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PRINCE WILLIAM SOUND
OIL SPILL RECOVERY Optimization Analysis

The opinions expressed in this PWSRCAC-commissioned report are not necessarily those of PWSRCAC.

Prepared for Prince William Sound Regional Citizens' Advisory Council

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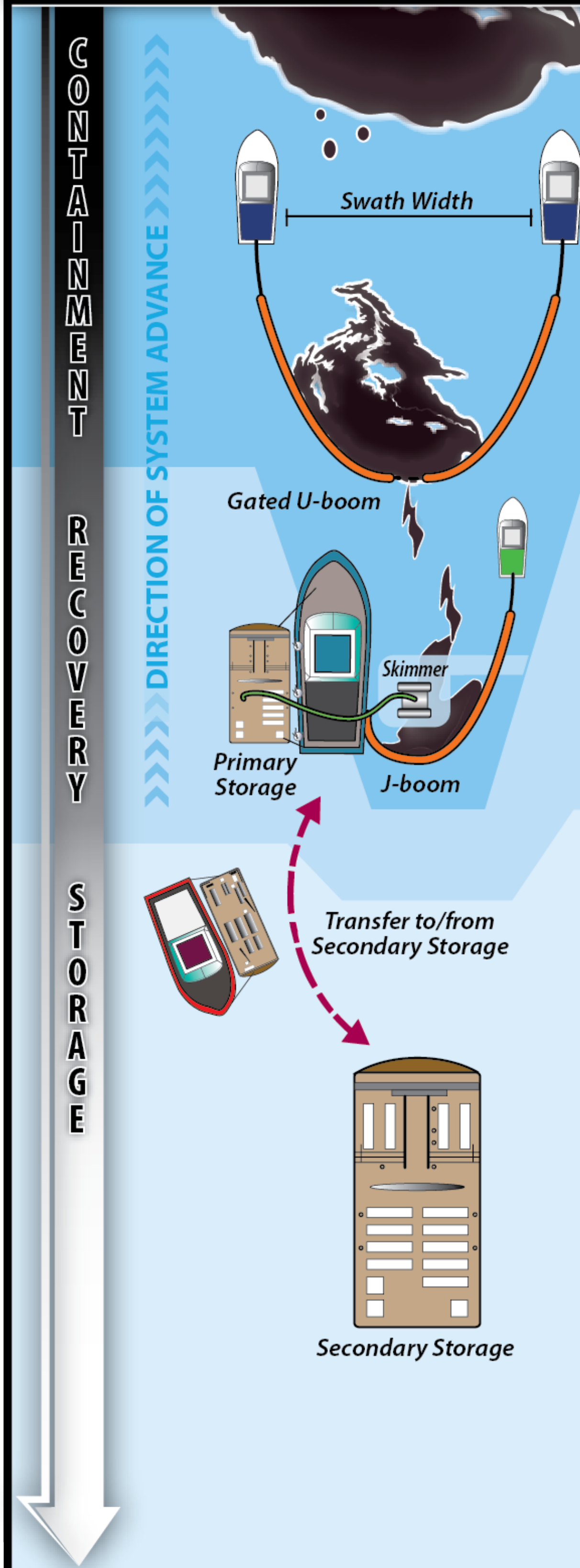
ABSTRACT

The marine oil spill recovery system in Prince William Sound is well established. The Prince William Sound Regional Citizens' Advisory Council commissioned a study to analyze potential options to increase oil recovery by optimizing both the open-water and nearshore on-water recovery systems based there. A suite of publically-available and custom-built oil spill response models was applied to a hypothetical oil spill of Alaska North Slope crude to first assess the extent to which recovery systems are currently optimized and then explore options to enhance recovery. After examining the extent to which the systems are currently optimized, modifications to the large, open-water recovery systems focused on increasing their capacity to *encounter* oil, while modifications for the smaller nearshore systems sought to increase their capacity to *recover* oil. Systems with disc skimmers performed best overall, particularly when the transfer of recovered fluids from primary to secondary storage was considered. The advantages of disc skimmers would apply to other types of oleophilic skimmers. Decanting mini-barges did not increase oil recovery for the nearshore system, but decanting did enable the open-water *Valdez Star* to skim longer and collect more oil. The results of this study can be used to inform potential real-world modifications, which, if deemed feasible by responders, will necessitate real-world testing and training.

RECOVERY SYSTEM TERMS



Slick thickness (in)
thickness of the oil/emulsion on the surface of the water, assumed to be uniform

Skimming speed (knots)
how fast the system advances while skimming

Swath width (feet)
distance between the two leading ends of the containment system/boom

Encounter rate (gal/min or bbl/hr)
amount of oil contained and directed to the skimmer per unit of time (function of slick thickness, skimming speed, and swath width)

Throughput efficiency (%)
oil encountered relative to amount recovered (some will escape containment before reaching skimmer)

Total oil recovered (gal or bbl)
volume of oil/emulsion recovered by system

Total fluids recovered (gal or bbl)
volume of fluids recovered (oil/emulsion + water)

Skimmer pump rate (gal/min or bbl/hr)
volume of fluids skimmer can pump per unit of time (manufacturer-designated "nameplate")

Oil recovery efficiency (%)
oil/emulsion recovered relative to the total volume of fluids recovered (oil/emulsion + free water)

Primary storage (bbl)
volume of fluids that can be retained without offloading (onboard, or in a storage device tethered to skimming vessel)

Decant pump rate (gal/min or bbl/hr)
volume of free water pumped (decanted) per unit of time

Decant efficiency (%)
% of free water recovered that is discharged through decanting

Secondary storage (bbl)
storage device to which fluids collected in primary storage are transfered

Transit time (min)
time to move primary storage (either on board or mini-barge) to secondary storage and back

Discharge pump rate (gal/min)
rate at which recovered fluids are transferred from primary to secondary storage

Offload time (min)
time spent to offload oil to secondary storage (function of primary storage volume and discharge pump rate)

Rig/derig time (min)
time spent at secondary storage from arrival until departure, except for actual offload time (tie up, connecting and disconnecting hoses, etc.)

Additional Terms Related to System Optimization

Derated encounter rate
encounter rate x throughput efficiency
Also referred to as "containment capacity"

Derated skimmer pump rate
skimmer pump rate x oil recovery efficiency
Also referred to as "recovery capacity"

Acronyms and Abbreviations

ADEC	Alaska Department of Environmental Conservation
ADIOS	Automated Data Inquiry for Oil Spills II
bbl	barrel(s) (of oil)
bph	barrels per hour
BSEE	Bureau of Safety and Environmental Enforcement (U.S.)
CBB	Current Buster® barge
CB2	Current Buster® 2
CB4	Current Buster® 4
CB8	Current Buster® 8
ERSP	Estimated Recovery System Potential
ft	foot/feet
hr	hour(s)
kt	knot(s)
min	minute(s)
nm	nautical mile(s)
NOAA	National Oceanic and Atmospheric Administration
OP	Operational period
PWS	Prince William Sound
PWSRCAC	Prince William Sound Regional Citizens' Advisory Council
RSC	Recovery Systems Calculator
ROC	Response Options Calculator
SERVS	Ship Escort/Response Vessel System
TGRB	TransRec/GrahamRec Barge
VS	*Valdez Star* (vessel)
USCG	U.S. Coast Guard

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February 2017

1 Introduction

The marine oil spill recovery system in Prince William Sound is well established and well documented through the Prince William Sound Tanker Oil Spill Prevention and Discharge Contingency Plan (PWS Tanker C-plan) (RPG, 2013) and Ship Escort/Response Vessel System (SERVS) Technical Manual (APSC, 2013). The Prince William Sound Regional Citizens' Advisory Council (PWSRCAC) contracted Nuka Research and Planning Group, LLC (Nuka Research) to analyze options for maximizing potential on-water oil recovery by optimizing the performance of the open-water and nearshore recovery systems used in Prince William Sound (PWS).

1.1 Project Scope

PWSRCAC developed this project to enhance understanding of the Prince William Sound oil spill response system with a focus on on-water, free-oil recovery. The goal of the project was to identify potential modifications to the current system that would increase potential oil recovery. The project considered hypothetical changes to equipment type, quantity, specifications, and operations (specifically speed). Both open-water and nearshore free-oil recovery systems were analyzed. Because the nearshore systems rely on the transfer of collected fluids from primary to secondary storage in order to sustain skimming operations, the analysis also explored the potential to optimize this process by considering different combinations of the number of skimmers, number of primary storage devices (mini-barges), number of offload stations available on the secondary storage barge, and the distance skimming vessels travel away from the secondary storage barge.

1.2 Project Design and Input

In November 2015, PWSRCAC hosted a design workshop for this project with participants from the Alaska Department of Environmental Conservation (ADEC), Alyeska Pipeline Services Company/SERVS, National Oceanic and Atmospheric Administration (NOAA), Oil Spill Recovery Institute, PWSRCAC staff and board members, and the U.S. Coast Guard (USCG). Workshop participants and the PWSRCAC representatives present agreed on the general project design as described in this report, with the shared priorities to: (1) explore options to optimize the system by studying one recovery system at a time, rather than developing the inputs needed to model the whole system present in Prince William Sound, and (2) disassociate the results from existing regulatory measures of planning standards. Nuka Research prepared a summary of the workshop, which was circulated as a draft prior to being finalized with comments from participants incorporated. (See Appendix A.)

PWSRCAC circulated two drafts of this report to workshop participants for review and input. Comments were incorporated and informed the analysis of the primary/secondary storage transfer process (conducted after the first-round draft review). The project benefited from input from Alyeska Pipeline Services Company (APSC).

1.3 Scope

Participants at the November 2015 project design workshop developed the following research question, which was applied to nine recovery systems (three open-water and six nearshore) as agreed with the group.

What is the optimal configuration of containment, skimming, and storage (primary and secondary) for nine PWS recovery systems (three open-water and six nearshore) over a five-day simulated spill response assuming favorable weather conditions?

In this project, we sought to **optimize** recovery system performance in a favorable spill scenario by aligning each system's containment capacity with its recovery capacity while also maximizing oil recovery. Oil spill recovery systems could theoretically be optimized for other purposes, such as reducing costs, personnel, or vessel requirements.

A note regarding model outputs and practical implications

This report presents the outputs from several models. While some practical considerations are noted, this study does not include a full examination of the real-world implications of the results. The authors note that practical considerations (e.g., the size skimmer a vessel can support or the speed at which a particular system can advance) are of paramount importance and must be fully assessed and tested prior to actually making any system changes.

1.4 Organization of this Report

This report provides general background on the Prince William Sound response system and the models used for this analysis (Section 2). Section 3 describes the methodology and key inputs applied to study each of the nine recovery systems. Sections 4 and 5 present the results of the optimization analysis for open-water and nearshore systems, respectively. Section 6 presents the results of the analysis of primary/secondary storage transfer. Finally, Section 7 provides a summary and discussion of the findings.

1.5 Background on Marine Oil Spill Fate and Behavior

Understanding the methodology and results presented in this report requires a basic understanding of what happens to oil spilled to the marine environment and how it is recovered using mechanical recovery techniques. Appendix B provides a brief description of oil spill fate and behavior and the basics of mechanical oil spill response.

2 Background

This section provides background information on the on-water recovery systems in PWS and the oil spill models used in the analysis.

2.1 Prince William Sound Oil Spill Response System

APSC/SERVS has developed a robust oil spill response capability within Prince William Sound. The response system is based on two complementary and supporting components – open-water and nearshore oil recovery systems:

- The **open-water response systems** are primarily high volume skimmers based on large tank barges maneuvered by tugs. These systems are designed to encounter and recover oil near the source of the spill before it spreads and thins. The open-water systems are designed to operate in sea states up to six feet (SL Ross Environmental Research, Ltd., 2013).

- The **nearshore response systems** are fishing vessels with crews trained for spill response. These systems have less capacity than the open-water systems but can be widely distributed and can operate in shallow water. The nearshore response is designed to encounter and recover oil that escapes the open-water systems and threatens sensitive areas. The nearshore recovery systems are designed to operate in sea states up to three feet.

One important difference in the open-water and nearshore recovery systems is the storage of recovered fluids. Open-water skimmers are deployed from large tank barges so recovered fluids are transferred directly into the barges. For two of the open-water systems, the volume of the barge tanks is large enough that there is no need to offload the fluids during the first few days of the spill (the *Valdez Star* is the exception, with the implications discussed in the results). The nearshore skimmers are operated from fishing vessels, which do not have built-in tanks for recovered fluids. The nearshore systems initially store recovered fluids in small barges. Once these fill, collected fluids are offloaded to a secondary storage barge so the small barge can continue to be used for skimming.

2.2 Oil Spill Models

Nuka Research used a combination of publically available and customized numeric models to analyze the recovery systems and options for their optimization. For the analysis of containment and skimming capability, a numeric model was developed based on the Response Options Calculator (ROC), Recovery System Calculator (RSC), and Estimated Recovery System Potential (ERSP) calculator. Genwest Systems, Inc. developed all three models. The ROC, RSC, and ERSP use similar algorithms to simulate simplified oil spill response scenarios and estimate the recovery potential for one or more recovery systems.

2.2.1 Response Options Calculator (ROC)

The ROC models oil weathering and spreading and estimates the outcomes of on-water mechanical recovery, dispersant application, and in-situ burning. (The analyses discussed here apply the model to mechanical recovery operations only.) Based on oil type, wind speed, and water temperature, ROC generates outputs characterizing the weathering and spreading of a slick for every hour up to five days. This is then incorporated into the modeling of the response operations to generate hourly estimates of oil recovered, evaporated, and remaining on the water for the same time period. Recovery system inputs include speed, swath width, decanting, skimmer type and pump rate, and decant pump rate as well as information about storage and offloading (Dale, 2011). ROC can be used to determine best-case mechanical recovery estimates in marine oil spills, incorporating transit times, spill timing, seasonality, and simplified environmental conditions (Mattox et al., 2014).

2.2.2 Estimated Recovery System Potential (ERSP) calculator

The ERSP calculator was developed in 2012 for the U.S. Bureau of Safety and Environmental Enforcement (BSEE) "with the intent of reinforcing incentives for creating and acquiring more effective oil recovery systems" (BSEE and Genwest Systems, Inc., 2012). The ERSP calculator does not model oil weathering the way ROC does, but instead uses nominal slick thicknesses for each day based on hundreds of ROC weathering outputs for different oils.

The ERSP calculator incorporates system-related parameters similar to ROC. The ERSP calculator's outputs are estimated oil recovery for days 1, 2, and 3 (BSEE and Genwest Systems, Inc., 2012).

2.2.3 Recovery System Calculator (RSC)

The RSC is similar to the ERSP, but it allows the user to identify a variable parameter and run a sensitivity analysis for that variable. RSC allows the user more control of the input parameters including slick thickness, but uses the same calculations as ERSP. (Genwest Systems, Inc., n.d.).

2.2.4 Automated Data Inquiry for Oil Spills (ADIOS) II

Automated Data Inquiry for Oil Spills (ADIOS) II is an oil-weathering model developed by NOAA (NOAA, 2016a). It was used as a comparison to the oil weather estimates developed by the ROC oil-weathering model.

2.2.5 Considerations regarding recovery model results

As with any model, the ROC, RSC, and ERSP do not actually predict what would happen in an oil spill. The calculators are simplified representations of highly complex systems. However, they incorporate enough complexity to allow analysts to consider the effect of oil type, a limited set of environmental factors, and variations in response force composition on a marine oil spill response. These tools provide a substantially more realistic and nuanced means of analyzing a recovery system than a simple measurement of boom length, pump rates, and storage capacity (BSEE and Genwest Systems, Inc., 2012; Mattox et al., 2014). The models also allow for the generation of multiple scenario outputs for comparative purposes.

For readability, we refer simply to "oil recovered" or "fluids recovered," though the reader should recognize that these are essentially best case estimated volumes since the calculations do not incorporate all possible factors that may negatively impact oil recovery operations. The results would more appropriately be considered to be "maximum potential oil recovered" or "maximum potential fluid recovered."

The following assumptions are inherent to the use of the models, because they exclude some of the many factors that will affect on-water recovery or the ultimate outcome of a spill response:

- Oil (and emulsion) remains on the surface of the water or evaporates. Submergence, dissolution, and shoreline stranding are not incorporated.
- Debris (including ice) does not impact the response.
- All equipment and vessels are well maintained and operational for the time periods applied. The potential for technical difficulties is not analyzed.
- Response personnel are trained and proficient to operate the systems as they are described (i.e., in the appropriate booming configurations, vessel maneuvers, etc.).
- Responders have accurate and timely information about slick movement.

The models also are not truly geographically specific: they incorporate some parameters that may be drawn from assumptions related to a single location (such as water temperature and wind speed), but do not include ocean or tidal currents, salinity, shoreline interactions, or other features of a particular location that may impact a response. Thus, the models also do not predict spill trajectory or the potential for shoreline impacts.

3 Methodology and Inputs

This section describes the methodology applied for the analysis and the inputs used. Nuka Research used a three-step approach to answer the research question in Section 1.3:

Step 1. Model spreading and weathering of a hypothetical oil slick over five days. This was implemented using the ROC and verified using ADIOS II. This modeling generated slick thickness, percentage of water in emulsification, viscosity, and area covered. Slick thickness and emulsification were *averaged* for each operating period and used as inputs for Step 2.

Step 2. Analyze each *recovery system* (containment, skimming, and primary storage) to identify modifications to optimize the system and maximize the amount of oil collected. This was implemented using the ERSP calculations modified to the estimated slick conditions for each operating period. This modeling generated estimated quantities of oil, water, and emulsified water collected for each recovery system. Variations on the recovery systems were then adjusted to understand the effect of modifications on estimated oil recovery.

Step 3. Analyze primary/secondary storage transfer process for nearshore recovery systems. Nuka Research developed a numerical model that analyzed the movement of fluids recovered by the nearshore recovery system. The model considers the flow of recovered fluids from skimmers to primary storage devices (mini-barges), and to a secondary storage barge. The model calculated the time it would take to implement each step in this process and compared the quantity of potential oil recovery based on different numbers of skimmers, mini-barges, offload stations, and the distance skimmers travel from the secondary storage device. This analysis assumed that the secondary storage would not be filled.

3.1 Step 1: Hypothetical Oil Slick

In order to model the recovery systems, a hypothetical oil slick needed to be established to generate estimates of slick thickness and emulsification over time. (The model also shows the amount of oil evaporated over time, which is not a direct input to the modeling of the recovery system but does impact oil viscosity and the amount of oil remaining on the water.)

Based on input from the workshop convened by PWSRCAC, the inputs shown in Table 3-1 were used for parameters related to slick weathering. The inputs are based on conditions favorable to a response. (Generally, as the weather degrades, the effectiveness of the recovery system declines; if weather conditions exceed system limits, then no response is possible.)

Table 3-1. Spill scenario inputs

Parameter	Input used	Explanation
Oil type	Alaska North Slope crude	• Chemical properties of oil based on a 2015 analysis (SL Ross Environmental Research, Ltd., 2015)
Spill size	150,000 bbl	• This is the equivalent of about two tanks in a typical tanker transiting Prince William Sound (based on input from the Design Workshop) • Affects modelled slick spreading and thickness
Location	Tanker lanes abeam Naked Island in Prince William Sound	• Location relates to hours of daylight/darkness (in combination with date) • Wind speed and water temperature taken from nearest data source
Date	March 19	• Spring equinox • Relates to hours of daylight/darkness (in combination with location) • Wind speed and water temperature based on monthly data
Time	2 AM	• Chosen by group • Favorable for oil recovery because response mobilizes during darkness and reaches oil in daylight while slick is still fairly fresh
Wind speed	5 kt.	• Approximately 25th percentile for March • Based on recordings taken from West Orca Bay Buoy (46060) • Favorable for oil recovery
Water temperature	4.5°C	• Median for spring • Based on personal communication with Scott Pegau, Oil Spill Recovery Institute
Duration of response	5 days	• Longest scenario option in modeling tools used (note that the spill itself is instantaneous)

The ROC was used to model oil weathering over the 5-day spill response scenario. These results were used to calculate an average slick thickness, average percentage of water in emulsification, and average viscosity for each of the 10 operational periods (OP) for use in the analysis of each recovery system.

3.1.1 Oil weathering

Based on input from the group at the November 2015 workshop, a 2015 analysis of Alaska North Slope crude (SL Ross Environmental Research, Ltd., 2015) was used as the oil in the scenario. [1] This analysis provided the API gravity (31.9), viscosity (9 cSt at 20°C), pour point (-13°C), and distillation cuts. It also found that after two days, the slick would have a water content of about 29% due to emulsification (SL Ross Environmental Research, Ltd., 2015). When the oil properties were entered into ROC, it predicted that emulsification would begin much sooner, but to keep with the chosen oil specifications, the model outputs were made to resemble the SL Ross study by delaying the start of emulsification so approximately 29% water emulsified at Hour 48, after which ROC showed that emulsification would increase much faster than the SL Ross study found. The slick was also modeled using ADIOS II, which validated the ROC results. Both the ROC and ADIOS II weathering models predict a much more rapid emulsification of the oil than the SL Ross Environmental Research, Ltd. analysis indicates.

The benzene levels[2] associated with the slick were also examined to determine whether the area would be considered safe to enter when recovery operations were expected to begin. It was determined that the levels could be expected to be low enough that personnel operating open-water recovery systems would need to use respirators during the first and second operational periods, but that operations could begin on the timeline in the scenario for this analysis (Hour 6).

3.1.2 Slick characteristics

Figures 3-1 to 3-5 show the ROC outputs for oil thickness, water content in emulsification, viscosity, area covered by the slick,[3] and volume of oil evaporated over five days. These figures illustrate the importance of mounting the response as quickly as possible, as the slick begins to spread rapidly. In each figure, the marked change with the onset of emulsification at Hour 40 is clearly visible. At this point, emulsification begins to increase rapidly up to almost 80% at the end of the five-day scenario (Figure 3-2), which causes an increase in slick thickness (Figure 3-1) and viscosity (though viscosity remains low generally, as shown in Figure 3-3).

The recovery systems are analyzed based on operational periods, discussed in Section 3.2.1. The average slick thickness for each operational period was calculated based on ROC outputs. The average slick thickness of OP 2 was calculated for the time after open water recovery began at 8 AM.

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[1] The companies shipping oil through Prince William Sound commission a study every five years to analyze how oil properties are changing. This is done in conjunction with the Tanker C-plan review cycle.

[2] As modeled by ADIOS II

[3] Area coverage has implications for secondary storage. The other figures show information that was used to develop inputs for the recovery system optimization analysis excluding secondary storage.

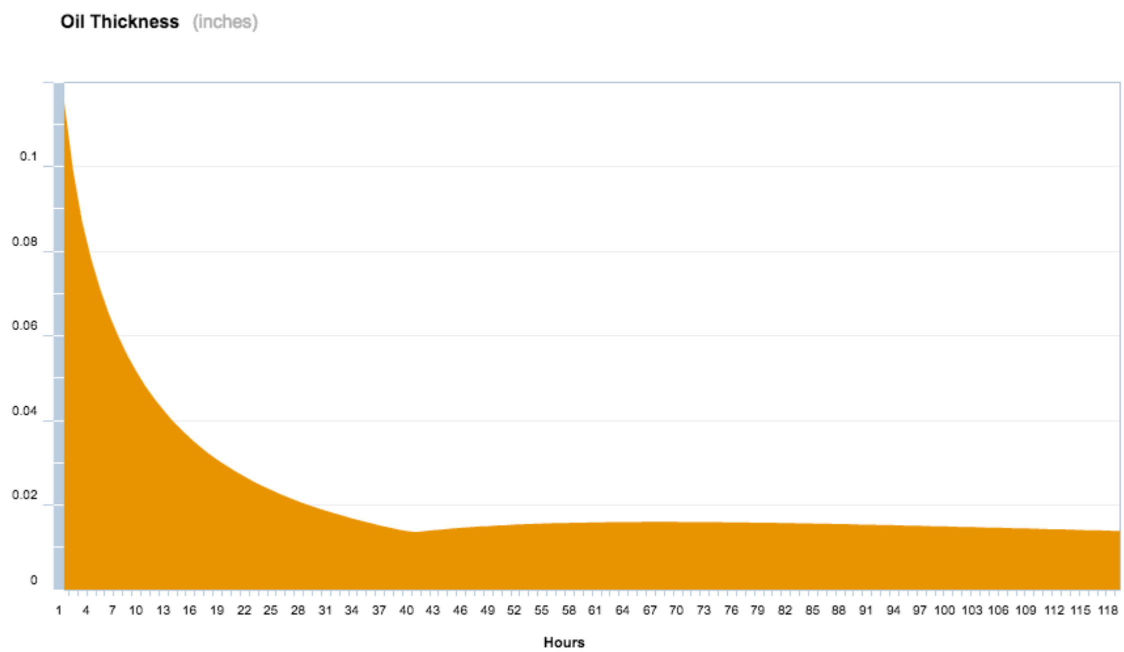


Figure 3-1. Oil thickness (inches) over five days based on ROC (ROC output)

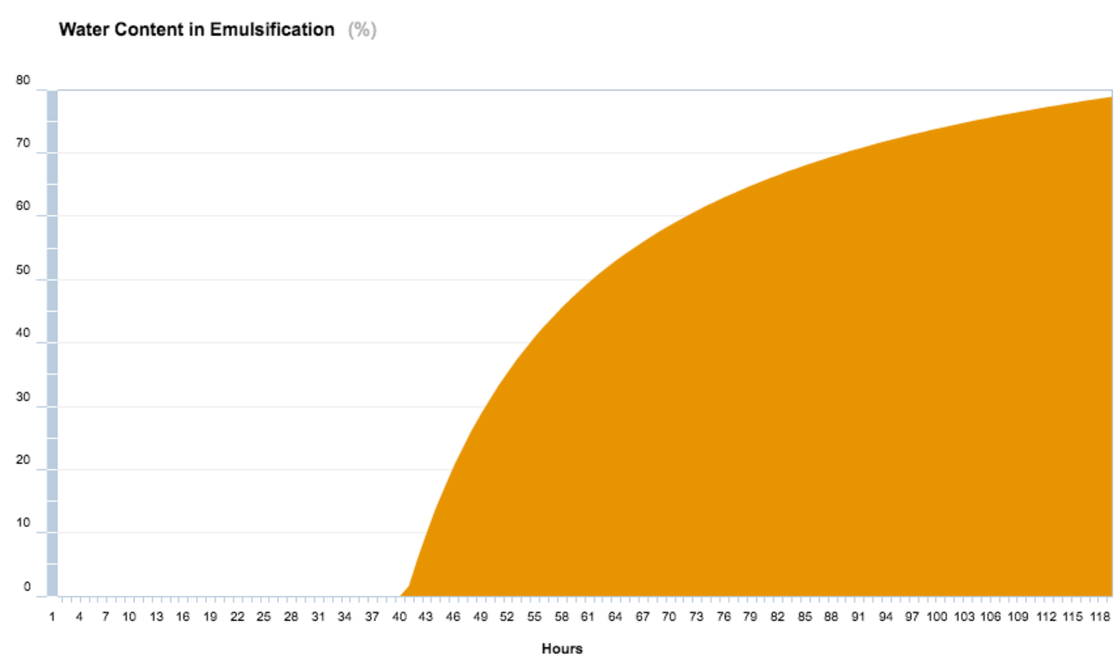


Figure 3-2. Water content in emulsification (%) over five days based on ROC (ROC output)

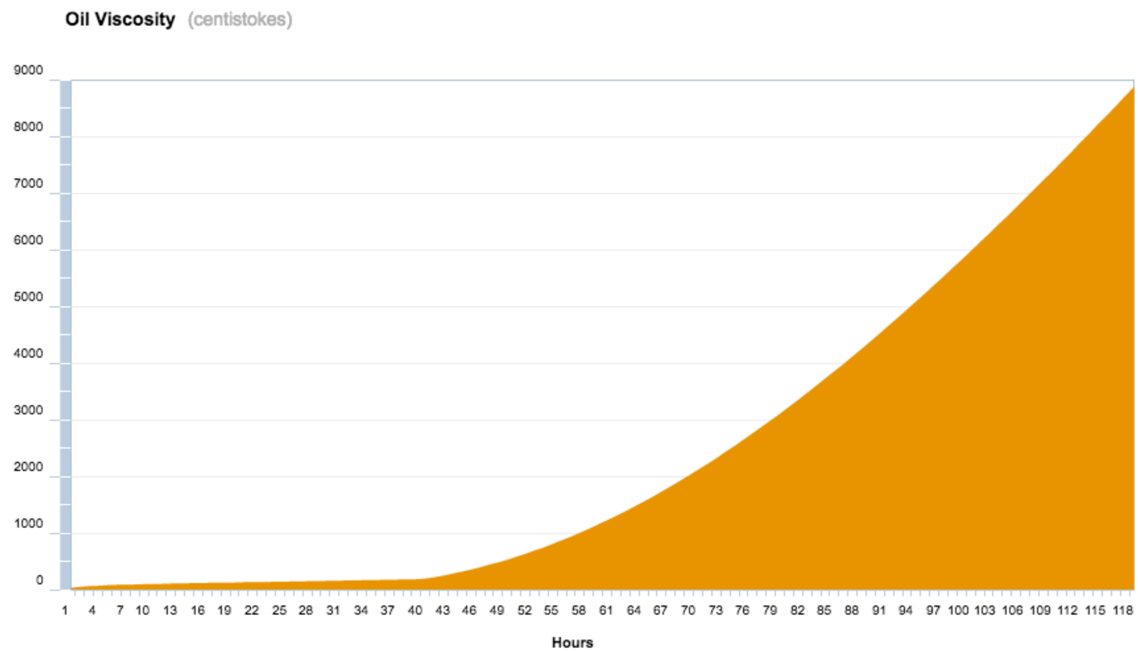


Figure 3-3. Viscosity (centistokes) over five days based on ROC (ROC output)

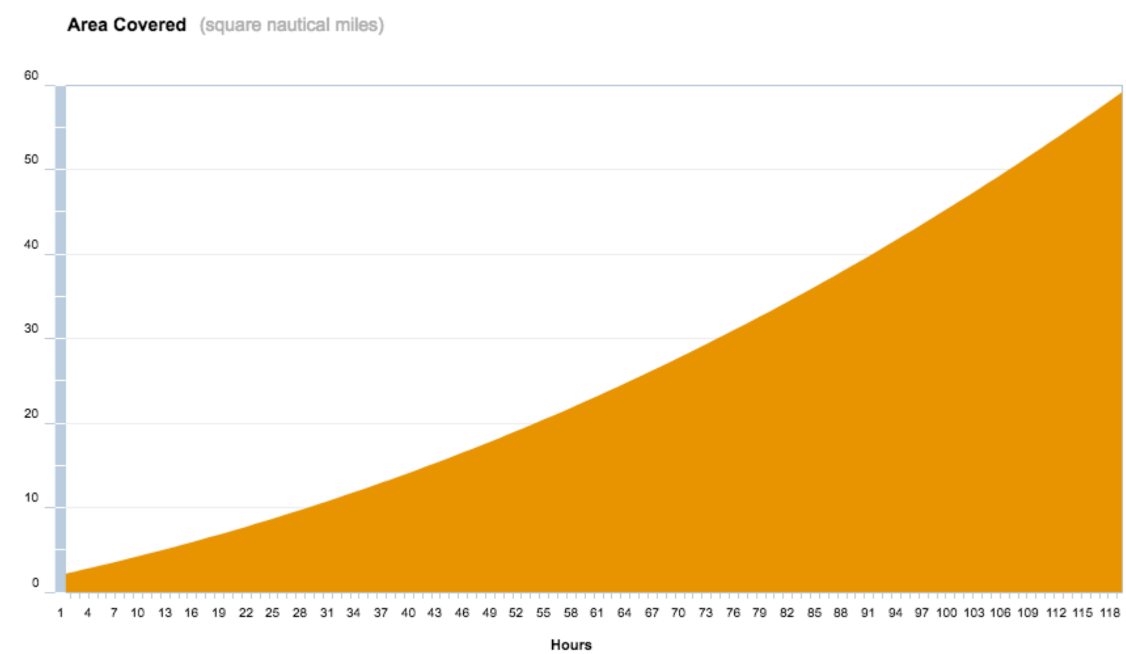


Figure 3-4. Area covered (square nautical miles) by slick over five days based on ROC (ROC output)

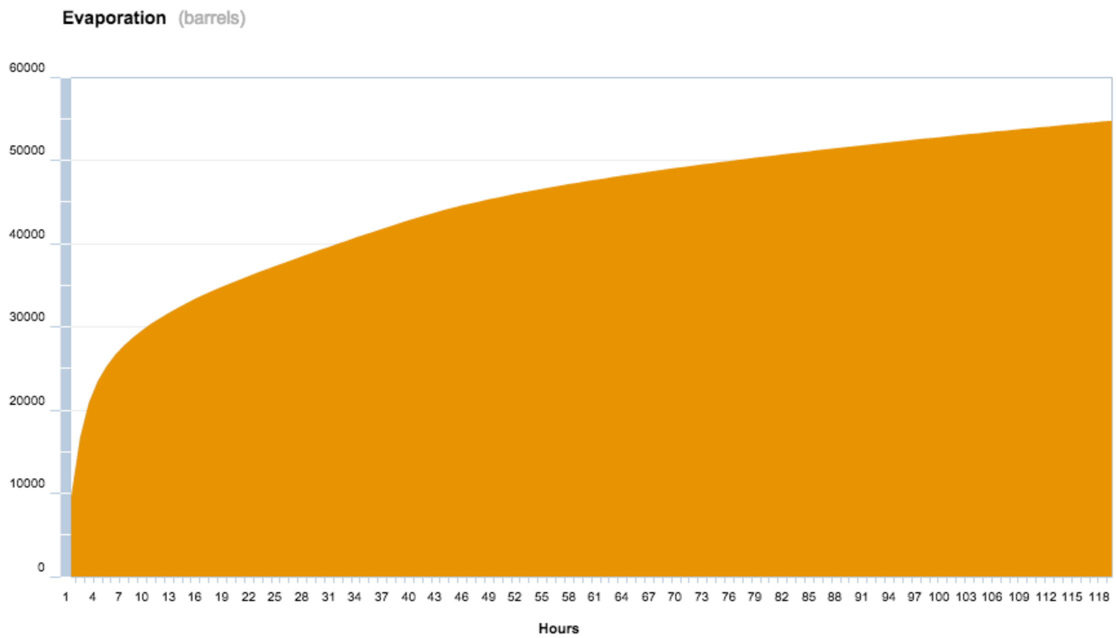


Figure 3-5. Volume of slick evaporated (bbl) five days based on ROC (ROC output)

Table 3-2. Average slick conditions for each operational period. Operational periods in darkness are shaded.

Operational Period	Average Slick Thickness (inches)	Average Viscosity (centistokes)	Average Water Content in Emulsion
1*	0.1869	44	0%
2	0.0439	105	0%
3	0.0254	137	0%
4	0.0163	174	1%
5	0.0148	428	24%
6	0.0158	1,133	47%
7	0.0160	2,176	60%
8	0.0157	3,549	67%
9	0.0152	5,164	72%
10	0.0145	6,993	76%

**No recovery occurs during OP1.*

3.2 Step 2: Model Recovery Systems for Containment and Recovery Optimization

Containment and recovery were modeled for nine recovery systems were to estimate fluid recovered (oil, emulsified water, and free water) for each operational period and the total across all operational periods. The initial model runs were based on the systems as they are described in the SERVS Technical Manual and manufacturer specifications. These provided the base case for each system. The necessary specifications were based on the calculator parameters, and are described in this section.

3.2.1 Operational periods and response timing

Based on the spill time of 2 AM, 10 operational periods (OP) were established. They are labeled OP 1 through OP 10 in Figure 3-6. The OP are designed to maximize the use of daylight, with 14-hour periods during daylight and 10-hour periods in darkness. (OP 1 occurs in darkness from the 2 AM spill time until daylight begins at 6 AM.)

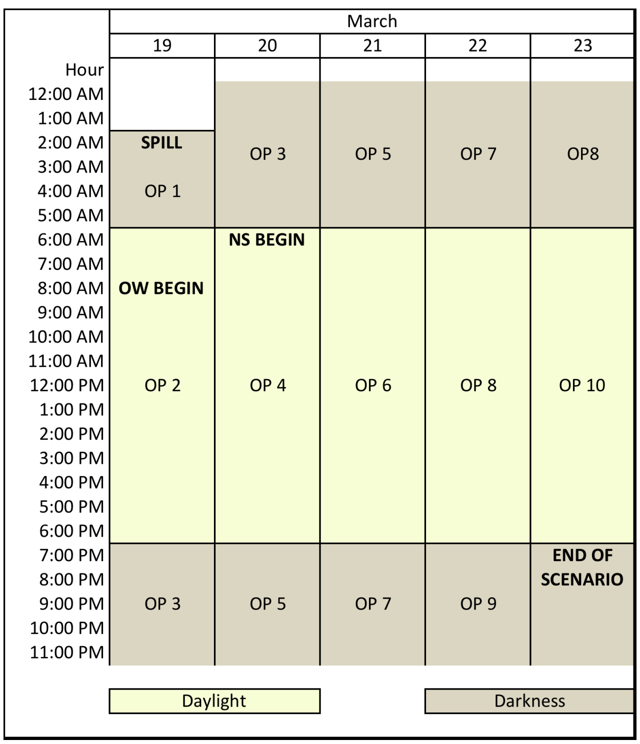


Figure 3-6. OP 1-10, extending over five days (March 19-23)

Open-water recovery systems are assumed to start at Hour 6 (after the spill), which is at 8 AM during OP 2. This timing is a little earlier than these recovery systems would arrive on scene according to the PWS Tanker C-plan (RPG, 2013).[4] These systems are assumed to operate 20 hours per day, with 4 hours for maintenance taking place during the OP in darkness. In the PWS

[4] For the study, open-water systems start recovery at Hour 6; the average time in the PWS Tanker C-plan is 7.7 hours after the spill.

Tanker C-plan, these systems are assumed to operate in darkness some of the time.[5] We assume a reduced throughput efficiency to account for the increased difficulty of locating oil and maintaining position in darkness.[6]

According to the PWS Tanker C-plan, the nearshore recovery systems will be ready to deploy on average at Hour 24. However, this is at 2 AM in the scenario and these systems do not conduct recovery operations in darkness, so for this study they deploy at the start of OP 4 (6 AM on March 20).

3.2.2 Recovery systems inputs

Nine recovery systems were analyzed: three open-water and six nearshore systems. Tables 3-2 and 3-3, below, show the containment, skimmers, and primary storage associated with each system. Figures 3-7 to 3-9 show more details about the three open-water recovery systems studied.

Table 3-2. Summary of open-water recovery systems

Name	Containment	Skimmer(s)	Primary Storage
TransRec/GrahamRec Barge	U-boom and Gated U-boom after OP 4	TransRec 350 Weir (2) GrahamRec Weir (1)	104,000 bbl barge
Current Buster® Barge	Current Buster® 8 (CB8)	Crucial 100/30 Disc (2)	104,000 bbl barge
Valdez Star	Gated U-boom	JBF Dynamic Incline Plane Skimmer	On-board and 12,000 bbl barge

[5] Operational periods were designed to facilitate analysis of oil recovery during night operations for the open-water recovery systems. They are based on daylight and darkness as determined by civil twilight from the Naval Observatory estimates for this latitude and longitude. Night operations are not a regular practice in marine oil spill response operations, due to difficulties in encountering and staying in the thickest part of the slick, lighting on vessels, staffing two shifts, and safety (Genwest Systems, Inc. 2012); however, night operations are part of the planning for spill response in Prince William Sound and are periodically exercised as such.

[6] Throughput efficiency was reduced to 50% to reflect the increased difficulty of locating the oil slick, maneuvering, and maintaining boom configuration during darkness.

Open-water recovery systems:

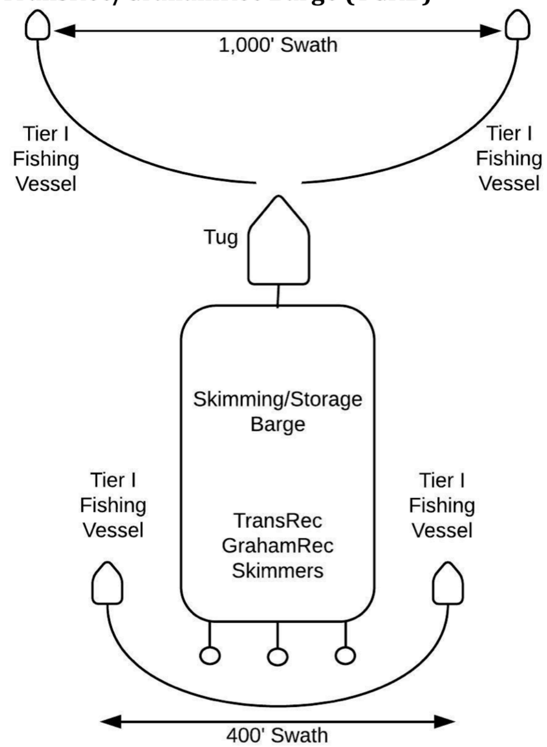
- **TransRec/GrahamRec Barge (TGRB):** This system is a combined skimming/storage barge pulled by a single tug as described in the SERVS Technical Manual (2013).[7] Three weir skimmers are available for deployment on the barge (two TransRec 350 and one GrahamRec). The PWS Tanker C-plan stipulates that the GrahamRec will be deployed only during the first 12 hours of skimming, so in this study it is utilized only in OP 2. Two support vessels tow boom for containment, with additional containment provided by gated U-boom (towed by two additional support vessels) that arrives on scene at Hour 24 (described in PWS-OW-5 in the 2013 SERVS Technical Manual). For our scenario, the gated U-boom is deployed beginning in OP 4.

- **Current Buster® Barge (CBB):** SERVS is developing a new open-water recovery system based on the same primary storage barges as used in the TGRB systems, but changing the associated containment system to two Current Buster® 8s (CB8) and the recovery system to a pair of Crucial 100/30 oleophilic disc skimmers. This system is not documented in the 2013 PWS Tanker C-plan, but specifications were taken from personal communications with SERVS, published drill reports, and equipment manufacturer publications. The system requires two support vessels to tow the outboard ends of the CB8s.

- ***Valdez Star* with Gated U-boom (VS):** The *Valdez Star* is a self-propelled skimming vessel that uses a JBF dynamic inclined plane skimmer. It is based on the description of PWS-OW-2 in the SERVS Technical Manual (2013). It can either skim independently or can be used – as it is here – in conjunction with gated U-boom towed by two support vessels (PWS-OW-5).

[7] In the 2013 SERVS Technical Manual, this is PWS-OW-1.

TransRec/GrahamRec Barge (TGRB)



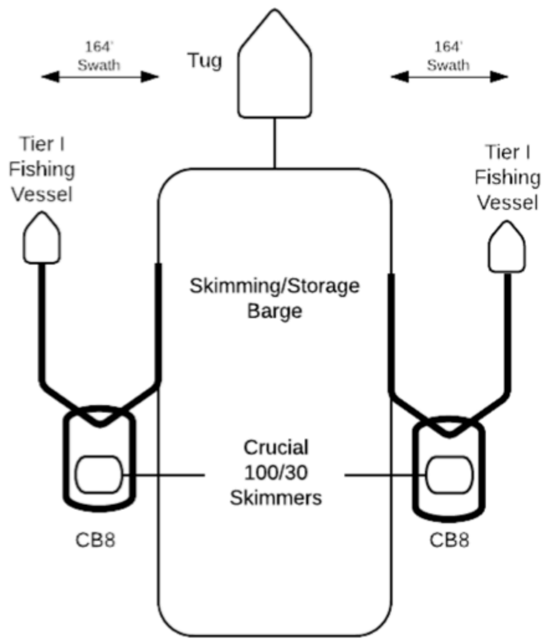
RESOURCES	
No.	*Identification*
1	Skimming/storage barge
2	TransRec weir skimmer
1	GrahamRec weir skimmer
1,200/4,200*	Open water boom
1	Tug (maneuvering barge)
2/4*	Tier I fishing vessels
1	Decanting pump/equipment
1	Cargo offload pump

INPUTS	
Skimmer Group	C
Throughput efficiency daylight	75%
Throughput efficiency darkness	50%
Oil Recovery efficiency	22.6%
Skimming Speed (knots)	0.7
Swath Width (feet) OP 2-3	400
Swath Width (feet) OP 4-10	1,000
Primary Storage (bbl)	104,000
Skimmer Pump Rate (bph) OP 2	6,561
Skimmer Pump Rate (bph) OP 3-10	4,374
Discharge Pump Rate (bph)	15,000
Decant Pump Rate (bph)	10,000
Offload Time (hh:mm)	09:00
NOTES: Open Water. Based on SERVS TM, Section 4.1 PWS-OW-01. Deployed at hour 6. * Necessary for Gated U-boom added in Op 4	

Figure 3-7. Schematic and specifications for TransRec/GrahamRec Barge system[8]

[8] "Skimmer group" refers to the type of skimmer. This is based on groupings defined in ROC.

Current Buster Barge (CBB)



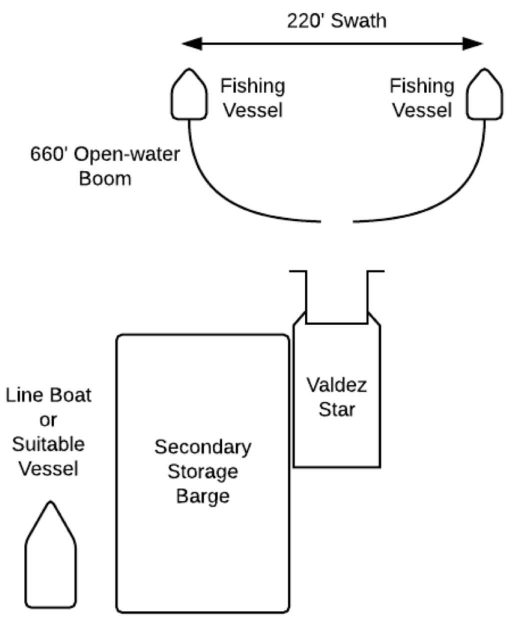
RESOURCES	
No.	*Identification*
1	Skimming/storage barge
2	Crucial 100/30 oleophilic disc skimmer
2	CB8 containment system
1	Tug (maneuvering barge)
2	Tier I fishing vessel
1	Decanting equipment
1	Cargo offload pump

INPUTS	
Skimmer Group	A
Throughput efficiency	80%
Oil Recovery efficiency	70%
Skimming Speed (knots)	2.5
Swath Width (feet)	328
Primary Storage (bbl)	104,000
Skimmer Pump Rate (bph) - ADEC	1,796
Skimmer Pump Rate (bph) - USCG	2,626
Discharge Pump Rate (bph)	15,000
Decant Pump Rate (bph)	10,000
Offload Time (hh:mm)	09:00

NOTES: Open Water, Based on drill reports. Swath and skimmer pump rate based on two units.

Figure 3-8. Schematic and specifications for Current Buster® Barge system

***Valdez Star* with Gated U-boom (VS)**



RESOURCES	
No.	*Identification*
1	Storage barge
1	Valdez Star DIP skimmer
1	Line boat or VOO
1	Decanting Equipment
1	Cargo transfer pump

INPUTS	
Skimmer Group	B
Throughput efficiency	75%
Oil Recovery efficiency	35%
Skimming Speed (knots)	1.0
Swath Width (feet)	220
Primary Storage (bbl)	13,090
Skimmer Pump Rate (bph)	1,429
Discharge Pump Rate (bph)	1,754
Decant Pump Rate (bph)	0
Offload Time (hh:mm)	9:45
NOTES: Based on SERVS TM, Section 4.2 PWS OW-2 Table 12-20, Valdez Star Transfer 1,429 bph which limits skimming pump rate of 2,000 bph	

Figure 3-9. Schematic and specifications for Valdez Star *system*

Table 3-3 summarizes the nearshore recovery systems studied, which represent typical combinations of containment, skimming, and primary storage resources based on the inventory in Prince William Sound. The specifications for each system were defined to use as inputs to the calculations. Table 3-4 lists the system inputs and sources. Specifications for these are provided in Figures 3-11 to 3-16. Each of the nearshore systems studied represents one of six possible configurations resulting from the combination of three containment systems -- Current Buster® 4 (CB4), Current Buster® 2 (CB2), and J-boom -- with one of the two different skimming systems (Desmi Terminator Weir and Crucial 13/30 Disc).[9] These systems are designed to be deployed from fishing and other vessels of opportunity, as pictured in Figure 3-10. For each system, a small barge is towed alongside the skimming vessel to serve as primary storage.

[9] There are different types of weir skimmers in SERVS' inventory. The Desmi Terminator was selected as an example.

Table 3-3. Summary of nearshore recovery systems (referred to by containment/skimmer type in remainder of report)

Containment	Skimmer(s)	Primary Storage
Current Buster® 4 (CB4)	Desmi Terminator Weir	Mini-barge (237 bbl)
Current Buster® 4 (CB4)	Crucial 13/30 Disc	Mini-barge (237 bbl)
Current Buster® 2 (CB2)	Desmi Terminator Weir	Micro-barge (114 bbl)
Current Buster® 2 (CB2)	Crucial 13/30 Disc	Micro-barge (114 bbl)
J-boom	Desmi Terminator Weir	Mini-barge (237 bbl)
J-boom	Crucial 13/30 Disc	Mini-barge (237 bbl)

Table 3-4. Inputs and associated sources for recovery system specifications used to analyze optimization of containment/recovery (not including secondary storage)

Input	Sources
Containment	
Skimming speed	SERVS Technical Manual (APSC, 2013) and best professional judgment of the authors
Swath width	SERVS Technical Manual
Throughput efficiency	Genwest and Spilltec, 2012 and best professional judgment of the authors
Recovery	
Skimmer pump rate	SERVS Technical Manual; Wood, 2015; Caplis, 2013; equipment manufacturers' data
Recovery efficiency	ADEC regulations and guidance documents, manufacturers' data
Storage	
Primary storage (volume)	SERVS Technical Manual
Decant pump rate	SERVS Technical Manual and personal communication with SERVS
Decant efficiency	SERVS Technical Manual, ADEC regulations and guidance documents

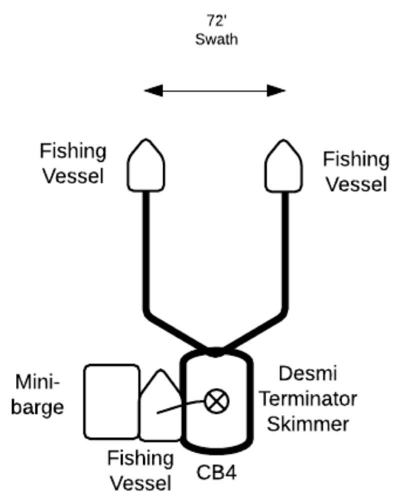
Figure 3-10. Example nearshore recovery system using Current Buster® containment deployed by three fishing vessels (Nuka Research photo)

The nearshore systems arrive on scene at Hour 24 and begin recovery operations at the beginning of OP 4 (the first daylight after they arrive). Because they only operate during daylight hours for the purpose of this study, the analysis only considers oil recovery during four 14-hour operations periods to maximize use of daylight hours (OP 4, 6, 8, and10)[10]. All systems are assumed to use mini-barges (237 bbl) or micro-barges (114 bbl) for primary storage. These are replaced when filled with collected fluids (with 15 minutes of downtime in skimming assumed). Decanting is not assumed in Step 2 of the analysis.

In Step 2, the two CB2 systems are the only nearshore systems that use micro-barges for primary storage instead of mini-barges. This means they can only recover 114 bbl of fluid instead of 237 bbl before needing to pause recovery operations to change out primary storage.

[10] The Tanker C-plan uses 12-hour operational periods. For this study, we chose to maximize the use of daylight by using 14-hour operational periods.

CB4, Weir Skimmer

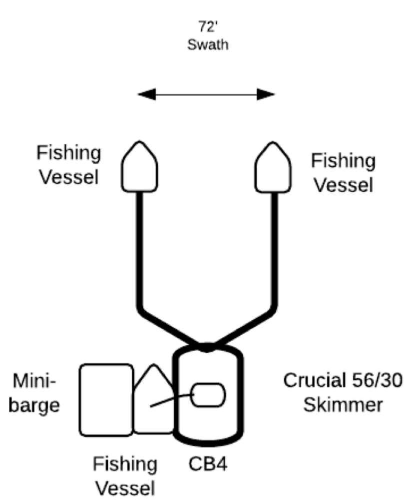


RESOURCES	
No.	*Identification*
1	CB 4 containment system
1	Desmi Terminator weir skimmer
1	Mini barges
3	Tier I/II fishing vessel
0	Decanting equipment
1	DOP 250 cargo offload pump

INPUTS	
Skimmer Group	C
Throughput efficiency	80%
Oil Recovery efficiency	20%
Skimming Speed (knots)	2.5
Swath Width (feet)	72
Primary Storage (bbl) (95%)	237
Skimmer Pump Rate (bph)	629
Discharge Pump Rate (bph)	625
Decant Pump Rate (bph)	17
Offload Time (hh:mm)	00:24
NOTES: Protected Water. Based on SERVS TM, Section 5.5 PWS-NS-5	

Figure 3-11. Specifications used for CB4/weir skimmer

CB4, Disc Skimmer

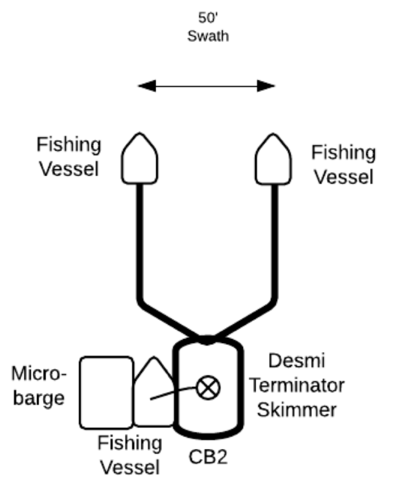


RESOURCES	
No.	*Identification*
1	CB 4 containment system
1	Crucial 13/30 oleophilic disc skimmer
1	Mini barges
3	Tier I/II fishing vessel
0	Decanting equipment
1	DOP 250 cargo offload pump

INPUTS	
Skimmer Group	A
Throughput efficiency	80%
Oil Recovery efficiency	70%
Skimming Speed (knots)	2.5
Swath Width (feet)	72
Primary Storage (bbl) (95%)	237
Skimmer Pump Rate (bph) - ADEC	113
Skimmer Pump Rate (bph) - USCG	197
Discharge Pump Rate (bph)	625
Decant Pump Rate (bph)	17
Offload Time (hh:mm)	00:24
NOTES: Protected Water. Based on SERVS TM, Section 5.5 PWS-NS-5	

Figure 3-12. Specifications used for CB4/disc skimmer

CB2, Weir Skimmer

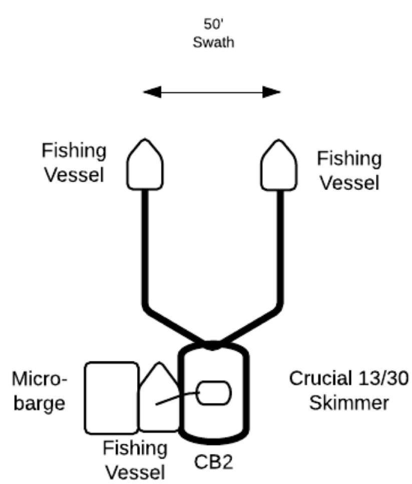


RESOURCES	
No.	*Identification*
1	CB 2 containment system
1	Desmi Terminator weir skimmer
1	Micro barges
3	Tier I/II fishing vessel
0	Decanting equipment
1	DOP 250 cargo offload pump

INPUTS	
Skimmer Group	C
Throughput efficiency	80%
Oil Recovery efficiency	20%
Skimming Speed (knots)	2.5
Swath Width (feet)	50
Primary Storage (bbl) (95%)	114
Skimmer Pump Rate (bph)	629
Discharge Pump Rate (bph)	625
Decant Pump Rate (bph)	17
Offload Time (hh:mm)	00:24
NOTES: Protected Water. Based on SERVS TM, Section 5.5 PWS-NS-5	

Figure 3-13. Specifications used for CB2/weir skimmer

CB2, Disc Skimmer

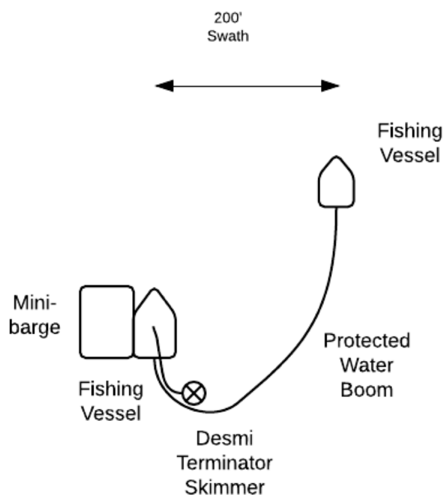


RESOURCES	
No.	*Identification*
1	CB 2 containment system
1	Crucial 13/30 oleophilic disc skimmer
1	Micro barges
3	Tier I/II fishing vessel
0	Decanting equipment
1	DOP 250 cargo offload pump

INPUTS	
Skimmer Group	A
Throughput efficiency	80%
Oil Recovery efficiency	70%
Skimming Speed (knots)	2.5
Swath Width (feet)	50
Primary Storage (bbl) (95%)	114
Skimmer Pump Rate (bph) - ADEC	113
Skimmer Pump Rate (bph) - USCG	197
Discharge Pump Rate (bph)	625
Decant Pump Rate (bph)	17
Offload Time (hh:mm)	00:24
NOTES Protected Water. Based on SERVS TM, Section 5.5 PWS-NS-5	

Figure 3-14. Specifications used for CB2/disc skimmer

J-Boom, Weir Skimmer

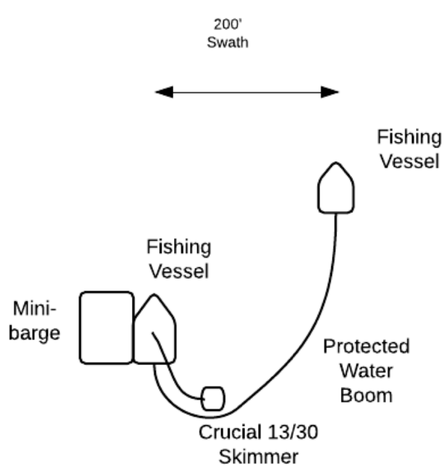


RESOURCES	
No.	*Identification*
500	Protected water containment boom
1	Desmi Terminator weir skimmer
1	Mini barges
2	Tier I/II fishing vessel
0	Decanting equipment
1	DOP 250 cargo offload pump

INPUTS	
Skimmer Group	C
Throughput efficiency	75%
Oil Recovery efficiency	20%
Skimming Speed (knots)	0.7
Swath Width (feet)	200
Primary Storage (bbl) (95%)	237
Skimmer Pump Rate (bph)	629
Discharge Pump Rate (bph)	625
Decant Pump Rate (bph)	17
Offload Time (hh:mm)	00:24
NOTES: Protected Water. Based on SERVS TM, Section 5.4 PWS NS-4	

Figure 3-15. Specifications used for J-boom/weir skimmer

J-Boom, Disc Skimmer



RESOURCES	
No.	*Identification*
500	Protected water containment boom
1	Crucial 13/30 oleophilic disc skimmer
1	Mini barges
2	Tier I/II fishing vessel
0	Decanting equipment
1	DOP 250 cargo offload pump

INPUTS	
Skimmer Group	A
Throughput efficiency	75%
Oil Recovery efficiency	20%
Skimming Speed (knots)	0.7
Swath Width (feet)	200
Primary Storage (bbl) (95%)	237
Skimmer Pump Rate (bph) - ADEC	113
Skimmer Pump Rate (bph) - USCG	197
Discharge Pump Rate (bph)	625
Decant Pump Rate (bph)	17
Offload Time (hh:mm)	00:24
NOTES: Protected Water. Based on SERVS TM, Section 5.4 PWS NS-4	

Figure 3-16. Specifications used for J-boom/disc skimmer

3.2.3 Optimizing systems for containment and recovery

The ERSP model generates an estimate for each recovery system of the amount of oil, oil/water emulsion, and free water collected for each operational period and for the total over five days. This was done for the base case for each system as well as sensitivity analyses based on modifications to the system to explore options for optimization. The analysis was carried through five days using calculations based on the ERSP model (the actual ERSP calculator stops after three).

The goal of this project was to identify ways to optimize the existing systems to maximize oil recovery for each system. Figure 3-17 summarizes the process used to analyze the optimization of containment and recovery.

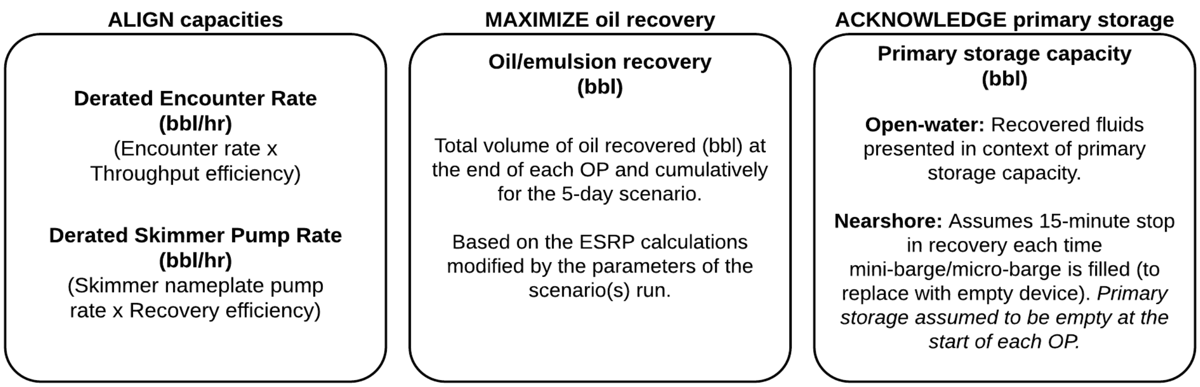


Figure 3-17. Summary of process used for optimization analysis for each system (not including secondary storage)

In seeking to optimize each system, Nuka Research first considered how well a system's ability to *encounter* oil and ability to *recover* oil are aligned. To compare these capacities, we need to consider each in terms of the same units, and so compared a derated encounter rate[11] and derated skimmer pump rate[12] for each system and each operational period. Any difference between the two rates indicates that the system is not fully optimized. For example, if the skimmers are capable of pumping much more oil than is being directed to them, skimming capacity is not optimized. We use the phrases "containment capacity" and "recovery capacity" in some cases for readability when referring to these metrics.

The optimization analysis then explores modifications to align the two rates as closely as possible *and* increase the estimated oil recovered. This is done by conducting sensitivity analyses to explore how estimated oil recovery changes as the system is modified to, for example, move faster, increase swath width (to expand containment), or recover more (different types of skimmers or larger ones). Different modifications are analyzed for different systems, depending on the results of the base case analysis comparing derated encounter rate and derated skimmer pump rate. The modifications explored also depend on the inherent limitations of each system.

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[11] Derated encounter rate = encounter rate x throughput efficiency

[12] Derated skimmer pump rate = skimmer pump rate x recovery efficiency

Primary storage capacity is considered as well, though this is applied differently for the open-water and nearshore systems. For the open-water recovery systems, under most circumstances, we assume that secondary storage is not needed or is readily available and unlimited.

For the nearshore systems, because these systems only operate during daylight hours (for the purpose of this study), the primary storage devices are assumed to be empty at the start of an operational period. The optimization analysis assumes a 15-minute stop in recovery each time the primary storage (a mini- or micro-barge) is filled with recovered fluids. The 15-minute stoppage represents time spent to replace the full primary storage device with an empty one, which was assumed to be readily available in Step 2.

3.3 Step 3: Model Primary/Secondary Storage Transfer for Optimization

Step 3 differs from Step 1 and Step 2 in that it considers multiple systems operating at the same time. For this step of the analysis, we consider the nearshore response system based on having 120 vessels available to engage in containment, recovery, and shuttling primary storage devices between skimmers and secondary storage. This mimics the nearshore recovery system with four task forces as described in the PWS Tanker C-plan.

For this step of the analysis, we developed a custom model to analyze the optimal configuration of skimmers, primary storage barges,[13] offload stations, and secondary storage barges. We also examined the effect of distance from the secondary storage on the optimal configuration. The flowchart in Figure 3-18 depicts the flow and decision process used to develop the model.

As was done in Step 2, the model uses the calculations from the ERSP calculator to estimate fluid recovery. The model assigns skimming systems to locations selected randomly in a circular operating area with the secondary storage barge at the center. The model is initiated with a given number of skimming systems, mini-barges, secondary storage offload stations, and the radius of the circle representing the operating area. These parameters were adjusted (as described in the next section) to create a series of scenarios. Each combination of the number of skimmers/storage devices, number of offload stations, and size of the response area was modeled 100 times in order to establish the variability associated with seeding the skimming into the operating area randomly.

The slick thickness was the same as used in the previous steps in this analysis for OP 4. Inputs for this portion of the analysis were based on the same parameters used in Step 2 for the CB2/Weir and CB2/Disc skimmer base cases, as shown in Figures 3-13 and 3-14 (the ADEC-approved rating for the disc skimmer pump rate was used), except that mini-barges (237 bbl) were used instead of micro-barges (114 bbl). The model was run in 5-minute time steps for the 14 hours of OP 4 (all daylight). Only OP 4 was examined, because the oil slick used in the analysis remains similar through the OPs during which the nearshore systems are skimming.

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[13] Only mini-barges were used in this step based on the results of Steps 1 and 2.

Modeling the Transfer of Recovered Fluids from Primary to Secondary Storage

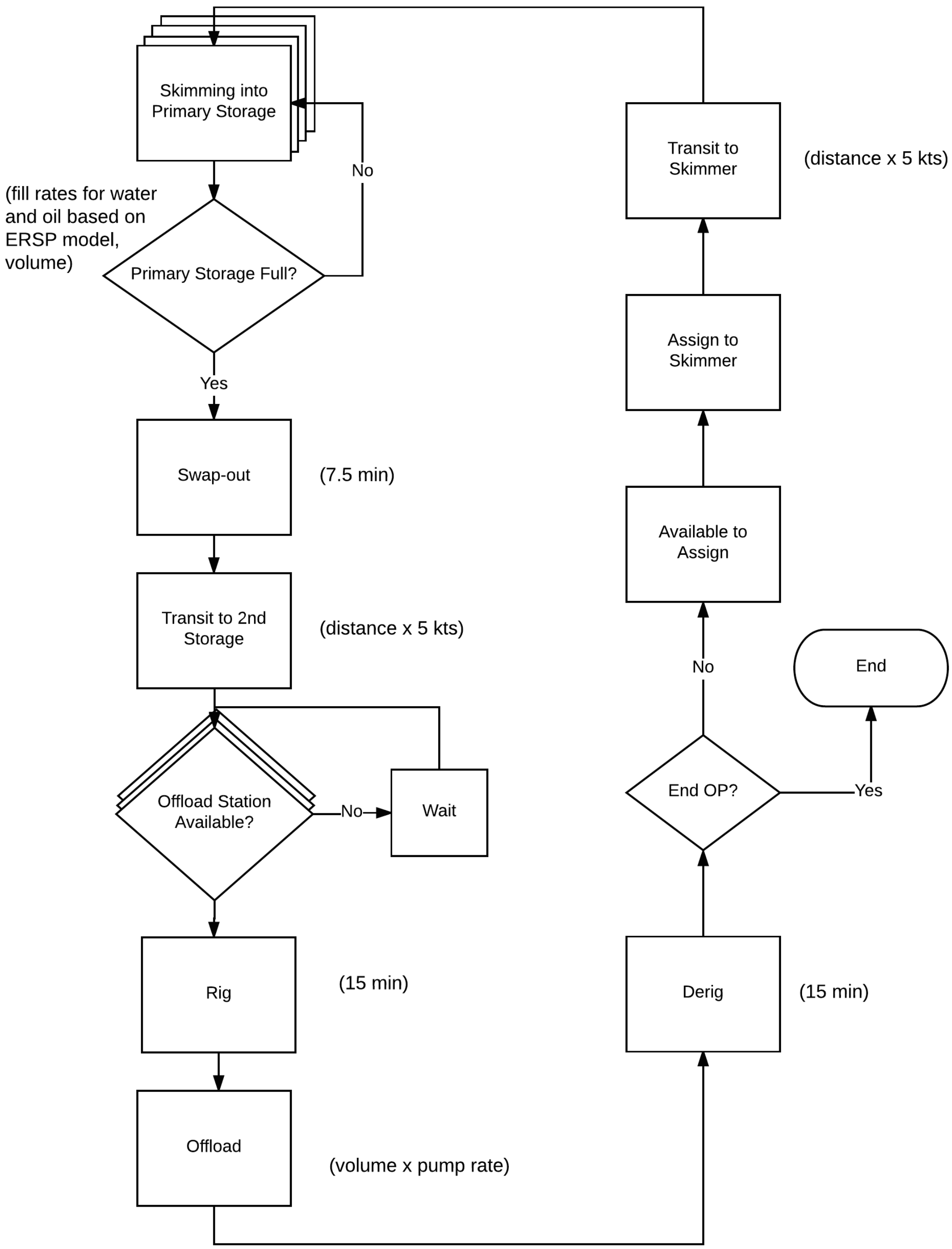

Figure 3-18. Flowchart of the process used primary/secondary storage transfer analysis

Further inputs were:

Weir Skimming System

- swath width = 50 ft
- skimmer pump = 629 bbl/hr
- throughput efficiency = 80 %
- oil recovery efficiency = 20 %
- skim speed = 2.5 knots

Disc Skimming System

- swath width = 50 ft
- skimmer pump = 113 bbl/hr
- throughput efficiency = 80 %
- oil recovery efficiency = 70 %
- skim speed = 2.5 knots

Mini-barge

- volume = 237 bbl
- transit speed = 5 knots
- discharge = 2,844 bbl/hr
- decant rate = 17 bbl/hr
- rig to skimmer time = 7.5 min
- derig to skimmer time = 7.5 min
- rig to secondary time = 15 min
- derig to secondary time = 15 min

We also derived mathematical formulas that estimate the limits to recovery capability represented by the number of skimmers, number of mini-barges, and number of off-load stations (on the secondary storage barge). These two approaches complement each other: the mathematical simplifications provide a clear view of the theoretical interaction between components of the response system, while the numerical model provides a more realistic view given the limitations of a real response.

3.3.1 Skimmer operations relative to primary storage

Each skimmer was assumed to be in position at the start of the 14-hour operational period, with empty mini-barges present but not yet rigged. Final unloading of mini-barges was assumed to happen after the end of the operational period, meaning that skimming could continue right to the end of the 14 hours.

At the start of the operational period, the model assigns skimmers a random location within a circle around the secondary storage barge. The size of the circle can be varied to explore the impact of skimming area on the process. Skimmers skim in a random direction at their assigned skimming speed until they have either filled their attached primary storage, or until they reach the edge of the circle. If they reach the edge of the circle, they are assigned a new skimming direction to stay within the area. When their mini-barge fills, they stop skimming until an empty mini-barge is attached. When this happens, they begin skimming in a new random direction within the circle.

3.3.2 Primary storage (mini-barge) operations

Each mini-barge is associated with a skimmer and will remain attached until filled (using the same constraints modeled in Step 2). When full, the mini-barge is detached from the skimmer and moved by a vessel directly to the secondary storage barge. Once there, it will be attached to an offload station if one is available. If no offload station is available, the mini-barge will wait until one is. Once it has unloaded and detached, the mini-barge will move back to a skimmer that needs a primary storage device. This will be the closest skimmer that has no primary storage already rigged. If all skimmers have primary storage already, the emptied mini-barge will be moved to a skimmer system that has a mini-barge rigged but does not have an empty mini-barge on standby (randomly selected if there is more than one option). If there are no barges lacking a mini-barge and all have a second mini-barge lined up, the empty mini-barge will wait at the secondary storage until this is no longer true.

3.3.3 Secondary storage barge operations

Secondary storage remains at the center of the circular operational area and does not move. The volume of the secondary storage barge is assumed to be unlimited. The secondary storage barge described in the SERVS Technical Manual as the primary barge to support nearshore response has 10 offload stations (APSC, 2013). The effect of the number of offload stations on oil recovery is explored in the analysis.

3.3.4 Number of support vessels and area covered

We applied the model to consider how total oil recovered varies based on the combination of skimmers and mini-barges used, keeping the number of support vessels constant at 120. Each mini-barge requires one support vessel, and each skimmer requires three support vessels (two to tow the containment system and one to support the skimmer).[14] We ran all possible combinations from the hypothetical extremes of zero skimmers and 120 mini-barges up to 40 skimmers and zero mini-barges to establish the outer limits for the results (both these extreme options resulted in zero oil recovery, as expected; even 40 skimmers do not recover oil if they have no primary storage into which to pump it).

Next, we considered how the radius of the response area affected response. The model was run for radiuses from one to 40-nm to establish how the size of the operating area affects oil recovery for the systems studied. We presented the results for 2-nm and 10-nm radius areas as examples, then summarized the overall effect of the size of the area out to a 40-nm radius.[15]

3.3.5 Complementary mathematical formulas

The outer limits for oil recovery based on the number of skimmers, mini-barges, and offload stations were calculated based on assumptions that describe a hypothetical perfect system. While the model described above assumes favorable conditions – such as mini-barges always

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[14] For example, a fleet of 120 vessels could support 20 skimmers and 60 mini-barges (20 x 3 + 60 = 120), or 24 skimmers and 48 mini-barges (24 x 3 + 48 = 120).

[15] The slick is predicted to spread to around 2 nm (12.6 nm^2) in the second day, while it will not reach 10 nm (314 nm^2) during the five-day scenario used.

moving directly to the closest skimmer in need of an empty barge – the numeric formulas use a single average transit time for a given radius of the skimming area. The results of the mathematical formulas are presented in the results to provide context for the results from the modeled system. They represent the upper bounds of oil collection possible given a number of skimmers, mini-barges, and offload stations and help to clarify the relationship among these. The calculations derived are shown in Appendix C.

3.3.6 Decanting mini-barges

Decanting is the process of removing free-water from the recovered fluids to maximize the amount of oil held in primary storage.[16] SERVS has developed a job aid for decanting mini-barges utilized in their nearshore response program (SERVS, no date). The job aid does not provide enough detail to estimate how long it will take to fully decant the free-water from a mini-barge, because the process is very situation dependent. However, we used the results of the ERSP calculations and the inputs developed for the model to estimate: (1) how long it would take to decant the free-water from the mini-barge, and (2) the breakeven point or distance away from secondary storage that the skimmer would have to be so that decanting would require the same amount of time as transiting back to secondary storage and offloading. We also calculated the amount of oil that could have been skimmed during the time that the skimmer was not operating during the decanting procedure.

[16] This analysis models a response system to understand whether there are ways to optimize that system. In a real response, decanting would require permitting. Permitting and many other aspects of a response are not discussed in this report.

4 Open-water System Results

This section describes the three open-water recovery systems studied and presents the results and findings from the optimization analysis for each.

4.1 Summary of Base Case Results for Open-water Systems

Before optimizing the systems, we examined the initial results of each system as currently configured, which is designated as the base case. While each system is essentially being optimized for maximum oil recovery, it is useful to compare the systems to understand their respective strengths and weaknesses.

A comparison of the encounter rate for each system provides an indication of their potential ability to contain oil: the encounter rate is the volume of oil captured by the containment system based on slick thickness, swath width, and speed of advance.[17] Figure 4-1 shows the encounter rate for each of the three open-water systems across all operational periods over the five days.[18] Initially, encounter rates for all three systems are at their highest due to the fact that the slick is at its thickest and has not yet spread. Encounter rates for all three systems drop significantly by OP 2 and essentially stabilize by OP 4 as the slick thickness stabilizes.

The Current Buster® Barge has the highest encounter rate in all operational periods, primarily due to its ability to move much more quickly while skimming (2.5 kt), than the TransRec/GrahamRec Barge (0.7 kt) and *Valdez Star* (1 kt). The TransRec/GrahamRec Barge is slightly slower than the *Valdez Star*, but has a larger initial swath width (400 ft) than the *Valdez Star* (220 ft). The TransRec/GrahamRec Barge's encounter rate increases during OP 4 when the gated U-boom is added to the system, increasing the swath width to 1,000 ft., while the *Valdez Star's* swath width does not change.

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[17] This is one factor in the *derated* encounter rate used in the optimization analysis.

[18] It should be noted that OP 1 is included in these figures to depict the rapid decline in encounter rate due to the thinning of the oil slick, but open-water recovery systems are not deployed until OP 2.

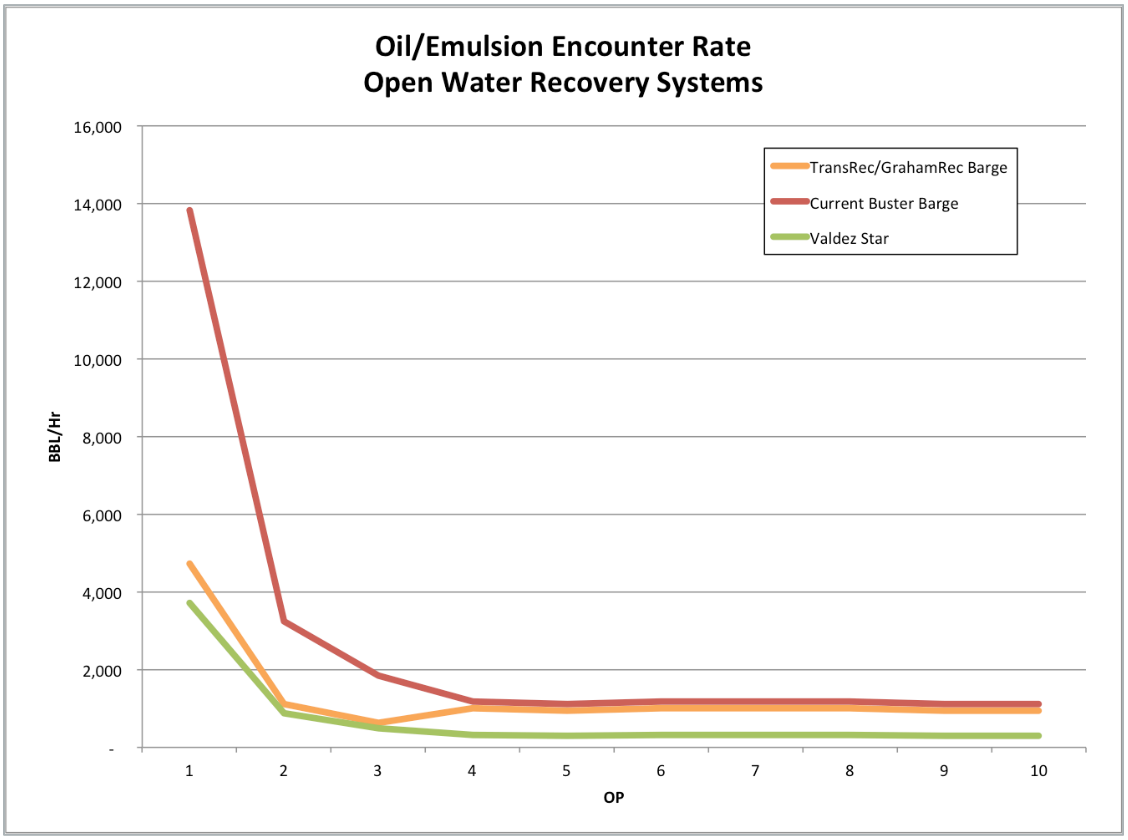


Figure 4-1. Potential encounter rates[19] for open-water systems, OP 1-10. Does not consider skimmer recovery rates.

Encountering the oil with speed and containment (swath width) is just the first stage of on-water recovery. Figure 4-2 compares the potential rate at which fluids might be recovered for each of the open-water skimmers used. Two different recovery rates are shown for the Crucial 100/30 Disc skimmer, because ADEC and the USCG assign two different skimmer pump rates for the same skimmer for regulatory purposes (Caplis, 2013 and Wood, 2015). For this analysis, we used the ADEC rate but included the USCG rate in the sensitivity analysis.

[19] Encounter rate is not derated by throughput efficiency

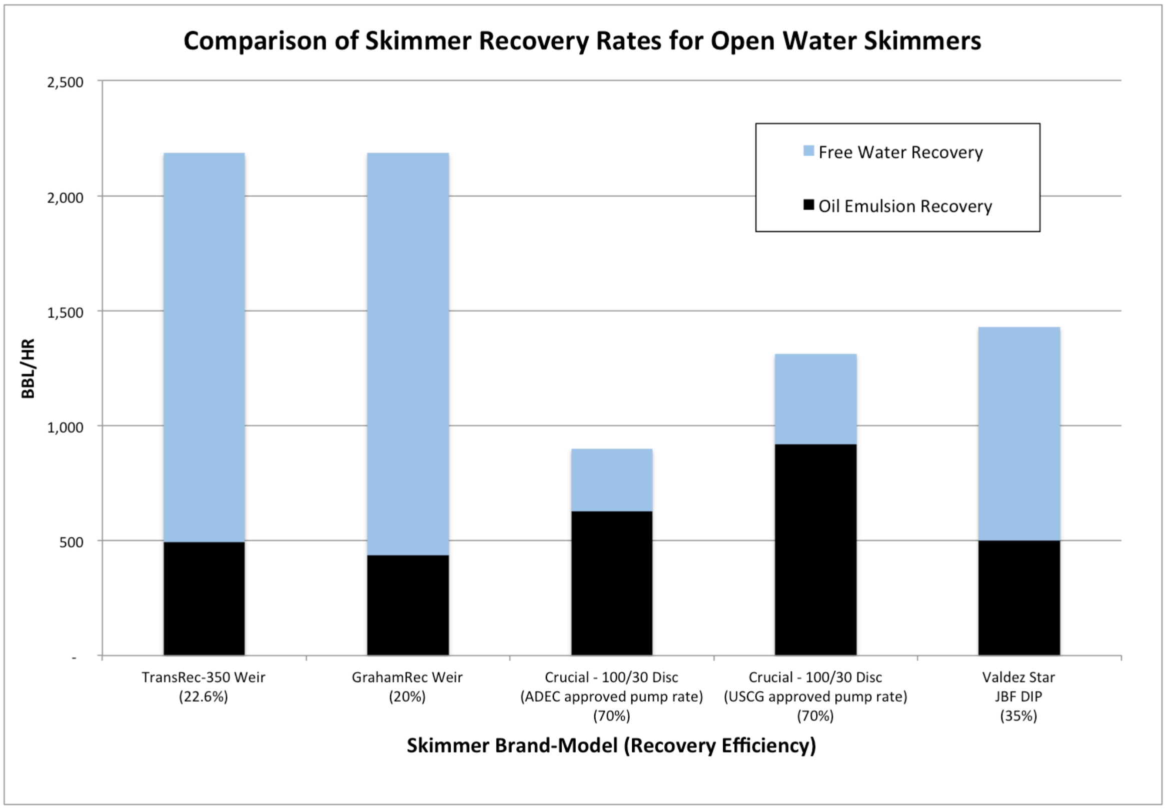


Figure 4-2. Comparison of potential recovery rates for open-water skimming systems used in this analysis. (Does not consider encounter rate.) The Crucial disc skimmer is shown twice: once based on the ADEC-approved skimmer pump rate (1,796 bbl/hr) and once based on the USCG-approved rate (2,626 bbl/hr), as noted in the figure.

The potential for containing the oil and the potential for recovering the oil are both considered in the ERSP calculations along with the ability to store the oil. Figure 4-6 shows the estimated volume of fluids recovered for each open-water system during OP 2-10. Free water, emulsified water, and oil are included. The figure shows the onset of emulsification starting in OP 4 with emulsified water representing an increasing proportion of fluids collected for the rest of the simulation.

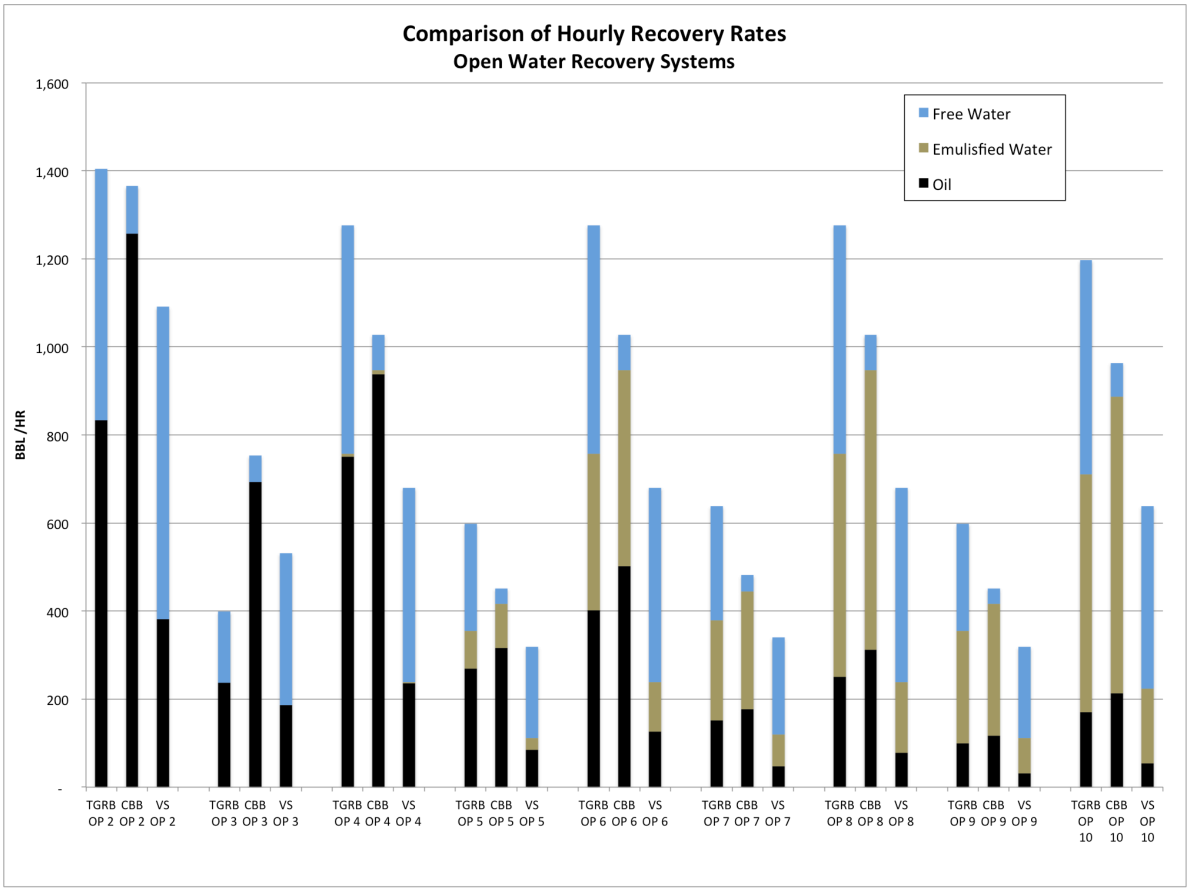


Figure 4-3. Comparison of fluids collected for each operating system, OP 2-10 (recovery operations do not begin until OP 2)

Finally, we look at the estimated volume of fluids recovered by each system cumulatively over OP 2-10. See Figures 4-4 through 4-6. (Recovery in OP 1 is hypothetical in all cases, since the open-water systems are not recovering until OP 2.)

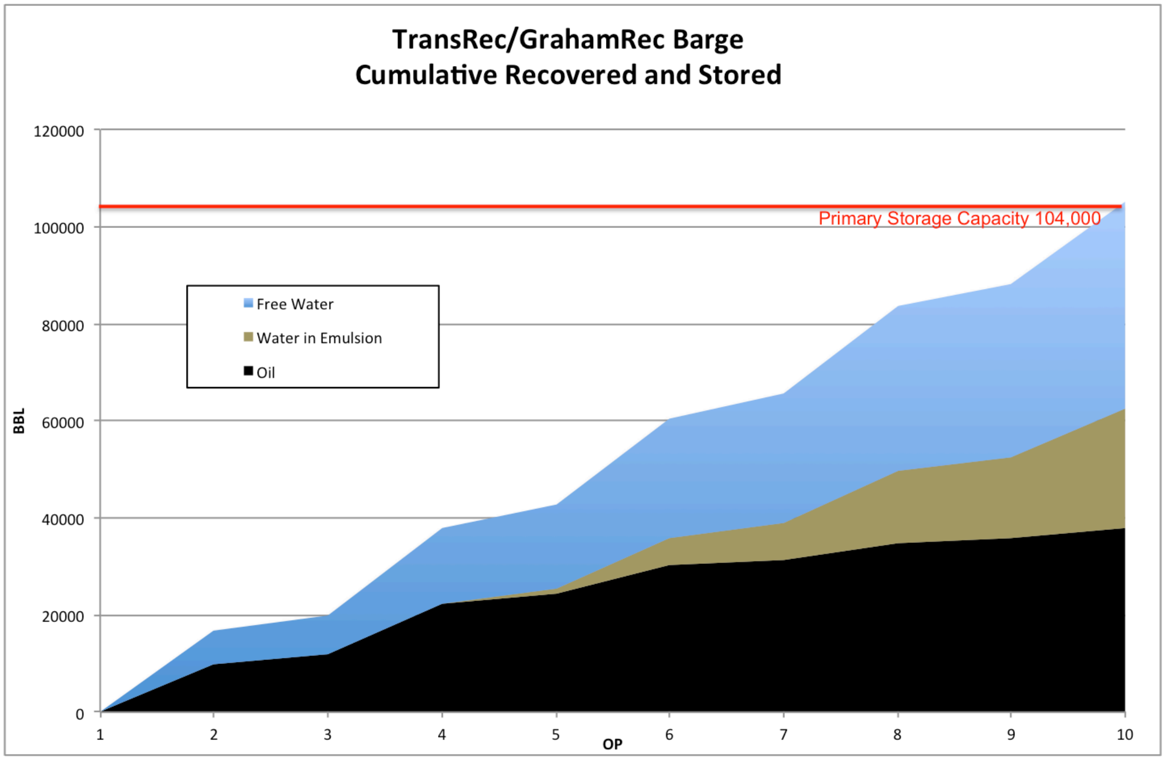


Figure 4-4. Base case cumulative recovery of oil, free water, and emulsion for TGRB system, OP 2-10. Total fluids collected = 105,084 bbl; total oil collected = 38,067 bbl. Primary storage does not fill until OP 10. Less than half of fluid retained is oil.

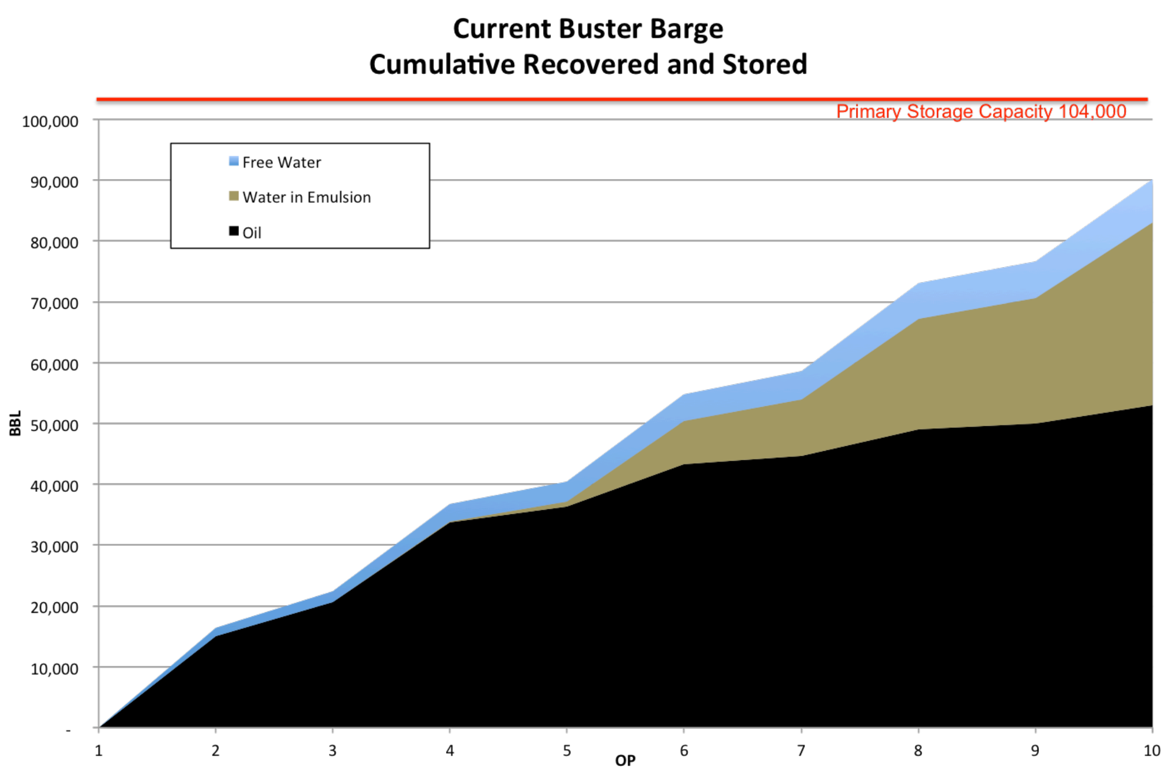


Figure 4-5. Base case cumulative recovery of oil, free water, and emulsion for CBB system, OP 2-10. Total fluids collected = 90,135 bbl; total oil collected = 53,012 bbl. Primary storage does not fill. More than half of fluid retained is oil.

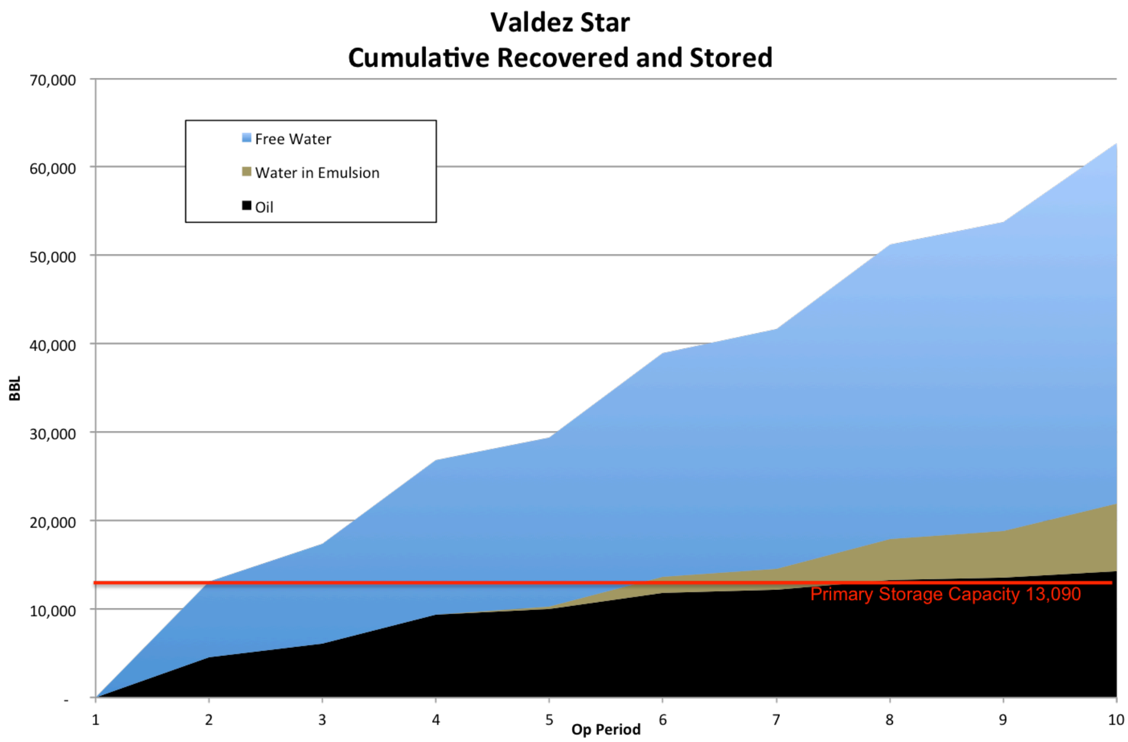


Figure 4-6. Base case cumulative recovery of oil, free water, and emulsion for VS system, OP 2-10. Total fluids collected = 62,664 bbl; total oil collected = 14,296 bbl. Primary storage fills in OP 2, though transit and offload to secondary storage is not considered at this stage of the analysis. A high percentage of free water is retained, as decanting is not considered.

4.2 Optimizing Systems for Containment and Recovery

This section describes the optimization analysis and findings for the three open-water systems studied.

4.2.1 TransRec/GrahamRec Barge

Figure 4-7 (top graph) shows the derated encounter rate and derated skimmer pump rate for the TransRec/GrahamRec Barge over OP 2-10 with no modifications. The derated encounter rate increases when the gated U-boom arrives to increase the swath width from 400 ft to 1000 ft in OP 4 and then fluctuates as the throughput efficiency changes from 75% for daytime operational periods and 50% for nighttime operational periods. The derated skimmer pump rate is static throughout, except during OP 2 when the GrahamRec skimmer is used.

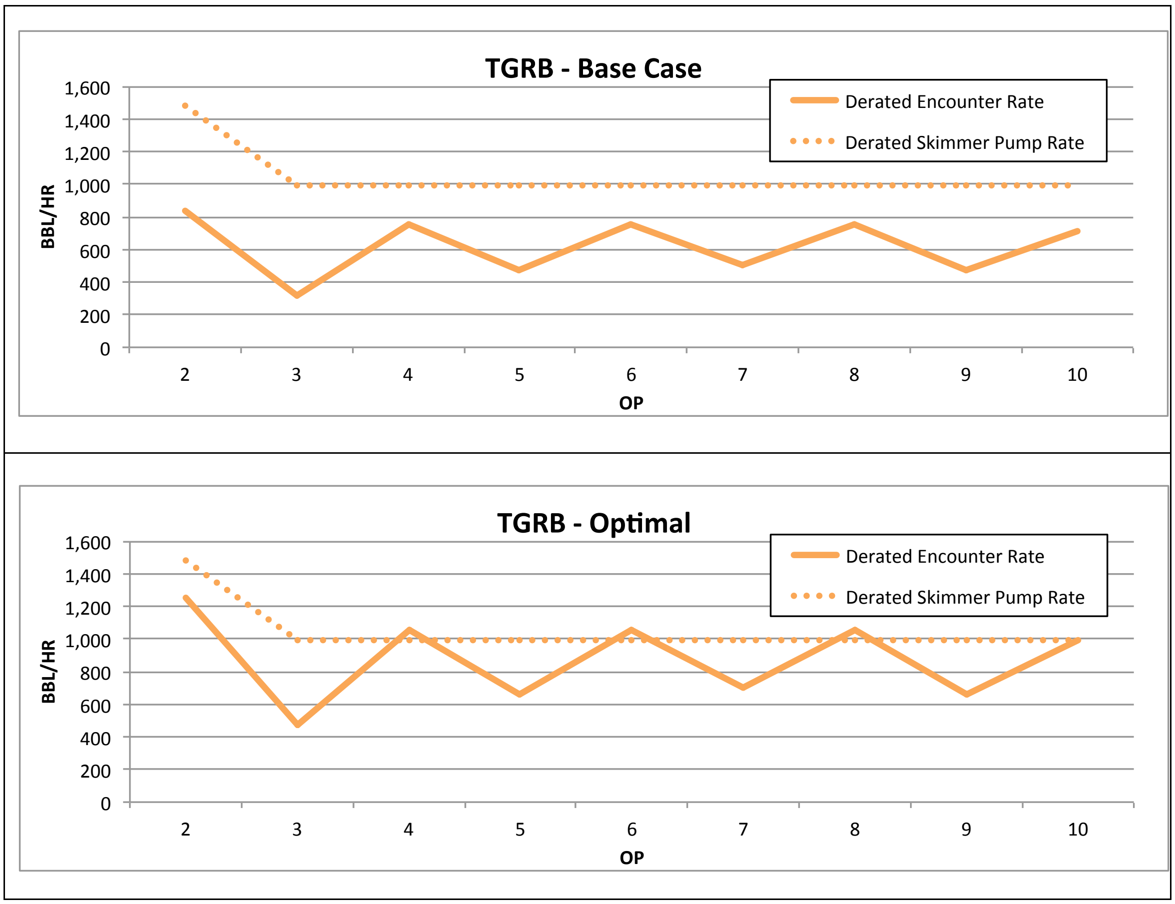


Figure 4-7. System optimization graphs from OP 2-10 for the TransRec/GrahamRec Barge, both the base case (top) and optimized system (bottom) with 600-ft. initial swath width and 1400-ft. swath width with gated U-boom

From this graph, we see that this system is capable of skimming more oil than the recovery system is encountering, because the derated skimmer pump rate is higher than the derated encounter rate (especially during OP 2). If the GrahamRec skimmer is removed completely, then reducing the skimmer pump rate from 1480 bbl/hr to 988 bbl/hr for OP 2, there is no change in oil collected even for that operational period.

Considering options for optimization, we focused on the potential to increase encounter rate and direct more oil to the skimmer to maximize the use of the GrahamRec skimmer in OP 2 in addition to the capacity of the two TransRec skimmers in all operational periods.

Six options for increasing swath width were analyzed, whether increasing the swath width for OP 2-3 or OP 4-10, or both. Table 4-1 shows the sensitivity analysis of the estimated oil recovered per operational period and cumulatively for the base case and options, with the swath widths for each. Adding 200 ft of initial swath width increased containment enough that at least some of the skimming capacity from the GrahamRec skimmer was used. This increased estimated oil recovered in OP 2 and 3 and resulted in the collection of 23% more oil than the base case.

Further increases to swath rate were considered because even with the GrahamRec skimmer in play, the derated encounter rate still exceeded the derated skimmer pump rate. Adding *both* 200 ft. additional of initial swath width *and* 400 ft. of swath with the gated U-boom resulted in a 46% increase in estimated oil recovered (55,392 bbl) as compared to the base case. This was also the optimal configuration based on aligning derated encounter rate and derated skimmer pump rate (see bottom graph of Figure 4-8). *However,* primary storage capacity becomes a limiting factor: oil collected *at the time the barge is full* is actually 48,021 bbl during OP 7. Increasing containment even further would increase estimated oil recovery even more, but this would just surpass the primary storage capacity further. If primary storage capacity was functionally increased (i.e., if the barge was larger) – and if towing these quantities of boom is realistic – then oil recovery for this system could be increased. Note also that 28% more oil could be recovered if the gated U-boom was on-scene as soon as the system began skimming. This is represented by having 1,000-ft swath width the whole time (also shown in Table 4-1).

Table 4-1. Total oil recovered (bbl) for base case and options considered to modify swath width for the TransRec/GrahamRec optimization analysis, OP 2-10

	Swath width (ft)							
OP 2-3	400	400	600	1,000	600	1,200	1,400	600
OP 4-10	400	1,000	1,000	1,000	1,200	1,200	1,400	1,400
		Base Case						Optimal
OP 1	(No recovery.)							
OP 2	10,000	10,000	17,793	17,793	17,793	17,793	17,793	17,793
OP 3	1,894	1,894	2,841	4,735	2,841	5,682	5,931	2,841
OP 4	4,200	10,500	10,500	10,500	12,600	12,600	13,701	13,701
OP 5	864	2,159	2,159	2,159	2,591	2,591	3,023	3,023
OP 6	2,248	5,621	5,621	5,621	6,745	6,745	7,335	7,335
OP 7	485	1,212	1,212	1,212	1,455	1,455	1,697	1,697
OP 8	1,400	3,500	3,500	3,500	4,200	4,200	4,567	4,567
OP 9	318	795	795	795	955	955	1,114	1,114
OP 10	955	2,386	2,386	2,386	2,864	2,864	3,321	3,321
Total oil (bbl)	*22,363*	*38,067*	*46,808*	*48,702*	*52,043*	*54,884*	*58,482*	*55,392*
% increase	-41%	0%	23%	28%	37%	44%	54%	46%
Total Fluid (bbl)	54,058	105,084	119,812	123,003	136,820	141,607	153,800	148,593

4.2.1.1 TransRec/GrahamRec Barge Findings

Findings for this recovery system are summarized as follows:

- Base case configuration of this system would collect 38,067 bbl of oil and 105,084 bbl total fluids. It fills its primary storage in OP 10.
- In the base case configuration, the recovery capacity to this system exceeds the containment capacity in this scenario for OP 2-10.
- Increasing the initial swath width from 400 ft to 600 ft and the later swath from 1,000 ft to 1,400 ft increases the potential oil recovery to 48,021 bbl. This is the volume at which primary storage is filled in OP 8.

4.2.2 Current Buster Barge

Figure 4-8 shows the derated encounter rate and derated skimmer pump rate for the CBB over OP 2-10. The derated encounter rate drops as the slick thins, then fluctuates between daytime and darkness as the other open-water recovery systems do. The derated skimmer pump rate remains static, as the skimming devices used in this recovery system remain the same throughout the operational periods. As shown in the figure, initially the system has the capacity to contain far more oil than it can pump. This remains the case until the end of OP 2, longer than for the TransRec/GrahamRec Barge system.

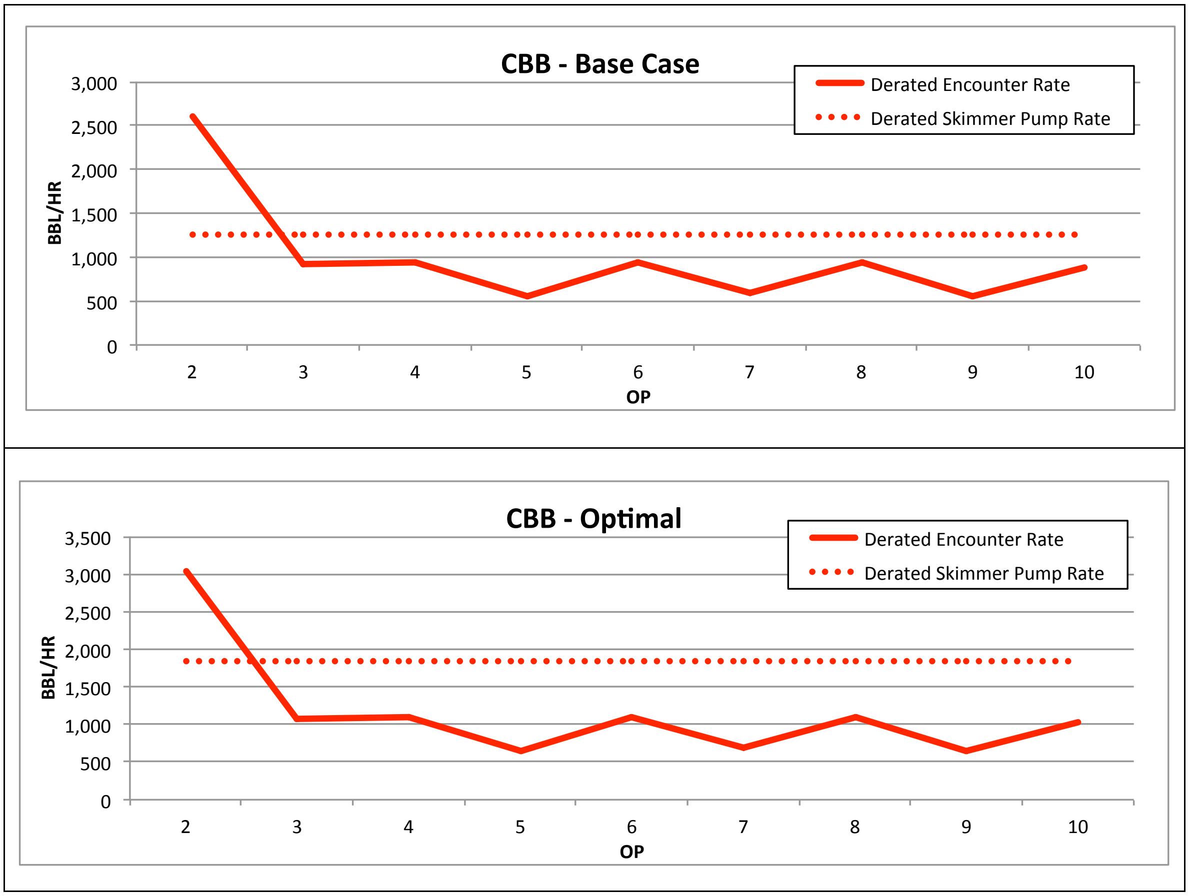


Figure 4-8. System optimization graphs for the CBB system, both the base case (top) and optimal system (bottom) with 348-ft swath width; 2.75-kt skimming speed; 2,626-bbl/hr skimmer pump rate, OP 2-10.

The optimization analysis considered three potential system modifications for the CBB: increasing swath width, moving faster (unlike the U-boom configuration used in the TRGB system, the CBB system has the potential to advance more quickly), and increasing the skimmer pump rate by using the USCG rating. These options are first considered independently. An optimal system is then identified that combines the results from considering all three options independently. The optimal system was based on our judgment that the skimmer speed could be increased by 0.25 knots, the swath of each CB8 could be increased 10 ft, and the skimmer pump rate designated by the USCG is realistic. The resulting optimal system (bottom graph of Figure 4-8) resulted in greater oil recovery by increasing both the capacity to encounter oil *and* the capacity to recover oil, although the recovery capacity (derated skimmer pump rate) remains higher. The lines in the lower graph (Optimal) appear farther apart than in the upper graph (Base Case), but the greater gain in hypothetical oil recovery occurs because the higher recovery rate takes better advantage of the thicker oil in OP2.

Table 4-2. Total oil recovered (bbl) for base case and options considered to increase swath width for CBB system

Swath Width (ft)					
	328 (Base Case)	338	348	358	368
OP 1	(No recovery.)				
OP 2	15,086	15,086	15,086	15,086	15,086
OP 3	5,546	5,716	5,885	6,054	6,223
OP 4	13,120	13,520	13,920	14,320	14,720
OP 5	2,529	2,606	2,683	2,760	2,838
OP 6	7,024	7,238	7,452	7,666	7,880
OP 7	1,420	1,463	1,506	1,550	1,593
OP 8	4,373	4,507	4,640	4,773	4,907
OP 9	932	960	989	1,017	1,045
OP 10	2,982	3,073	3,164	3,254	3,345
Total oil (bbl)	*53,012*	*54,168*	*55,325*	*56,481*	*57,637*
% increase	0%	2%	4%	7%	9%
Total fluid (bbl)	90,135	92,384	94,632	96,881	99,129

Table 4-3. Total oil recovered (bbl) for base case and options considered to increase CBB system speed

Speed (kt)					
	2.00	2.25	2.50 (Base case)	2.75	3.00
OP 1	(No recovery.)				
OP 2	15,086	15,086	15,086	15,086	15,086
OP 3	4,437	4,992	5,546	6,101	6,656
OP 4	10,496	11,808	13,120	14,432	15,744
OP 5	2,023	2,276	2,529	2,782	3,035
OP 6	5,619	6,321	7,024	7,726	8,428
OP 7	1,136	1,278	1,420	1,562	1,704
OP 8	3,499	3,936	4,373	4,811	5,248
OP 9	745	839	932	1,025	1,118
OP 10	2,385	2,684	2,982	3,280	3,578
Total oil (bbl)	45,427	49,220	53,012	56,805	60,597
% increase	-14%	-7%	0%	7%	14%
Total fluid (bbl)	75,384	82,759	90,135	97,510	104,886

Table 4-4. Total oil recovered (bbl) for base case and options considered to increase skimmer pump rate for CBB system

Skimmer Pump Rate (bbl/hr)					
	1,796 (Base Case)	2,626 (USCG)	3,302	3,978	4,500
OP 1	(No recovery.)				
OP 2	15,086	22,058	27,737	31,237	31,237
OP 3	5,546	5,546	5,546	5,546	5,546
OP 4	13,120	13,120	13,120	13,120	13,120
OP 5	2,529	2,529	2,529	2,529	2,529
OP 6	7,024	7,024	7,024	7,024	7,024
OP 7	1,420	1,420	1,420	1,420	1,420
OP 8	4,373	4,373	4,373	4,373	4,373
OP 9	932	932	932	932	932
OP 10	2,982	2,982	2,982	2,982	2,982
Total oil (bbl)	*53,012*	*59,984*	*65,662*	*69,163*	*69,163*
% increase	0%	13%	24%	30%	30%
Total fluid (bbl)	90,135	97,704	103,870	107,670	107,670

Table 4-5. Total oil recovered (bbl) for base case and optimal CBB system (increased swath width, speed, and skimmer pump rate)

	Base Case	**Optimal**
Swath width (ft)	328	348
Speed (kt)	2.50	2.75
Skimmer pump rate (bbl/hr)	1,796	2,626
OP 1	(No recovery.)	
OP 2	15,086	22,058
OP 3	5,546	6,473
OP 4	13,120	15,312
OP 5	2,529	2,952
OP 6	7,024	8,197
OP 7	1,420	1,657
OP 8	4,373	5,104
OP 9	932	1,087
OP 10	2,982	3,480
Total oil (bbl)	*53,012*	*66,320*
% increase	0%	25%
Total fluid (bbl)	90,135	110,027

4.2.2.1 Current Buster Barge Findings

Findings for this recovery system are summarized as follows:

- Base case configuration of this system would recover 53,012 bbl of oil and 90,135 bbl of total fluid.
- In the base case, the skimmer recovery rate for this system exceeds the encounter rate in this scenario for all OP 2-10.
- The optimal system collects 25% more oil than the base case, with an increase to a 348-ft swath width, 2.75-kt speed, and 2,626-bbl/hr skimmer pump rate. This higher skimmer pump rate is the one approved by the USCG.
- Neither the CBB base case nor the optimal case would fill primary storage in this scenario.

4.2.3 Valdez Star

Figure 4-9 shows the optimization graphs for the *Valdez Star* (VS) for OP 2-10. As with the other two open-water systems discussed, the capacity to encounter oil quickly drops below the capacity to recover it.

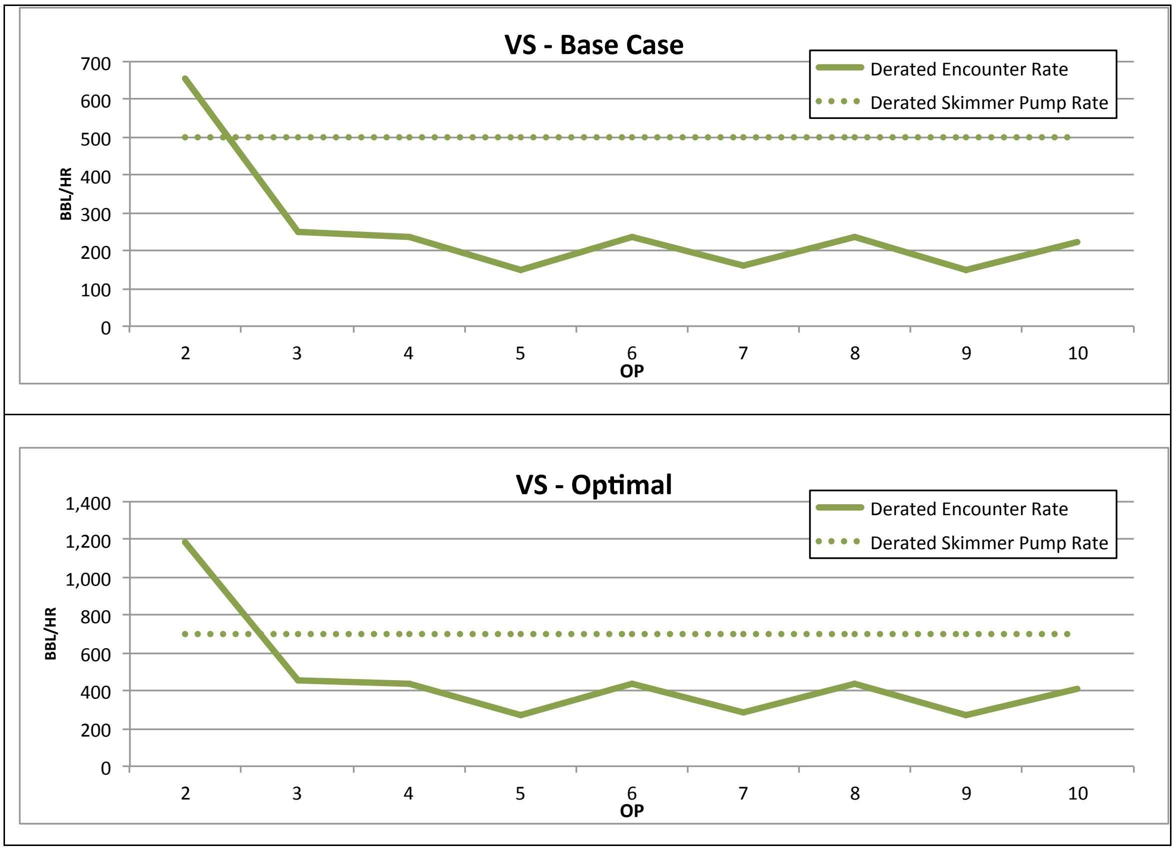


Figure 4-9. System optimization graphs for the Valdez Star system, both the base case (top) and optimal (bottom) with 400-ft swath width; 80% decant; 2,000-bbl/hr skimmer pump rate, OP 2-10.

Increasing the swath width of the gated U-boom can increase encounter rate of the recovery system. The sensitivity analysis results for increased swath width are presented in Table 4-6. Note that oil recovery does not increase with swath width in OP 2, but does in subsequent operational periods. The increase is more during dark periods than daylight periods due to the lower recovery efficiency during darkness. Note that daylight oil recovery does not increase beyond 400 ft of swath. We considered this the optimal swath width for this system.

Table 4-6. Oil recovery sensitivity analysis swath width for the Valdez Star recovery system

Swath width (ft)					
	220 (Base Case)	300	400	500	600
OP 1	(No recovery.)				
OP 2	4,582	4,582	4,582	4,582	4,582
OP 3	1,488	2,029	2,706	3,001	3,001
OP 4	3,300	4,500	4,536	4,536	4,536
OP 5	679	925	1,234	1,542	1,851
OP 6	1,767	2,409	2,428	2,428	2,428
OP 7	381	519	693	866	1,039
OP 8	1,100	1,500	1,512	1,512	1,512
OP 9	250	341	455	568	682
OP 10	750	1,023	1,100	1,100	1,100
Total oil (bbl)	*14,296*	*17,828*	*19,243*	*20,134*	*20,729*
% increase	0%	25%	35%	41%	45%
Total fluid (bbl)	62,664	80,691	87,404	91,803	95,359

Increasing the skimmer pump rate will increase oil recovery if the containment rate is greater than the recovery capacity. Note that in the sensitivity analysis presented in Table 4-7, increasing the skimmer pump rate alone *does not* increase oil recovery. However, if swath width is increased as well, then increasing the skimmer pump rate *can* help increase oil recovery. In this case the *Valdez Star* has a skimmer pump rate of 2,000 bbl/hr but a transfer pump rate of 1,429 bbl/hr for moving recovered fluids from the skimmer storage tank to the attending barge. This transfer pump rate is the limiting factor in the recovery capability of this system. Increasing the transfer pump rate and swath width can increase total recovery.

Table 4-7. Oil recovery sensitivity analysis for skimmer pump rate for the Valdez Star recovery system. Increasing the skimmer pump rate does not change oil recovery because the transfer pump rate (moving fluids from the skimmer to primary storage) is the limiting factor.

	Skimmer Pump Rate (bbl/hr)				
	1,429 (Base Case)	1,572	1,715	1,857	2,000
OP 1	(No recovery.)				
OP 2	4,582	4,582	4,582	4,582	4,582
OP 3	1,488	1,488	1,488	1,488	1,488
OP 4	3,300	3,300	3,300	3,300	3,300
OP 5	679	679	679	679	679
OP 6	1,767	1,767	1,767	1,767	1,767
OP 7	381	381	381	381	381
OP 8	1,100	1,100	1,100	1,100	1,100
OP 9	250	250	250	250	250
OP 10	750	750	750	750	750
Total oil (bbl)	*14,296*	*14,296*	*14,296*	*14,296*	*14,296*
% increase	0%	0%	0%	0%	0%
Total fluid (bbl)	62,664	62,664	62,664	62,664	62,664

In the base case, the *Valdez Star* does not decant free water. As shown in the sensitivity analysis presented in Table 4-8, increasing the percent decant increases the oil recovery in OP 2 but does not affect oil recovery in any other operational period. This is because primary storage capacity is not the limiting factor in any operational period after OP 2.

Table 4-8. Oil recovery sensitivity analysis for percent decant for the Valdez Star *recovery system*

	% Free-water Decanted				
	0 (Base Case)	20	40	60	80
OP 1	(No recovery.)				
OP 2	4,582	5,266	6,002	6,002	6,002
OP 3	1,488	1,488	1,488	1,488	1,488
OP 4	3,300	3,300	3,300	3,300	3,300
OP 5	679	679	679	679	679
OP 6	1,767	1,767	1,767	1,767	1,767
OP 7	381	381	381	381	381
OP 8	1,100	1,100	1,100	1,100	1,100
OP 9	250	250	250	250	250
OP 10	750	750	750	750	750
Total oil (bbl)	*14,296*	*14,980*	*15,716*	*15,716*	*15,716*
% increase	0%	5%	10%	10%	10%
Total fluid (bbl)	62,664	56,219	49,374	40,700	32,026

Without empirical evidence to the contrary, we have chosen to use the recovery efficiency established by ADEC for each recovery system. In this case, we ran a sensitivity analysis for recovery efficiency to demonstrate its impact on oil recovery, presented in Table 4-9. The manufacturer claims recovery efficiency of 70% for this system. Note that increasing the recovery efficiency greatly increases the oil recovery in OP 2 but has no effect in other operational periods. This is because the encounter rate is the limiting factor in those later periods.

Table 4-9. Oil recovery sensitivity analysis for recovery efficiency for the Valdez Star recovery system

	Recovery Efficiency				
	35% (Base Case)	45%	55%	65%	75%
OP 1	(No recovery.)				
OP 2	4,582	5,891	7,200	7,857	7,857
OP 3	1,488	1,488	1,488	1,488	1,488
OP 4	3,300	3,300	3,300	3,300	3,300
OP 5	679	679	679	679	679
OP 6	1,767	1,767	1,767	1,767	1,767
OP 7	381	381	381	381	381
OP 8	1,100	1,100	1,100	1,100	1,100
OP 9	250	250	250	250	250
OP 10	750	750	750	750	750
Total oil (bbl)	*14,296*	*15,605*	*16,914*	*17,571*	*17,571*
% increase	0%	9%	18%	23%	23%
Total fluid (bbl)	62,664	51,647	44,637	38,781	33,610

By increasing swath width and thus encounter rate, improvements in recovery rate and storage efficiency can also be realized. The optimal configuration of this system, presented in Table 4-10, increases the swath width to 400 feet, the skimmer rate to 2,000 bbl/hr, and the percent decant to 80%, which increases the overall oil recovery 82%. While changing the oil recovery percentage from the ADEC figure to the manufacturer's was not considered as part of the optimal configuration, this change would result in an increase of oil recovery potential of 108% greater than the base case (also shown in Table 4-10).

Table 4-10. Base case and optimal configuration for the Valdez Star recovery system

	Base Case	**Optimal**	
Swath width (ft)	220	400	400
Skimmer pump rate (bbl/hr)	1,429	2,000	2,000
% Decant	0%	80%	80%
Recovery efficiency	35%	35%	70%
OP 1	(No recovery.)		
OP 2	4,582	8,400	12,057
OP 3	1,488	2,706	2,706
OP 4	3,300	6,000	6,000
OP 5	679	1,234	1,234
OP 6	1,767	3,212	3,212
OP 7	381	693	693
OP 8	1,100	2,000	2,000
OP 9	250	455	455
OP 10	750	1,364	1,364
Total oil (bbl)	*14,296*	*26,062*	*29,719*
% increase	0%	82%	108%
Total fluid (bbl)	62,664	54,784	47,341

4.2.3.1 Valdez Star *Findings*

Findings for this recovery system are summarized as follows:

- The base case *Valdez Star* configuration would collect 14,296 bbl of oil and 62,664 bbl of total fluid.
- In the base case, primary storage is filled in OP 2.
- The optimal *Valdez Star* system collects 54,784 bbl of fluid, including 26,062 bbl of oil. This is achieved by making several changes: increasing swath width to 400 ft, increasing skimmer pump rate to 2,000 bbl/hr, and adding decanting for 80% of free water.

5 Nearshore System Results

This section presents the six nearshore recovery systems studied, including the results and findings for each optimization analysis.

5.1 Summary of Base Case Results for Nearshore Systems

The nearshore systems use three different types of containment: CB4, CB2, and J-boom. The encounter rate for these can be considered independent of the associated skimmer, and is presented in Figure 5-1. Until OP 4, when the nearshore systems begin recovery, this can be considered a *potential* recovery rate for illustrative purposes only. Throughout the scenario, the CB4 system has the highest recovery rate, followed by the CB2 and then the J-boom.

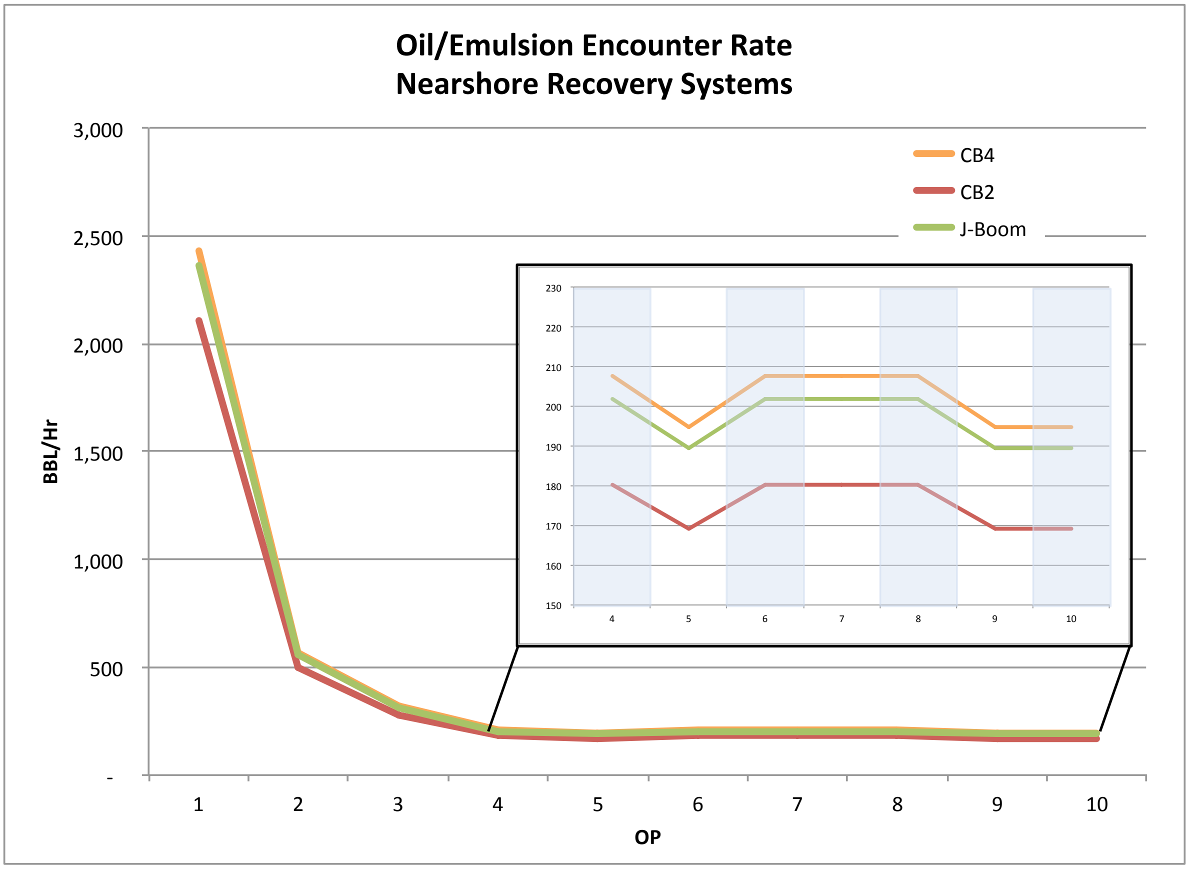


Figure 5-1. Potential encounter rate for OP 1-10 for three types of containment used in the nearshore systems (CB4, CB2, and J-boom). Recovery does not begin until OP 4 due to the time required to mobilize, transport, and deploy the systems.

Figure 5-2 compares the fluid recovery rates for the two skimmers used in the nearshore systems. One Recovery Efficiency value is used for the weir skimmer, but there are three options for the disc skimmer, all of which are shown in the graph below. As noted, ADEC and the USCG assign different oil recovery efficiencies to this disc skimmer. ADEC assigns a 70% recovery efficiency to the disc skimmer when it is used in a Current Buster® containment system, but a lower recovery efficiency when the same skimmer is used with the J-boom (20%) because the oil does not pool to the same thickness as in the Current Buster® system and is therefore harder to recover. Thus, there are three different estimated fluid recovery rates for that skimmer depending on which agency's skimmer pump rate is used and, if ADEC's rate is used, whether the skimmer is used in conjunction with a Current Buster® or J-boom. (This analysis uses ADEC's approved rates throughout, thus we use the lower recovery efficiency for the J-boom/Disc skimmer nearshore system. The implications are explored in the sensitivity analyses.)

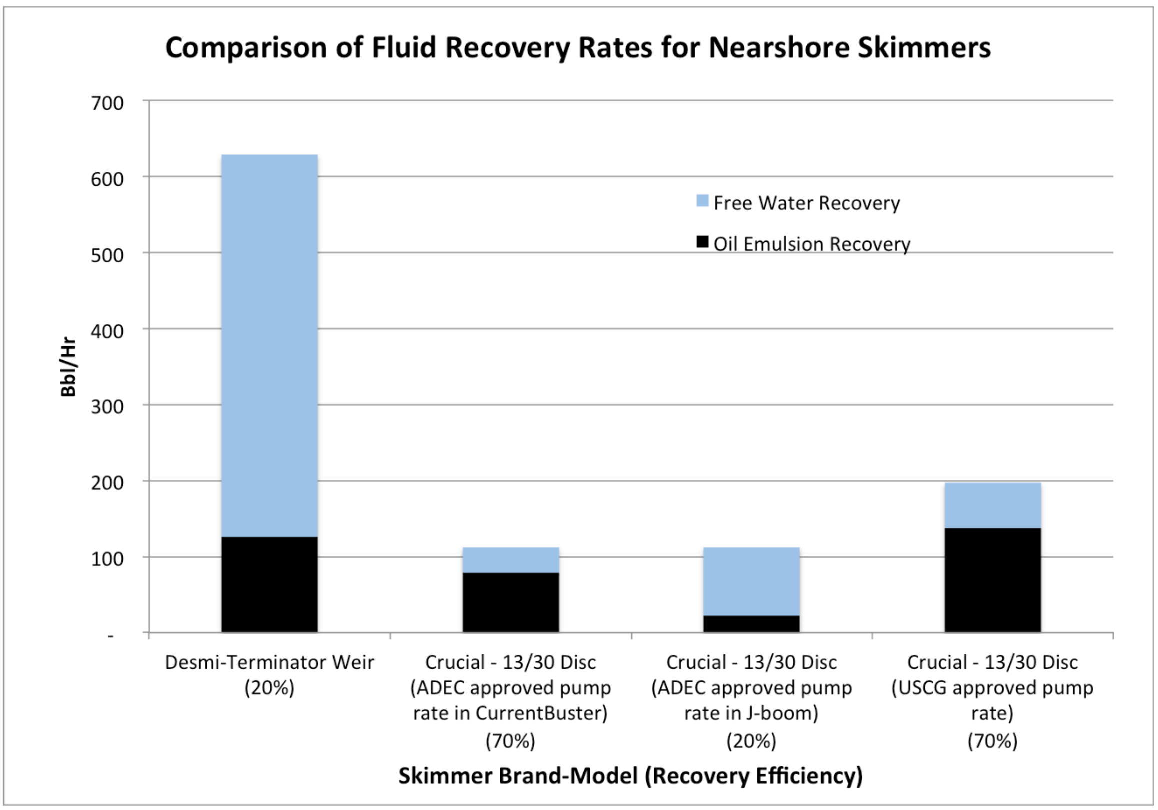


Figure 5-2. Comparison of fluid recovery rates for skimmers used in nearshore systems (ADEC values were used in the analysis)

Figure 5-3 shows rate at which free water, emulsion, and oil are collected by each system during each of the four operational periods, while Figure 5-4 shows the cumulative volume of fluids collected during the scenario. In this latter figure, the significantly higher volume of water collected by the weir skimmer as compared to the disc skimmer is evident. However, since this analysis does not consider storage beyond allowing for 15 minutes of downtime to replace a filled mini-barge (or micro-barge) with an empty one, this does not have a strong effect on the analysis at this stage. The systems otherwise collect roughly similar volumes of oil regardless of the skimmer used with a containment configuration. The exception to this is the J-boom/Disc skimmer, which collects significantly less due to the reduced recovery efficiency assigned the skimmer when used with J-boom. In Figure 5-3, the total fluid recovery rate remains the same for each skimmer across all operational periods but the recovery rate for oil drops significantly as the oil slick emulsifies. This emphasizes the need to begin recovery operations as soon as possible.

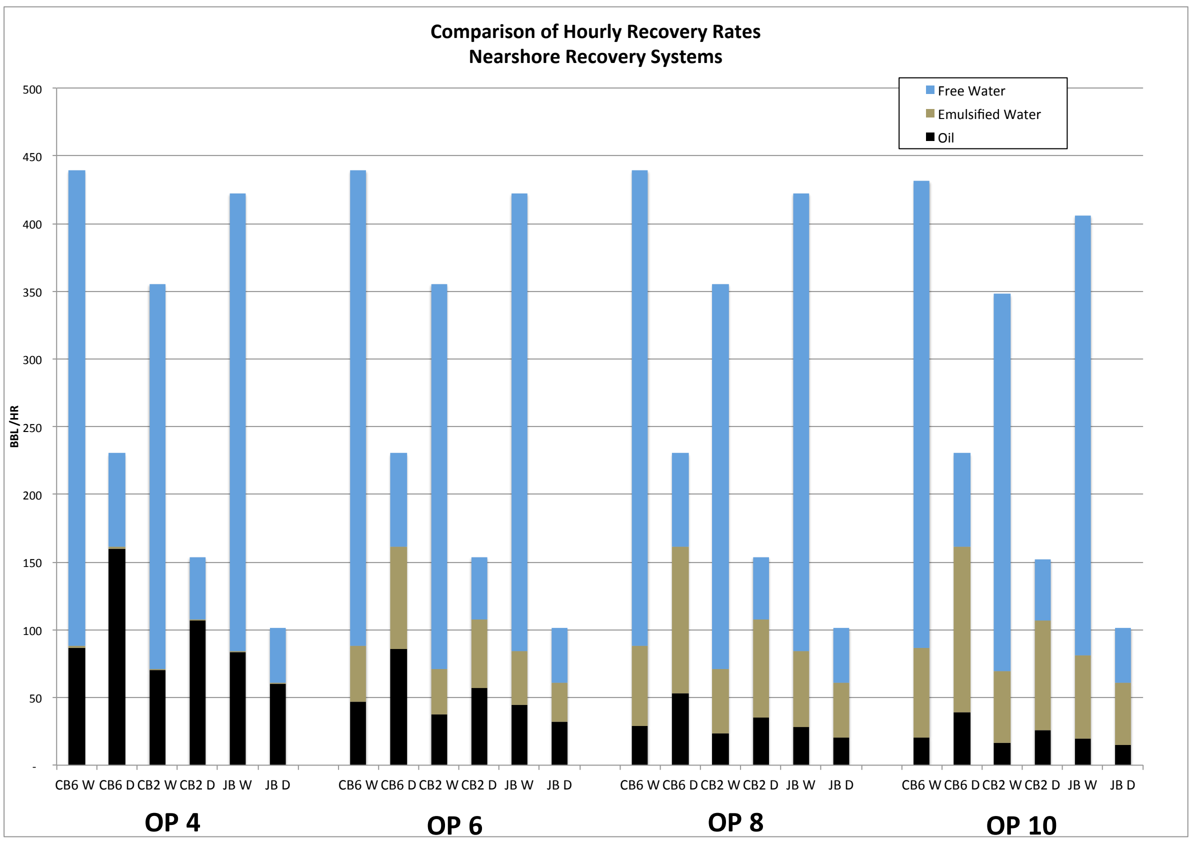


Figure 5-3. Comparison of hourly recovery rates for each nearshore system – OP 4, 6, 8, and 10

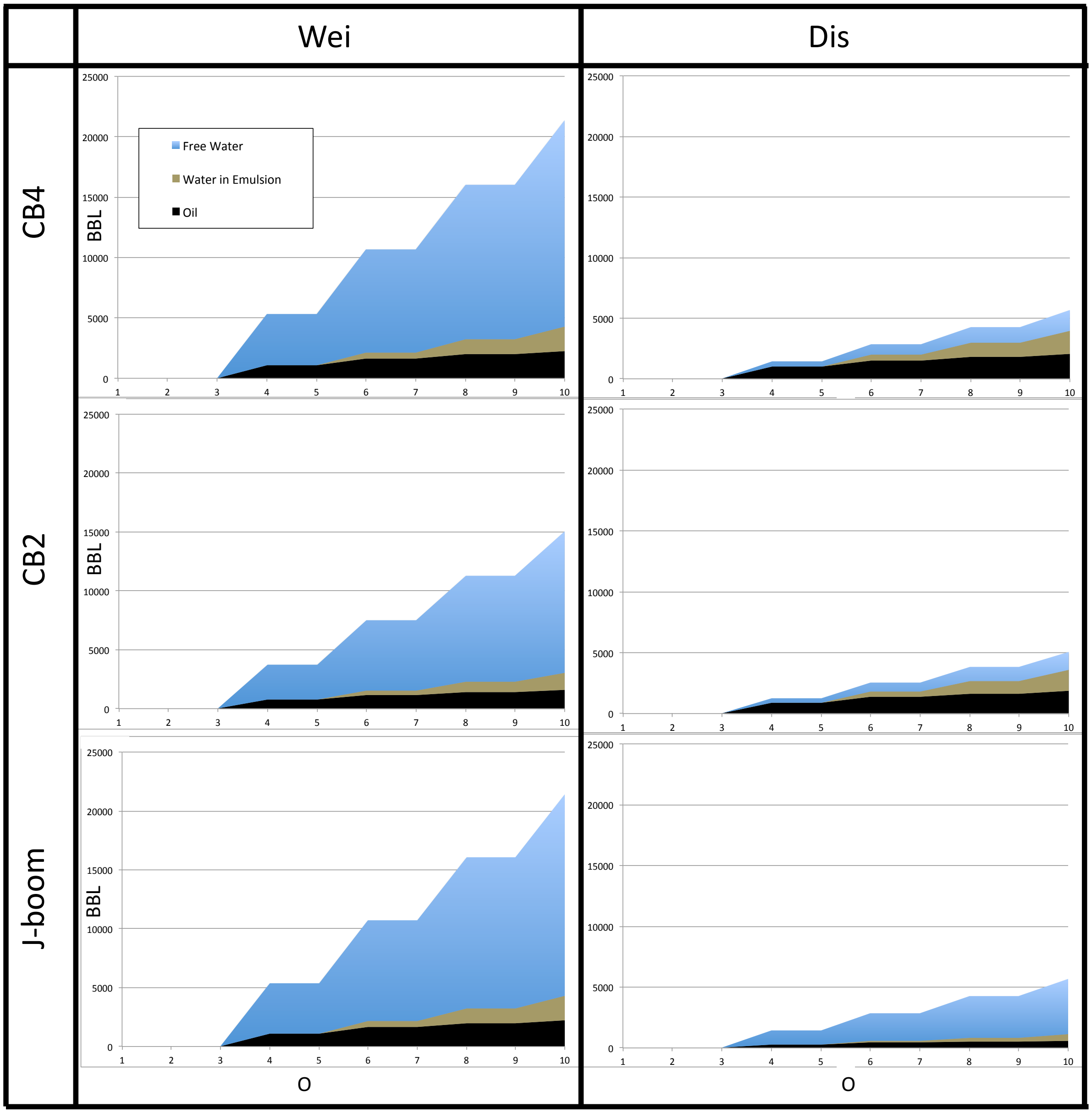


Figure 5-4. Cumulative fluids collected by each combination of containment and skimmer used in the nearshore systems for OP 3-10. "Steps" reflect operational periods during darkness when no nearshore recovery is underway.

5.2 Optimizing Systems for Containment and Recovery

Figure 5-5 shows a summary optimization graph, with the derated encounter rates for the three containment systems and the derated skimmer pump rates for the two containment systems (one of which is shown with two different recovery efficiencies). The systems are shown on the same graph because they are all various combinations of the same containment and skimming systems. From this figure, we can see that the combination of the CB2 containment with the weir skimmer is already the most optimally configured. The *least* optimally configured system to start with is the CB4 containment with disc skimmer (the bottom, black line would be even less optimal, but this refers to the disc skimmer when used with the J-boom only). In all cases, containment capacity exceeds recovery capacity.

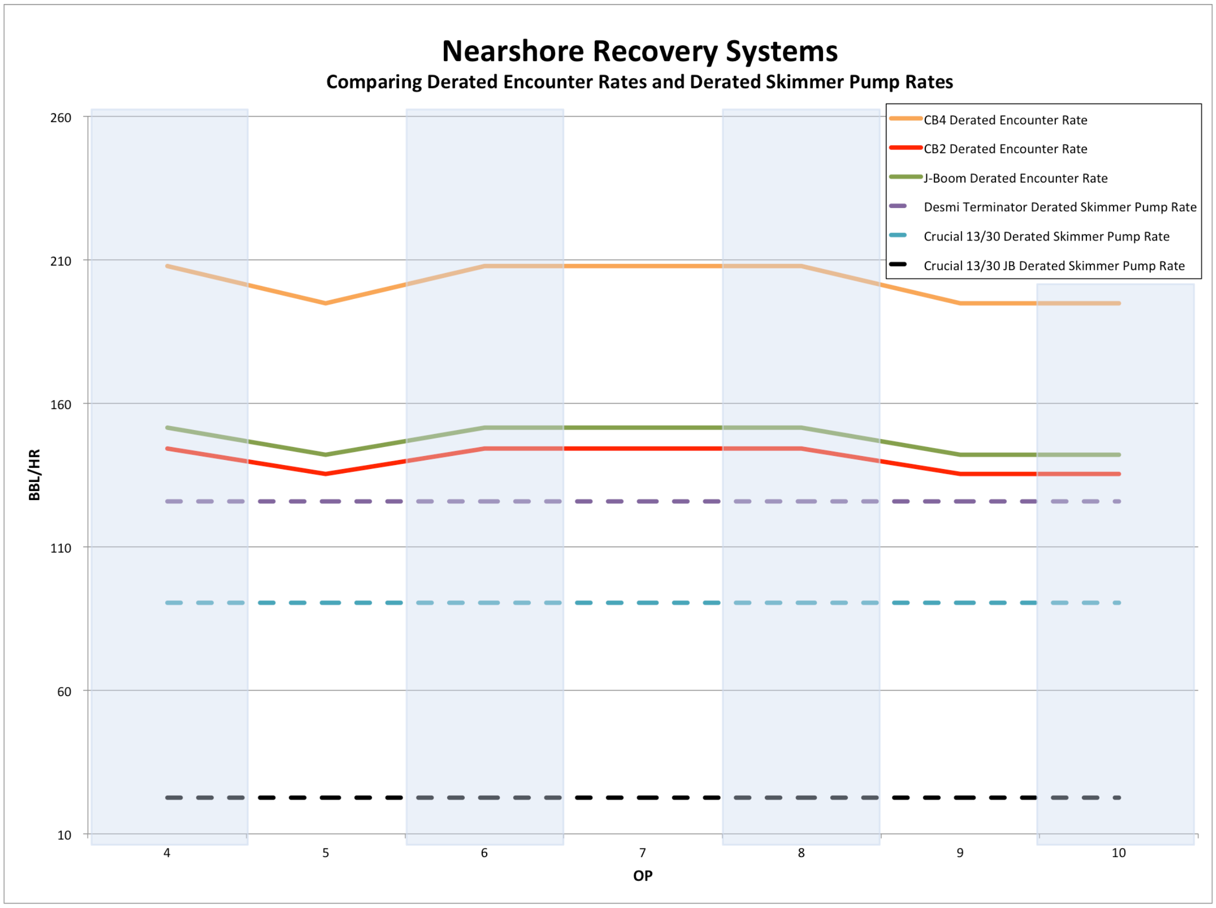


Figure 5-5. Base case optimization graph for each containment and skimming option independently. Shaded areas are daylight operational periods where recovery occurs.

5.2.1 CB4 containment with weir skimmer

The CB4/Weir skimmer combination starts out with a greater capacity to encounter oil than the capacity to pump it (top graph, Figure 5-13). The optimization analysis focused on increasing skimming capacity, with sensitivity analysis shown in Table 5-1. Increasing the derated skimmer pump rate enough to maximize the containment capacity (as shown in the bottom graph, Figure 5-6) would require increasing the skimmer pump rate to 800 bbl/hr. This would increase the total oil recovery from 2,236 bbl to 2,566 bbl (15%). However, there are no skimmers in SERVS' inventory suitable for deployment from a fishing vessel with this high a recovery rate.

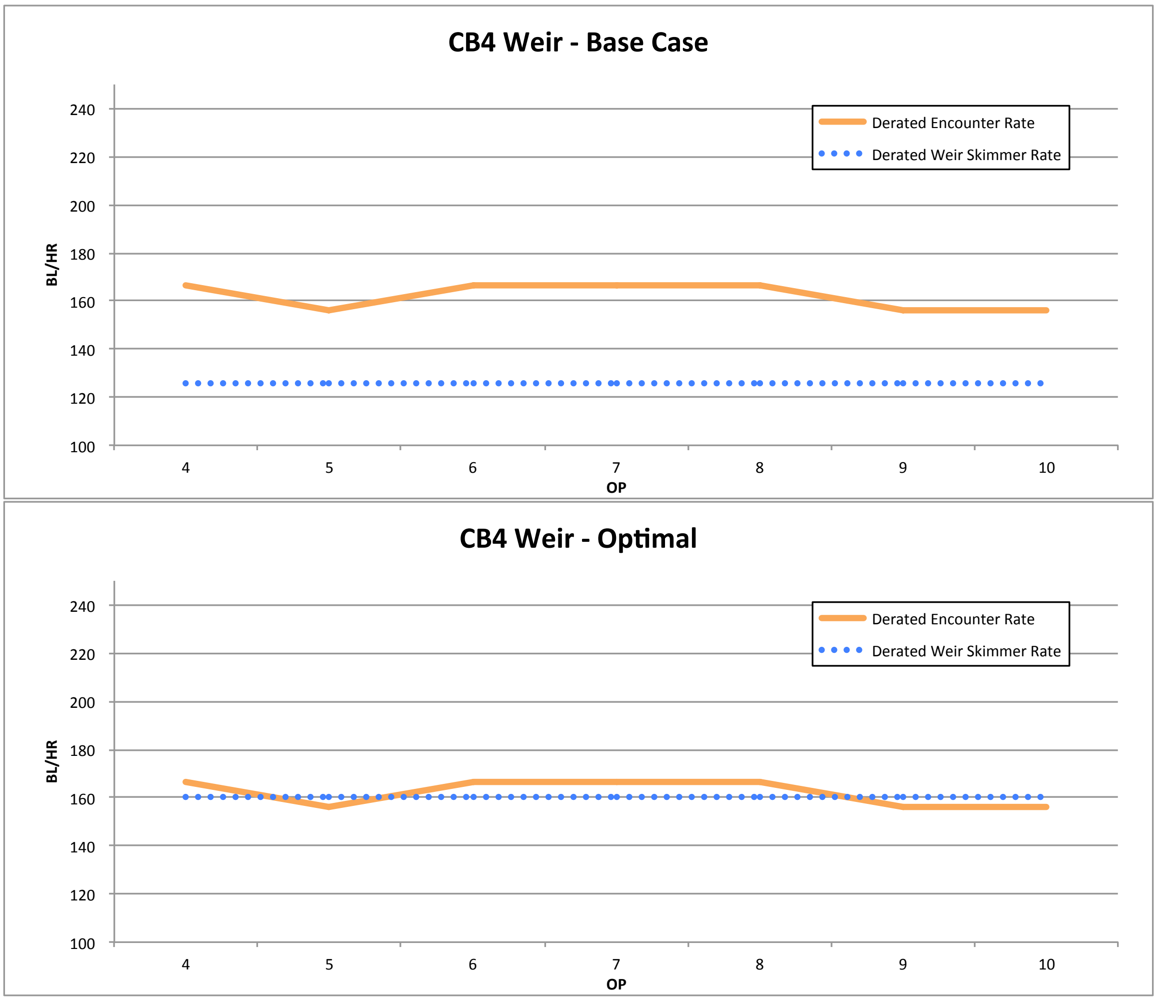


Figure 5-6. Optimization graphs for CB4/Weir skimmer – top graph shows base case, bottom shows optimized case with an increase to an 800 bbl /hr skimmer pump rate

Table 5-1. Total oil recovery for CB4/Weir recovery system for base case options with increased skimmer pump rate

	Skimmer Pump Rate (bbl/hr)				
	629 (Base Case)	700	800 (Optimal)	900	1,000
OP 4	1,059	1,124	1,218	1,235	1,235
OP 6	567	602	652	661	661
OP 8	353	375	406	412	412
OP 10	257	273	290	290	290
Total oil (bbl)	*2,236*	*2,373*	*2,566*	*2,598*	*2,598*
% increase	0%	6%	15%	16%	16%
Total fluid (bbl)	21,395	22,709	24,493	24,753	24,753

5.2.1.1 Findings for CB4/Weir

Findings for this recovery system are summarized as follows:

- The base case configuration would recover 2,236 bbl of oil and 21,395 bbl total fluids.
- The system has more containment capacity than its recovery capacity.
- Oil recovery could be increased by 15% (to 2,566 bbl) if the skimmer pump rate is increased to 800 bbl/hr. However, this may not be practical.
- This change would also increase total fluid recovery to 24,493 bbl.

5.2.2 CB4 containment with disc skimmer

Initially, the CB4/Disc skimmer recovery system has significantly more containment capacity than recovery capacity, as shown in the top graph of Figure 5-7. Table 5-2 shows the effect on oil recovery from using the USCG skimmer rate and then further increasing the pump rate up to 350 bbl/hr. Oil recovery increases with when skimmer pump rate is increased, but only up to 300 bbl/hr. At skimmer pump rates above 300 bbl/hr, the encounter rate becomes the limiting factor. Encounter rate can also be increase by increasing the skimming speed, if the conditions and vessel allow. The optimization analysis for this system considered the effects of both increasing skimmer pump rate and increasing the speed to maximize oil recovery. Table 5-3 shows that increasing the speed from 2.5 to 2.75 knots while increasing skimmer pump capacity from 113 bbl/hr to 300 bbl/hr represented the best alignment of containment capacity and skimming capacity, while also increasing oil recovery to 4,719 bbl (127% increase). This could be achieved by replacing the Crucial 13/30 disc skimmer with a Crucial 56/30 disc skimmer. The optimized system would also increase total fluid recovery from 5,677 bbl to 12,902 bbl.

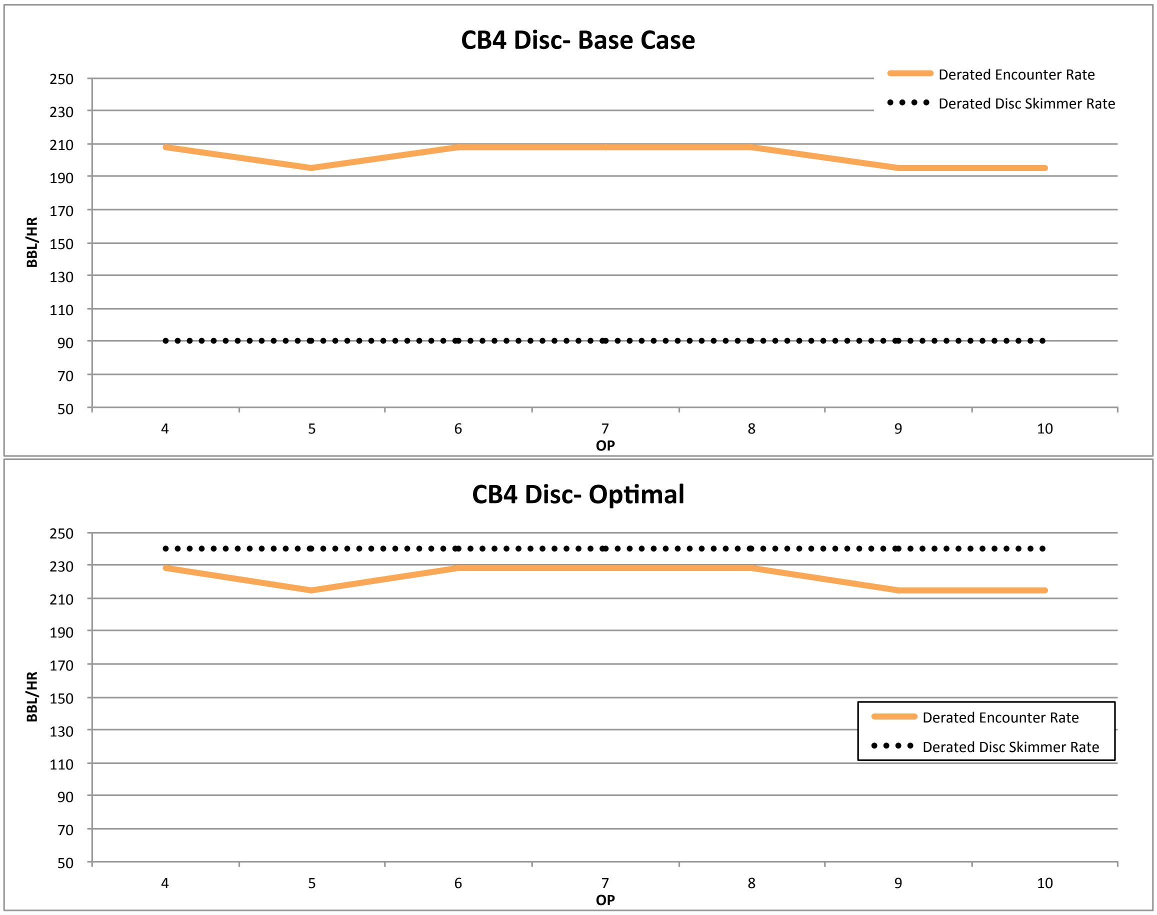


Figure 5-7. Optimization graphs for CB4/Disc skimmer – top graph shows base case, bottom shows optimized case with an increase to a 2.75-kt. tow speed and 300 bbl/hr skimmer pump rate.

Table 5-2. Oil recovered for each operational period and cumulatively for options considered to optimize CB4/Disc skimmer system by increasing skimmer pump rate

	Skimmer Pump Rate (bbl/hr)				
	113 (Base Case)	197 (USCG)	250	300 (Optimal)	350
OP 4	984	1,604	1,949	2,212	2,212
OP 6	527	859	1,044	1,184	1,184
OP 8	328	535	650	737	737
OP 10	238	389	473	514	514
Total oil (bbl)	*2,076*	*3,387*	*4,115*	*4,648*	*4,648*
% increase	0%	63%	98%	124%	124%
Total fluid (bbl)	5,677	9,260	11,252	12,637	12,637

Table 5-3. Oil recovered for each operational period and cumulatively for the base case and optimal system (skimmer pump rate increased to 300 bbl/hr and system speed increased to 2.75 knots)

	Base Case	**Optimal**
Speed (kt)	2.50	2.75
Skimmer pump rate (bbl/hr)	113	300
OP 4	984	2,235
OP 6	527	1,197
OP 8	328	745
OP 10	238	542
Total oil (bbl)	*2,076*	*4,719*
% increase	0%	127%
Total fluid (bbl)	5,677	12,902

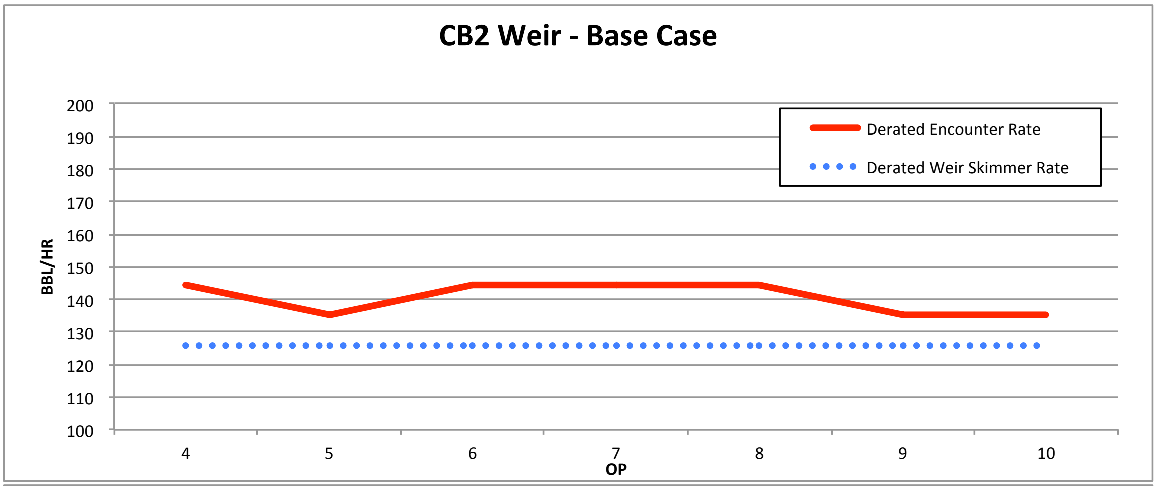
5.2.2.1 Findings for CB4/Disc

Findings for the CB4/Disc skimmer system are summarized as follows:

- The base case configuration would recover 2,076 bbl of oil and 5,677 bbl total fluids.
- The system has significantly more containment capacity than its recovery capacity.
- Oil recovery could be increased by 127% (to 4,719 bbl) if the skimmer pump rate is increased to 300 bbl /hr and the speed to 2.75 knots. This could be accomplished by using a Crucial 56/30 in place of the 13/30 model.
- This change would also increase total fluid recovery to 12,902 bbl.

5.2.3 CB2 containment with weir skimmer

Figure 5-8 shows the optimization graphs for the base case and optimal configurations for the CB2/Weir skimmer system. As with the other nearshore recovery systems, the CB2/Weir skimmer system has a higher containment capacity than recovery capacity, though not to the extent seen in the other systems. From an optimization perspective, CB2 containment is better matched to the skimming systems studied in this analysis than either the CB4 or J-boom containment systems. Two modifications to increase and optimize recovery capacity were analyzed: using a mini-barge instead of a micro-barge for primary storage and increasing the skimmer pump rate. Increasing primary storage capacity does not affect the rate at which oil is contained or recovered, but adds to the total skimming time for this system since it does not have to stop as often for replacement of a filled the primary storage barge. Table 5-4 shows that when primary storage was increased alone, oil recovery increased by 26%. Oil recovery increased more when the skimmer pump rate was also increased to 700 bbl/hr, which is considered to be optimal. The optimized option would increase total fluid recovery from 15,048 bbl to 19,802 bbl. However, as mentioned before, there is not a weir skimmer in SERVS inventory that matches this specification.



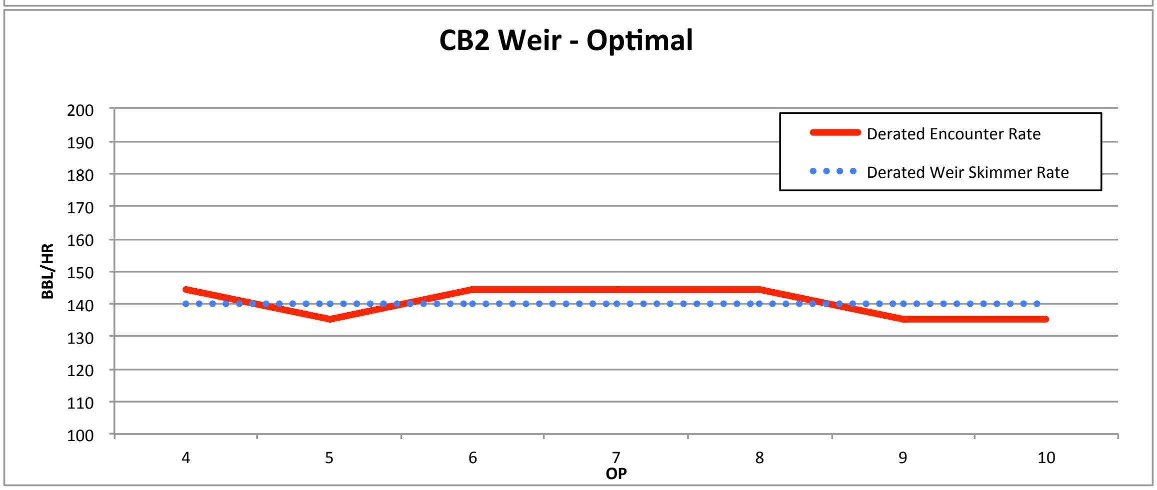


Figure 5-8. Optimization graphs for the CB2/Weir skimmer system, with base case (top) and optimal case (bottom) based on increasing primary storage and the skimmer pump rate

Table 5-4. Options considered for optimizing CB2/Weir skimmer system by increasing skimmer pump rate to 700 bbl/hr and primary storage to 237 bbl

	Base Case	**Optimal**	
Primary storage (bbl)	114 (micro-barge)	237 (mini-barge)	237
Skimmer pump rate (bbl/hr)	629	700	629
OP 4	745	985	939
OP 6	399	528	502
OP 8	248	328	313
OP 10	181	234	228
Total oil (bbl)	*1,573*	*2,075*	*1,981*
% increase	0%	32%	26%
Total fluid (bbl)	15,048	19,802	18,960

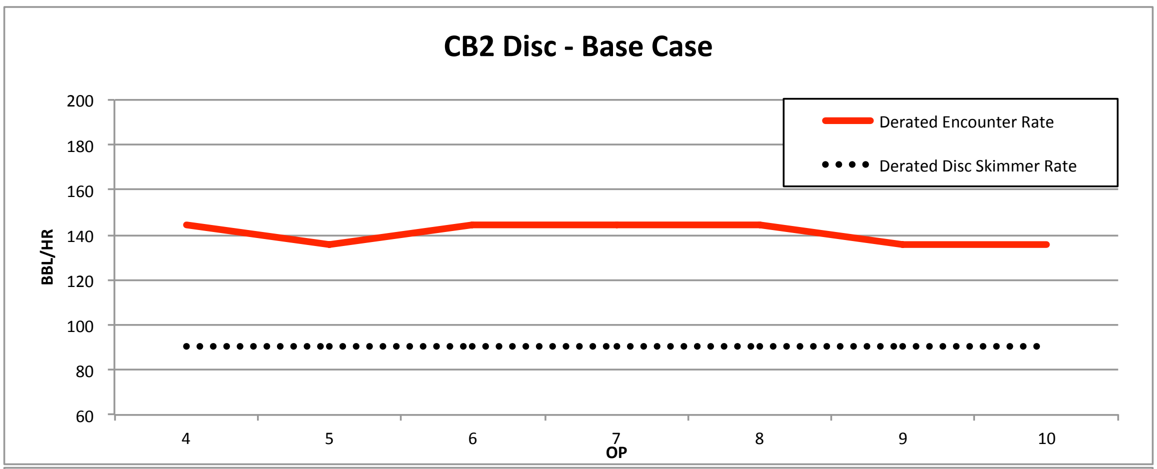
5.2.3.1 Findings for CB2/Weir

Findings for the CB2/Weir disc system are summarized as follows:

- The base case configuration would recover 1,573 bbl of oil and 15,048 bbl total fluids.
- The system has more containment capacity than its recovery capacity.
- Oil recovery could be increased by 32% (to 2,075 bbl) if the skimmer pump rate is increased to 700 bbl/hr and the primary storage to 237 bbl.
- This change would also increase total fluid recovery to 19,802 bbl.

5.2.4 CB2 containment with disc skimmer

Figure 5-9 shows the optimization graphs for the CB2/Disc skimmer system. As with the others, it has more containment capacity than recovery capacity. The optimization analysis for this system mirrored the approach applied to the CB2/Weir skimmer system: increasing the skimmer pump rate and increasing primary storage capacity to reduce downtime. The results, shown in Table 5-5, below, indicated that an optimized system would include both modifications considered (skimmer and primary storage). Sixty-percent more oil could be recovered by increasing the skimmer pump rate to 197 bbl/hr (which is the USCG de-rated recovery rate for this skimmer) and primary storage to 237 bbl (a mini-barge instead of a micro-barge).



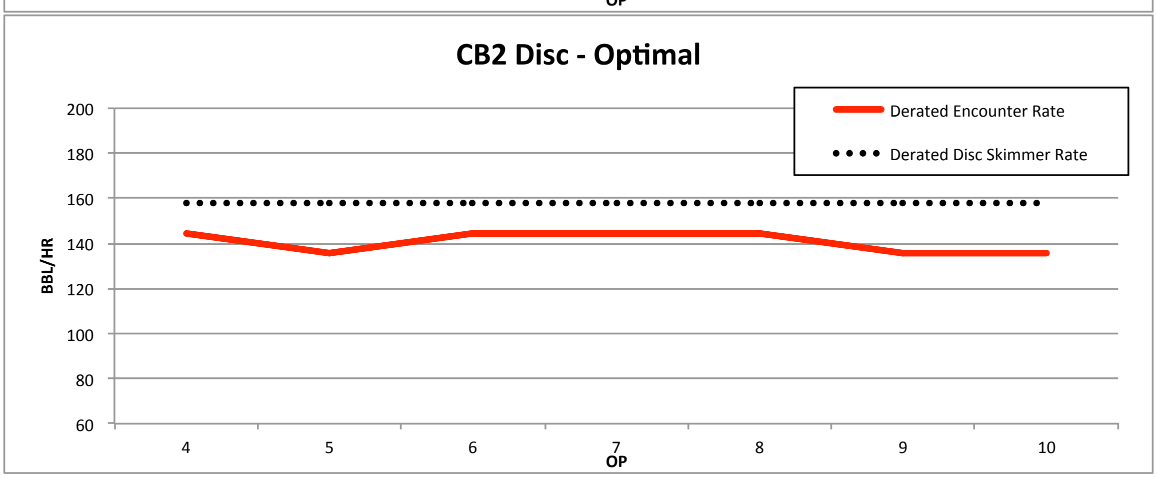


Figure 5-9. Optimization graphs for the CB2/Disc system, with base case (top) and optimized case (bottom) based on increasing primary storage and the skimmer pump rate

Table 5-5. Oil recovery per operational period and cumulatively for the options considered to optimize the CB2/Disc skimmer system by increasing both the skimmer pump rate and primary storage capacity

	Base Case	**Optimal (USCG)**	
Primary storage (bbl)	114 (micro-barge)	237 (mini-barge)	237
Skimmer pump rate (bbl/hr)	113	197	113
OP 4	881	1,407	963
OP 6	472	753	516
OP 8	294	469	321
OP 10	214	341	234
Total oil (bbl)	*1,860*	*2,971*	*2,033*
% increase	0%	60%	9%
Total fluid (bbl)	5,085	8,122	5,560

5.2.4.1 Findings for CB2/Disc

Findings for the CB2/Disc skimmer system are summarized as follows:

- The base case configuration of this system would recover 1,860 bbl oil and 5,085 bbl total fluids.
- The system has more containment capacity than recovery capacity, but is better matched to this skimming system that either of the other two containment systems studied.
- Increasing the skimmer pump rate to 197 bbl/hr (USCG rating for this skimmer) *and* increasing primary storage capacity to 237 bbl (mini-barge instead of micro-barge) could result in a 60% increase in oil recovery.
- Changing the micro-barge for a mini-barge alone (with no change in skimmer) would result in a 9% increase in oil recovery potential.

5.2.5 J-boom containment with weir skimmer

Figure 5-10 shows the optimization graphs for the J-boom/Weir skimmer system. As with the others, it has more containment capacity than recovery capacity. In fact, the J-Boom containment system has very nearly the same containment potential as the CB4, so the conclusions of the analysis are similar. A sensitivity analysis presented in Table 5-6 shows that the swath width could be decreased to 175 feet without affecting oil recovery potential. The optimization analysis focused on increasing the skimmer pump rate. As shown in Table 5-7, the optimal skimmer pump rate for this containment system would be 750 bbl/hr. As noted, there is not a weir skimmer in the SERVS inventory with this specification.

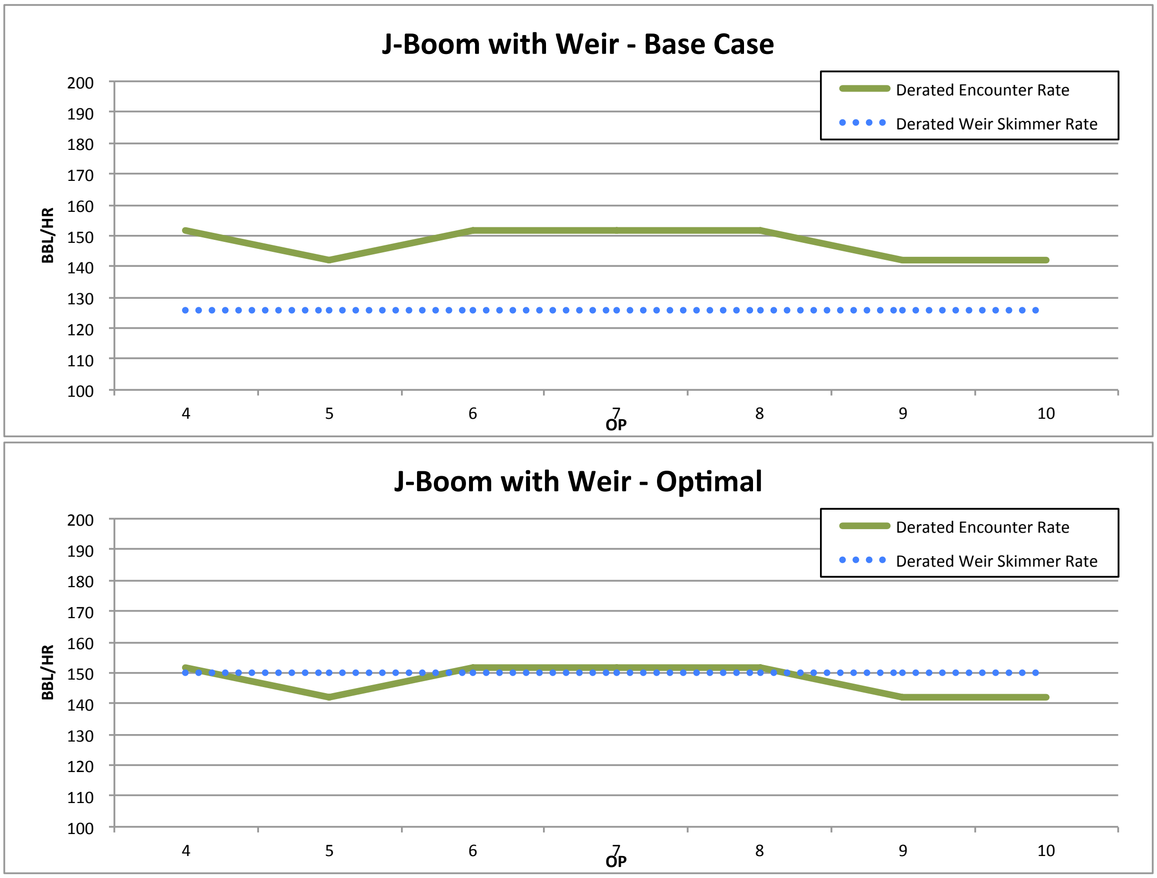


Figure 5-10. Optimization graphs for J-boom/Weir skimmer system, with base case (top) and optimized case (bottom) based on increasing skimmer pump rate to 750 bbl/hr

Table 5-6. Oil recovered each OP and cumulatively for base case and options considered to reduce swath width for the J-boom/Weir skimmer system

Swath Width (ft)		
	200 (Base Case)	175
OP 4	1,059	1,059
OP 6	567	567
OP 8	353	353
OP 10	257	254
Total oil (bbl)	*2,236*	*2,233*
% increase	0%	0%
Total fluid (bbl)	21,395	21,330

Table 5-7. Oil recovered each OP and cumulatively for base case and options considered to increase skimmer pump rate for the J-boom/Weir skimmer system

	Skimmer Pump Rate (bbl/hr)				
	629 (Base Case)	700	750 (Optimal)	800	850
OP 4	1,059	1,124	1,171	1,171	1,171
OP 6	567	602	627	627	627
OP 8	353	375	390	390	390
OP 10	257	273	273	273	273
Total oil (bbl)	*2,236*	*2,373*	*2,461*	*2,461*	*2,461*
% increase	0%	6%	10%	10%	10%
Total fluid (bbl)	21,395	22,709	23,426	23,426	23,426

5.2.5.1 Findings for J-boom/Weir

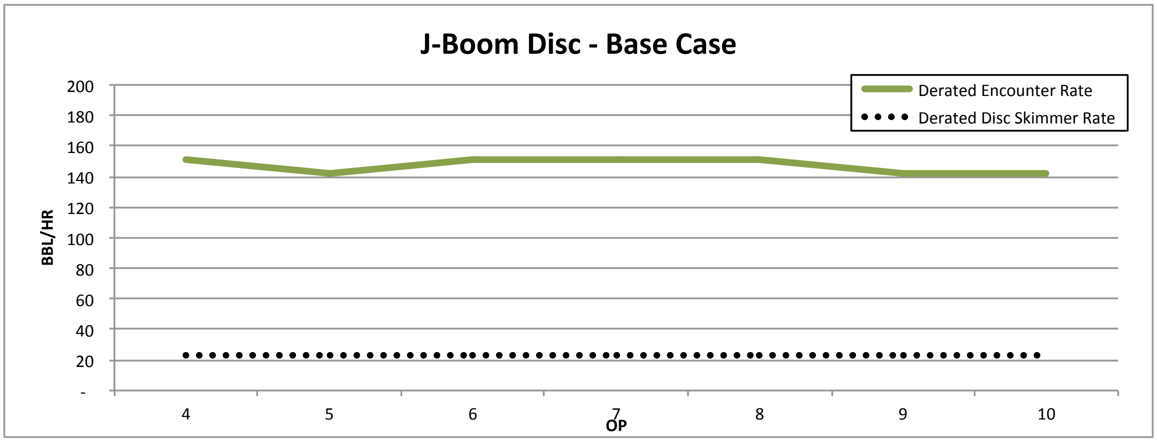
Findings for the J-boom/Weir skimmer system are summarized as follows:

1) The base case configuration would recover 2,236 bbl of oil and 21,395 bbl total fluids.
2) The system has slightly more containment capacity than its recovery capacity.
3) Oil recovery could be increased by 10% (to 2,461 bbl) if the skimmer pump rate is increased to 750 bbl/hr, but this may not be feasible given the skimming systems available.
4) This change would also increase total fluid recovery to 23,426 bbl.

5.2.6 J-boom containment with disc skimmer

Figure 5-11 shows the optimization graphs for the J-boom/Disc skimmer system. As with the others, it has more containment capacity than recovery capacity. The sensitivity analysis of skimmer pump rate (Table 5-8) shows the effect on oil recovery resulting from the use of the USCG skimmer rate and also additional increases up to 350 bbl/hr. For this system, oil recovery increases as the skimmer pump rate increases, up to 350 bbl/hr. Sixty-three percent (63%) more oil could be recovered by increasing the skimmer pump rate to 197 bbl/hr (which is the USCG rating for this skimmer). One hundred and fifty-three percent (153%) more oil could potentially be recovered by increasing the skimmer pump rate to 350 bbl/hr, which could be accomplished by using the Crucial 56/30 skimmer instead of the 13/30 model.

The optimization analysis for this system considered the effects of increasing skimmer pump rate and the possibility of increasing the recovery efficiency. Without empirical evidence to the contrary, we have chosen to use the recovery efficiency established by ADEC for each recovery system. In this case, we ran an analysis for recovery efficiency to demonstrate the effect of recovery efficiency on oil recovery, presented in Table 5-9. The manufacturer claims recovery efficiency of 80% for this system and ADEC allows 70% recovery efficiency (when used with a Current Buster® containment system). We explored the option of setting the recovery efficiency to 60% and the skimmer pump rate at 250 bbl/hr, which increased oil recovery to 3,506 bbl. This is a 500% increase over the base case. This would also drastically reduce the amount of free-water recovered. However, we established the optimal case base on the ADEC recovery efficiency and 350 bbl/hr skimmer pump rate, which is still 153% higher than the base case.



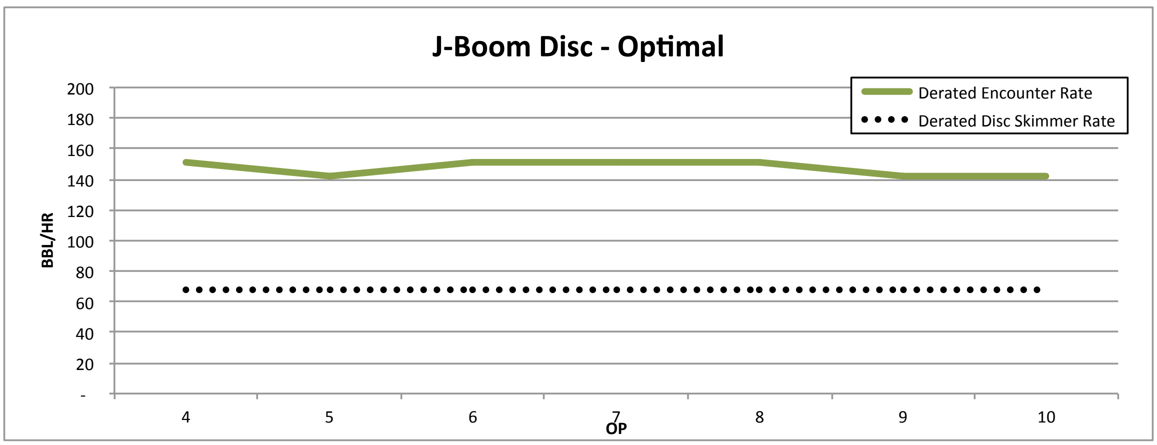


Figure 5-11. Optimization graphs for base case (top) and optimal system (bottom) for the J-boom/Disc skimmer system

Table 5-8. Sensitivity analysis for skimmer pump rate for the J-boom/Disc skimmer system

	Skimmer Pump Rate (bbl/hr)				
	113 (Base Case)	197 (USCG)	250	300	350 (Optimal)
OP 4	281	458	557	639	710
OP 6	150	245	298	342	380
OP 8	94	153	186	213	237
OP 10	68	111	135	155	172
Total oil (bbl)	*593*	*968*	*1,176*	*1,348*	*1,500*
% increase	0%	63%	98%	127%	153%
Total fluid (bbl)	1,371	9,260	11,252	12,902	14,353

Table 5-9. Oil recovered each OP and cumulatively for base case and options considered to reduce swath width and increase recovery efficiency for the J-boom/Disc skimmer

	Base Case	**Optimal**	
Skimmer pump rate	113	350	250
Recovery efficiency	20%	20%	60%
OP 4	281	710	1,671
OP 6	150	380	895
OP 8	94	237	557
OP 10	68	172	384
Total oil (bbl)	*593*	*1,500*	*3,506*
% increase	0%	153%	491%
Total fluid (bbl)	5,677	14,353	11,103

5.2.6.1 Findings for J-boom/Disc

Findings for the J-boom/Disc skimmer system are summarized as follows:

- The base case configuration would recover 593 bbl of oil and 5,677 bbl total fluids.
- The system has significantly more containment capacity than its recovery capacity.
- Oil recovery could be increased by 153% (to 1,500 bbl) if the skimmer pump rate was increased to 350 bbl/hr, which could be achieved by substituting the Crucial 56/130 for the 13/30 model.
- This change would also increase total fluid recovery to 14,353 bbl.
- If the recovery efficiency was increased to more closely match the efficiency used for this skimmer with other containment systems, the potential oil recovery for this system could be increased 500%.

6 Primary/Secondary Storage Transfer Results

Appendix C contains plots of the results of the modeled scenarios and the corresponding formulas depicting theoretical limits for each asset.

6.1 Weir Skimmers

Table 6-1 presents the results of the model runs for weir skimmers. For weir skimmers, the number of offload stations limits oil recovery under the conditions modeled for this study. The water recovered by weir skimmers must be transported, offloaded, and stored. This requires more mini-barges and more offload stations to service a given number of skimming systems. Examination of the individual model runs show that most mini-barges are queued up at secondary storage waiting to offload. The optimal configuration for the scenarios studied is 18 offload stations, 20 skimming systems, and 60 mini-barges.

Table 6-1. Results of primary/secondary storage transfer model runs for weir skimmers

Radius of Operating Area (nm)	Number of Offload Stations	Total Oil Recovery in OP 4 (bbl)	Optimal Number of Skimmers	Optimal Number of Mini-barges
2	10	13,040	14	78
2	18	19,419	20	60
10	10	11,412	15	75
10	18	13,362	20	60

6.2 Disc Skimmers

Table 6-2 presents the results of the model runs for disc skimmers. The results for disc skimmers show that the number of offload stations is much less limiting under the conditions modeled for this study. The recovered fluids contain a much higher percentage of oil, requiring fewer mini-barges and offload stations to service a given number of skimming systems. The optimal configuration is 10 offload stations, 26 skimming systems, and 42 mini-barges.

Table 6-2. Results of primary/secondary storage transfer model runs for disc skimmers

Radius of Operating Area (nm)	Number of Offload Stations	Total Oil Recovery in OP 4 (bbl)	Optimal Number of Skimmers	Optimal Number of Mini-barges
2	6	22,870	24	48
2	10	24,206	26	42
10	6	19,860	22	54
10	10	20,014	22	54

6.3 Size of Operating Area

Figure 6-1 depicts the relationship of total oil recovery to the size of the operating area for weir and disc skimming systems (both using 10 offload stations). As would be expected, total oil recovery decreases as the size of the operating area increases. The effect is more complex for disc skimmers than for weir skimmers. For the disc skimmer fleet (24 skimmers and 48 mini-barges), there is little distance effect for the first 5 nm. This is because the system is skimmer limited; there are sufficient mini-barges to keep all skimmers operating to capacity. Beyond 5 nm, the system becomes limited by mini-barges and declines an average of 2% per nm increase.

For the weir skimmer fleet (20 skimmers and 60 mini-barges) the effect is essentially linear for the range modeled. The recovery is limited by secondary storage offload stations until about 10 nm distance, then by mini-barge availability. For each nautical mile of distance from the secondary storage barge that the operating area is increased, the total recovery during the operating period will decrease by 2%.

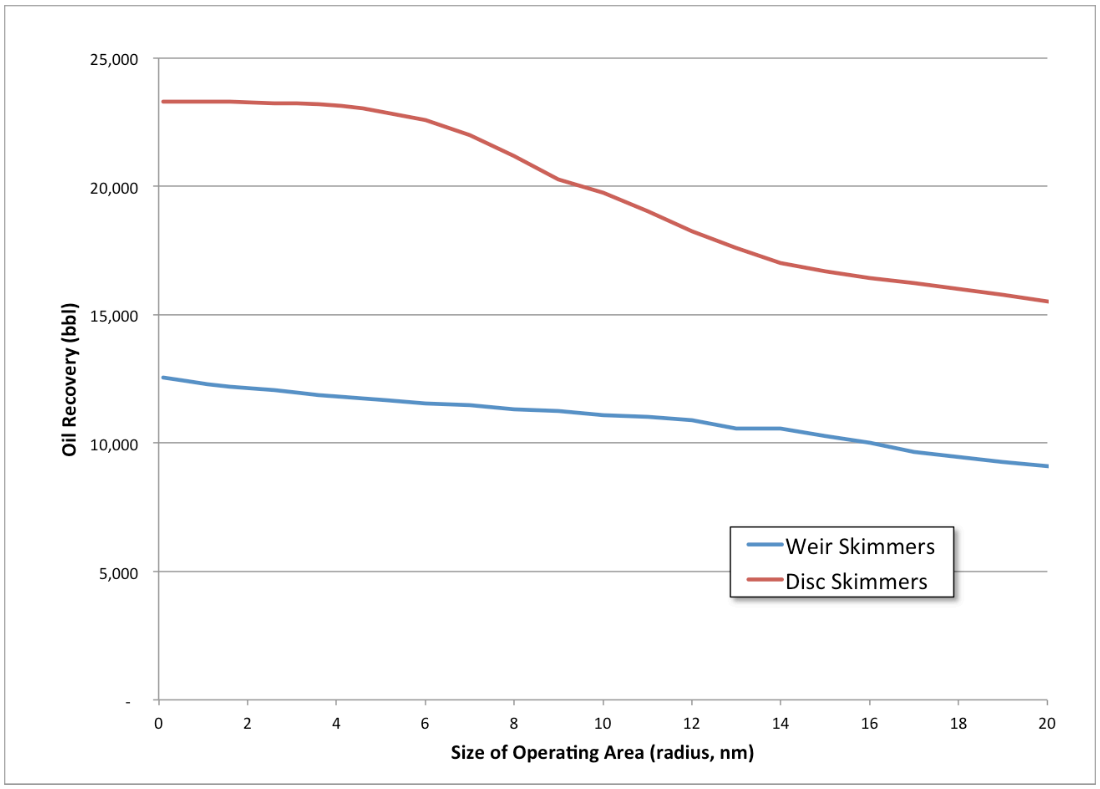


Figure 6-1. Modeled results of median oil recovery (bbl) vs. radius of the operating area (nm) for optimal configurations of weir and disc skimming systems with 10 offload stations.

6.4 Decanting Mini-barges

The ERSP recovery calculations result in two key estimates: (1) during OP 4 the weir skimmer can potentially fill an empty mini-barge in 22.5 minutes, and (2) 189 bbl of the 237 bbl capacity of the mini-barge is free-water, due to the low oil recovery efficiency. It would take 8.9 hours to pump 80% of the free-water out of the mini-barge with the available decanting pump, which pumps at 17 bbl/hr.

Assuming that an offload station is available, the time estimated to rig, derig, and offload at the secondary storage barge is 0.6 hours. Subtracting this time from the time required to decant the mini-barge leaves 8.3 hours[20] available to transit to and from the skimming system's location to the secondary storage barge in order to break even with the time required to decant. With a 5-kt transit speed, this would be 20.8 nm one way. So, for distances less than 20.8 nm it would be best to transport the mini-barge back to the secondary storage barge and offload it rather than use a decanting process to remove the free-water. The same analysis for the disc skimmer recovery system indicates the decanting time would be 3.3 hours, making the associated distance 6.9 nm one way with the same 5-kt transit speed.

This analysis does not consider the loss of potentially recovered oil due to the fact that the skimming system does not operate during the decanting process. For the weir-based system this opportunity loss is 1,108 bbl of oil that potentially could have been skimmed. For the disc-based system the opportunity loss is 263 bbl. Based on this opportunity loss, we conclude that decanting mini-barges is not the optimal procedure to maximize oil recovery in this scenario.

6.5 Findings for Primary/Secondary Storage Transfer

The following findings were drawn from the analysis of the movement of recovered fluids from the skimming systems to secondary storage.

- Oil recovery systems based on weir skimmers recover much more free-water than disc skimmer-based systems. Free water then must be decanted or transported to secondary storage and stored. Because of this, weir skimmer-based systems require more mini-barges and offload systems to operate optimally.
- For a given set of assets, a recovery system based on disc skimmers will recover significantly more oil than one based on weir skimmers. The difference in performance varies with the size of the operating area, but if the operating area has a radius of 2 nm, the disc skimmer system modeled removes 184% more oil than the weir skimmer system.
- Once a skimming fleet becomes limited by the number of available mini-barges, oil recovery declines as the size of the operating area increases. For the combination of resources modeled, this decrease was about 2% oil recovery per nautical mile radius of skimming area.
- Decanting mini-barges does not improve oil recovery for either the weir or disc skimming systems under the circumstances modeled.

[20] 4.15 hours each way

7 Discussion of Results

This section summarizes and discusses the study results

7.1 Open-water Systems

The three open-water recovery systems analyzed are generally limited by encounter rate, meaning that their oil recovery would be improved by better containment systems. Table 7-1 summarizes the results of the optimization of the open-water recovery systems.

Table 7-1. Summary of results for open-water systems

	TransRec/GrahamRec Barge	Current Buster Barge	*Valdez Star*
Base case oil recovered (bbl)	38,067	53,012	14,296
Limiting process	Encounter Rate	Recovery Rate in OP 2 then Encounter Rate	Encounter Rate
Modifications explored	+ 200-ft swath width (initial) and 400-ft swath width with U-boom	+ 20-ft swath width + 0.25-kt speed + 830 bbl/hr skimmer pump rate[21]	+ 180-ft swath width + 571 bbl/hr skimmer pump rate + decanting 80% of free water (vs. no decanting)
Optimized oil recovered (bbl)	48,021 bbl[22]	66,320	26,062
Increase achieved	46%	25%	82%
Storage	Optimized system fills primary storage in OP 8. (Base case system does not fill in the timeframe of the study.)	Primary storage does not fill in either base case or optimized system.	Base case fills primary storage in OP 2. With decanting in optimized system, primary storage does not fill.

[21] This skimmer pump rate is currently approved by USCG

[22] Could be 55,392 bbl, but primary storage fills in OP 8

With advantages in both containment and recovery efficiency, the Current Buster Barge recovery system has the greatest potential for oil recovery overall and collects far less free-water which has to be stored or decanted. This has many advantages when compared to the TransRec/GrahamRec Barge recovery system.

The TransRec Barge recovery system can be significantly improved by increasing the swath width, but will still suffer from the lower oil recovery efficiency.

The *Valdez Star* recovery system can also be improved by increasing the swath width and by using a transfer pump that equals or exceeds the skimmer pump rate. In our opinion, the oil recovery efficiency rating for this system is too low.

7.2 Nearshore Systems

The nearshore recovery systems are all limited by recovery rate, meaning that their oil recovery would be improved by more skimmer capacity. Table 7-2 summarizes the results of the optimization of the nearshore recovery systems.

As with the open-water recovery system, nearshore recovery systems that utilize disc skimmers recover far less free-water, reducing the amount that must be stored or decanted (see discussion of storage below).

The CB2 encounters sufficient oil to feed either skimmer system studied. The CB4 provides no additional benefits with these skimmers. If a Crucial 56/30 disc is utilized with the CB4, then the benefits of this larger containment system could be realized.

We suggest that the oil recovery efficiency rating for the disc skimmer when used for the J-boom should be reconsidered.

Table 7-2. Summary of results for nearshore systems

	Disc Skimmers			Weir Skimmers		
	CB4	**CB2**	**J-boom**	**CB4**	**CB2**	**J-boom**
Base case oil recovered (bbl)	2,076	1,860	593	2,236	1,573	2,236
Limiting process	Recovery Rate			Recovery Rate		
Modific-ations explored	+ 187 bbl/hr skimmer pump rate[23] + 0.25-kt speed	+ 84 bbl/hr skimmer pump rate[24] Replace micro-barge w/ mini-barge	+ 237 bbl/hr skimmer pump rate[25]	+ 171 bbl/hr skimmer pump rate[26]	+ 71 bbl/hr skimmer pump rate Replace micro-barge w/ mini-barge	+ 121 bbl/hr skimmer pump rate[27]
Optimized oil recovered (bbl)	4,719	2,971	1,500	2,566	2,075	2,461
Increase achieved	124%	60%	153%	15%	32%	10%

7.3 Storage Optimization

Our analysis shows that a set of nearshore response systems based on 120 vessels will collect more oil if all skimmers deployed are disc skimmers than if they are weir skimmers. The primary way to increase recovery for weir skimmers is to make more offload stations available. (If only 10 offload stations are available, weir skimmers operate significantly below optimal efficiency due to queuing at secondary storage.) The number of offload stations is less of a limiting factor for the disc skimmers. The only way to increase recovery beyond the optimal configuration of 26 skimmers and 42 mini-barges[28] used with a 120 vessel system would be to add more vessels (and thus more skimmers and mini-barges).

---

[23] Equivalent of using Crucial 56/30 skimmer in place of the 13/30
[24] Equivalent of USCG-approved rating
[25] Equivalent of using Crucial 56/30 skimmer in place of the 13/30
[26] May not be practical
[27] May not be feasible with systems available
[28] 6 fewer mini-barges than in the current system

The analysis also showed that a system based on weir skimmers will result in higher oil recovery if mini-barges keep shuttling back and forth rather than spending time decanting. This is primarily attributed to the pump rate of the decanting pumps and the large volume of water recovered by weir skimmers.

The relationships explored here are likely useful descriptions of response systems, even if specific variables or assumptions do not hold across all possible scenarios. The optimal number of skimmers relative to primary storage devices will depend on skimmer specifications and the characteristics of the oil slick. The lower the oil recovery efficiency of the skimmer, the greater the number of primary storage devices needed. However, if there are a limited number of secondary storage unloading stations, the balancing act between skimmers and primary storage may be moot: the system bottlenecks in the queue at the secondary storage barge.

It is also worth noting that the range of possible recovery values is larger for weir skimmers than for disc skimmers in the numerical model. We believe this is because weir skimmers are more dependent on the efficient shuttling of oil from skimmers to secondary storage, while disc skimmers make better use of each mini-barge (with less shuttling required to collect the same amount of oil). Disc skimmers are thus less vulnerable to inefficiencies in dispatching or other practical constraints that slow the shuttling process.

7.4 Considerations and Observations

We offer the following considerations and observations based on the process of conducting the study:

- **Potential oil recovery is valuable as a comparative metric only.** None of the volumes of oil recovered resulting from scenario runs in this analysis represents a predicted volume of oil that would actually be recovered.

- **Real-world testing and training are critical.** Models allow us to test the effect of many factors on oil recovery without the costs or inherent risks of deploying people, vessels, or equipment on the water. However, the only potential modifications to a system that matter are the ones that will work in the real world. The results from this study could be tested first against different conditions (such as winds or length of daylight) using the models. Those that are upheld must then be tested in on the water, and, if they work, then responders must be trained to implement them safely.

- **Oil properties impact results.** Oil properties and the way they are interpreted have a significant effect on the results of the study. For this study, we applied the inputs from the SL Ross analysis of 2015 ANS crude as agreed with the workgroup at the start of the project. Based on this approach, the slick thickness stabilized in OP 4 and remained the same through OP 10. This meant that the optimization graphs essentially flat-lined. In most spills, we would expect to see a slick that continues to thin as they days go by. If this happens, then encounter rate becomes much more important the more the oil spreads. The results of the analysis would be different if the slick continued to thin.

- **Realistic equipment assumptions are critical.** The models used in this study incorporate many, but not all, factors that will determine the amount of oil that could be recovered in a spill response. The inputs describing each system can have a significant impact on the estimated oil recovery for that system as it plays out over the five-day scenario. In two cases, the ADEC and USCG have approved different values for the same skimmer type (skimmer pump rate in one case, and recovery efficiency in the other). Understanding which one is most accurate to the real world would greatly enhance the study and results.

- **Results regarding disc skimmers could apply to oleophilic skimmers generally.** The models used in this study require several inputs to describe the recovery systems being studied. This means identifying specific pieces of equipment – in this case, most of the equipment identified is in the 2013 SERVS Technical Manual. The disc skimmers identified for this study belong to a group of skimmers that collect oil using oleophilic (oil-attracting) material. This group of skimmers is generally known for having many of the attributes discussed here for the disc skimmers, most notably the relatively high recovery efficiency. Some of the findings related to the disc skimmers may also apply to other skimmers in this group.

- **A prompt response is critical.** While this analysis did not seek to model the overall result of an oil spill response, for the individual systems studied the recovery volumes over time highlight the importance of a prompt response. Regardless of whether a system is optimized, recovery will be harder as the slick spreads and thins.

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APPENDIX A – DESIGN WORKSHOP SUMMARY

SUMMARY

Design Workshop:
Prince William Sound Response Capacity Analysis
Prince William Sound College Training Room
Valdez, Alaska

November 3, 2015
Participants
Anna Carey, Steve Russell (ADEC)
Mike Day, Scott Hicks, Andres Morales (APSC/SERVS)
Catherine Berg (NOAA)
Sharry Miller (PWSC)
Scott Pegau (OSRI)
Roy Robertson, Jeremy Robida, Donna Schantz, Linda Swiss, Nelli Vanderburg (PWSRCAC)
Jim Herbert, John LeClair, Alisha Sughroue (PWSRCAC – OSPR)
Sierra Fletcher, Tim Robertson (Nuka Research)
CDR Joe Lally, LT Keyth Pankau, LT Jason Scott (USCG)

Purpose of the project & workshop

The purpose of the project is to:

1) Better understand PWS response system *as a system*
2) Analyze impact of potential enhancements/modifications
3) **NOT FOR** regulatory compliance

The purpose of this workshop is to:

1) Ensure that PWSRCAC staff, board, and key partners understand the purpose of the project and the analytical approach.
2) Gain input on research questions, assumptions, and inputs that will be used for the analysis.

This project is being conducted as part of PWSRCAC's current Fiscal Year budget. They are currently working on the next 5-year plan, but anticipate potentially implementing additional analysis and/or outreach related to this project.

Presentation

Tim Robertson (Nuka Research) presented the approach Nuka Research has developed to conduct a response capacity analysis using the Response Options Calculator (ROC), which models oil weathering and potential on-water recovery. Another option is to use the Recovery System Calculator (RSC), also developed by Genwest Systems, Inc., which facilitates the analysis of individual systems (i.e., strike teams) though does not incorporate oil weathering directly (instead, inputs such as slick thickness are entered by the user rather than modeled). The presentation focused on the use of the ROC to develop estimated potential capacity of an overall response system based on a series of modeled scenarios, with the potential to change inputs such as response system composition, transit time, wind, water temperature, time of year, and other factors. Nuka Research has used this approach in previous response capacity analyses.

Slides are available at: nukaresearch.com/pws

Approach

The group first agreed on the conditions for a baseline response scenario (see below):

- Location: Abeam of Naked Is. in tanker lanes
- Type of Release: Continuous release over 10 hrs (may be changed to batch spill)
- Size of spill: 150,000 bbl
- Oil: 2012 ANS crude (if RSC is used for potential recovery, ROC can still be used for weathering model to determine slick thickness, etc. at different times)
- Time of spill: 2 am
- Date of spill: Spring equinox
- Duration of modeled response: 5 day response (modeled)
- Wind = 25^{th} percentile for spring
- Water temp = Median for spring
- Recovery in darkness would be included for open water task forces (OWTF) at a reduced throughput (TBD); transit & offloading OK (using civil twilight to delineate)

Next, the group discussed subsequent scenario inputs to understand the impact of changes in wind speed, season, skimmer type, and transit/offload time on potential recovery capacity.

After extensive discussion, the group instead recommended that the approach should be to analyze "systems within the system" as representative of the system overall. For example, to compare the potential recovery achieved with different variations of a single open-water strike team (OWST), instead of estimating total potential recovery from all the OWST that could possibly be mobilized in PWS.

The intent behind this alternate approach is two-fold: (1) focus time and resources on exploring options to optimize the system by studying one strike team at a time, rather than developing inputs to model the whole system, and (2) foster collaboration by disassociating the results from existing regulatory measures of performance or planning requirements (i.e., the response planning standard, or recovery calculations used in the state contingency plan).

In studying the optimization of OWST and nearshore strike team (NSST), consideration will be given to decant time, availability of mini-barges, and queuing for secondary storage offload.

The ability of responders to implement the J-boom configuration is a concern to some, but not something that can be studied in this analysis. Nor will it study the impact of resources coming from outside PWS (as this would require a study of the whole system) or modifications to strike teams beyond those listed above.

Research questions

Research questions will determine the inputs and assumptions used for the analysis. The group discussed multiple options, as discussed above, but ultimately suggested that the study should focus on the optimization of system configurations relate to containment (swath width and speed of advance), skimming, and both primary and secondary storage. This will be examined for both OWST and NSST.

- What is the optimal configuration of containment, skimming, and storage (primary and secondary) for the following on days 1-5:[29]
    - OWTF: Transrec weir
    - OWTF: CB8 w/ oleophilic skimmer
    - NSST w/ CB4:
        - Weir skimmer
        - Oleophilic skimmer
    - NSST w/ J-boom:
        - Weir skimmer
        - Oleophilic skimmer
    - Valdez Star
    - NSST w/ CB2:
        - Weir skimmer
        - Oleophilic skimmer

Next steps

1. Nuka Research circulates draft workshop summary for review (Deadline: Nov. 20, 2015)
2. Nuka Research circulates proposed method based on workshop input, and specs for strike teams to be studied (Deadline: Dec. 15, 2015)
3. Nuka Research briefs participants on preliminary results; ID additional analysis if warranted (Deadline: TBD w/ PWSRCAC; early 2016)
4. Final results, report, and presentation (Deadline: May 31, 2016)

[29] Model will assume that strike teams are operating in thickest oil; does not consider location relative to slick or changes in slick such as windrows.

APPENDIX B – OIL SPILL FATE AND BEHAVIOR AND MECHANICAL RECOVERY CONCEPTS

Oil spilled to the marine environment will immediately begin to move with the tides, current, and wind. Oil will also begin to undergo physical and chemical changes through a process known as weathering. Oil movement and weathering will depend on the type of oil spilled and the characteristics of the marine environment at the time. Physical and biological processes involved in oil weathering include spreading, evaporation, dispersion, dissolution, emulsification, oxidation, sedimentation, and biodegradation as shown in Figure B-1.

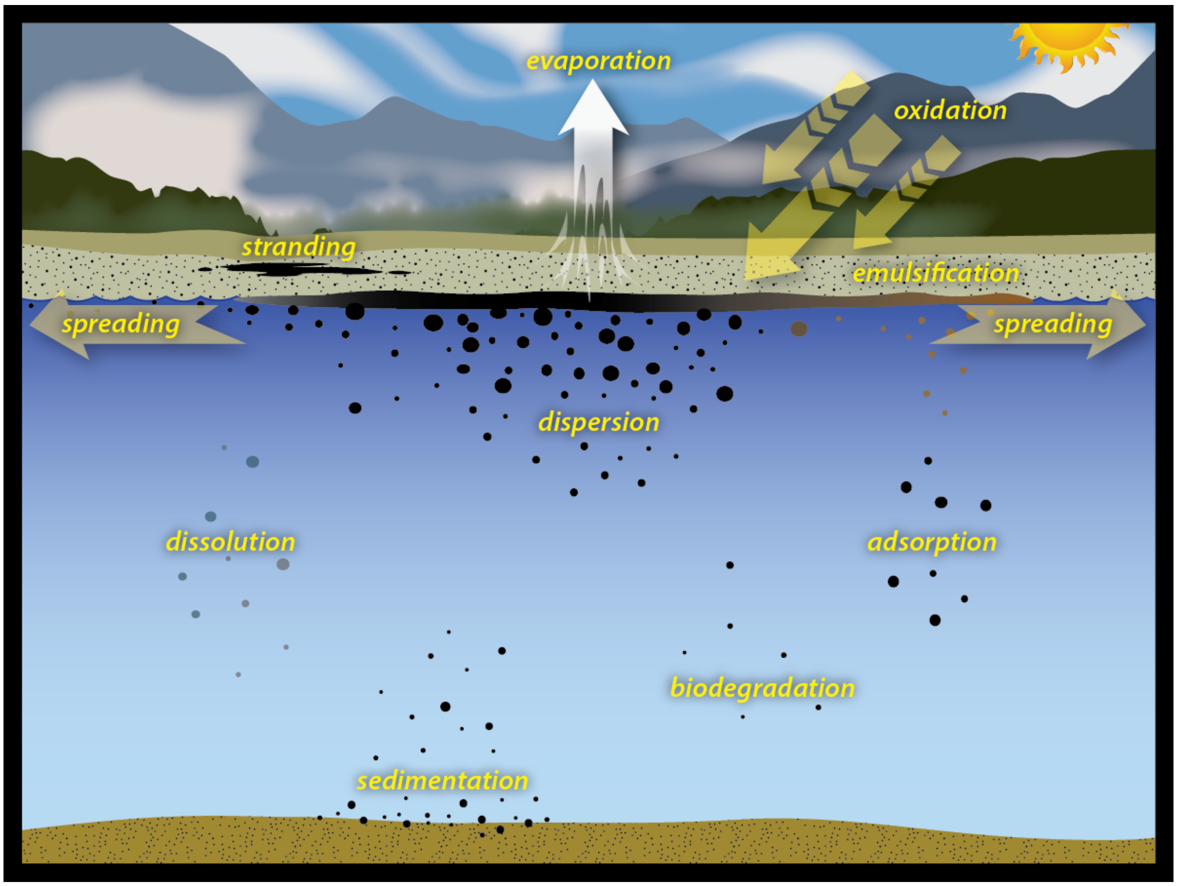


Figure B-1. Oil weathering processes (based on NOAA, 2016b; ITOPF, 2011a)

The way oil weathers and moves will depend on the properties of the oil spilled, in combination with the marine environment and conditions over time. Oils are comprised of hundreds of compounds that behave differently, and oil produced from a particular location may change over time. Table B-1 shows key oil properties related to behavior and effects that were included in this analysis.

Table B-1. Select oil properties related to oil behavior and oil spill response (based on Fingas, 2015)

Oil Property	Explanation	Relevance to Spill Response
Viscosity	Resistance to flow (in a liquid). Oils typically become more viscous at lower temperatures.	• Viscous slick will spread and thin more slowly • Very viscous oil may affect skimmers/pumps
Density	Mass of a unit of oil. Oil density relative to water density indicates whether oil will float, submerge, or sink. Reference to "light" or "heavy" crude oil is based on density.	• Oils with density higher than water may submerge or sink (and thus not be available to free-oil recovery) • Oils that initially float may become more dense as they evaporate, emulsify, or incorporate sediments and sink later
API gravity	Oil density relative to water density, which may vary as densities change with temperature changes. American Petroleum Institute (API) uses densities at 60F.	• Another expression of density
Pour point	Temperature at which oil does not visibly flow from a standard measuring vessel in 5 seconds. Oil may still pour, but will do so very slowly.	• Not a direct indicator of slick behaviour

The behavior of a slick can have a significant affect on its recoverability, or whether it is recoverable at all. If a slick becomes too viscous (thick), some skimmers will not work effectively or may not work at all (Potter, 2013). If a slick spreads and thins, it becomes increasingly difficult to recover from the water's surface. If a slick sinks, that oil will not be recoverable using mechanical recovery methods such as those described in this report. Thus, the oil properties and the interplay of the wind and water temperature entered into the recovery model will affect the results of the analysis.

Mechanical Oil Spill Recovery

There are different approaches to containing, cleaning up, and treating oil spills. This study focuses on the mechanical recovery of oil that is floating on the water, sometimes referred to as free-oil recovery. Mechanical recovery of free-floating oil is considered the preferred method to remove oil from the marine environment in Alaska (ADEC, 2014). This approach uses oil recovery systems – containment boom, oil skimmers, pumps, hoses, and storage devices deployed from vessels – to contain, recover, and store spilled oil.

Containment

In on-water free-oil recovery, oil is contained using different configurations of floating oil containment boom moved through the water with vessels. Boom may be towed in different configurations depending on vessels, equipment, and conditions. There are four configurations relevant to this study, shown in Figure B-2: U-boom, gated U-boom (with an opening used to concentrate oil rather than recover it directly), Current Buster® containment, and J-boom. These four configurations – or tactics – are included because they part of the Prince William Sound response system.

"Current Buster" refers to a NOFI Current Buster® which comes in four sizes: Current Buster® 2, Current Buster® 4, Current Buster® 6, Current Buster® 8 (referred to in the study as CB2, C4, and CB8; there is no CB6 in the analysis). Based on information provided on the company's website, the systems differ in their front opening (swath width in the study), total length, temporary storage tank volume, and maximum towing speed. These specifications also translate to the intended operating environment, with the CB2 designed for sheltered waters and the CB8 for exposed waters. (NOFI, no date)

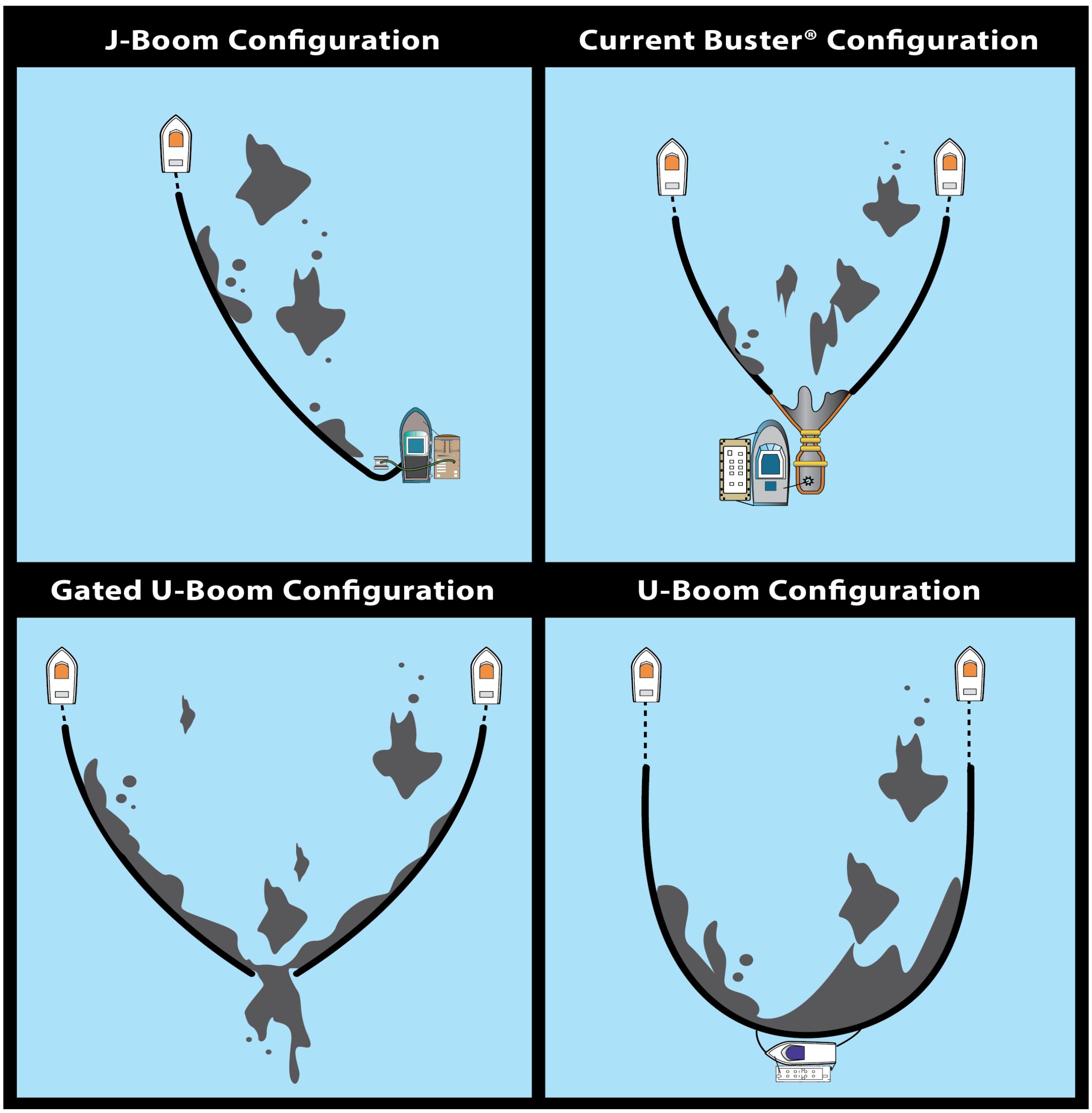


Figure B-2. Booming configurations used for on-water free-oil recovery that are included in the recovery systems used in this study (based on ADEC, 2014)

Recovery

Skimmers are recovery systems used to collect oil, water, emulsification (water/oil combination), and floating debris encountered during skimming (see Figure B-3). There are many different types of skimming devices that recover the oil from the water's surface (Potter, 2013). There are three basic types of on-water oil skimmers used in the recovery systems in this study: (1) weir skimmers, (2) oleophilic disc skimmers, and (3) a dynamic inclined plane belt skimmer. Weir skimmers create a sump in the water, which captures the oil and water that pour into it. Oleophilic skimmers move an oil-attracting material through the oil (in various shapes and configurations, including discs). The oil is scraped from the oleophilic material and pumped to storage. (ADEC, 2014) The dynamic inclined plane skimmer uses a moving belt to push the oil below the water surface. When it reaches the back of the belt it is released into an enclosure that is closed on the sides but open at the top and bottom. The oil surfaces in the enclosure where it is trapped and can be pumped to storage as it accumulates. Figure B-4 shows a weir skimmer and oleophilic disc skimmer.

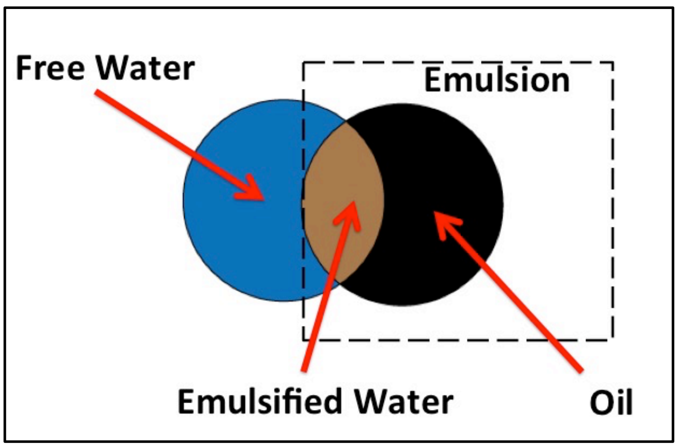


Figure B-3. Recovered fluids consist of a combination of free water, water that is emulsified with oil (if any), and oil

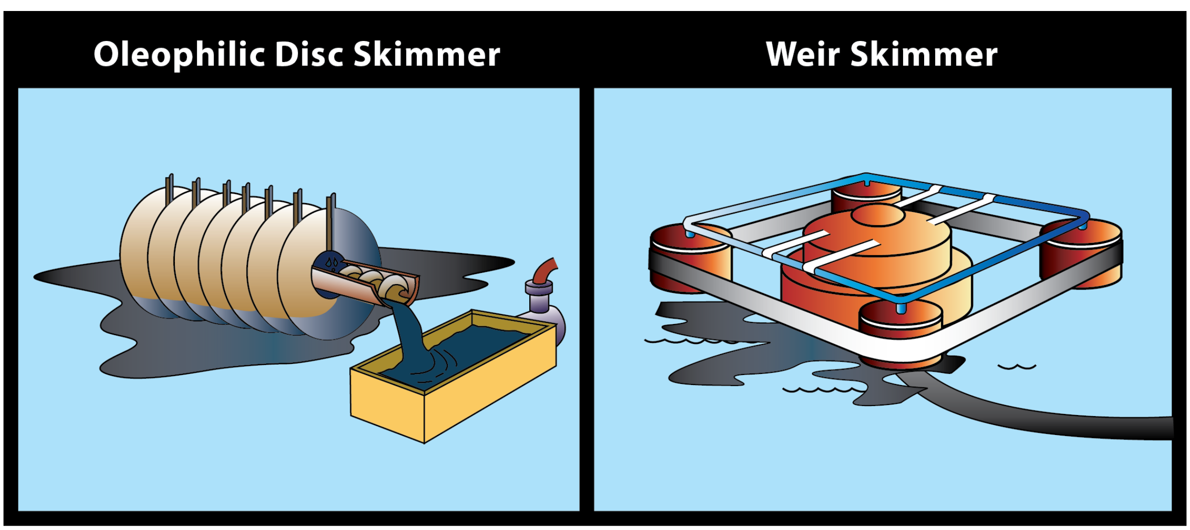


Figure B-4. Example oleophilic disc skimmer and weir skimmer (based on ADEC, 2014)

Storage and decanting

Fluids recovered by skimming are held in primary storage tanks, which are proximate to (or integrated into) the on-water recovery operations. Once these tanks are full, the recovered fluids must be transferred to secondary storage tanks so the primary storage systems can be returned to service. These recovered liquids must eventually be transported to a shore-based facility for long-term storage, treatment, and disposal. Adequate storage is critical to on-water mechanical recovery operations. When storage runs out, recovery must cease.

Decanting is the process of removing some of the excess free water from the fluids recovered. Decanting is a technique used to reduce the amount of storage required. The recovered fluids are allowed to sit without agitation and the oil or oil emulsion will separate from the free water and float to the top. The free water can then be pumped from the bottom of the tank and discharged overboard. Because of the possibility of pumping contained oil overboard, decanting can only occur in the area where oil recovery is taking place.

Other critical elements

Although not included in this analysis, finding and tracking the oil are critical to the on-water recovery systems' effectiveness. In addition, they require logistical support for personnel and equipment, and management of the oily waste collected in compliance with state and federal law.

APPENDIX C – MATHEMATICAL MODEL OF PRIMARY/SECONDARY STORAGE TRANSFER

This Appendix presents the calculations used for the mathematical model, and a set of figures depicting the results.

INDEPENDENT VARIABLES

Number of Skimmers: N_S
Number of Primary Storage Barges: N_P
Number of Unload Stations at Secondary Storage: N_U
Operational Period Duration: T *[14 hrs]*
Primary Storage Volume: V_P *[237 bbl]*
Skimming Pump Discharge: D_S
Unload Pump Discharge: D_U *[2844 bbl/hr]*
Time to Rig or Derig Skimmer: X_S *[7.5 min]*
Time to Rig or Derig for Unload: X_U *[15 min]*
Operational Radius: R
Characteristic Radius as % of R: P_R
Skim Speed: U_S *[2.5 kts]*
Transit Speed: U_T *[5 kts]*
Oil Recovery Efficiency: E_S
Throughput Efficiency: E_T *[80%]*
Proportion of Emulsion that is Oil: P_O
Swath Width: R_S *[50 ft]*
Slick Thickness: R_O

Dependent Variables

Volume of Emulsion in a Given Primary Storage Barge: V_E
Volume of Oil in a Given Primary Storage Barge: V_O
Encounter Limited Rate Fluid Acquired During Skimming: D_E
Rate Fluid Acquired During Skimming: D_F
Maximum Oil that can be Captured Using a Specific Number of Skimmers: M_S
Maximum Oil that can be Captured Using a Specific Number of Primary Storage Barges: M_P
Maximum Oil that can be Captured Using a Specific Number of Unload Stations: M_U
Time to Fill a Primary Barge while Skimming: t_S
Total Skimming Time, Including Rig/Derig: T_S
Time to Unload a Primary Barge: t_U
Total Unload Time, Including Rig/Derig: T_U
Characteristic Transit Time: t_T

Standard Relationships

$V_E = V_P * E_S$
$V_O = V_E * P_O$
$D_F = \min(D_E, D_S)$
$D_E = R_S * R_O * U_S * E_T / E_S$
$T_S = 2 * X_S + t_S$
$T_U = 2 * X_U + t_U$

Approximations

$t_S = V_P / D_F$
$t_U = V_P / D_U$
$t_T = R * P_R / U_T$

Limiting Maximums

$M_S = N_S * (T / Ts) * V_O$
$M_P = N_P * (\max((T - t_S - X_S), 0) / (2 * t_T + T_S + T_u) + \min(T / (t_S + X_S), 1)) * V_O$
$M_U = (N_U * (\max((T - T_S - t_T), 0) / T_u) + \min(T / (t_S + X_S), 1) * N_P) * V_O$

Calculations

Skimmer-limited

If skimmers always have primary storage available, then the amount of oil captured is simply related to how many times they can fill mini-barges in the 14-hour period. Each mini-barge will need the rig and derig time, plus the time to fill the barge. Given the relatively thick slick in the scenario, the limitation on filling the skimmer is simply the pump, so the filling time is just the mini-barge volume divided by the pump discharge rate. So 14 hrs / (rig and derig time + mini-barge volume / skimmer pump) * mini-barge volume results in an absolute limiting maximum for skimming.

$$M_S = N_S * (T / Ts) * V_O$$

Mini-barge-limited

This limitation is best pictured if you imagine that every mini-barge never has to wait, either at the skimmer, or at the unload station on secondary storage. Given this, they might unload themselves a number of times equal to 14 hrs divided by the time for a complete skim then transit then unload cycle. Additionally, they might capture oil that they never deliver to secondary storage. The combination of the oil delivered to secondary storage and the oil that is in the mini-barges at the end of the operational period can be estimated to be less than a certain amount, however this depends on knowing the mean transit distance for mini-barges. For simplicity, we assumed this distance was 71% (1/sqrt(2)) of the response-area radius – as it would on average be when the skimmers were initially seeded into the response area in the numerical analysis.

$$M_P = N_P * (\max((T - t_S - X_S), 0) / (2 * t_T + T_S + T_u) + \min(T / (t_S + X_S), 1)) * V_O$$

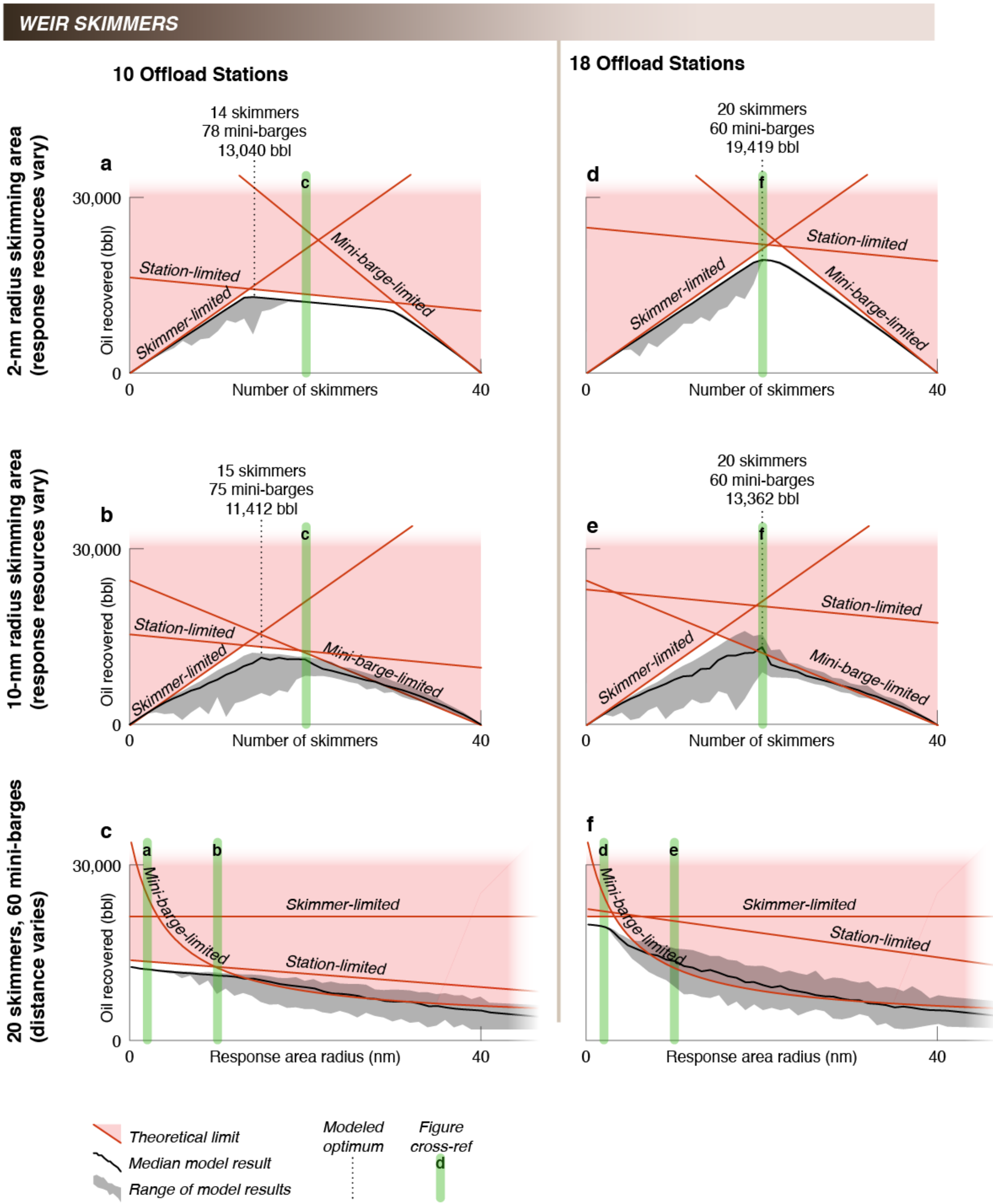
Offload station-limited

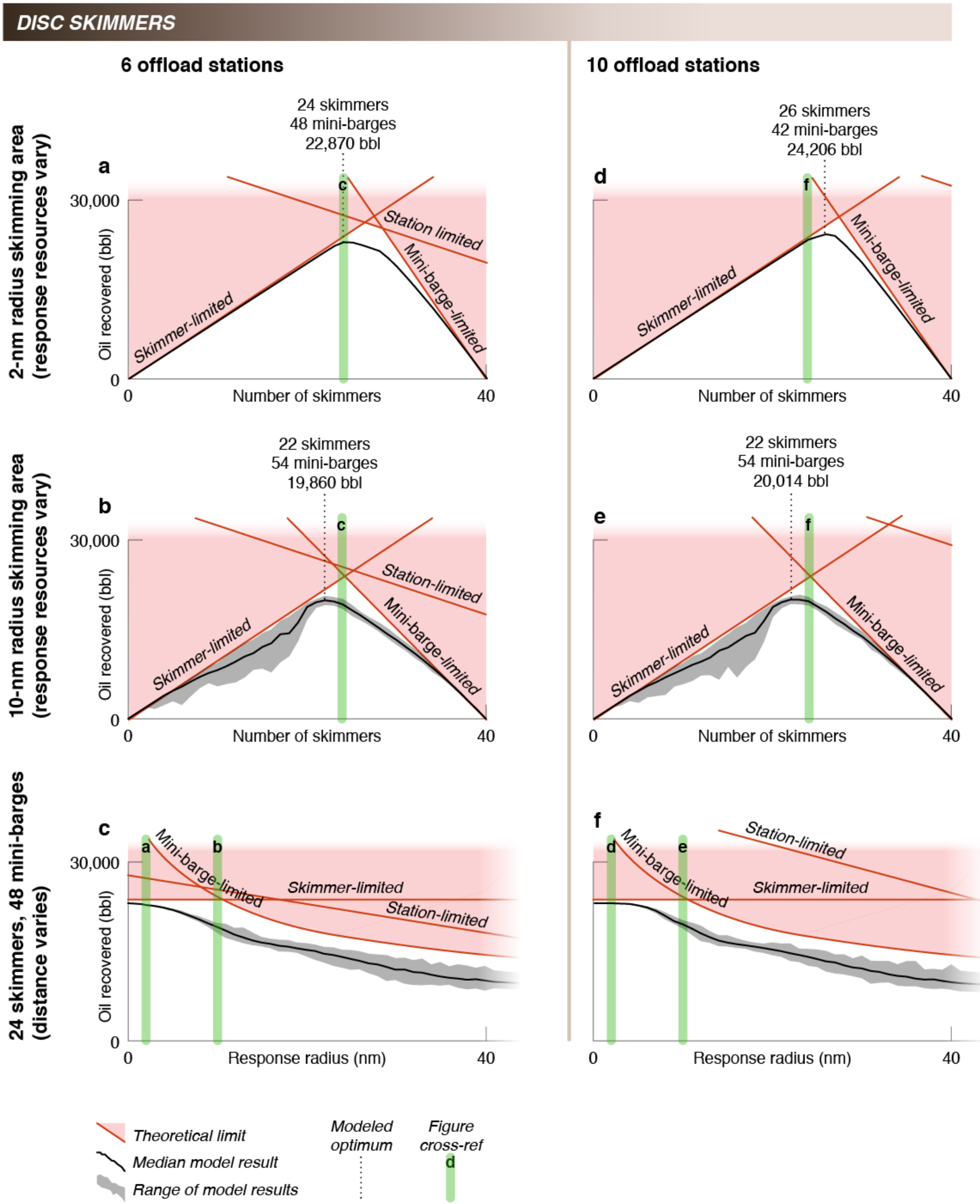
Secondary stations are limiting if there is always a vessel unloading – similarly one might divide 14 hours by the unloading time (including rig and de-rig) to get a number of unload cycles, and then multiply that by mini-barge volume. This is complicated by two details. First, we must account for the volume in mini-barges that are never unloaded. Second, we must discount the 14 hours to account for the time it takes the first wave of mini-barges to fill up and arrive at secondary storage.

$$M_U = (N_U * (\max((T - T_S - t_T), 0) / T_u) + \min(T / (t_S + X_S), 1) * N_P) * V_O$$

Model Summary Graphics

The following two graphics summarize the models used for weir skimmers and disc skimmers. Red lines represent theoretical limits based on the mathematical calculations described above in this appendix (for different system elements, as labeled), while black lines represent results from running multiple iterations of the model. Each of the graphs shown is labeled, a-f. The green shaded cross-references indicate how the figures fit together in a three-dimensional portrayal that incorporates the size of the response area, number of skimmers, oil recovered, and number of mini-barges.


WEIR SKIMMERS
10 Offload Stations
18 Offload Stations
2-nm radius skimming area
(response resources vary)
10-nm radius skimming area
(response resources vary)
20 skimmers, 60 mini-barges
(distance varies)
a
14 skimmers
78 mini-barges
13,040 bbl
b
15 skimmers
75 mini-barges
11,412 bbl
c
d
20 skimmers
60 mini-barges
19,419 bbl
e
20 skimmers
60 mini-barges
13,362 bbl
f
Oil recovered (bbl)
30,000
0
Number of skimmers
40
Response area radius (nm)
Skimmer-limited
Station-limited
Mini-barge-limited
Theoretical limit
Median model result
Range of model results
Modeled optimum
Figure cross-ref


DISC SKIMMERS
6 offload stations
10 offload stations
2-nm radius skimming area (response resources vary)
10-nm radius skimming area (response resources vary)
24 skimmers, 48 mini-barges (distance varies)
24 skimmers
48 mini-barges
22,870 bbl
26 skimmers
42 mini-barges
24,206 bbl
22 skimmers
54 mini-barges
19,860 bbl
22 skimmers
54 mini-barges
20,014 bbl
Station limited
Station-limited
Mini-barge-limited
Skimmer-limited
Oil recovered (bbl)
Number of skimmers
Response radius (nm)
30,000
0
40
Theoretical limit
Median model result
Range of model results
Modeled optimum
Figure cross-ref