capacity would increase the ERSP to 2,800 barrels. However, with the same assumptions, the storage would also need to increase 700 barrels to achieve an ERSP of 3,500 barrels, slightly more than the skimming system's EDRC. Increases in onboard storage would not be feasible for the standard vessel configuration defined here; but it might be possible to increase storage using towable storage tanks or bladders.

It is important to note that any skimming system, including System "F" with a relatively small onboard storage, need not be evaluated only by its ability to match or exceed its existing EDRC calculation. The role that a skimming system plays within the overall response plan for a given offshore or nearshore operation is dependent on much more than the system's estimated recovery potential each day. A system similar to System "F" could have other equally important characteristics such as maneuverability, speed to get on location and to transit to backup storage, etc. It could also be of a design for specific oil types and smaller most-probable spill events that outweigh its need for a high recovery potential.

System “F”, because of its high recovery rate skimmers, fills its onboard storage quickly, requiring as many as eleven fills on Day 1. The number of fills would be reduced by having greater onboard storage, thus reducing the time needed to transit and offload recovered fluids. The ERSP Calculator can be used to determine the sensitivity of those operating characteristics, helping in the planning and design of future recovery systems. It can also be used to assess the extent to which achievable enhancements in an existing system might affect an estimated daily recovery potential.

III.F. Summary Observations

The examination of four recovery systems in the previous section helps illustrate the importance of each operational parameter for a given recovery system. Certain operational parameters stand out as having significant impact on the amount of oil that can be accessed and recovered by any system within a given time frame. The degree of impact depends on the actual system components and their configuration. Some basic guidelines do result from the analyses involving the ERSP Calculator. They include:

III.F.1 Maximum Effective and Achievable Swaths

The greatest recovery potential for any system is strongly dependent on its ability to access as much oil as its skimmer(s) can handle. That is, the system should operate at or near its MES, a swath that must be achievable with the system’s own oil deflection/collection booms and/or by operating downstream of an open-apex U-boom deflection system.

III.F.2 Nameplate Recovery Rate

Since the MES is directly proportional to the Nameplate recovery rate for a given skimmer, the greater the recovery rate the better. Within the obvious constraints of vessel/barge size, maneuverability, transit and skimming speed, etc., there are also constraints that involve costs, staffing, maintenance, staging, and possible multi-purpose uses for an OSRV. However, for a major offshore spill event, the greater the Nameplate recovery potential, the greater the MES it can handle.

III.F.3 Onboard Storage

The greater the onboard storage for any skimming system, the longer it can go without having to stop and offload recovered fluids to backup storage. The size of tanks that handle the volume of oil, emulsion, and/or water recovered will be constrained by the size of the OSRV. The ERSP Calculator facilitates an analysis of existing storage capability based on predicted times to fill a given storage system (tank, bladder, other towable storage, etc.) and the available operating period.

III.F.4 Skimming Speed

A skimmer's MES is inversely proportional to its effective skimming speed. An increase from 1 to 2 knots might enable a recovery system to operate with half of the swath it needed at 1 knot to keep its encounter rate the same. The reduced MES at a higher speed, however, may have a negative effect upon RE and TE. This effect is measurable and would need to be tested and evaluated for the degree of impact on recovery potential associated with changes in speed, RE, and TE.

III.F.5 Recovery Efficiency (RE) and Throughput Efficiency (TE)

As noted above, TE and RE are almost always reduced to some extent with increased skimming speed, especially above ¾ knot. A higher TE (i.e., more oil being recovered from the oil encountered) means that the MES is reduced for a given average oil thickness while still matching the capabilities of the skimming system. A higher RE (i.e., less free water picked up by the system) means that the skimmer can recover more oil within a given period of time. Any increase in RE means that the MES can increase as well. Therefore, an increase in swath results in the coverage of area more quickly.

III.F.6 Area Coverage

The area covered by a skimming system per unit of time is provided as output with the ERSP Calculator. It is given as acres per minute, typically on the order of an acre/minute or less for nearly all skimming systems. Referred to as Areal Coverage Rate, it is dependent on the swath and speed of a recovery system. Its importance is sometimes misrepresented and misunderstood because it is not just the area per minute or hour that should be considered, but the area potentially covered by a skimming system over an entire Operating Period. The Areal Coverage Rates and areas covered per operating period in the ERSP Calculator are based on specific swath and speed inputs. The actual areal coverage could vary considerably depending upon the skills of the vessel operators, the nature and distribution of the oil being skimmed, and the needs to slow down or stop for minor repairs or adjustments to the equipment.

The areas covered by the skimming systems analyzed in this report provide insight to both the <u>quantity of oil</u> that could be recovered per day as well as the <u>total area</u> covered per day. Figure III.F-1 is a plot of the areas covered by each of three recovery systems ("A", "C", and "D"). They are selected because they are large recovery systems, representative of skimming OSRVs that might be involved in a large, wide-spread offshore oil spills. The areas covered for each system on Days 1, 2, and 3 following an oil spill are used to create the spread of coverage areas accomplished in twelve hours.

The spread of areal coverage values are shown as vertical arrows on Days 1, 2, and 3. The colors of those arrows represent the system's standard configuration in green, its use with a MES in orange, and its use with MES and a full 100% decant of free water in blue.

An approximation of the upper bound of the areas swept by a single skimming system in those 3 configurations is represented by the solid line labeled "1". It shows that the greatest areas swept by any one of these three systems is around ¾ mi^2 on Day 1, slightly over 1 mi^2 on Day 2, and about 2 mi^2 on Day 3. The increasing areas swept with time (i.e., Days 1 through 3) result from the thinning of oil with time, and the corresponding increases in MES for each system.

Figure III.F-1 also shows how the areas being skimmed on Days 1, 2, and 3 could be increased using 2, 5, and 10 skimming systems. For example, using the maximum areas swept by any of the three recovery systems selected, ten such systems on Day 1 might operate over 7 sq. miles. By Day 2, those same ten recovery systems could address another 13 mi^2, and by Day 3, they could conceivably skim nearly 20 sq. miles.

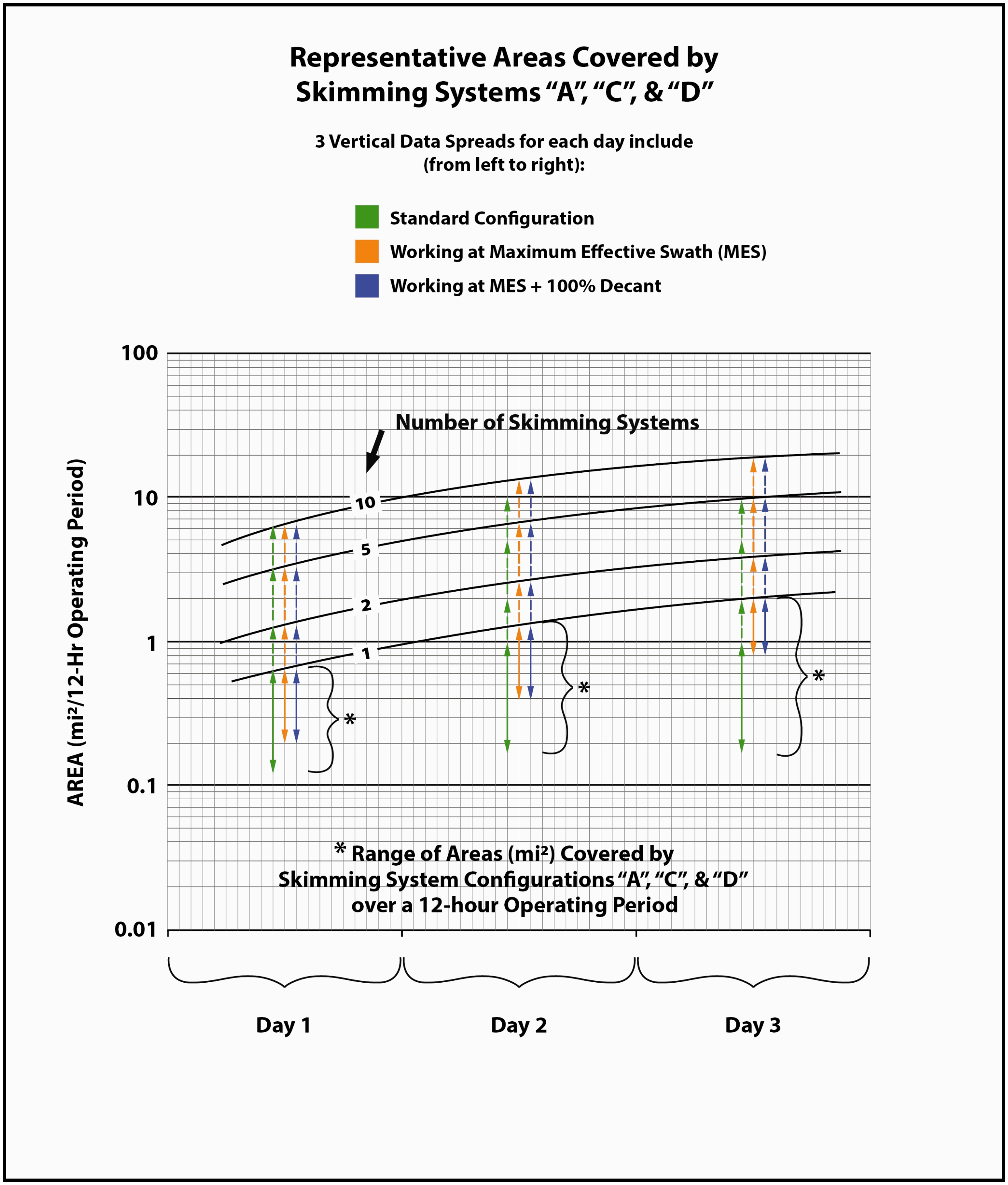


Figure III.F-1: Areas covered by Skimming Systems "A", "C" and "D" over a 3-day period involving standard and enhanced configurations and an operating period of 12 hours.

Caution should be used when comparing these potential areal coverage estimates to achievable areal coverage during actual field operations for the following reasons:

1. The highest areal coverage estimates by day are based on the MES for nominal average oil thicknesses that diminish each day as spreading continues; but the oil thickness averages remain constant through each day's operating period within the model. The constant thickness for the 12-hour operating period used in this study does not allow for possible reductions in the volume and distribution of oil on the surface from recovery operations during the preceding hours and days.

2. The TE of a recovery system does account for the percentage of oil encountered that is actually taken onboard; however, a given swath and speed (the parameters used to calculate areal coverage rate) could lead to an overly optimistic assumption that the area swept per hour can be related to the area of the spill left to access. Sweeping through an oil slick is not like mowing a lawn – the "grass" in this analogy behind the "mower" could be growing nearly as quickly as that which is removed – a cleared swath of oil does not remain cleared very long. The overall size of the slick (or the "lawn" in this analogy) may be growing as well.

3. The use of areal coverage rate calculations and the resulting estimates of area accessed per operating period do not account for a skimming system's requirement for stops or modifications of speed and direction to adjust for changing slick conditions and necessary equipment repairs or replacement.

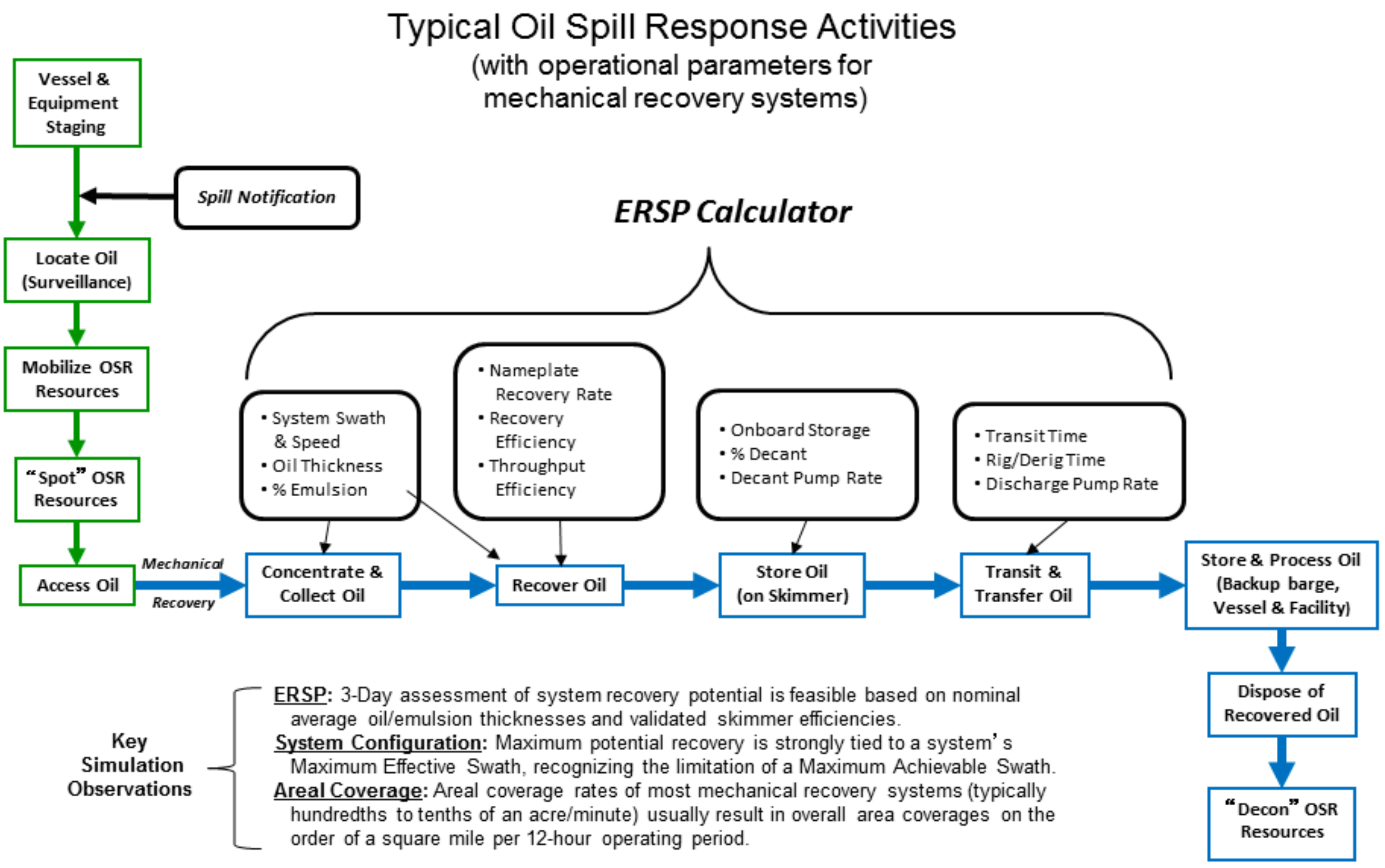
The approximation of areal coverage potential is important as it illustrates the limitations of any response option constrained by typical swaths of a few hundred feet and speeds of only a few knots or less. The areas accessible with booms (to support skimming, burning, or dispersant use with boats) can provide impressive results if available and given aerial "spotter" support during a major spill event. However, spills of typically 5,000 to 10,000 barrels or more can spread quickly to areas of 10 to 20 sq. miles or more in just a day or two. Larger spills, such as the *Exxon Valdez* that released approximately 200,000 barrels within the first twelve hours (USCG, 1993) and spread to nearly 10 sq. miles during that period, can approach areas of coverage on the order of 100 sq. miles in less than two days.

The Estimated Recovery System Potential and areas of possible coverage for a given skimming system can be estimated with the ERSP Calculator. These estimates provide useful performance-based measures of a recovery system's potential that can help in developing a meaningful planning standard. These and other factors are described in Figure III.F-2 where primary response operations and their associated input parameters are identified for a mechanical recovery system. This figure indicates those portions of a total response that can be simulated for a 12-hour operating period along with some of the most important conclusions regarding estimated recovery potential.

A reliance on only one factor such as Nameplate recovery rate used in calculating an EDRC is insufficient to determine the actual recovery potential of a skimming system. By combining the influence of each key operational parameter (shown in Figure III.F-2) into a single performance-based measure, a representation of a system's ability to access, recover, store, and offload recovered fluids over a selected period of time can be evaluated. The selection of a nominal average oil thickness for the three days following a spill (as used in the ERSP Calculator) provides a quantitative tool that can help regulators establish a reliable performance-based "Planning Standard" for a skimming system's recovery potential.

III.G. Other Factors Affecting Response

The input parameters used in the ERSP Calculator define the physical characteristics, efficiency, and use of a recovery system so that its recovery potential within a given period of time can be estimated. There are other factors, however, that influence the success of any oil spill recovery operation. Many of these have been mentioned in other parts of this report; but, because of their importance, they are addressed in greater depth below. Most of these topics were found to be of great interest to the interview participants from OSROs, manufacturers, oil companies, and regulatory groups who participated in this study. The following comments reflect many of the issues discussed during those meetings as well as the results of literature searches and personal experiences of the project team.



ERSP: 3-Day assessment of system recovery potential is feasible based on nominal average oil/emulsion thicknesses and validated skimmer efficiencies.

System Configuration: Maximum potential recovery is strongly tied to a system's Maximum Effective Swath, recognizing the limitation of a Maximum Achievable Swath.

Areal Coverage: Areal coverage rates of most mechanical recovery systems (typically hundredths to tenths of an acre/minute) usually result in overall area coverages on the order of a square mile per 12-hour operating period.

Figure III.F-2: Key observations from the ERSP simulation of typical oil spill response activities.

III.G.1 Surveillance & Spotting

The ability to provide an experienced “eye-in-the-sky” is one of the most important requirements for locating spilled oil at sea and for directing personnel and response systems to the heaviest concentrations of oil. Qualified aerial observers are necessary for the ongoing positioning of response resources in heavy oil; it is extremely difficult to see or detect the best oil concentrations using remote sensors. There have been responses where the aerial surveillance component by helicopters, fixed-wing aircraft, and satellites has been effective (Allen, et al, 2011; Mabile, 2012). However, in some cases there was little provision for qualified aerial observers to guide response systems and keep them working effectively. As stated by the USCG WLB Commanding Officers (2010),

> *“Satellite imagery data (particularly infrared) was good for narrowing down search areas, but not sufficient to task surface skimming assets. Trained eyes, often the result of actual skimming experience, were necessary to determine whether sightings were oil, and if they were recoverable.”*

There are several ways to improve the positioning of surface resources with the use of remote sensing platforms currently under development (e.g., vessel-mounted Radar/IR slick detection systems, UAVs and Aerostats) (Aptomar, 2012). Experience has shown that some of the most efficient surface operations have resulted from the nearly continuous aerial guidance (or “spotting”) of response vessels thereby maximizing the oil encounter rate and minimizing down time to search for heavy oil. Combinations of vessel-mounted or controlled remote sensing systems might be used with aerial systems to free up aerial spotters to assist other vessels. Spotting teams can provide the initial guidance of recovery systems to heavy oil, but then switch to locally controlled sensing packages to keep the recovery systems in the heaviest oil.

The provision of both surveillance and spotting capabilities by qualified aerial observers early during a response and then maintained throughout the incident is critical. The Estimated Recovery System Potentials for the systems described in the previous section would be difficult to achieve on a large, wide-spread oil spill without aerial guidance.

An exception to constant aerial support could occur where it is safe to operate fairly close downstream of a continuous, point-source spill. If the source is burning, its fire could eliminate dangerous vapors downwind, spread only to oil nearby that is thick enough to support combustion, and provide an easily seen source even with reduced visibility/darkness. Under these conditions, OSRVs could likely maintain position and work in heavy concentrations with minimal reliance on air support. Surveillance would still be advisable to provide confirmation of prime recovery locations, the monitoring of system performance, and the possible need for spotting should winds and/or currents modify the spread and distribution of surface slicks.

III.G.2 Staging & Response Time

The positioning of response personnel, vessels, and equipment is strongly tied to the success of any oil spill response. The ability of a recovery system to be on-scene quickly and to maximize the hours available for response is especially important on Day 1 of a spill as the oil will normally be at its thickest and most concentrated. The early arrival of response resources must be coordinated with the provision of surveillance and spotting aircraft so that time is not lost looking for suitable oil to recover. The ERSP Calculator has been developed so that the "Operating Period" for each of the first three days of a spill can be set at the suggested 12-hour duration; or, it can be set for specific conditions that best represent a spill scenario and region for which a Planning Standard has been established. In certain parts of the U.S., offshore petroleum operations have evolved so that some OSROs and individual operators rely on nearly immediate response. Depending upon the distances offshore, the number of drilling or production platforms involved, and the regions over which these activities are spread, there may be a significant portion of response resources on standby within a short distance of any potential spill location. Some of the resources may be located (anchored or mobile) at a central location for rapid response, while other resources may be staged on shore.

The assessment of appropriate staging locations, numbers of response resources and the setting of time constraints for personnel and equipment to arrive at the spill location are important; however, these factors are not addressed by the ERSP Calculator. Planning Standards almost always include specific requirements for different types of spillage (i.e., drilling, pipelines, tankers, etc.) and for different operating environments or conditions, such as offshore versus nearshore; temperate versus cold-climate; deep-water versus shallow-water sites, etc. If a plan holder or OSRO cannot meet the requirements with respect to staging and specified response times, one alternative with the ERSP Calculator might involve an appropriate adjustment of the Operating Period. A modification of this kind creates “a level playing field” for all response organizations while giving room for creativity in meeting a common goal to be able to access, recover, store and offload an expected volume of oil each day.

III.G.3 Vessels-Of-Opportunity

Vessels-of-Opportunity (VOOs) and their Captains and crews have been and will continue to be a topic of concern as there are many reasons why they have worked well for some incidents and not for others. Issues that contribute to these mixed results include:

- The qualifications of personnel and the reliability of vessels/equipment;
- The appropriate levels of training needed for different response roles and the time/costs to provide such training;
- The functions that VOOs and their crews should be allowed to carry out because of the experience needed to handle response equipment, the risks of working with petroleum products, and the limitations of some VOOs to work for extended periods far offshore;
- The reliability of such resources in being willing or able to “stay the course” when the climate (environmental or political) becomes uncomfortable; and,
- Liability issues involving injury or loss of life, damage to or loss of equipment and law suits against the Responsible Party, OSRO or government, possibly provoked by observations or experiences on location.

The use of VOOs and their Captains/crews for spill response has been used successfully in several parts of the U.S. and abroad (*Exxon Valdez* spill in Valdez, Alaska, 1989; during the DWH spill in the Gulf of Mexico, 2010; the *Kirki* Incident in 1999 of the coast of Brittany; and the tanker Prestige in 2002 off Galicia, Spain). An in-depth study by The Glosten Associates for the Washington State Department of Ecology (Glosten Associates, 2005) addresses several of these spills and provides an excellent summary of the pros and cons of using VOOs for oil spill response. There are currently no federal or state requirements to use VOOs, however, if a plan holder or OSRO lists VOOs in its plans or counts on them to qualify for an Open Ocean OSRO

Classification, then those resources must be identified and involved in routine training exercises. While the use of VOOs is not a factor in the calculation of an ERSP, their use might play a significant role in providing a key support function that can help OSRVs of nearly any configuration to achieve their MES. Some industry and regulatory groups favor the use of VOOs, but prefer that they not be involved with the handling of skimmers and recovered products. They do, however, see the VOO Captains/crews as highly knowledgeable about local environmental conditions and experienced in handling over-the-side equipment, towing nets, etc. For this reason, VOOs might play an important role as boom-tending boats in creating open-apex, U-boom deflection systems to enhance the ERSP values for various skimming systems.

III.G.4 Human Factors

The safe and effective recovery of oil, as with all other response options, is not only dependent on the nature and amount of physical resources available (i.e., boom, skimmers, vessels, etc.), but also the qualifications and number of personnel available, and the ability to support personnel in the field. Human factors include:

- **Appropriate number of personnel for the task(s) to be conducted:** The number of responders required to operate and support a recovery system is dependent upon the size and complexity of the skimmer, the power requirements, deployment configuration, and recovered fluid storage requirements. The proposed ERSP calculations do reflect certain components of these issues (e.g., system swath, speed, storage capacity, discharge pump rate, etc.); however, the calculator does not account for the number responders needed to operate a given system. It is assumed that the number of operators for a recovery system is sufficient to conduct safe and effective operations, even over sustained periods. Provision must be made for backup personnel to support possible day/night shifts, and to provide adequate off-time for personnel during sustained operations (IPIECA, 2007).

- **Qualifications of personnel:** Beyond the requisite HAZWOPER and Safety training, there could be additional position-specific training and certification requirements that would enhance the recovery potential. This training might include aerial observation and spotting techniques, boat-handling, boom deployment and recovery, skimming system deployment and operation, etc.

- **Provision of adequate food, berthing, and support needs:** Most medium-to-large recovery systems are mounted on or supported by vessels or barges that can accommodate the needs of response personnel for eating, sleeping, and other day-to-day functions. It is important, however, that regulators and industry planners and operators consider these needs for all personnel involved with a skimming operation. These support services are necessary for the full range of skimmer sizes, types and configurations, and must be available for sustained operations.

- **Allowance for rest, sleep, and emergency/medical needs:** Oil spill responders are often expected to work for extended periods under difficult conditions. It is important that personnel be given adequate time to rest, hydrate, and be relieved as necessary from the demands of emergency response, extreme weather conditions, and rotational shifts (IPIECA, 2007). In addition, personnel must have access on location (or rapid transport available) to medical facilities and qualified medical support personnel.

- **Provision of personnel to monitor, document, and ensure safe operating conditions:** All operations, especially those conducted on or over water, often involve difficult operating conditions, heavy equipment, limited visibility, slippery surfaces and exposure to toxic and / or flammable materials. Response personnel must be trained and qualified to work under such conditions, and there must be dedicated safety personnel to monitor and oversee unusually risky activities and potential exposures to hazardous materials. It is often difficult during “the heat of battle” to secure and implement dedicated safety personnel for specific tasks. The protection of response personnel, however, must be given the highest level of attention and operations should commence only when all safety and operational supervisors are satisfied that responders are adequately protected.

These human factors are critical for the protection of everyone involved with the operation and support of mechanical recovery operations. These factors, as with each of the other topics addressed in this section, do not represent quantifiable parameters that enter into the calculation of a system's recovery potential. They do, however, require careful consideration by planners, operators, regulators, and all support personnel in order to maximize performance, minimize environmental impact, and keep all personnel safe.

III.G.5 Night Operations

As mentioned in the surveillance/spotting section, technology is rapidly improving the ability to locate and identify oil, and in some cases, give fairly reliable indications of relative oil thickness. Radar and infrared sensors can be used on vessels under certain wind/wave conditions for distances out to a mile or more (Aptomar, 2012). Other multi-spectral sensors can expand these capabilities for possible use in aircraft as well. Regardless of the technology for finding and identifying thick oil at sea at night, there are strong feelings among industry and regulatory groups that night operations should not be encouraged. While the choice to work at night should likely remain the Responsible Party's or OSRO's choice for a given part of the response and for specific properly trained personnel, certain activities may well be accomplished safely and efficiently after dark. These activities might include the cleaning and maintenance of equipment on deck, the refueling of equipment and small boats, the transferring of recovered oil/emulsion to backup storage, etc.

Undoubtedly, far more important than all of these activities, is the need for responders to get some personal time, food, and sleep. History has shown that the likelihood of an accident or personal injury is clearly tied to sleep deprivation, and the working of personnel under difficult conditions and/or rotational shifts (IPIECA, 2007). In addition to the difficulties of working at night is a series of other issues that must be overcome to proceed safely: limited lighting on deck; problems associated with finding and staying in oil; requirements for a second shift of responders and their food and berthing needs; and the reduced ability to respond to man-overboard situations. It quickly becomes evident that oil spill recovery at night should only be considered if all of the above concerns have been adequately addressed. Maximizing skim time during the day and offloading recovered product at night with a small dedicated crew for that purpose may be a safe and effective way to improve an OSRV's ESRP.

III.G.6 Offshore vs. Nearshore Operations

The ERSP Calculator works for OSRVs that are large and small; shallow- or deep-drafted; self-propelled, pushed, or towed; and capable of working for long periods offshore. The calculator works for OSRVs that might depend on daily support for personnel, fuel, supplies, and a safe haven should night fall or conditions at sea worsen. ***Section III.D.4 ESRP Output*** and ***Section III.E. Selected System Comparisons and Analysis*** addresses the input parameters that define and allow assessment of nearly any kind of skimming system. The input parameters used for large offshore OSRVs are the same parameters used to calculate an ERSP value for a smaller, nearshore skimming system.

III.G.7 Cold-Climate Operations

One of the objectives in this study was to consider how any replacement or enhancement of the EDRC calculation could be done with appropriate consideration of cold-climate conditions. Study directives included a request to not address the presence of ice, but to include possible effects that very cold water could have on the development of an improved EDRC-type assessment of recovery system potential. Key factors considered involved:

- Fate and behavior of oil and how cold conditions might affect oil thickness with time. This was necessary, as nominal average oil thicknesses would likely be considered in a study that could include oil encounter rate in its formulations.

- Oil viscosity and how cold air and water temperatures might create highly viscous oil/emulsion that would be difficult to skim and pump.

- Cold air temperature effects upon personnel and equipment performance.

The first factor involves the effects of cold in reducing spreading rates and the likely increase in the equilibrium thickness of various oils. This effect was addressed by including water temperatures as low as 0°C in the hundreds of computer simulations described in ***Section III.C Analysis of Oil Thickness***. The recommendation involving the 3-day nominal average oil thicknesses of 0.1 inch, 0.05 inch, and 0.025 inch included the results of data generated at that temperature. The thicknesses were based on the heavy skewing of the data toward values at or below a tenth of an inch (~2 ½ mm) average oil thickness after twelve hours of spreading with a very large range of oil spill volumes. Estimates of the average oil thickness on near freezing waters of Prince William Sound eight to twelve hours after a release of nearly 200,000 barrels of medium weight crude oil from the *Exxon Valdez* tanker were on the order of a tenth of an inch (Allen, 1990). Other publications, including the NOAA's **Job Aid for Aerial Observation** (NOAA, 2007), indicate that crude oil spilled on cold water will often spread to thicknesses between a few hundredths of an inch to a tenth of an inch. Should the ERSP Calculator be used in Arctic regions, tests could confirm the appropriate rate of spreading and average oil thicknesses over a 3-day period for use with the calculator.

The issue of cold climate influences on viscosity and skimmer performance might best be evaluated through winter tests at the Ohmsett facility in Leonardo, New Jersey or at comparable test facilities that can provide reliable evaluations using ASTM Standards. As with any skimming system where Nameplate recovery rates and skimming efficiencies (TE and RE) need to be confirmed for use with the ERSP Calculator, similar "cold-climate" testing should be required for skimmers and pumps used to comply with a National Recovery System Planning Standard.

The final factor involving the effects of cold climates on personnel and equipment is extremely important as it impacts the time that people can work efficiently and equipment can be operated safely and effectively. Cold temperatures also impact the safe and effective transport of responders, vessels, and equipment; and the ability to sustain operations where environmental conditions (i.e., wind chill, icing of surfaces, snow and increased darkness) present unique challenges. As difficult as these challenges may be, they do not preclude the use of the ERSP Calculator. The effects of cold air and water temperatures on oil properties and behavior, the performance of responders, and the operation of vessels and equipment would affect the choice of input "values" for the ERSP Calculator. These cold-climate influences, however, do not affect the basic format and use of those parameters within the ERSP Calculator.

III.G.8 Interaction of Mechanical Recovery, Controlled Burning, and Dispersants

When oil spills flow directly onto the surface of the sea with light to moderate wind/wave conditions, it is possible that one or more recovery systems could maintain position at a safe location downstream, intercepting a portion of the released oil. Some spills, however, may be released below the surface and into rough wind and sea conditions so that the oil is rapidly scattered into numerous patches and windrows over a very large area. The wind and waves may, in fact, prevent mechanical recovery operations from taking place due to the condition and distribution of the oil, and the limitations of boom use in short-period, wind-generated waves with breaking crests.

The actual removal of spilled oil at sea, even in relatively calm or protected nearshore waters, may result in oil recovery volumes that are considerably lower than the estimated recovery potentials derived with the ERSP Calculator. Mechanical recovery estimates following the *Exxon Valdez* Spill in 1989 (USCG, 1993)[8] and the DWH spill in 2010 (The Federal Interagency Solutions Group, 2010) confirm just how difficult it can be to recover large volumes of an oil spill at sea.

It is important to consider how a recovery system planning standard like the ERSP Calculator might help in addressing the benefits of controlled burning and the application of chemical dispersants. To begin, it is important to recognize that no single response option is adequate to handle the wide range of conditions that can accompany a large oil spill on open water. Large widespread spills may occur in areas where skimming assets are not effective. As discussed in ***Section III.F.6 Area Coverage***, most skimming systems have a limited coverage capability (on the order of a square mile per operating period, or less). Major spills, however, can grow to hundreds of square miles in just a few days.

Even when a large number of skimmers are available, it is a significant task to direct skimmers into the heaviest oil slicks. If they are successful in accessing and recovering oil or emulsions, there is then the time-consuming task of offloading recovered fluids to backup storage. Some of the shortcomings in covering large areas and handling large volumes of oil can be overcome by employing controlled (in-situ) burning of oil in fire-resistant boom. The successful history of burning oil offshore, inshore, and in wetland areas over the past 25 years has resulted in in-situ burning (ISB) being considered a safe and effective means for eliminating large quantities of oil quickly, under a broad range of conditions. The successful elimination of

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[8] From Volume I of this report.

oil in Prince William Sound during the *Exxon Valdez* incident (USCG – Volume II, 1993) and the removal of approximately 300,000 barrels of oil in over four hundred burn operations during the DWH response in the Gulf of Mexico (Mabile, 2012), provide ample evidence of the potential of ISB under the right conditions. The burning of oil at sea requires the same wind/sea conditions that are needed for mechanical recovery; fire-resistant boom and its ability to contain oil and keep it in place during the combustion process is limited operationally to relatively calm seas and wind-induced, short-period waves without breaking whitecaps (typically waves of three to five feet and winds of 15 to 20 knots).

Those familiar with the controlled burning of oil and the participants interviewed during this study feel that meaningful guidelines can be created for ISB from which planning standards could be developed for a broad range of spill scenarios for offshore and nearshore environments. As accomplished during DWH response, fire boom, boom-tending vessels, and ignition systems can remain on location for extended periods along with dedicated OSRVs and platform supply vessels (PSVs) in the same way that skimmers and conventional boom are kept in a state of readiness.

In line with the terminology suggested for mechanical recovery, an Estimated Burn System Potential (EBSP) could be calculated using the same oil encounter rate considerations of the ERSP. A controlled burn "system" could be defined involving a standard length of fire boom, towboats, ignition systems, and residue recovery equipment. These system components could be defined using known performance benchmarks for a variety of oil types and conditions, wind and sea states, and well-established oil burn rates, to estimate the potential of a given system to eliminate a certain quantity of oil per day. The calculations for an EBSP could involve the testing of equipment using ASTM Standards to develop protocols for safe operations and the monitoring of air emissions and other products of combustion.

The application of chemical dispersants is also recognized as one of the best spill response options for a wide range of oil types under a broad range of environmental conditions. Dispersants can be applied at very high areal coverage rates using large, fixed-wing aircraft. They can also be applied from small, fixed-wing aircraft, helicopters, and vessels when greater accuracy is needed for targeting patches and streamers of oil. One of the greatest benefits of dispersant use involves the application from the air when wind and sea conditions preclude the effective use of boom (conventional or fire-resistant) for the physical recovery and/or burning of oil.

When used properly (with sufficient mixing energy and applied over water depths that allow for good distribution, dilution, and decomposition of the treated oil), chemical dispersants offer a unique response option for covering large areas quickly. Aircraft can be staged and loaded with fuel and dispersants to arrive quickly on location. Although application aircraft can often find and evaluate appropriate thick layers of oil for treatment, their most effective use requires spotter support in the same way that skimming systems and burn teams need direction.

Figure III.G-1 illustrates the primary activities of controlled burning and the application of chemical dispersants. All three options (mechanical recovery, controlled burning, and dispersant applications) were used simultaneously during the DWH incident (USCG, 2011a; 2011b) demonstrating that multiple response options can be carried out safely and successfully.

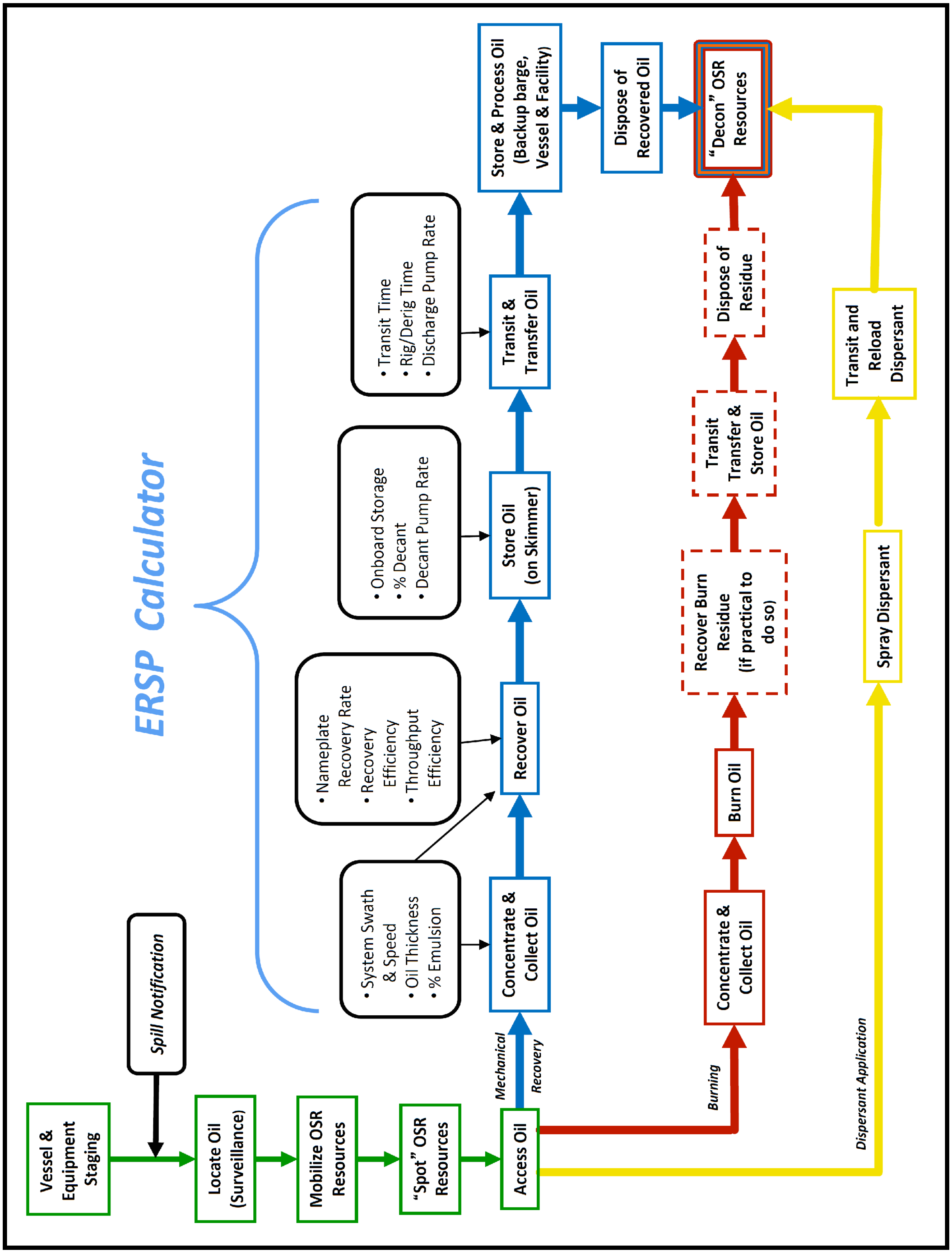

Figure III.G-1: Typical oil spill response activities Including Controlled Burning and Dispersants.

The Project Team has developed computer models to support oil spill response and planning, including the previously described Response Options Calculator (ROC) and the NOAA Spill Tools™. The Mechanical Equipment Calculator (MEC), the In-Situ Burn Calculator (ISBC) and the Dispersant Mission Planner 2 (DMP2) comprise the NOAA Spill Tools suite. The DMP2 is currently used by the USCG for dispersant application decision-making as described in 33 CFR 155 Appendix B.

IV. Conclusions

A primary goal of this project was to find a practical, reliable, performance-based method or "tool," to estimate the recovery potential of skimming systems under a broad range of operational and environmental conditions. This goal focused on the enhancement or replacement of the current Effective Daily Recovery Capacity (EDRC) method that emphasizes the Nameplate recovery or pumping capacity of a skimmer. The EDRC formulation does not consider the spreading and thinning of oil slicks over time, and it does not account for other factors that influence a fully integrated recovery "system". A relatively simple set of algorithms involving key oil spill recovery operations was developed so that a skimming system could be described and its recovery potential estimated over the first few days of a response on open water. The input parameters for a new computer model, the Estimated Recovery System Potential (ERSP) Calculator, were selected so that the model's output could help create a new, operationally-meaningful Planning Standard.

Figure III.G-1 in the previous section illustrates the primary activities of a typical oil spill response including the mechanical recovery of oil, the controlled burning of oil, and the application of chemical dispersants. This study is aimed at the physical removal of oil only. However, it is recognized that controlled burning and the application of dispersants are viable response options that should be given serious consideration when conditions are right for their use.

The burning of oil has been proven safe and effective for eliminating large volumes of oil quickly and with minimal impact on the environment. As with most skimming systems, however, the collection and controlled burning of oil at sea is limited to wind and sea conditions where booms are considered effective – typically below three to five foot wind-generated waves where white caps are beginning to form. Dispersants, therefore, may become the favored response option when wind and sea conditions preclude the effective use of skimming and burning.

With the focus of this report on mechanical cleanup, the ERSP Calculator was designed to account for those parameters that facilitate a quantitative assessment of a given recovery system's effectiveness in accessing and recovering oil spilled on water. The calculator also accounts for the characteristics of the vessel or barge used to support the skimmer as well as all components of the system that involve its ability to store, handle, and offload its recovered fluids.

The ERSP Calculator includes the results of a comprehensive assessment of average oil thicknesses for a variety of oil types under a broad range of wind, wave, and temperature conditions. The results allow for the selection of nominal average oil thicknesses on each of Days 1, 2, and 3 following the release of hundreds to thousands of barrels of oil. It is recognized that many factors influence the actual thickness of an oil spill and that these variations in thickness can vary by several orders of magnitude within a very small area. However, in order to provide a meaningful, standardized method for calculating skimming system recovery potential from oil encounter rate, the ERSP calculator uses nominal average oil thicknesses that reflect the results of many hundreds of computer simulations. The use of “nominal” or “reasonably representative” oil slick thickness values for each of three days following a release of oil was determined to be a meaningful approximation for the encounter rate component for a new and improved planning standard. This approach also allowed the use of a Day-1 average oil thickness to address encounter rates for a continuous release of oil.

The Day-1 ERSP value could represent the daily recovery system potential relatively close to a continuous spill source. The Day-2 and Day-3 ERSPs would still have value for a recovery system as it accesses and recovers oil that had escaped Day-1 operations and continued to spread downstream or away from the source.

ERSP values of thousands to even tens of thousands of barrels per day were calculated for a number of skimming system configurations in this report. The ERSP values depend on the selected system’s ability to optimize its potential by working at or near its Maximum Effective Swath and by enhancing its Throughput and Recovery Efficiencies. Improved ERSPs are also realized by maximizing a system’s time spent skimming (not transiting or offloading) during each Operating Period with enhanced decanting and processing of recovered fluids, and using improved transfer rates (e.g. higher Discharge Pump Rates) of those fluids to secondary storage. The ERSP Calculator helps identify and quantify what system modifications will maximize daily recovery potential as slicks spread and thin during the first three days of a spill. Some of the skimming system configurations used as examples in this report were shown to have ERSP values that match or even exceed their EDRC values over a three-day period.

In addition to the recovery potential volume of a given system, the ERSP Calculator provides an estimate of the rate at which a skimming system covers area. With typical areal coverage rates of an acre/minute or less for most skimming systems, it is important to consider the total area that can be covered by a system over a full operating period. The thinning of oil over time increases the Maximum Effective Swath for a given system and therefore the areal coverage rate as well. These increases, however, are accompanied by reductions in volume of oil accessed and recovered.

Total areal coverage potentials for recovery systems moving at speeds of a knot or less with swaths of a few hundred feet may approach areas on the order of a square mile in a 12-hour operating period. Such potential coverage, however, should be evaluated in light of the rapid spreading rate of most large spills. Spills of 5,000 to 10,000 barrels, for example, can spread to areas of ten to twenty mi^2 or more in just a day or two. The ERSP for a given system is a good measure of its daily volume recovery potential; however, its ability to function effectively with enhanced swaths and good aerial spotting should also be considered when establishing a fully integrated planning standard.

System recovery and areal coverage potentials are strongly tied to response activities that are not quantified within the ERSP calculations. The pre-staging of vessels, aircraft, and response equipment sufficiently close to a facility or areas of possible need should be established to minimize the time to mobilize and get on location. Depending on the nature and location of the possible spill source(s), the potential outcome of a Day-1 response depends on the ability to access oil as soon as it is safe to do so and to maximize the amount of daylight available for skimming operations. In addition to getting response resources on location as quickly as possible, those resources are of little value unless they can be safely directed to the heaviest concentrations of oil. Considerations of human health and safety, toxic and/or explosive vapors, and proximity to source control activities need to be addressed prior to any response operation.

Good aerial observations and direction of surface operations are essential to an effective recovery operation. Surveillance, involving broad regional coverage with trained aerial observers and/or remote sensors aboard satellites or aircraft, must be planned and ready for mobilization on short notice. The role and value of early oil identification and characterization of oil depends on the nature, magnitude, and location of a spill. Aerial observations and the guidance of resources need to be carried out daily as oil continues to spread over increasingly larger areas. Recovery systems need frequent directions to keep them in oil concentrations to maximize ongoing access to, and recovery of, the greatest volume of oil possible. These same "spotting" capabilities with low-flying, fixed-wing aircraft or helicopters are needed to reposition skimming systems in the best available oil upon completion of an oil offloading operation.

The response activities and input parameters of the ERSP Calculator, as shown in Figure III.G-1, should be considered with a full appreciation of recovery characteristics that are both desired and achievable. A recovery system's potential can be enhanced using its Maximum Effective Swath (where its Nameplate Recovery Rate matches its Total Fluid Recovery Rate), and by improving its Throughput Efficiency, Recovery Efficiency, and decant capabilities. Along with these enhancements, realistic operational constraints need to be considered as they influence what is actually achievable. The calculator provides alerts for some constraints:

- If a calculation swath exceeds 1,000 feet, a difficult field accomplishment.
- If the calculated decant rate needed for a "% decant" input is greater than the system's Decant Pump Rate.
- If the Time to Offload Full Tank(s) (system's onboard storage) is greater than the time available to do so between Operating Periods.

The ERSP Calculator provides a means to calculate the maximum recovery potential of a given skimming system as part of a "Planning Standard" based on nominal average oil thicknesses and reasonably good operating conditions. The calculator includes realistic operational parameters and performance-based algorithms; however, it does not calculate, nor does it imply, any given level of expected performance. There are far too many variables associated with an actual spill, the environment, and the range of responses that could be implemented to ever predict the success of any given recovery system. The ERSP Calculator does offer a standardized method by which different skimming system's recovery potential can be compared and evaluated for offshore or nearshore operations. The calculator can also be used to estimate recovery system potential for warm or cold climates, and for batch or continuous releases of oil. The estimated recovery potential can only be considered with a full awareness and appreciation of the support functions mentioned earlier: properly staged resources in a state of readiness; surveillance and spotting capability available on short notice with trained and qualified aerial observers; and skimming systems capable of implementing enhanced swath, decant, and offload operations.

In conclusion, the ERSP Calculator helps in meeting the following objectives. It could:

- Replace the use of the EDRC calculation involving a skimming system's daily capacity, and provide an operationally-based planning standard for mechanical recovery systems;
- Help with the design and implementation of better field and tank test measurements of skimmer performance and associated ASTM Standards;
- Provide a template or format for the equally important creation of an Estimated Burn System Potential (EBSP) and an Estimated Dispersant System Potential (EDSP); and
- Serve as a catalyst for meaningful dialogue involving "Expectation Management".

The objective associated with expectation management involves oil spill response resources and their perceived capabilities, and the linking of such information to the type, number, and location of response resources (vessels, equipment, and people) to achieve an acceptable level of success. The management of expectation takes on many different challenges depending upon the individual or group forming the expectation. EDRC sets an unrealistically high expectation even though it is a "planning" standard. ERSP is a more defendable measure of a systems capability but it is not intended to be a "performance" standard.

OSROs and their member companies expect a level playing field with respect to skimmer performance validations, dedicated onsite response versus response from unmanned warehouses, credit for burning and dispersant preparedness, etc. Offshore exploration and production companies expect reward or credits for spill prevention and control measures (e.g., well-capping systems, containment domes, subsea dispersant application systems, etc.). Manufacturers expect to have their products tested and evaluated fairly and in a timely way in order to be competitive and recover research and development expenses. Regulators expect relatively simple, widely accepted, and technically sound guidelines and tools by which they can provide and enforce meaningful and fair regulations. The general public, and therefore regulators, expects that industry provide the highest level of spill prevention and source control as possible.

The general public has minimal background and experience involving oil spill fate and behavior, the impacts of oil on marine ecosystems, and the equipment used to prevent and control oil spills. Most people do not fully understand the “tradeoffs” of one response option over another and what levels of success can be achieved with the tools and techniques under various environmental conditions. In the same way that public perception and regulations often tolerate reasonable risks involving commercial air travel, highway traffic conditions, fire department locations and response times, there needs to be an educated and hopefully more balanced perspective regarding oil spill impacts and our ability to clean up spilled oil. The results of this project could help stimulate discussion and generate awareness of the need to consider what constitutes a reasonable risk of spillage.

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Appendix A: Contacts

In conducting meetings and interviews regarding this project, prepared talking points were used, though the specific questions asked and topics discussed varied depending on the areas of expertise and interest of the individuals being contacted. A summary of the key talking points included:

- EDRC Project Goals and Objectives
- The Role and Importance of Planning Standards for Spill Prevention and Control
- The latest Technology and Equipment for Oil Spill Prevention and Source Control
- “Systems” Approach to Spill Control – including all operational parameters and options
- Surveillance/Spotting Technology and Importance During Response Operations
- Night Operations (pros and cons)
- Oil Encounter Rate – Importance in Developing a New Planning Standard
- New Technology (Mechanical) – Recent Improvements, Strategies & Tactics
- Importance of Standardized Tank Tests and Field Trials for Equipment Evaluation
- Staging of Resources (Personnel, Vessels and Equipment) and Response Time
- Use of Controlled Burning – New Technology, Strategies & Tactics
- Use of Dispersants (incl. sub-sea injection) – New Technology, Strategies & Tactics
- Training (Surveillance, Spotting, Mechanical Recovery, In-Situ Burning and Dispersants)
- Preferences and Experience regarding Planning Standards (State, Federal, other)
- Expectation Management – Public, Regulators, OSROs, Manufacturers, etc.
- Vessels-Of-Opportunity (VOOs)

The table below provides a complete list of the organizations contacted and work location and title of the individuals interviewed. While most of these interviews were conducted in-person, some were conducted over the phone. In all cases, in order to secure the most candid input, the interviewees were assured that no conversations would be recorded. The interviewer made brief notes during or after the discussion, but in each case assurances were given that there would not be any specific attribution of their comments in the final report. This report includes comments that were repeated or given particular emphasis during the interview process.

Organization, Work Location	Title
API, Washington, DC	MEP Industry Coordination
API, Washington, DC	Policy Advisor, Marine and Security
API, Washington, DC	Senior Policy Advisor
API, Washington, DC	Marine and Security
Applied Fabrics Technology	President, Chairman of ASTM F-20 Committee
Aramco Services, Houston, TX	Supervisor, Environmental Services
BP, Houston, TX	GCRO Technology
BP, Naperville, IL	Oil Spill Senior Advisor
Chevron, San Ramon, CA	Emergency Response Coordinator
Chevron, San Ramon, CA	Senior Staff Scientist
Clean Gulf Associates, New Orleans, LA	Executive Director
ConocoPhillips, Houston, TX	Emergency Response Coordinator
DNV, Katy, TX - NOFO Associate	Senior Consultant
DNV, Katy, TX - NOFO Associate	Senior Principal Consultant
DNV, Katy, TX - NOFO Associate	Senior Vice President
DNV, Norway	Business Manager, Environmental Risk
Elastec / American Marine, Carmi, Illinois	President
Elastec / American Marine, Carmi, Illinois	Vice President
ExxonMobil, Baytown TX	Strike Team Coordinator
ExxonMobil, NJ	Senior Scientific Associate
Frank Mohn, La Porte, TX	General Manager
Haaga Helia, Univ. of Appl. Sc., R&D Helsinki, Finland	Project Manager, EnSaCo - Central Baltic
IPIECA, London, UK	Manager, Oil Spill Preparedness Regional Initiative
IPIECA, London, UK	Technical Director
ITOPF, London, UK	Technical Advisor
Marine Exchange, Seattle, WA	Executive
MPA, Scottsdale, AZ	Executive
MSRC, Herndon, VA	Executive
MSRC, Herndon, VA	Executive

Organization, Work Location	Title
MSRC, Richmond, CA	Executive
MSRC, Naples, FL	Executive
NRC, London, UK	VP, International Operations
NRC, Long Island, NY	VP East & Gulf Coasts
NUKA, Alaska	General Manager
OceanPact, Brazil	Executive
Ohmsett, NJ, + ASTM	General Manager
Ohmsett, NJ, + ASTM	Test Director / Engineer
OSRL, England	Technical Director
PEW	Director, US Arctic Program
PEW / Harvey Consulting, LLC	Consultant with PEW
Regional Citizens Advisory Council, Kenai, AK	Executive Director
SeaCor Environmental, Seattle, WA	VP & General Manager
Shell, Anchorage, AK	Emergency Response Superintendent
Shell, Anchorage, AK	VP, Alaska Exploration and Appraisal
Shell, Houston, TX	Upstream Americas Response Manager
Shell, Houston, TX	SOPUS LSDR / HSE, Emergency Management
Shell, Houston, TX	Director, HSE and Emergency Management
Shell, Houston, TX	EP Global Emergency Response Manager
Shell, Houston, TX	Spill Response Specialist/Environmental Scientist
Shell, SEPCo Regulatory Affairs, Houston, TX	Team Leader-Permits and Issues
Spill Control Association of America, Florida	Executive Director
Tesoro, San Antonio, TX	Manager, Contingency Planning & Emergency Resp.
USCG R&D, New London, CT	Spill Response Program Area Manager
USCG, Seattle, WA	Engineer, District Response Advisory Team
USCG, Seattle, WA	Numerous USCG personnel attending Luncheon & Presentation
USCG, Washington, DC	USCG Advisor (CG retired)
USCG, Washington, DC	Civilian Technical Advisor
Wash. State Dept. of Ecology, Bellevue, WA	Lead Drill/Policy Analyst, WDOE Spills Prog.

Organization, Work Location	Title
Wash. State Dept. of Ecology, Lacey, WA	Program Manager, WDOE Spills Program
Wash. State Dept. of Ecology, Lacey, WA	Preparedness Section Manager, WDOE Spills Prog.
Wash. State Dept. of Ecology, Lacey, WA	Response Technology Specialist, WDOE Spills Prog.
Wash. State Maritime Cooperative (WSMC), Seattle, WA	Incident Commander
Wash. State Maritime Cooperative (WSMC), Seattle, WA	Incident Commander
Wash. State Maritime Cooperative (WSMC), Seattle, WA	Incident Commander
Wash. State Maritime Cooperative (WSMC), Seattle, WA	Executive Director
Wash. State Maritime Cooperative (WSMC), Seattle, WA	Response Manager

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Appendix B: ERSP Calculator User's Guide

The Estimated Recovery System Potential (ERSP)
Calculator User's Guide

Genwest Systems, Inc. developed this calculator under GSA Contract GS-00F-0002W, BSEE Order # E12-PD-00012. User input defines an oil spill skimming system, which is then evaluated for its Estimated Recovery System Potential (ERSP) for each of three days following a major spill (thousands to tens of thousands of barrels). This ERSP User's Guide describes the calculator and provides guidance for its use.

Background

The ERSP Calculator involves the input of a defined skimmer or system to identify the simulation being run, and 11 inputs that describe the operating characteristics of that skimming system. There are also two preset inputs involving the Operating Period and Emulsion %. Details for each of the inputs and sample calculations are provided in the project final report submitted to BSEE in December, 2012. A brief summary of key assumptions related to the use of the calculator are provided here.

Recovery System Approach

The ERSP Calculator was developed to provide an encounter-rate, performance-based measure of daily recovery potential for skimming systems operating on water offshore or nearshore, in warm or cold climates, without the effects of ice, debris or extreme weather conditions. The calculator was to accommodate a broad range of skimmer configurations and to address response activities including the accessing, containment and recovery of oil. The calculator was also to account for the storage and possible decanting of recovered fluids, the transiting of a skimmer to and from backup storage, and the offloading of recovered fluids. The goal was to provide a computer model that could facilitate the calculation of a "Planning Standard", not a "Performance Standard".

Encounter Rate

Computer models, such as the ROC and the Mechanical Equipment Calculator (MEC) developed by Genwest, along with other sophisticated models described in the project final report, were used to establish average nominal oil thicknesses for each of three days following a major spill (typically thousands to tens of thousands of barrels). The spreading and weathering of a broad range of oil types and volumes were simulated under varying wind/sea conditions and water temperatures. These simulations revealed reasonable average nominal oil thicknesses so that daily recovery potentials could be estimated based on changing oil encounter rates each day. The results of hundreds of computer simulations suggested that a 12-hour release of oil (assumed mid-day on Day 1) could be given a 0.1inch average nominal oil thickness. The mid-day thicknesses for each of Days 2 and 3 could be represented by 0.05inch (for 36 hours of spread) and 0.025 inch (for 60 hours of spread). Real-world average oil thicknesses could span several orders of magnitude for so many different oil types and conditions that could spill. However, the three values reflect reasonable average nominal thicknesses for "planning" purposes.

3-Day Simulation Period

The decision to simulate a skimming system's oil recovery potential over three days only is based upon the very small change in calculated oil thicknesses after three days. The data to support this finding is illustrated in ***Section III.C. Analysis of Oil Thickness*** of the project final report.

Batch vs. Continuous Spill

The computer simulations used to arrive at average nominal oil thicknesses were based on relatively sudden, short-release periods or "batch" type oil spills. As already noted, the nominal thickness values result from an averaging of thickness values (including exponential best-fit trend analyses) for a wide range of oils and environmental conditions. The range of possible oil thicknesses for "continuous" releases would be as great, if not greater, for a 3-day analysis because of the same variations regarding oil type/volume and conditions both at the time of release and each day thereafter. The range of uncertainties regarding average oil thickness would grow as one considers the additional effects of such possible releases - for example, blowouts with variations in their rates of release from different depths into changing surface and subsurface currents. The approximation of average nominal oil thicknesses from the batch spill analyses for Days 1 through 3 are assumed to be within a reasonable range of the thickness values for continuous releases considering the uncertainties of both types of spills.

The acceptance of the Day-1, -2, and -3 average nominal oil thicknesses for either a batch release or an ongoing continuous release is supported by the realization that a Day-1 average thickness would occur day after day with a continuous spill. The ERSP value for a skimming system on Day 1 would therefore continue to apply each day for that skimmer working in fairly close proximity to the continuous spill source. Oil that manages to escape Day-1 operations and continues to drift farther from the continuous source (i.e., into Days 2 and 3), would continue to spread and thin down similarly to the oil spilled from a batch spill under the same conditions.

The calculation of ERSP for each of Days 1, 2 and 3 are, therefore, reasonable approximations for "planning purposes" of the oil recovery potentials for skimming systems following both batch and continuous releases of oil.

Emulsion %

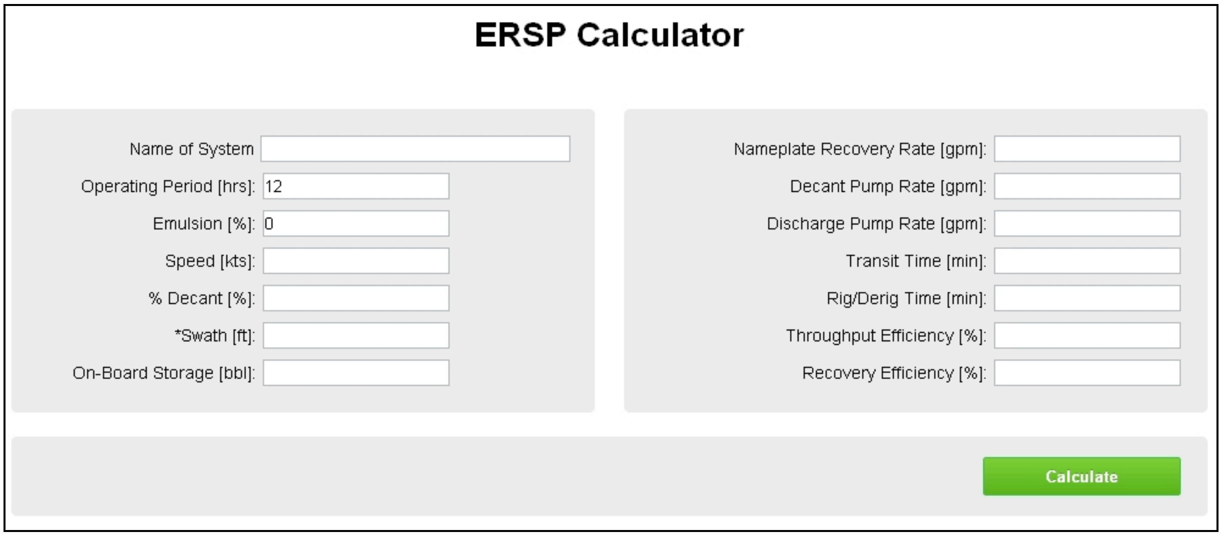
The ERSP Calculator has a default value of "zero" for the Emulsion % input. This is because of the difficulty of predicting the water content of a broad range of oils under an equally broad range of environmental conditions. Emulsion percentages can be measured and controlled to some extent during the testing of skimmers in tank tests. When known, the results of controlled tests can be used in the ERSP Calculator for the starting "Emulsion %" value, and for the input of an appropriate Recovery Efficiency (RE). For consistency and simplification in comparing skimming systems, the use of a "zero" value for Emulsion % is suggested for planning purposes.

Operating Period

The user of the ERSP Calculator can provide the values for all skimming system operational parameters, except for the default value of "12" for the simulated operational period in hours. The input value for Operational Period represents the number of hours that the skimming system (identified in "Name of System") is assumed to be available on location each day. The 12-hour operating period, set during this project by BSEE and the USCG, is the time during which all skimming, transiting and offloading of recovered fluids are accounted for in the results section.

User Inputs

The ERSP Calculator is a small html file named “ersp calculator.html” that opens in most Internet browsers. Launching displays the following window:



ERSP Calculator

Name of System
Operating Period [hrs]: 12
Emulsion [%]: 0
Speed [kts]:
% Decant [%]:
*Swath [ft]:
On-Board Storage [bbl]:

Nameplate Recovery Rate [gpm]:
Decant Pump Rate [gpm]:
Discharge Pump Rate [gpm]:
Transit Time [min]:
Rig/Derig Time [min]:
Throughput Efficiency [%]:
Recovery Efficiency [%]:

- **Name of System** – Enter (up to 48 characters) the name or identifier of the system described.
- **Speed [knots]** – The velocity of a skimming system with respect to the water / oil slick.
- **% Decant [%]** – The % of free water taken on-board that is to be decanted.
- **Swath [ft]** – The width of advance over which oil is intercepted on a skimming system.
- **On-Board Storage [bbl]** – The volume available to the skimming system for the collection of total fluids recovered.
- **Nameplate Recovery Rate (NP) [gpm]** – The maximum rate at which a skimming system can recover fluids under ideal conditions.
- **Decant Pump Rate [gpm]** – The rated capacity of the pump used to remove free water from the fluids collected by the skimming system.
- **Discharge Pump Rate [gpm]** – The rated capacity of the pump used to offload the on-board storage tank(s) to secondary storage.

- **Transit Time [min]** – The one-way time necessary to transit from the oil collection area to secondary or backup storage for offloading.
- **Rig/Derig Time [min]** – The time necessary for a skimming system to: 1) tie up to secondary storage, rig hoses, and complete paperwork in preparation for offloading, and 2) the additional time necessary at the end of offloading to derig hoses & lines.
- **Throughput Efficiency (TE) [%]** – The ratio, expressed as a percentage, of the volume of oil recovered to the volume of oil encountered.
- **Recovery Efficiency (RE) [%]** - The ratio, expressed as a percentage, of the volume of oil recovered to the total volume of fluids recovered.

After all fields are entered, click on the Calculate button. A popup window appears if input fields are left empty. Results for an example system are displayed here (Figure App. B-1).

The five sections in the ERSP calculator page include: user inputs, tabular results, graphical results, Response Timelines, and Simulation Notes.

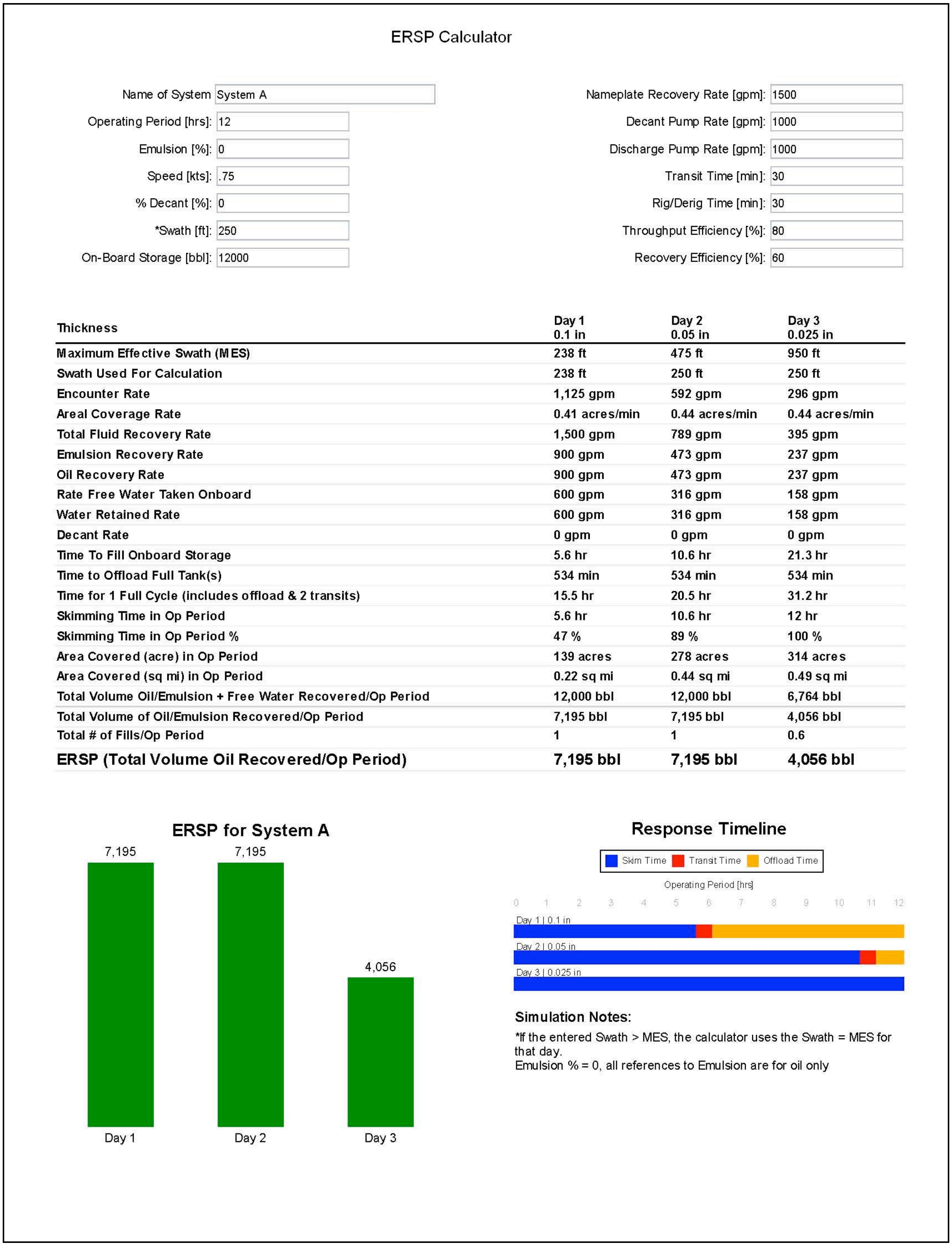
Tabular Results

The tabular results section contains the results of calculations for each of three days. For Day 1 the calculations are made with an average nominal thickness of 0.1 inch. Day 2 uses 0.05 inch and Day 3 uses a thickness of 0.025 inch.

For each day a defined skimming system has a calculated Maximum Effective Swath (MES). This is the swath (in feet) where the rate at which total fluids are being recovered is equal to the Nameplate Recovery Rate of the skimming system (in gallons/minute). If the input Swath of the system is greater than the MES for that day, the Swath Used For Calculation is set automatically to the MES.

The remaining items in the tabular results section are defined here along with the equations used for their calculation:

Note: Percent values (e.g. RE, TE & %Emulsion) should be expressed as a decimal value in the equations.



ERSP Calculator

Name of System: System A
Operating Period [hrs]: 12
Emulsion [%]: 0
Speed [kts]: .75
% Decant [%]: 0
*Swath [ft]: 250
On-Board Storage [bbl]: 12000

Nameplate Recovery Rate [gpm]: 1500
Decant Pump Rate [gpm]: 1000
Discharge Pump Rate [gpm]: 1000
Transit Time [min]: 30
Rig/Derig Time [min]: 30
Throughput Efficiency [%]: 80
Recovery Efficiency [%]: 60

Thickness	Day 1 0.1 in	Day 2 0.05 in	Day 3 0.025 in
Maximum Effective Swath (MES)	238 ft	475 ft	950 ft
Swath Used For Calculation	238 ft	250 ft	250 ft
Encounter Rate	1,125 gpm	592 gpm	296 gpm
Areal Coverage Rate	0.41 acres/min	0.44 acres/min	0.44 acres/min
Total Fluid Recovery Rate	1,500 gpm	789 gpm	395 gpm
Emulsion Recovery Rate	900 gpm	473 gpm	237 gpm
Oil Recovery Rate	900 gpm	473 gpm	237 gpm
Rate Free Water Taken Onboard	600 gpm	316 gpm	158 gpm
Water Retained Rate	600 gpm	316 gpm	158 gpm
Decant Rate	0 gpm	0 gpm	0 gpm
Time To Fill Onboard Storage	5.6 hr	10.6 hr	21.3 hr
Time to Offload Full Tank(s)	534 min	534 min	534 min
Time for 1 Full Cycle (includes offload & 2 transits)	15.5 hr	20.5 hr	31.2 hr
Skimming Time in Op Period	5.6 hr	10.6 hr	12 hr
Skimming Time in Op Period %	47 %	89 %	100 %
Area Covered (acre) in Op Period	139 acres	278 acres	314 acres
Area Covered (sq mi) in Op Period	0.22 sq mi	0.44 sq mi	0.49 sq mi
Total Volume Oil/Emulsion + Free Water Recovered/Op Period	12,000 bbl	12,000 bbl	6,764 bbl
Total Volume of Oil/Emulsion Recovered/Op Period	7,195 bbl	7,195 bbl	4,056 bbl
Total # of Fills/Op Period	1	1	0.6
ERSP (Total Volume Oil Recovered/Op Period)	**7,195 bbl**	**7,195 bbl**	**4,056 bbl**

Simulation Notes:

*If the entered Swath > MES, the calculator uses the Swath = MES for that day.
Emulsion % = 0, all references to Emulsion are for oil only

Figure App. B-1: Sample ERSP Calculator simulation.

- **Encounter Rate [gpm]** – The rate at which oil and/or emulsion is accessed by a skimming system. It is a function of 3 parameters: skimming Speed, operating Swath, and the average oil/emulsion thickness entering the system's swath.

Encounter Rate (ER) [gpm] = 63.13 x Swath [ft] x Speed [kts] x Oil / Emulsion Thickness [in]

- **Areal Coverage Rate [acre/min]** – The rate at which a skimmer system covers area.

Areal Coverage Rate [acre/min] = Swath [ft] x Speed [kts] / 430

- **Total Fluid Recovery Rate [gpm]** – TFRR is the rate at which all fluids (oil/emulsion, free water) are taken on board the skimming system.

TFRR [gpm] = Emulsion Recovery Rate [gpm] + Rate Water Taken Onboard [gpm] (see equation on following page for Rate Water Taken Onboard)

TFRR can also be expressed by:

TFRR [gpm] = Encounter Rate [gpm] x TE/RE

- **Maximum Effective Swath (MES) [ft]** - The swath of a response system that presents an amount of oil/emulsion and collected free water after skimming that matches the system's ability to handle that volume of oil/emulsion and water. This occurs when the TFRR is equal to the Nameplate Recovery Rate (NP).

$$\text{MES [ft]} = \frac{\text{NP [gpm]} \times \text{RE}}{63.13 \times \text{Speed [kts]} \times \text{Oil Thickness [in]} \times \text{TE}}$$

- **Emulsion Recovery Rate (ERR) [gpm]** – The rate at which mousse (formation of stable water-in-oil emulsion) is taken on board the skimming system.

Emulsion Recovery Rate (ERR)[gpm] = Emulsion Encounter Rate [gpm] x Throughput Efficiency (TE)

(Note: used only if % Emulsion ≠ zero)

- **Oil Recovery Rate (ORR) [gpm]** – The rate at which oil is taken on board the skimming system.

Oil Recovery Rate (ORR) [gpm] = Oil Encounter Rate x Throughput Efficiency (TE)

OR

= *Emulsion Recovery Rate [gpm] x (1 – % Emulsion)*

- **Rate Water Taken Onboard [gpm]** – The rate at which free (not bound up in emulsion) water is taken on board the skimming system.

Rate Water Taken Onboard [gpm] = *TFRR [gpm] – Emulsion Recovery Rate [gpm]*

OR

= *TFRR [gpm] x (1 – Recovery Efficiency)*

- **Water Retained Rate [gpm]** – The free water that is retained on board the skimming system after any decanting has taken place.

Water Retained Rate [gpm] = *TFRR [gpm] x (1 – RE) x (1 - % Decant)*

- **Decant Rate [gpm]** – The rate at which free water is decanted from the skimming system.

Decant Rate [gpm] = *Rate Water Taken Onboard [gpm] x % Decant*

Note: If the computed Decant Rate is greater than the entered Decant Pump Rate, a Simulation Note to that effect is generated.

- **Time to Fill Onboard Storage (T_f) [hr]** – The time in which the onboard storage of the skimming system is filled with oil/emulsion + free water.

T_f [hr] = *0.7 x On-board Storage [bbl] / (Emulsion Recovery Rate [gpm] + Water Recovery Rate [gpm] – Decant Rate [gpm])*

- **Time To Offload Full Tank(s) [min]** – The time necessary to offload the entire contents of the onboard storage of the skimming system.

Time To Offload Full Tank(s) [min] = *42 x On-board Storage [bbl] / Discharge Pump Rate [gpm] + Rig / Derig Time [min]*

Note: The ERSP Calculator assumes that the last complete or partial offloading can take place during hours of darkness between Day 1 and Day 2 and between Day 2 and Day 3. If the Time To Offload Full Tank(s) exceeds this time, a Simulation Note to that effect is generated.

- **Time For 1 Full Cycle [hr]** – The total time to fill onboard storage, transit to secondary storage, offload (including Rig/Derig Time), and transit back to the oil slick to resume skimming.

Time For 1 Full Cycle [hr] = T_f [hr] + (2 x Transit Time [hr]) + Time To Offload Full Tank(s) [min] / 60

- **Skimming Time in Op Period [hr]** – The total time in the Operating Period that the skimming system is engaged in skimming.

Skimming Time in Op Period [hr] = T_f [hr] x Total # of Fills / Op Period

- **Skimming Time in Op Period % [%]** – The percentage of the Operating Period time that the skimming system is engaged in skimming.

Skimming Time in Op Period % [%] = T_f [hr] x Total # of Fills/Op Period / Operating Period [hr]

- **Area Covered (acre) in Op Period [acre]** – The total area in acres covered by the skimming system in the Operating Period.

Area Covered (acre) in Op Period [acre] = Skimming Time in Op Period [hr] x Areal Coverage Rate [acre/min] / 60

- **Area Covered (sq. mi) in Op Period [sq. mi]** - The total area in square statute miles covered by the skimming system in the Operating Period.

Area Covered (sq. mi) in Op Period [sq. mi] = Area Covered (acre) in Op Period [acre] / 640

- **Total Volume of Oil/Emulsion + Free Water Recovered/Op Period [bbl]** – The total volume of fluids recovered and retained by the skimming system in an Operating Period.

Total Volume of Oil/Emulsion + Free Water Recovered/Op Period [bbl] = Total # of Fills/Op Period x On-board Storage [bbl]

- **Total Volume of Oil/Emulsion Recovered/Op Period [bbl]** – The total volume of oil/emulsion recovered and retained by the skimming system in an Operating Period.

Total Volume of Oil / Emulsion Recovered / Op Period [bbl] = Total Volume of Oil / Emulsion + Free Water Recovered / Op Period [bbl] – (Water Retained Rate [bbl/hr] x Total # of Fills / Op Period x Time To Fill Onboard Storage [hr])

- **Total # of Fills/Op Period** – This is a function of the Operating Period [hr], the Time to Fill Onboard Storage [hr], and the Time for 1 Full Cycle [hr]. The Time to Fill Onboard Storage [hr] will always be less than the Time for 1 Full Cycle [hr] but could be less than, equal to, or greater than the Operating Period [hr]. Similarly, the Time for 1 Full Cycle [hr] could be less than, equal to, or greater than the Operating Period [hr]. In the general case:

*Total # of Fills/Op Period = MIN (Operating Period [hr] / Time To Fill Onboard Storage [hr] MIN(((Operating Period [hr] / MIN(Time for 1 Full Cycle [hr], Operating Period [hr])-INT(Operating Period [hr] / MIN(Time for 1 Full Cycle [hr], Operating Period [hr])))*MIN(Time for 1 Full Cycle [hr], Operating Period [hr])), Time To Fill Onboard Storage [hr]) / Time To Fill Onboard Storage [hr]+INT(Operating Period [hr] / MIN(Time for 1 Full Cycle [hr], Operating Period [hr])))*

- ERSP (Total Volume of Oil Recovered /Op Period) [bbl] – The bottom line.

ERSP (Total Volume of Oil Recovered /Op Period) [bbl] = Total Volume of Oil/Emulsion Recovered / Op Period [bbl] x (1- Emulsion [%])

Graphical Results

The Graphical Results section provides a visual representation in the form of a bar chart of the calculated ERSP values of the skimming system for the three-day simulation.

Response Timeline

The Response Timeline is a visual representation of each day of the simulation with blue representing the time actually skimming, red for transiting to and from the location of secondary storage for offloading, and gold for offloading and rig / derig time. The Timelines are useful as Skimming time differences between days can be seen at a glance.

Simulation Notes

This section contains alerts and notes that are displayed when specific conditions are met in the calculator. Note that some of these alerts are merely notifications; others will require action from the user to correct. The calculator expects realistic input, and provides alerts for some out-of-range entries. It is not able to provide alerts for all parameters that are impractical such as skimming at speeds of five knots or more.

One alert always appears in the Simulation Notes and begins with an asterisk which matches the asterisk next to the Swath input field:

> *"*If the entered Swath > ME, the calculator uses the Swath that is equal to MES for that day."*

When the Emulsion % is set to zero the alert is:

> *"Emulsion % = 0, all references to Emulsion are for oil only."*

If a calculation swath exceeds 1,000 feet, the alert is:

> *"Swath used for calculation may not be achievable."*

If the calculated decant rate needed for a desired "% decant" is greater than the systems decant pump rate the alert is:

> *"Calculated Decant Rate is greater than Decant Pump Rate."*

If the time to offload a system's onboard storage is greater than the time available to do so between operating periods the alert is:

> *"Offload not achievable between Operating Periods."*

Appendix C: Skimmer Recovery Efficiency Estimates

During this project and during previous efforts to evaluate skimming system performance, RE was recognized as a major factor for the assessment of a mechanical recovery system. RE is the ratio of the oil recovered to the total liquid recovered; and, along with a system's oil recovery rate (ORR), is essential for the assessment of system performance under a variety of oil types, wind and sea conditions.

The user of the ERSP Calculator should, if possible, use actual validated inputs for Nameplate Recovery Rates, TE and RE, etc. Data from "actual usage," however, is often unavailable or very difficult to obtain. The following figures represent a consolidation of recovery efficiency data from an extensive literature search while developing the ROC. All of the sources from which that data was taken are listed in ***Section V. Bibliography***, but do not include actual recovery rates from skimming operations during the Deepwater Horizon (DWH) Blowout in 2010. To date, DWH skimmer performance data has not been available with sufficient detail or information to list here as validated RE values.

Through an extensive examination of historical data for the development of the ROC skimmers were grouped into three categories: Group A, the most efficient, including oleophilic skimmers (drums, disk, brush, belt, and rope-mop); Group B, involving skimmers with paddle belts and fixed or moving submersion planes; and Group C, including air conveyer, weir, direct suction, and vortex skimmers. Based on these groupings, the following two graphs were derived, the first dealing with RE vs. Wind/Sea Conditions (Figure App.C-1), and the second with RE vs. Oil Type/Condition (Figure App.C-2).

Should it be necessary to use these charts (in the absence of actual validated values for a given skimmer), a final selected Recovery Efficiency (RE) estimate should be the lesser value obtained from the two charts. For example, if the RE value was being sought for a Class C skimmer working on crude oil with wind-waves of 6 to 8 feet, Figure App.C-2 might suggest that its RE for a medium-weight crude oil could be given a mid-range value of about 50%. Note that Figure App.C-2 suggests an RE value of ~50% based on performance with oils in the mid-range of Group III oils (i.e., medium-weight crude oils).

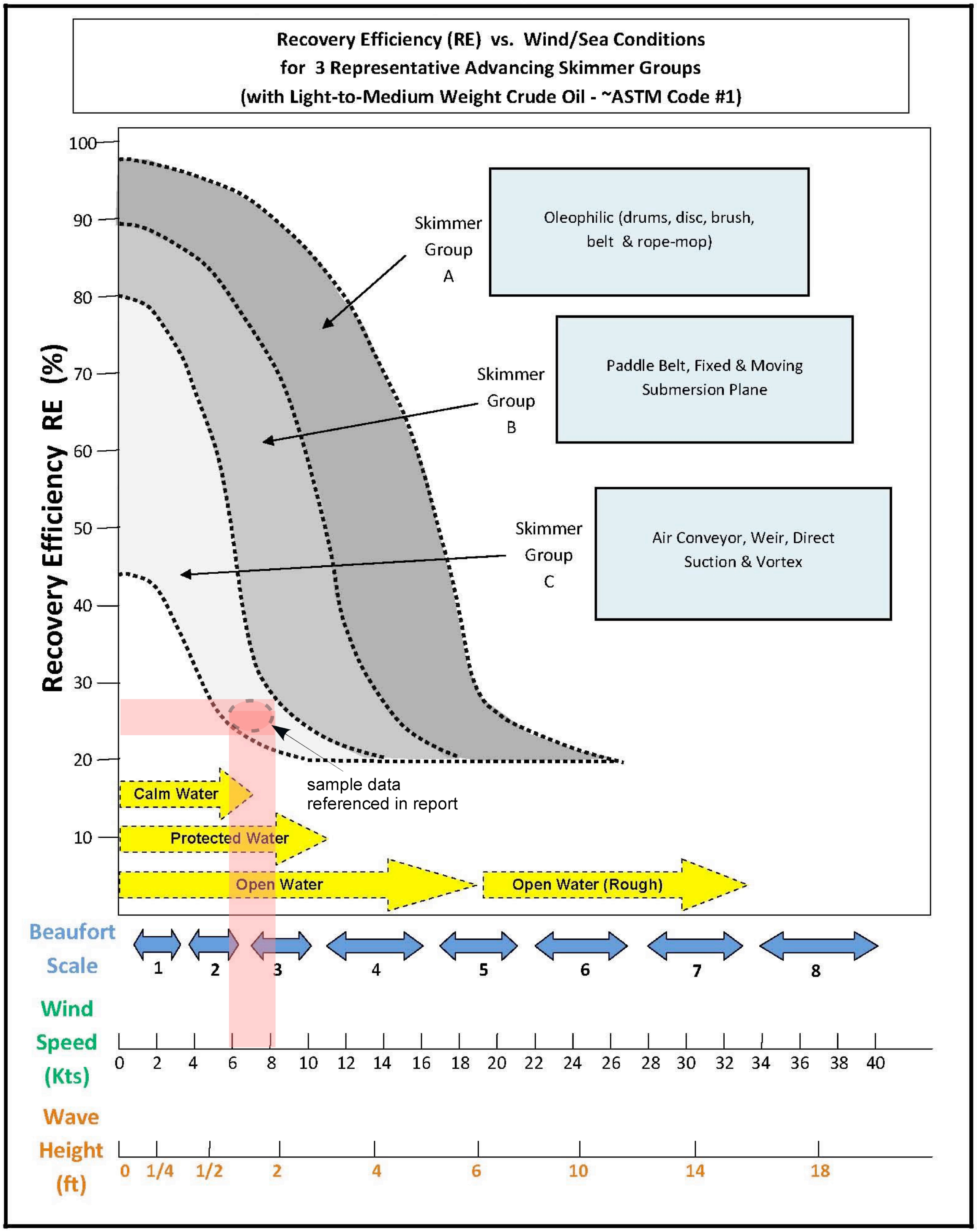


Figure App.C-1: Recovery Efficiency vs. Wind Speed.

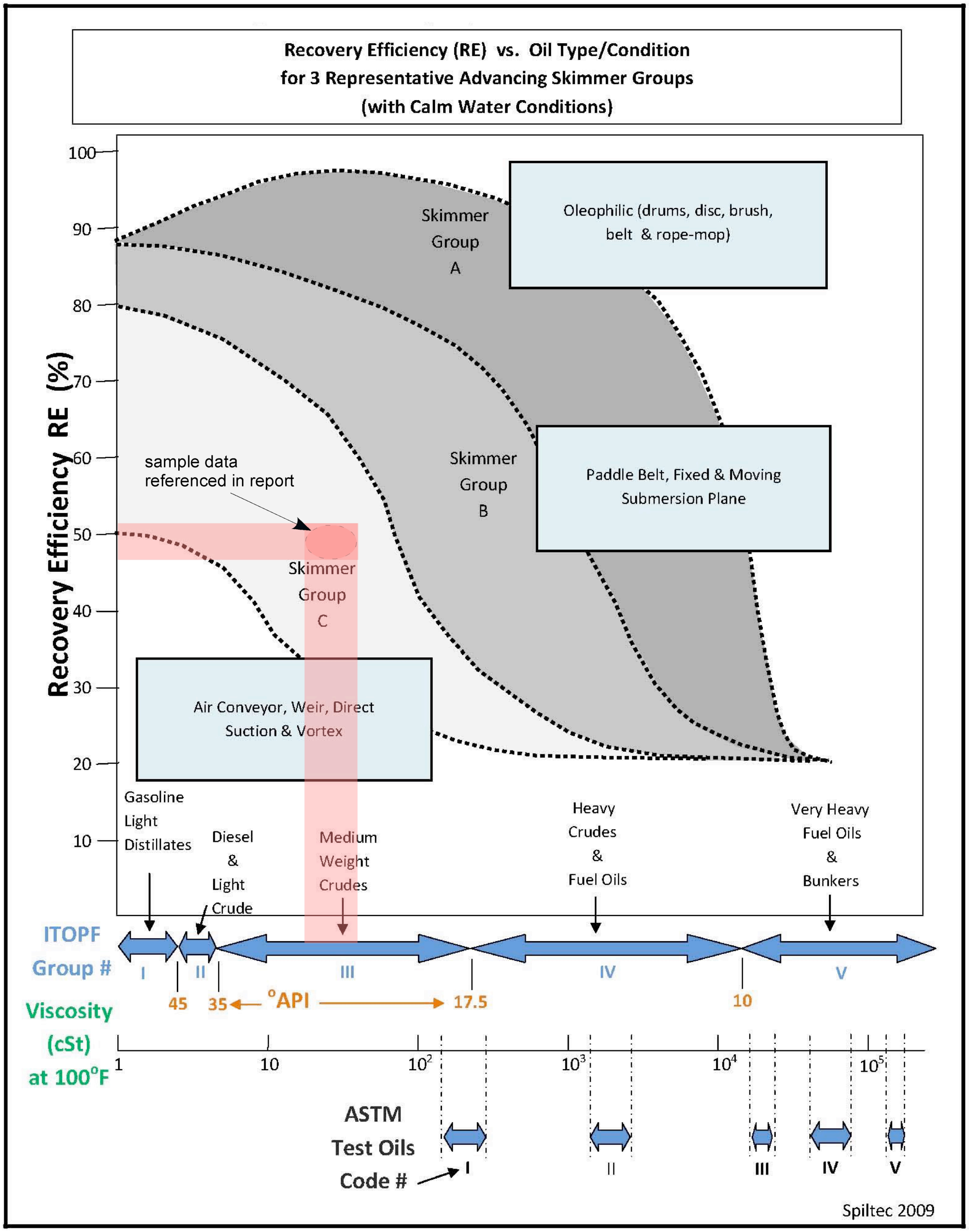


Figure App.C-2: Recovery Efficiency vs. Oil Viscosity.

The previous chart, Figure App.C-1, however, suggests that the same skimmer in waves of 1 to 2 feet with winds of 6 to 8 knots, would likely be closer to 25% for its RE (note sample data high-lighted in Figure App.C-1). In this case, the suggested RE would be the lower value of 25%.

Should the user of these plots have more specific information on the type of oil being recovered (e.g., the ^{o}API or viscosity of the oil), it may be possible to narrow down the range of RE values suggested by the RE plots. The broad range of RE values suggested by these plots for a given type of oil and wind/sea condition is representative of the equally broad range of reported skimmer efficiencies one finds in the literature. Better, more reliable RE values can only be achieved through carefully conducted and standardized test procedures under controlled conditions.

Under certain conditions, an individual skimmer's actual validated RE may fall outside the RE ranges suggested here. These plots will undoubtedly be improved and the range of RE values narrowed down as ASTM Standards continue to be refined and controlled tests of recovery system performance are expanded at test tanks such as those at the Ohmsett facility in Leonardo, New Jersey.

Appendix D: ROC Thickness Data

The following table lists the thickness results for the 432 ROC model runs for each listed combination of Oil Type, Spill Volume, Temperature and Wind Speed for midday on Day 1, Day 2 and Day 3 (12 hours, 36 hours, and 60 hours). These results are included in the Figure III.C-5.

Oil Type	Spill Volume (bbl)	Temperature (deg C)	Wind Speed (kts)	Day	ROC Thickness (in)	ROC % water
Alaska North Slope Crude	500	0	0	1	0.008	5
Alaska North Slope Crude	500	0	5	1	0.005	33
Alaska North Slope Crude	500	0	10	1	0.016	68
Alaska North Slope Crude	500	0	15	1	0.017	83
Alaska North Slope Crude	500	10	0	1	0.008	6
Alaska North Slope Crude	500	10	5	1	0.004	35
Alaska North Slope Crude	500	10	10	1	0.014	69
Alaska North Slope Crude	500	10	15	1	0.016	83
Alaska North Slope Crude	500	15	0	1	0.006	7
Alaska North Slope Crude	500	15	5	1	0.004	36
Alaska North Slope Crude	500	15	10	1	0.013	69
Alaska North Slope Crude	500	15	15	1	0.014	83
Alaska North Slope Crude	5,000	0	0	1	0.032	3
Alaska North Slope Crude	5,000	0	5	1	0.02	30
Alaska North Slope Crude	5,000	0	10	1	0.068	66
Alaska North Slope Crude	5,000	0	15	1	0.075	82
Alaska North Slope Crude	5,000	10	0	1	0.026	5
Alaska North Slope Crude	5,000	10	5	1	0.017	34
Alaska North Slope Crude	5,000	10	10	1	0.059	68
Alaska North Slope Crude	5,000	10	15	1	0.065	83
Alaska North Slope Crude	5,000	15	0	1	0.023	6
Alaska North Slope Crude	5,000	15	5	1	0.015	35
Alaska North Slope Crude	5,000	15	10	1	0.055	69

Oil Type	Spill Volume (bbl)	Temperature (deg C)	Wind Speed (kts)	Day	ROC Thickness (in)	ROC % water
Alaska North Slope Crude	5,000	15	15	1	0.061	83
Alaska North Slope Crude	50,000	0	0	1	0.091	0
Alaska North Slope Crude	50,000	0	5	1	0.063	24
Alaska North Slope Crude	50,000	0	10	1	0.232	62
Alaska North Slope Crude	50,000	0	15	1	0.273	80
Alaska North Slope Crude	50,000	10	0	1	0.071	4
Alaska North Slope Crude	50,000	10	5	1	0.054	31
Alaska North Slope Crude	50,000	10	10	1	0.209	67
Alaska North Slope Crude	50,000	10	15	1	0.241	82
Alaska North Slope Crude	50,000	15	0	1	0.063	5
Alaska North Slope Crude	50,000	15	5	1	0.049	33
Alaska North Slope Crude	50,000	15	10	1	0.192	68
Alaska North Slope Crude	50,000	15	15	1	0.221	83
Alaska North Slope Crude	500,000	0	0	1	0.185	0
Alaska North Slope Crude	500,000	0	5	1	0.144	15
Alaska North Slope Crude	500,000	0	10	1	0.584	56
Alaska North Slope Crude	500,000	0	15	1	0.766	77
Alaska North Slope Crude	500,000	10	0	1	0.135	3
Alaska North Slope Crude	500,000	10	5	1	0.127	28
Alaska North Slope Crude	500,000	10	10	1	0.557	64
Alaska North Slope Crude	500,000	10	15	1	0.709	81
Alaska North Slope Crude	500,000	15	0	1	0.116	4
Alaska North Slope Crude	500,000	15	5	1	0.114	31
Alaska North Slope Crude	500,000	15	10	1	0.51	66
Alaska North Slope Crude	500,000	15	15	1	0.652	81
Alaska North Slope Crude	500	0	0	2	0.0014	19
Alaska North Slope Crude	500	0	5	2	0.0011	62
Alaska North Slope Crude	500	0	10	2	0.0054	85
Alaska North Slope Crude	500	0	15	2	0.0031	85
Alaska North Slope Crude	500	10	0	2	0.0012	20
Alaska North Slope Crude	500	10	5	2	0.001	63

Oil Type	Spill Volume (bbl)	Temperature (deg C)	Wind Speed (kts)	Day	ROC Thickness (in)	ROC % water
Alaska North Slope Crude	500	10	10	2	0.0053	87
Alaska North Slope Crude	500	10	15	2	0.004	90
Alaska North Slope Crude	500	15	0	2	0.0011	20
Alaska North Slope Crude	500	15	5	2	0.001	63
Alaska North Slope Crude	500	15	10	2	0.0049	87
Alaska North Slope Crude	500	15	15	2	0.0037	90
Alaska North Slope Crude	5,000	0	0	2	0.008	17
Alaska North Slope Crude	5,000	0	5	2	0.0072	61
Alaska North Slope Crude	5,000	0	10	2	0.0326	85
Alaska North Slope Crude	5,000	0	15	2	0.0189	85
Alaska North Slope Crude	5,000	10	0	2	0.0069	19
Alaska North Slope Crude	5,000	10	5	2	0.0063	62
Alaska North Slope Crude	5,000	10	10	2	0.0305	86
Alaska North Slope Crude	5,000	10	15	2	0.0233	90
Alaska North Slope Crude	5,000	15	0	2	0.0064	19
Alaska North Slope Crude	5,000	15	5	2	0.0058	62
Alaska North Slope Crude	5,000	15	10	2	0.0283	86
Alaska North Slope Crude	5,000	15	15	2	0.0215	90
Alaska North Slope Crude	50,000	0	0	2	0.0345	15
Alaska North Slope Crude	50,000	0	5	2	0.0329	59
Alaska North Slope Crude	50,000	0	10	2	0.1601	85
Alaska North Slope Crude	50,000	0	15	2	0.0927	85
Alaska North Slope Crude	50,000	10	0	2	0.0284	28
Alaska North Slope Crude	50,000	10	5	2	0.0284	61
Alaska North Slope Crude	50,000	10	10	2	0.1416	86
Alaska North Slope Crude	50,000	10	15	2	0.1111	90
Alaska North Slope Crude	50,000	15	0	2	0.0257	19
Alaska North Slope Crude	50,000	15	5	2	0.0262	62
Alaska North Slope Crude	50,000	15	10	2	0.1308	86
Alaska North Slope Crude	50,000	15	15	2	0.1016	90
Alaska North Slope Crude	500,000	0	0	2	0.1016	12

Oil Type	Spill Volume (bbl)	Temperature (deg C)	Wind Speed (kts)	Day	ROC Thickness (in)	ROC % water
Alaska North Slope Crude	500,000	0	5	2	0.1133	57
Alaska North Slope Crude	500,000	0	10	2	0.6044	85
Alaska North Slope Crude	500,000	0	15	2	0.3855	85
Alaska North Slope Crude	500,000	10	0	2	0.0816	17
Alaska North Slope Crude	500,000	10	5	2	0.0965	60
Alaska North Slope Crude	500,000	10	10	2	0.5262	86
Alaska North Slope Crude	500,000	10	15	2	0.4449	90
Alaska North Slope Crude	500,000	15	0	2	0.0718	18
Alaska North Slope Crude	500,000	15	5	2	0.087	61
Alaska North Slope Crude	500,000	15	10	2	0.4773	86
Alaska North Slope Crude	500,000	15	15	2	0.3994	90
Alaska North Slope Crude	500	0	0	3	0.0005	29
Alaska North Slope Crude	500	0	5	3	0.0005	73
Alaska North Slope Crude	500	0	10	3	0.0019	85
Alaska North Slope Crude	500	0	15	3	0.0001	85
Alaska North Slope Crude	500	10	0	3	0.0005	29
Alaska North Slope Crude	500	10	5	3	0.0005	74
Alaska North Slope Crude	500	10	10	3	0.0024	90
Alaska North Slope Crude	500	10	15	3	0.0014	90
Alaska North Slope Crude	500	15	0	3	0.0004	30
Alaska North Slope Crude	500	15	5	3	0.0005	74
Alaska North Slope Crude	500	15	10	3	0.0023	90
Alaska North Slope Crude	500	15	15	3	0.0013	90
Alaska North Slope Crude	5,000	0	0	3	0.0037	28
Alaska North Slope Crude	5,000	0	5	3	0.0041	73
Alaska North Slope Crude	5,000	0	10	3	0.0133	85
Alaska North Slope Crude	5,000	0	15	3	0.0077	85
Alaska North Slope Crude	5,000	10	0	3	0.0033	29
Alaska North Slope Crude	5,000	10	5	3	0.0036	73
Alaska North Slope Crude	5,000	10	10	3	0.0166	90
Alaska North Slope Crude	5,000	10	15	3	0.0096	90

Oil Type	Spill Volume (bbl)	Temperature (deg C)	Wind Speed (kts)	Day	ROC Thickness (in)	ROC % water
Alaska North Slope Crude	5,000	15	0	3	0.003	29
Alaska North Slope Crude	5,000	15	5	3	0.0034	73
Alaska North Slope Crude	5,000	15	10	3	0.0154	90
Alaska North Slope Crude	5,000	15	15	3	0.0089	90
Alaska North Slope Crude	50,000	0	0	3	0.0192	26
Alaska North Slope Crude	50,000	0	5	3	0.0226	72
Alaska North Slope Crude	50,000	0	10	3	0.0747	85
Alaska North Slope Crude	50,000	0	15	3	0.0432	85
Alaska North Slope Crude	50,000	10	0	3	0.0164	18
Alaska North Slope Crude	50,000	10	5	3	0.0199	73
Alaska North Slope Crude	50,000	10	10	3	0.0911	90
Alaska North Slope Crude	50,000	10	15	3	0.0527	90
Alaska North Slope Crude	50,000	15	0	3	0.0151	29
Alaska North Slope Crude	50,000	15	5	3	0.0183	73
Alaska North Slope Crude	50,000	15	10	3	0.0837	90
Alaska North Slope Crude	50,000	15	15	3	0.0483	90
Alaska North Slope Crude	500,000	0	0	3	0.0708	23
Alaska North Slope Crude	500,000	0	5	3	0.094	71
Alaska North Slope Crude	500,000	0	10	3	0.342	85
Alaska North Slope Crude	500,000	0	15	3	0.2005	85
Alaska North Slope Crude	500,000	10	0	3	0.0577	27
Alaska North Slope Crude	500,000	10	5	3	0.08	72
Alaska North Slope Crude	500,000	10	10	3	0.3976	90
Alaska North Slope Crude	500,000	10	15	3	0.2369	90
Alaska North Slope Crude	500,000	15	0	3	0.0515	28
Alaska North Slope Crude	500,000	15	5	3	0.0729	73
Alaska North Slope Crude	500,000	15	10	3	0.3595	90
Alaska North Slope Crude	500,000	15	15	3	0.2156	90
Light Louisiana Sweet	500	0	0	1	0.006	6
Light Louisiana Sweet	500	0	5	1	0.004	34
Light Louisiana Sweet	500	0	10	1	0.013	68

Oil Type	Spill Volume (bbl)	Temperature (deg C)	Wind Speed (kts)	Day	ROC Thickness (in)	ROC % water
Light Louisiana Sweet	500	0	15	1	0.014	83
Light Louisiana Sweet	500	10	0	1	0.005	7
Light Louisiana Sweet	500	10	5	1	0.003	36
Light Louisiana Sweet	500	10	10	1	0.011	69
Light Louisiana Sweet	500	10	15	1	0.012	83
Light Louisiana Sweet	500	15	0	1	0.005	7
Light Louisiana Sweet	500	15	5	1	0.003	36
Light Louisiana Sweet	500	15	10	1	0.01	70
Light Louisiana Sweet	500	15	15	1	0.011	83
Light Louisiana Sweet	5,000	0	0	1	0.025	5
Light Louisiana Sweet	5,000	0	5	1	0.016	33
Light Louisiana Sweet	5,000	0	10	1	0.055	67
Light Louisiana Sweet	5,000	0	15	1	0.061	82
Light Louisiana Sweet	5,000	10	0	1	0.02	6%
Light Louisiana Sweet	5,000	10	5	1	0.013	35
Light Louisiana Sweet	5,000	10	10	1	0.047	69
Light Louisiana Sweet	5,000	10	15	1	0.052	83
Light Louisiana Sweet	5,000	15	0	1	0.045	7
Light Louisiana Sweet	5,000	15	5	1	0.034	36
Light Louisiana Sweet	5,000	15	10	1	0.043	69
Light Louisiana Sweet	5,000	15	15	1	0.047	83
Light Louisiana Sweet	50,000	0	0	1	0.068	3
Light Louisiana Sweet	50,000	0	5	1	0.05	29
Light Louisiana Sweet	50,000	0	10	1	0.19	65
Light Louisiana Sweet	50,000	0	15	1	0.22	81
Light Louisiana Sweet	50,000	10	0	1	0.052	6
Light Louisiana Sweet	50,000	10	5	1	0.041	34
Light Louisiana Sweet	50,000	10	10	1	0.161	67
Light Louisiana Sweet	50,000	10	15	1	0.188	83
Light Louisiana Sweet	50,000	15	0	1	0.045	7
Light Louisiana Sweet	50,000	15	5	1	0.034	36

Oil Type	Spill Volume (bbl)	Temperature (deg C)	Wind Speed (kts)	Day	ROC Thickness (in)	ROC % water
Light Louisiana Sweet	50,000	15	10	1	0.146	69
Light Louisiana Sweet	50,000	15	15	1	0.17	83
Light Louisiana Sweet	500,000	0	0	1	0.129	3
Light Louisiana Sweet	500,000	0	5	1	0.116	29
Light Louisiana Sweet	500,000	0	10	1	0.486	65
Light Louisiana Sweet	500,000	0	15	1	0.633	81
Light Louisiana Sweet	500,000	10	0	1	0.094	6
Light Louisiana Sweet	500,000	10	5	1	0.093	34
Light Louisiana Sweet	500,000	10	10	1	0.419	67
Light Louisiana Sweet	500,000	10	15	1	0.539	83
Light Louisiana Sweet	500,000	15	0	1	0.08	6
Light Louisiana Sweet	500,000	15	5	1	0.082	35
Light Louisiana Sweet	500,000	15	10	1	0.376	68
Light Louisiana Sweet	500,000	15	15	1	0.486	83
Light Louisiana Sweet	500	0	0	2	0.0011	19
Light Louisiana Sweet	500	0	5	2	0.0009	62
Light Louisiana Sweet	500	0	10	2	0.0049	86
Light Louisiana Sweet	500	0	15	2	0.0037	90
Light Louisiana Sweet	500	10	0	2	0.0009	20
Light Louisiana Sweet	500	10	5	2	0.0008	63
Light Louisiana Sweet	500	10	10	2	0.0042	87
Light Louisiana Sweet	500	10	15	2	0.0032	90
Light Louisiana Sweet	500	15	0	2	0.0008	20
Light Louisiana Sweet	500	15	5	2	0.0007	63
Light Louisiana Sweet	500	15	10	2	0.0039	87
Light Louisiana Sweet	500	15	15	2	0.0029	90
Light Louisiana Sweet	5,000	0	0	2	0.0065	18
Light Louisiana Sweet	5,000	0	5	2	0.0058	62
Light Louisiana Sweet	5,000	0	10	2	0.0284	86
Light Louisiana Sweet	5,000	0	15	2	0.0211	90
Light Louisiana Sweet	5,000	10	0	2	0.0054	19

Oil Type	Spill Volume (bbl)	Temperature (deg C)	Wind Speed (kts)	Day	ROC Thickness (in)	ROC % water
Light Louisiana Sweet	5,000	10	5	2	0.0049	62
Light Louisiana Sweet	5,000	10	10	2	0.0243	86
Light Louisiana Sweet	5,000	10	15	2	0.0185	90
Light Louisiana Sweet	5,000	15	0	2	0.0049	20
Light Louisiana Sweet	5,000	15	5	2	0.0044	63
Light Louisiana Sweet	5,000	15	10	2	0.0221	87
Light Louisiana Sweet	5,000	15	15	2	0.0169	90
Light Louisiana Sweet	50,000	0	0	2	0.027	17
Light Louisiana Sweet	50,000	0	5	2	0.0266	61
Light Louisiana Sweet	50,000	0	10	2	0.1327	86
Light Louisiana Sweet	50,000	0	15	2	0.1059	90
Light Louisiana Sweet	50,000	10	0	2	0.0217	19
Light Louisiana Sweet	50,000	10	5	2	0.0222	62
Light Louisiana Sweet	50,000	10	10	2	0.1113	86
Light Louisiana Sweet	50,000	10	15	2	0.0867	90
Light Louisiana Sweet	50,000	15	0	2	0.0194	19
Light Louisiana Sweet	50,000	15	5	2	0.02	62
Light Louisiana Sweet	50,000	15	10	2	0.101	86
Light Louisiana Sweet	50,000	15	15	2	0.0782	90
Light Louisiana Sweet	500,000	0	0	2	0.0771	15
Light Louisiana Sweet	500,000	0	5	2	0.0903	59
Light Louisiana Sweet	500,000	0	10	2	0.4886	85
Light Louisiana Sweet	500,000	0	15	2	0.4274	90
Light Louisiana Sweet	500,000	10	0	2	0.0595	18
Light Louisiana Sweet	500,000	10	5	2	0.0732	61
Light Louisiana Sweet	500,000	10	10	2	0.4036	86
Light Louisiana Sweet	500,000	10	15	2	0.3408	90
Light Louisiana Sweet	500,000	15	0	2	0.0516	19
Light Louisiana Sweet	500,000	15	5	2	0.065	62
Light Louisiana Sweet	500,000	15	10	2	0.3629	86
Light Louisiana Sweet	500,000	15	15	2	0.3046	90

Oil Type	Spill Volume (bbl)	Temperature (deg C)	Wind Speed (kts)	Day	ROC Thickness (in)	ROC % water
Light Louisiana Sweet	500	0	0	3	0.0004	29
Light Louisiana Sweet	500	0	5	3	0.0004	73
Light Louisiana Sweet	500	0	10	3	0.0023	90
Light Louisiana Sweet	500	0	15	3	0.0013	90
Light Louisiana Sweet	500	10	0	3	0.0003	30
Light Louisiana Sweet	500	10	5	3	0.0004	74
Light Louisiana Sweet	500	10	10	3	0.0019	90
Light Louisiana Sweet	500	10	15	3	0.0011	90
Light Louisiana Sweet	500	15	0	3	0.0003	30
Light Louisiana Sweet	500	15	5	3	0.0003	74
Light Louisiana Sweet	500	15	10	3	0.0018	90
Light Louisiana Sweet	500	15	15	3	0.001	90
Light Louisiana Sweet	5,000	0	0	3	0.003	28
Light Louisiana Sweet	5,000	0	5	3	0.0034	73
Light Louisiana Sweet	5,000	0	10	3	0.0156	90
Light Louisiana Sweet	5,000	0	15	3	0.009	90
Light Louisiana Sweet	5,000	10	0	3	0.0025	29
Light Louisiana Sweet	5,000	10	5	3	0.0028	73
Light Louisiana Sweet	5,000	10	10	3	0.0132	90
Light Louisiana Sweet	5,000	10	15	3	0.0077	90
Light Louisiana Sweet	5,000	15	0	3	0.0023	30
Light Louisiana Sweet	5,000	15	5	3	0.0026	74
Light Louisiana Sweet	5,000	15	10	3	0.012	90
Light Louisiana Sweet	5,000	15	15	3	0.007	90
Light Louisiana Sweet	50,000	0	0	3	0.0155	27
Light Louisiana Sweet	50,000	0	5	3	0.0186	73
Light Louisiana Sweet	50,000	0	10	3	0.0863	90
Light Louisiana Sweet	50,000	0	15	3	0.0498	90
Light Louisiana Sweet	50,000	10	0	3	0.0218	29
Light Louisiana Sweet	50,000	10	5	3	0.0155	73
Light Louisiana Sweet	50,000	10	10	3	0.0715	90

Oil Type	Spill Volume (bbl)	Temperature (deg C)	Wind Speed (kts)	Day	ROC Thickness (in)	ROC % water
Light Louisiana Sweet	50,000	10	15	3	0.0414	90
Light Louisiana Sweet	50,000	15	0	3	0.0115	29
Light Louisiana Sweet	50,000	15	5	3	0.014	73
Light Louisiana Sweet	50,000	15	10	3	0.0646	90
Light Louisiana Sweet	50,000	15	15	3	0.0375	90
Light Louisiana Sweet	500,000	0	0	3	0.0548	26
Light Louisiana Sweet	500,000	0	5	3	0.0753	72
Light Louisiana Sweet	500,000	0	10	3	0.382	90
Light Louisiana Sweet	500,000	0	15	3	0.2273	90
Light Louisiana Sweet	500,000	10	0	3	0.0432	28
Light Louisiana Sweet	500,000	10	5	3	0.0616	73
Light Louisiana Sweet	500,000	10	10	3	0.3073	90
Light Louisiana Sweet	500,000	10	15	3	0.184	90
Light Louisiana Sweet	500,000	15	0	3	0.038	29
Light Louisiana Sweet	500,000	15	5	3	0.0551	73
Light Louisiana Sweet	500,000	15	10	3	0.2755	90
Light Louisiana Sweet	500,000	15	15	3	0.1654	90
IFO 300	500	0	0	1	0.0242	0
IFO 300	500	0	5	1	0.0096	0
IFO 300	500	0	10	1	0.0155	0
IFO 300	500	0	15	1	0.0089	0
IFO 300	500	10	0	1	0.0223	0
IFO 300	500	10	5	1	0.0088	0
IFO 300	500	10	10	1	0.0142	0
IFO 300	500	10	15	1	0.0081	0
IFO 300	500	15	0	1	0.0213	0
IFO 300	500	15	5	1	0.0084	0
IFO 300	500	15	10	1	0.0135	0
IFO 300	500	15	15	1	0.0077	0
IFO 300	5,000	0	0	1	0.1406	0
IFO 300	5,000	0	5	1	0.058	0

Oil Type	Spill Volume (bbl)	Temperature (deg C)	Wind Speed (kts)	Day	ROC Thickness (in)	ROC % water
IFO 300	5,000	0	10	1	0.0941	0
IFO 300	5,000	0	15	1	0.0539	0
IFO 300	5,000	10	0	1	0.1251	0
IFO 300	5,000	10	5	1	0.0517	0
IFO 300	5,000	10	10	1	0.0837	0
IFO 300	5,000	10	15	1	0.0478	0
IFO 300	5,000	15	0	1	0.1179	0
IFO 300	5,000	15	5	1	0.0488	0
IFO 300	5,000	15	10	1	0.0789	0
IFO 300	5,000	15	15	1	0.045	0
IFO 300	50,000	0	0	1	0.6348	0
IFO 300	50,000	0	5	1	0.2773	0
IFO 300	50,000	0	10	1	0.4612	0
IFO 300	50,000	0	15	1	0.2675	0
IFO 300	50,000	10	0	1	0.5403	0
IFO 300	50,000	10	5	1	0.2392	0
IFO 300	50,000	10	10	1	0.399	0
IFO 300	50,000	10	15	1	0.2313	0
IFO 300	50,000	15	0	1	0.499	0
IFO 300	50,000	15	5	1	0.2224	0
IFO 300	50,000	15	10	1	0.3714	0
IFO 300	50,000	15	15	1	0.2151	0
IFO 300	500,000	0	0	1	2.153	0
IFO 300	500,000	0	5	1	1.06	0
IFO 300	500,000	0	10	1	1.851	0
IFO 300	500,000	0	15	1	1.1	0
IFO 300	500,000	10	0	1	1.74	0
IFO 300	500,000	10	5	1	0.88	0
IFO 300	500,000	10	10	1	1.56	0
IFO 300	500,000	10	15	1	0.93	0
IFO 300	500,000	15	0	1	1.57	0

Oil Type	Spill Volume (bbl)	Temperature (deg C)	Wind Speed (kts)	Day	ROC Thickness (in)	ROC % water
IFO 300	500,000	15	5	1	0.804	0
IFO 300	500,000	15	10	1	1.43	0
IFO 300	500,000	15	15	1	0.856	0
IFO 300	500	0	0	2	0.0024	0
IFO 300	500	0	5	2	0.0009	0
IFO 300	500	0	10	2	0.0015	0
IFO 300	500	0	15	2	0.0008	0
IFO 300	500	10	0	2	0.0022	0
IFO 300	500	10	5	2	0.0008	0
IFO 300	500	10	10	2	0.0014	0
IFO 300	500	10	15	2	0.0008	0
IFO 300	500	15	0	2	0.0022	0
IFO 300	500	15	5	2	0.0008	0
IFO 300	500	15	10	2	0.0015	0
IFO 300	500	15	15	2	0.0008	0
IFO 300	5,000	0	0	2	0.019	0
IFO 300	5,000	0	5	2	0.0076	0
IFO 300	5,000	0	10	2	0.0123	0
IFO 300	5,000	0	15	2	0.0071	0
IFO 300	5,000	10	0	2	0.0017	0
IFO 300	5,000	10	5	2	0.007	0
IFO 300	5,000	10	10	2	0.0144	0
IFO 300	5,000	10	15	2	0.0065	0
IFO 300	5,000	15	0	2	0.017	0
IFO 300	5,000	15	5	2	0.0067	0
IFO 300	5,000	15	10	2	0.0109	0
IFO 300	5,000	15	15	2	0.0062	0
IFO 300	50,000	0	0	2	0.1213	0
IFO 300	50,000	0	5	2	0.0507	0
IFO 300	50,000	0	10	2	0.0825	0
IFO 300	500,00	0	15	2	0.0472	0

Oil Type	Spill Volume (bbl)	Temperature (deg C)	Wind Speed (kts)	Day	ROC Thickness (in)	ROC % water
IFO 300	50,000	10	0	2	0.1092	0
IFO 300	50,000	10	5	2	0.0457	0
IFO 300	50,000	10	10	2	0.0741	0
IFO 300	50,000	10	15	2	0.0423	0
IFO 300	50,000	15	0	2	0.1036	0
IFO 300	50,000	15	5	2	0.0433	0
IFO 300	50,000	15	10	2	0.0701	0
IFO 300	50,000	15	15	2	0.04	0
IFO 300	500,000	0	0	2	0.5957	0
IFO 300	500,000	0	5	2	0.2653	0
IFO 300	500,000	0	10	2	0.4436	0
IFO 300	500,000	0	15	2	0.2574	0
IFO 300	500,000	10	0	2	0.513	0
IFO 300	500,000	10	5	2	0.2312	0
IFO 300	500,000	10	10	2	0.3873	0
IFO 300	500,000	10	15	2	0.2245	0
IFO 300	500,000	15	0	2	0.4762	0
IFO 300	500,000	15	5	2	0.2159	0
IFO 300	500,000	15	10	2	0.3618	0
IFO 300	500,000	15	15	2	0.2096	0
IFO 300	500	0	0	3	0.0007	0
IFO 300	500	0	5	3	0.0002	0
IFO 300	500	0	10	3	0.0004	0
IFO 300	500	0	15	3	0.0002	0
IFO 300	500	10	0	3	0.0006	0
IFO 300	500	10	5	3	0.0002	0
IFO 300	500	10	10	3	0.0004	0
IFO 300	500	10	15	3	0.0002	0
IFO 300	500	15	0	3	0.0006	0
IFO 300	500	15	5	3	0.0002	0
IFO 300	500	15	10	3	0.0004	0

Oil Type	Spill Volume (bbl)	Temperature (deg C)	Wind Speed (kts)	Day	ROC Thickness (in)	ROC % water
IFO 300	500	15	15	3	0.0002	0
IFO 300	5,000	0	0	3	0.0063	0
IFO 300	5,000	0	5	3	0.0025	0
IFO 300	5,000	0	10	3	0.0041	0
IFO 300	5,000	0	15	3	0.0023	0
IFO 300	5,000	10	0	3	0.0059	0
IFO 300	5,000	10	5	3	0.0023	0
IFO 300	5,000	10	10	3	0.0038	0
IFO 300	5,000	10	15	3	0.0022	0
IFO 300	5,000	15	0	3	0.0057	0
IFO 300	5,000	15	5	3	0.0022	0
IFO 300	5,000	15	10	3	0.0037	0
IFO 300	5,000	15	15	3	0.0021	0
IFO 300	50,000	0	0	3	0.0467	0
IFO 300	50,000	0	5	3	0.0192	0
IFO 300	50,000	0	10	3	0.0312	0
IFO 300	50,000	0	15	3	0.0179	0
IFO 300	50,000	10	0	3	0.0429	0
IFO 300	50,000	10	5	3	0.0176	0
IFO 300	50,000	10	10	3	0.0284	0
IFO 300	50,000	10	15	3	0.0163	0
IFO 300	50,000	15	0	3	0.0411	0
IFO 300	50,000	15	5	3	0.0168	0
IFO 300	50,000	15	10	3	0.0271	0
IFO 300	50,000	15	15	3	0.0155	0
IFO 300	500,000	0	0	3	0.2722	0
IFO 300	500,000	0	5	3	0.1183	0
IFO 300	500,000	0	10	3	0.1953	0
IFO 300	500,000	0	15	3	0.1125	0
IFO 300	500,000	10	0	3	0.2412	0
IFO 300	500,000	10	5	3	0.1053	0

Oil Type	Spill Volume (bbl)	Temperature (deg C)	Wind Speed (kts)	Day	ROC Thickness (in)	ROC % water
IFO 300	500,000	10	10	3	0.1737	0
IFO 300	500,000	10	15	3	0.0977	0
IFO 300	500,000	15	0	3	0.2269	0
IFO 300	500,000	15	5	3	0.0993	0
IFO 300	500,000	15	10	3	0.1636	0
IFO 300	500,000	15	15	3	0.0937	0

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