Technology Assessment of the Use of Dispersants on Spills from Drilling and Production Facilities in the Gulf of Mexico Outer Continental Shelf

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Summary

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Objective

The objective of the research project was to conduct a comprehensive assessment of the operational and environmental factors associated with the use of chemical dispersants to treat oil spills from Outer Continental Shelf (OCS) facilities that are regulated by the U.S. Minerals Management Service (MMS). The scope of the study is restricted to waters of the U.S. Gulf of Mexico.

Review of Basics

The study begins with a detailed review of the basics of (a) marine oil spill behavior, (b) chemical dispersants, (c) factors that can affect dispersant effectiveness, and (d) field trials and actual spills where dispersants were used successfully. The review indicates that dispersant treatment will likely be effective if: (1) the response effort takes place quickly while the spilled oil is unemulsified, relatively thick, and low in viscosity; (2) the thick portions of the spill are targeted and treated with state-of-the art chemicals until properly dosed; and (3) sea states are light-to-medium or greater. If the spilled oil becomes highly viscous through the process of water-in-oil emulsification, dispersant use will not be effective.

Likely Dispersibility of GOMR Oils

An analysis was performed to determine the general applicability of dispersants on spills involving oils that are produced in the Gulf of Mexico OCS Region (GOMR). There are many distinct oils to consider because there are thousands of wells in operation. A publicly available MMS database, which provides average API oil gravities for all plays in the GOMR, shows that the vast majority of GOMR oils are relatively light (average API gravity is about 33^{o} = 0.86 specific gravity). This is generally favorable, but more information is required to evaluate an oil's likely chemical dispersibility, especially data on the tendency of the oil to emulsify as a function of weathering (evaporation). Although such information is generally not available, it is for 28 specific GOMR oils that were thoroughly analyzed and modeled in previous projects funded by MMS. The oils are listed in Table S-1, ranked according to emulsion formation tendency. Batch spills of size 1000 barrels and 10,000 barrels are used as examples to calculate windows of opportunity for using dispersant.

If it can be assumed that these 28 oils are representative of the Gulf oils in general, the following conclusions can be made regarding the dispersibility of GOMR oils with respect to batch spills in the size range shown.

Table S-1 GOMR Crude Oils That Have Undergone Spill-Related Testing

Crude Oil Name	API Gravity	Fresh Oil Pour Point °F	Oil Viscosity @ 60°F at Various Weathered States			Emulsion Formation Tendency[a]	Size of "Window of Opportunity" for Successful Dispersant Use	Hours for Oil to reach Specified Viscosity in 6 m/s (12 kt) winds					
			0%	~ 15%	~ 25%			1000 Barrel Batch Spill			10,000 Barrel Batch Spill		
								2000 cP	5000 cP	20,000 cP	2000 cP	5000 cP	20,000 cP
HIGHLY EMULSIFIABLE OILS (Hi-E Oils) (Emulsion forms at 0 to10 % spill evaporation)													
Green Canyon 65	20	-18	177	800	4250	yes @ 0 %	very narrow	3.3	5	11	3.9	6	15
Miss. Canyon 807 (1999)	28	?	33	404	2237	yes @ 8%	very narrow						
Miss. Canyon 807 (1998)	28	-29	41	491	3454	yes @ 0%	very narrow	3.2	4	9	3.7	5	12
West Delta 143	29	?	32	-	1572	yes @ 6 %	very narrow	5	7	30	5.9	9	54
MEDIUM EMULSIFIABLE OILS (Av-E Oils) (Emulsion forms at 11 to 29 % spill evaporation)													
Green Canyon 205	29	?	26	157	543	yes @ 23%	narrow						
Green Canyon 109	27	-33	39	225	690	yes @ 22 %	narrow	33	35	45	53	55	72
Garden Banks 387	30	-38	29	181	579	yes @ 23%	narrow	15.5	17	28	23	25	45
West Delta 30	11-23?	-9	1180	-	1350	yes @ 24 %	narrow	67	68	73	109	111	117
Mississippi Canyon 72	32	-18	16	34	195	yes @ 18%	narrow						
Main Pass 69/225	34	?	13	-	118	yes @ 25 %	narrow						
Viosca Knoll 826 #1	32	25	16	132	325	yes @ 24%	narrow						
Viosca Knoll 826 #2	31	?	17	84	186	yes @ 15%	narrow						
SLOWLY EMULSIFIABLE OILS (Low-E Oils)(Emulsion forms at 30 to 50+ % spill evaporation)													
Garden Banks 426	39	-8	6	13	34	yes @ 38%	wide	48	52	246	78	82	>360
Green Canyon 184	39	-47	5	11	31	yes @ 38%	wide	141	143	162	234	236	267
Main Pass 37	39	27	7	16	36	yes @ 50 %	wide	disperse@117			disperse@186		
Ship Shoal 239	26	5	34	70	74	yes @ 50 %	wide						
South Pass 49	29	?	23	-	146	yes @ 30 %	wide						
South Pass 93	33	5	19	23	32	yes @ 34 %	wide						
South Pass 67	16	16-55?	39	-	110	yes @ 45 %	wide						
South Pass 60	36	16	1	22	41	yes @ 38 %	wide	40	45	215	65	69	360
Viosca Knoll 990	38	?	7	12	31	yes @ 35%	wide						
OILS THAT DO NOT EMULSIFY (No-E Oils) (Emulsion does not form)													
Main Pass 306	33	-63	9	19	54	no	very wide	341	>360	>360	>360	>360	>360
Eugene Island 43	37	32	13	36	65	no	very wide	306	>360	>360	>360	>360	>360
Eugene Island 32	37	45	10	16	21	no	very wide	231	>360	>360	>360	>360	>360
Mississippi Canyon 194	35	-40	7	15	21	no	very wide	disperse@117			disperse@197		
Ship Shoal 269	39	-44	5	7	18	no	very wide						
South Timbalier 130	35	-17	7	10	19	no	very wide						
West Delta 97	50	-17	1		1	no	very wide						

a. The percentage value refer to the amount of oil evaporation that must occur to start the emulsification process.

Fourteen percent of GOMR-OCS oils (four of the 28 oils in Table S-1) are highly emulsifiable and will have a very narrow "window of opportunity" for treatment with chemical dispersants. These are called **Hi-E oils** in this study. They are defined as oils that will start to emulsify either immediately or after up to 10% of the spill has evaporated. The next category is for **Av-E oils** (29% of total). For these, there is a relatively narrow time-window for effective dispersant response, but still significantly more time available than the Hi-E oils. For **Low-E oils** (32% of total) the "window of opportunity" for effective dispersant use becomes wide, and one has several days to respond to the spill. Finally, **No-E oils** (25% of total) are ideal dispersant-use candidates because they do not emulsify regardless of the extent of evaporation. This class of oils would also include diesel oils.

In summary, the opportunity for using dispersants effectively on the example oils shown in the table is very good. Only the Hi-E oils, representing 14% of the total, present problems due to their tendency to emulsify rapidly, thus quickly closing the window of opportunity for effective dispersant use. The remaining 86% offer a reasonable chance of being good targets for a dispersant response program. Indeed, both Low-E oils and No-E oils, representing 57% of all spill possibilities, are excellent candidates for responding with dispersants. There is generally much time available for dispersing such spills before the oils become too viscous, at least when considering batch spills in the spill size range of 1000 bbl to 10,000 bbl.

For other spills the dispersant-use time window will vary as a function of spill type (e.g., blowout vs. batch spill), spill size and environmental conditions. To analyze this variation, a detailed modeling exercise was initiated.

Spill Scenario Modeling

Representatives of each category in Table S-1 were selected for modeling purposes (these are the rows marked by gray fill) and a number of spill scenarios were developed to reflect the range of spill possibilities associated with OCS installations. These scenarios are shown in Table S-2. The following describes general features of the spills that will affect dispersant use and effectiveness.

Batch Spills: Scenarios 1 through 3**.** Batch spills involving diesel oil and No-E oils (scenarios 1a, 1b and 2a) have large windows of opportunity for the use of dispersants because of the low tendency of these oils to form emulsions. The batch spill involving Av-E oil (scenario 2b) is a good candidate for dispersant use because it is relatively persistent (> 30 days)—and, thus, a threat to even distant shorelines—and yet it does not emulsify quickly (96 hours), allowing ample time to implement a spraying operation. Such time is not available in scenarios 2c and 3 where emulsion viscosities for the batch spills involving Hi-E oil will exceed chemically dispersible levels within only 10 to 15 hours.

Above-Sea Blowouts: Scenarios 4 and 5**.** The primary difference between the above sea blowout results and the batch spills of similar oil and total spill volume is the initial small thickness and widths of the oil slicks and the long-term release characteristics of the blowouts. An above-sea, low-flow blowout involving Lo-E oil (scenario 4a) will disperse quickly on its own (within 15 hours). The same blowout involving an Av-E oil (4b) will emulsify relatively rapidly (10 to 15 hours), as it did in the batch spills, but because this spill is continuous and lasts over a period of four days it is possible to mount a spraying operation to treat the freshly released oil during daylight hours.

Table S-2 GOMR Spill Scenarios

#	Spill Description	Spill Volume	Model Oil [a]	Comments
1	Batch Spill	(1a) 2000 bbl and (1b) 20,000 bbl	(1a) Diesel (1b) No-E Oil	Demonstrates the large dispersant-use *time window* for diesel spills and spills of crude oils that do not emulsify.
2	Batch Spill	20,000 bbl	(2a) Lo-E Oil (2b) Av-E Oil (2c) Hi-E Oil	Could be tank rupture on platform or "dead crude" pipeline spill. Shows the effect of oil type on *time window*, as compared to Spill#1.
3	Batch Spill	100,000 bbl	(3) Hi-E Oil	Could be worst-case FPSO spill or shuttle tanker spill.
4	Surface Blowout, average rate, short duration	20,000 bbl = 5000 BOPD[b] x 4 days	(4a) Lo-E Oil (4b) Av-E Oil	Demonstrates the fast initial evaporation of oil in air, and its effect on *time window.*
5	Surface Blowout, high flow rate	1,400,000 bbl = 100,000 BOPD x 14 days	(5a) Hi-E Oil (5b) Av-E Oil	Extremely large spill that will challenge all countermeasures methods for Hi-E oils and even Av-Oils and lighter.
6	Subsurface Blowout, shallow water, low flow	20,000 bbl = 5000 BOPD x 4 days	Av-E Oil (6a) 35 m deep (6b) 50 m deep (6c) 150 m	Shows the differences between same-sized batch spill (Spill#2) and surface blowout (Spill#4). Could also represent Alive crude@ pipeline spill.
7	Subsurface Blowout, shallow water, high flow	100,000 bbl = 7200 BOPD x 14 days	Av-E Oil (7a) 35 m deep (7b) 50 m deep (7c) 150 m	Worst-case, but more manageable than surface blowout (Spill#5) because no fast initial evaporation in air.
8	Subsurface Blowout, deep water, high flow	9,000,000 bbl = 100,000 BOPD x 90 days	(8a) HI-E Oil (8b) Av-E Oil	Represents worst-case blowout in deep water, and 90 days to drill relief well

a. Model oils are marked in Table S-1

b. BOPD = barrels of oil per day

The above-surface, high-flow blowout involving Hi-E oil (scenario 5a) emulsifies very quickly and provides a window of opportunity for dispersant application of only five hours. Much of the oil that is released overnight during this blowout will not be amenable to effective dispersant treatment the next day. The fresh oil released will be relatively thick (2.5 to 4 mm) and narrow (<100m) making this spill a good candidate for vessel-based dispersant application as long as the dispersant is applied very close to the source.

Scenario 5b has the same high flow rate as 5a, but the lighter oil (Av-E) results in a larger window of opportunity for dispersant application (up to 36 hours). This scenario is also a good candidate for dispersant use because the slicks will survive a long time if left untreated (> 30 days), but dispersants should be effective on all of the oil, even that discharged over night.

Subsea Blowouts: Scenarios 6 and 7**.** In these scenarios the a, b and c designations refer to the different release depths of 35, 50 and 150 m, respectively. As the release point gets deeper the surface slick becomes wider (increasing from approximately 300 m to 750 m) and thinner (decreasing from about 0.15 mm to 0.05 mm) . The higher flow rates of scenario 7 increase the slick widths and thicknesses somewhat, but not radically. The window of opportunity for dispersant application in these scenarios is between 4 to 7 hours. Because these spills are all continuous releases, the fresh oil emanating from the blowout site during the day will be treatable as long as it can be dosed within about 6 hours of its release. However, much of the oil released overnight will not be chemically dispersible the following morning. The dispersant application system used to apply the dispersant will have to be designed to properly dose the relatively thin slicks that result from these blowouts.

Analysis of Logistics and Other Operational Factors

A detailed analysis of the above scenarios was performed with respect to dispersant-use logistics and factors that affect operational efficiency. The objective was to assess the current level of dispersant capability in the Gulf as tested against the selected spill scenarios. Two key factors are the availability of dispersant and the capability of various platforms for delivering and applying the dispersant.

Dispersant Availability. The quantities of dispersant immediately available to fight spills in the GOM area are of the order of 183,000 gallons (147,000 gallons from Region 6 and 36,000 gallons from Region 4). At least a portion of the remaining 222,000 gallons of dispersant located elsewhere could be made available for use on spills in the Gulf within 24 hours. In addition to the stockpiles already in place, dispersant manufacturers claim to be capable of producing approximately 44,000 gallons per day on an emergency basis.

Application Platforms. A crucial component of the dispersant response system is the spraying platform used to apply dispersants. Key features of the available platforms are outlined as follows.

> C-130/ADDS Pack**.** The C-130 aircraft, equipped with the ADDS Pack (Airborne Dispersant Delivery System) has the greatest overall dispersant delivery capacity of any existing platform. This is by virtue of its high payload, spray rate, swath width and transit speed. At present, its main drawback in the Gulf of Mexico is that start-up times may be lengthy. At

present (December 2000), spraying would not begin until the morning of the second day of the spill, in most cases.

DC-4**.** This platform is modeled after the dedicated dispersant spraying aircraft owned by Airborne Support Incorporated of Houma, LA. This aircraft has the greatest delivery capacity of any dedicated aircraft application system currently available in the U.S. The key feature of the system is that it operates on a "firehouse" basis, meaning that it is dedicated to the task of dispersant spraying and is in a constant state of readiness. Its start-up time is one hour or less.

DC-3**.** This platform is also modeled after the dedicated dispersant spraying aircraft owned by Airborne Support Incorporated. The aircraft has the second greatest delivery capacity of the dedicated aircraft systems. This system also reports a start-up time of one hour or less.

Cessna AT-802 (Agtruck**).** These are small, single engine aircraft that are purpose-built for aerial spraying. In the U.S. a group of operators have organized to offer a dispersant spraying service using this aircraft. A number of these are available in the Gulf area. These operators guarantee a start-up time of four hours or less. These have a lesser payload capacity than certain of the larger aircraft, but this deficiency is somewhat compensated for by availability of multiple platforms. These have a somewhat more limited range over water than the large, multi-engine aircraft.

Helicopter**.** Helicopters equipped with spray buckets have the advantage of availability. They are limited by their small payload and limited range. They are highly maneuverable and capable of being re-supplied near a spill site, which greatly increases their operational efficiency.

Vessels**.** There are a number of vessel systems currently available in the Gulf area. These vary widely in terms of their payloads, pump rates and swath widths. Certain of the response vessels have relatively low payloads, which severely limits their capabilities. However, the recent addition of larger, high-speed crew-cargo vessels, equipped with portable dispersant spray systems and deck-mounted marine portable tanks have greatly improved the response capability of this group.

Results of Analysis. The following are the main results of the logistics analysis.

1. In the batch spill scenarios the rate of emulsification exerts a very strong influence over dispersion efficiency. In scenarios involving oils that have little tendency to emulsify, the oil dissipates naturally within hours or days and the effect of dispersants is to reduce the persistence of oil only slightly. In scenarios involving oils with a high tendency to emulsify, the time windows are very short, approximately seven hours. For some platforms this allows time for one or two sorties at most, while for others the time window is too brief to complete even a single sortie. Changing platforms had little impact on the results: The systems with the largest payloads (e.g., C-130) reduced the volume of persistent oil present by a few tens of percentage points in only the smaller spill scenario (20,000 bbl scenario).

2. The impact of dispersants is most evident in scenarios with oils that do emulsify, but also do have a relatively long time window, up to 58 hours. In the smallest of these scenarios (Scenario 2b, 20,000 bbl), the platforms with the highest delivery capacities (C-130 and DC-4) are capable of dispersing the entire spill, but the smaller platforms are not. When the capacities of all platforms to deliver dispersant over a 12-hour period and a 30-mile distance were compared to the C-130, their relative performances would be as follows: DC-4, 0.57 times the C-130, DC-3, 0.23; Agtruck AT-802, 0.25; helicopter,0.12; Vessel A, 0.08 and Vessel D, 0.73.

3. Both helicopter and vessel systems have the advantage of being capable of being re-supplied at the spill site, thus avoiding the necessity of traveling to their base of operations. By re-supplying at the spill site, their performance can be improved by factors of 2.7 (helicopter) and 4.5 (vessel). The performance of these platforms relative to the C130, when supplied at site would be 0.32 and 0.36, respectively.

4. The distance from the spill site to the base of re-supply influences performance. Increasing the operating distance from 30 miles to 100 miles reduces performance of most platforms to 50 to 75 percent of their capacities at 30 miles. By increasing the operating distance to 300 miles, delivery capacities are reduced to 40 to 60 percent of their capacities at 30 miles. The helicopter system could not be used for responses at 100 miles, nor the AT-802 at 300 miles because of range limitations.

5. For blowout spills, as with batch spills, the effects of dispersant use on oil fate depends on the properties and behavior of the oil. Blowouts of oils that do not emulsify or that emulsify very slowly will disperse quickly by natural means, and dispersants may not affect their persistence greatly. Other oils which emulsify relatively quickly can be strongly affected by dispersant operations.

6. Blowouts which emulsify quickly cannot be fully dispersed because dispersant operations must be suspended at night and a portion of the oil that is spilled overnight will emulsify to undispersible levels. When a blowout and batch spill of identical size (20,000 bbl) and oil type (Av-E) are compared, the batch spill can be fully dispersed, but the blowout can not because of the “overnight effect”. The more quickly the oil emulsifies, the greater the proportion that will become undispersible.

7. When surface and subsea blowouts of identical size and oil type are compared, dispersion of the subsea blowout is much less effective operationally than the surface blowout due to its larger width, smaller oil thickness and more rapid emulsification.

8. Payload and operating distance control overall operational effectiveness in blowout spills as in batch spills, but these influences are less evident when blowout rates are of the order of 5000 BOPD or less. At these discharge rates the larger platforms have excess capacity, and so their logistic advantage over the smaller platforms are less pronounced.

9. Overall, the results of the scenarios analyzed suggest that the largest spill that can be fully treated using existing response capabilities lies in the area of 3180 m^3 for batch spills or 800 m^3 /day for 4 days for continuous spills.

10. Response to the large, deepwater blowout scenarios (Scenarios 8a and 8b) is difficult for several reasons. First, these spills occur furthest from any base of operations. At this long distance, a spill of even modest size is beyond the capabilities of single units of most aerial systems, except the C-130/ADDS Pack system. In theory the amount of oil discharged each day, 100,000 barrels, is within the operating capacity of all of the large fixed-wing response resources in the Gulf of Mexico region, provided this were supplemented with two, preferably three, of the ADDS Pack systems from outside the region. This assumes that the operation achieves both a very high level of dispersant effectiveness and operational efficiency. Second, these two scenarios involve extremely large amounts of oil. The daily discharge rates for oil are so large that they would exhaust the North American stockpiles of dispersant within the first two to six days of the spill, assuming that the dispersant could be delivered to the spill that quickly. The operation would prove extremely difficult because the daily dispersant requirements vastly exceed the available delivery capability by many times (from 5 to 19 C-130/ADDS Pack systems would be needed).

Net Environmental Benefit of Dispersant Use

A detailed analysis of selected scenarios was conducted to study the environmental risks associated with untreated and chemically dispersed spills from offshore MMS-regulated facilities in the Gulf of Mexico. The objective was to determine whether or not dispersants offered a net environmental benefit in treating spills from these facilities. The key variables in these assessments were spill location, distance from shore, and the type of spill (i.e., batch spill versus blowout spill).

An important variable in the environmental assessment was the location of the spill. At the initiation of the project six launch sites were suggested by Minerals Management Service for consideration, including: a) shallow water off Texas; b) shallow water off Louisiana; c) a mid-shelf site part way between sites a) and b); d) the Flower Gardens Area; e) a deepwater offshore site; and f) the Destin Dome Area. Upon consideration of the fate and movement of oil and a preliminary assessment of environmental issues, spills from three sites; a), c) and f) were considered in detail.

Results of the Analysis

From the perspective of environmental risk and potential net environmental benefit of dispersant-use, the scenarios analyzed here fall into three categories.

a. One group includes oils that disperse very quickly, by natural means. Regardless of launch point, these spills disperse naturally in offshore waters; do not threaten shorelines or nearshore waters; and pose only very modest environmental risks. Chemical dispersion does little to reduce the impact of these spills and therefore offers little in the way of a net environmental benefit.

b. A second group of scenarios includes those in which the oils are persistent and could cause significant impact if untreated, but in which spills are small enough and time windows are long enough to permit dispersant operations to disperse all or most of the oil. In these spills, dispersants can greatly reduce the risks associated with the untreated slick and can offer a net environmental benefit provided the risks posed by the dispersed oil are low. Net environmental benefit issues are clearest in these scenarios.

c. The last group includes all of the spills in which oils emulsify too quickly for dispersant operations to be mounted or in which spill volumes greatly exceed the capability of platforms. In these scenarios dispersants do little to reduce the impact of the untreated spill and therefore offer little net environmental benefit.

The main conclusion from this work is that if dispersants are used to treat spills from MMS-regulated offshore facilities in the Gulf of Mexico, there will be a net environmental benefit in almost every case. The reason for this is that the launch sites considered in this study are all offshore. If spills from these sites are sprayed with dispersants near the spill site (as they must be if the dispersant is to be effective), the spraying will take place offshore and the environmental risks from the dispersed oil will be very low or at least lower than the risks from the untreated spill.

The detailed analysis of a spill from an offshore launch site, Mid-Point, showed that there was a net environmental benefit of dispersant use. In this case, the untreated slick persisted to reach the shoreline and caused damage, while the same spill dispersed offshore caused far less damage. This situation is likely to hold in many other locations in the Gulf, even near the shallowest of the offshore hard-bottom communities, such as the Flower Garden Banks. The latter are deep enough to be relatively safe from damage in cases where dispersants are used nearby.

The spill from a near shore launch site, Texas Nearshore, was unique because only in this scenario there were there significant drawbacks from using dispersants. However, despite this, dispersants still offered a net environmental benefit. In this case, the untreated spill posed important risks to both economic and biological resources. However, unlike all other scenarios in which the dispersed case posed very few risks, in the Texas Nearshore case, the dispersed case posed a significant risk to at least one major economic resource, namely the shrimp fishery. On balance dispersants still appeared to offer a net environmental benefit, but there is some uncertainty surrounding this result. The risk posed by the dispersed case involved the shrimp fishery. The dispersed spill posed no biological risk to the shrimp stock, but the cloud of dispersed oil might result in a temporary and localized closure to the fishery. The local policies toward fishery closures and local attitudes toward the valuation of economic and biological resources could have a bearing on the analysis of net benefit.

The Destin Dome scenario demonstrated that the benefits of dispersants vary from place to place in the Gulf. This is because there are wide variations in the sensitivities of coastal zones to the effects of untreated oil. There are also spatial variations in the sensitivity of the offshore community to dispersed oil, as well, but these differences appear to be less dramatic. This supports the conclusion that there will be a net benefit of using dispersants on offshore spills throughout most of the study area. The only variation appears to be in the size of the benefit.

The blowout scenario showed that the net environmental benefit of using dispersants is far greater in blowout spills than in batch spills of the same size. This is because the impact of an untreated blowout spill can be far greater than for a batch spill. The damage caused by an untreated batch spill will involve only small, localized area, while that from a blowout will cover a larger area and be greater as a consequence. On the other hand, when a blowout is treated with dispersants, any resulting damage is restricted to the vicinity of the spill site and is no greater than in the case of the batch spill.

While spills will certainly fall into these categories, at present the behavior of any given spill cannot be accurately predicted. It is important to recognize that the results of the scenarios analyzed here were based on computer simulations and assumptions concerning dispersant effectiveness rates and rates of emulsification. Many of the processes involved cannot be estimated precisely enough to allow a prediction of the effectiveness of a dispersant operation in advance. Rather, during an actual spill, it will be necessary to make decisions about the potential usefulness of dispersants and the effectiveness of dispersant applications based on direct real-time observations rather than on computer simulations. For this reason, it will be necessary to have these monitoring capabilities in place in order to use dispersants effectively.

For purposes of future work, it is important to recognize that natural resource databases such as Gulf-Wide Information System and Texas Coastal Oil Spill Planning and Response Toolkit contain little information concerning resources, such as fish, shellfish and fisheries, that are at risk from chemically dispersed oil. As a consequence, assessments of risk and net environmental benefit that are based solely on these sources would under-represent risks to these groups and would be biased in favor of dispersants.

Table of Contents

1. Introduction

1.1 Background

Major initiatives are underway in the U.S. to facilitate the use of chemical dispersants to treat marine oil spills. U.S. and State governments have preauthorized the use of dispersants in many areas, and response organizations are prepared to use dispersants on a major scale if need be. In general, after many years of debate and study, there is a consensus that dispersant use could become an integral part of the response network for spills in coastal waters.

Work to date on dispersants has focused on instantaneous spills from vessels, and not on spills from blowouts at offshore oil and gas facilities. It is recognized, however, that such continuous discharges are generally good candidates for dispersant treatment because fresh, unemulsified oil is constantly available for treatment at source. Also, vessel-based dispersant application systems are well suited to such spills, and recent research has shown that fire monitors, such as those typically found on supply boats serving the oil and gas industry, can be used effectively in applying dispersant.

1.2 Objective

The objective of the research project is to conduct a comprehensive assessment of the operational and environmental factors associated with the use of chemical dispersants to treat oil spills from Outer Continental Shelf (OCS) facilities that are regulated by the U.S. Minerals Management Service (MMS). The scope of the study is restricted to the OCS waters of the U.S. Gulf of Mexico. One goal is to help expedite dispersant-use decision-making and planning for such spills. Another goal is to provide a basis for MMS regulation writing.

1.3 Study Approach

The study approach involves a detailed assessment of all factors associated with the use of chemical dispersants to treat oil spills from MMS-regulated OCS facilities. As mentioned, the focus is on the

Gulf of Mexico (GOM) area at this time. This area is the most advanced in terms of operations and public support for dispersant-use, has a range of OCS oils that are likely amenable to dispersant treatment, and has already been the focus of numerous dispersant-use studies and training programs. A future study could include the MMS Pacific OCS Region.

Many factors can influence the effectiveness of a dispersant operation in removing oil slicks from the surface and reducing the environmental risks from spills. The main ones are listed in Table 1-1.

Table 1-1 Factors influencing the feasibility, effectiveness or usefulness of dispersants

Factors affecting effectiveness	Factors affecting operational efficiency	Factors affecting net environmental benefit

$ type of oil
$ type of dispersant
$ spill characteristics
$ salinity
$ temperature
$ mixing energy
$ application systems and application strategies
	$ distance offshore
	$ navigability
	$ weather
	$ characteristics and availability of application platforms and spraying systems
	$ timeliness of response
	$ availability and type of dispersant
	$ capability to identify target slicks and direct platforms to them
	$ capability for effectiveness monitoring
		$ resources at risk
		- ecological resources
		- commercial resources
		- rig-reef communities
		- human-use resources
		$ fate and persistence of oil
		- suspended sediments
		- nearshore circulation
		$ sensitivity of resources
		$ vulnerability of resources
		$ resource recovery potential

For each of the factors listed in Table 1-1 the task is to:

1. provide an overview of the subject and its relevance to decision-making, operations and planning;
2. define the existing knowledge base, highlighting significant developments and their implications; and
3. identify significant gaps in knowledge and make recommendations on steps that could be taken to address the deficiencies.

Several factors are well understood, but others are not, and for these it becomes important to identify gaps in knowledge. These deficiencies can be used by MMS managers when developing priorities for future work in these areas.

1.4 Structure of Report

The report starts with a long chapter **(Chapter 2)** that covers the basics of marine oil spill behavior and the use of chemical dispersants as a countermeasure. Particular reference is made to the general factors that affect dispersant effectiveness. This chapter will help non-specialists with the subsequent chapters where a basic knowledge of spills and dispersants is taken for granted.

Chapter 3 presents a detailed analysis of the oils that are produced in the Gulf of Mexico Outer Continental Shelf (GOMR). The purpose of this is (1) to determine whether there is a reasonable number of GOMR oils that are likely to be good candidates for dispersant use, and (2) to select a group of oils for modeling purposes that are representative of oils produced in GOMR that range from being highly dispersible to poorly dispersible. These oils are used in **Chapter 4** to describe and evaluate eight basic spill scenarios involving blowouts, pipeline and tank spills of various size. The spills in these scenarios are described quantitatively in terms of the spills' properties (area, thickness, viscosity, etc.) and fate (percent evaporated, dispersed, etc.) as a function of time. Of particular importance is a description the properties of each spill that affect dispersant effectiveness and dispersant-use feasibility.

In **Chapter 5** a logistical analysis is performed to evaluate the appropriateness and effectiveness of various dispersant systems and platforms to disperse the selected spills. Analysis of the dispersant response systems is quantitative and uses a computer model designed especially for the project.

The goal of **Chapter 6** is to assess the potential net environmental benefit of using dispersants to treat the selected spills in the GOMR. The first part of the chapter identifies the valued natural and human-use resources that might be at risk from the spills, both untreated and dispersed. The second part estimates the level of risk posed by specific spills to the species.

Finally, **Chapter 7** presents a discussion of the study's major findings and **Chapter 8** presents conclusions and recommendations arising from the study.

1.5 Scope and Limitations of Study

This research project covers the entire Gulf of Mexico OCS area, and attempts to address all aspects of dispersant use within this area, including dispersant effectiveness, operational feasibility, logistics and environmental effects. The approach used to cover these conditions has been to analyze a large number of spill and response scenarios that span the full range of conditions encountered in the area.

The report is lengthy due to the large scope of the study. To help simplify the report and make it readable, we have focused directly on the issue of the "feasibility" of dispersant use on spills in the Gulf, and not on the details that will have to be analyzed in developing a credible dispersant response capability for the area. For any spill and dispersant-response scenario, there are numerous parameters to consider, including: spill factors (type, size, duration, and location); dispersant factors (type, dosage, and availability); and platform factors (type, specifications, availability and operational conditions and limitations). The following assumptions have been made regarding these parameters:

1. The analysis of dispersant logistics focuses on estimating the operating capacity of each type of platform, given its logistics characteristics and the fate and behavior of the slicks in question. The objectives are: 1) to identify the platforms that are clearly well suited or poorly suited to handling the types of spill scenarios in question; and 2) to estimate the approximate upper limit of dispersant delivery capacity of each platform as a function of spill type and distance from the spill to the base of operations. As such, the estimates of delivery capacity reported here represent the “best-possible” delivery capacities of a single unit of each platform type. It is recognized that in an actual operation, the actual delivery rates of these platforms will be less than estimated due to factors such as delays due to slow start-up, maintenance requirements, availabilities of crews and problems with coordinating the various components of the spraying operation. These factors are not easily predicted at present. It is also recognized that for larger spills, operators will deploy various delivery systems at once, thereby greatly increasing the capacity of the overall response beyond that of any single operating unit.

2. It is assumed that dispersant operations at nighttime are not feasible. Although approaches to nighttime operations have been suggested from time to time, these have not yet been tested or proven. Research is needed in this area because of its importance in improving dispersant operational efficiency.

3. In this study, the ratio of volume of oil dispersed per volume of dispersant sprayed is set at 20:1. Historically, during actual spills, the ratios of volume of oil dispersed to volume of dispersant sprayed have ranged from less than 1:1 to 75:1. Clearly in any situation this value will vary widely depending on a variety of variables including the type of oil, sea state and efficiency of the operation, to name only a few. For purposes of this work an intermediate value of 20:1 is assumed. Coincidentally, this value (or 25:1) has been the value recommended for years by the manufacturer of Corexit (the predominant dispersant available in the U.S.)

4. The rates of spill emulsification and windows-of-opportunity for effective dispersant use that are used in the study were derived from computer model spill simulations based on a few selected oils and average environmental conditions for the Gulf of Mexico region. It is important to recognize that during an actual spill, emulsification rates and time windows will vary widely with the composition and properties of the oil and the environmental conditions. In addition, different parts of the spill may weather and emulsify at different rates.

5. There is limited field information available on the effectiveness of dispersants as a function of oil viscosity. One accepted rule of thumb is that the transition point between dispersibility and non-dispersibility lies in the range of 2000 to 20,000 cP, depending on the dispersant used, oil type and other factors. For the analysis of scenarios in this study we have assumed that the viscosity threshold for effective dispersibility is 5000 cP.

6. It is important to remember that within the Gulf of Mexico study area there are hundreds of oil-producing formations yielding thousands of oils. Only a few of these oils (approximately 28 oils) have been characterized well enough to simulate their spill behavior. For purposes of the present study these 28 oils have been assumed to be representative of the full range of oils produced within the Gulf of Mexico region.

2. Basics of Spill Behavior and Dispersants

The purpose of this chapter is to describe the basics of marine oil spill behavior and the use of chemical dispersants as a countermeasure, with particular reference to factors that can affect dispersant effectiveness. This will help in understanding subsequent sections that discuss the practicalities and limitations of using dispersants

2.1 General Aspects of Spill Fate and Behavior

2.1.1 Oil Type

The fate and behavior of a marine oil spill are strongly influenced by the chemical composition of the oil being spilled, either a crude oil or a refined product.

Crude oils contain thousands of different compounds. Hydrocarbons are the most abundant, accounting for up to 98% of the total composition. The chemical composition can vary significantly from different producing areas, and even from within a particular formation. As oil from a particular field is exploited over the years its composition can change significantly. Most Asales@ crude oils from a specific area are blends of oils from several distinct fields. As some fields become depleted and others are brought onto stream, the composition of the Asales@ oil changes accordingly.

Petroleum contains a significant fraction (0 to 20%) of compounds called asphaltenes which are of higher molecular weight (1000 to 10,000 g/mole). In spill situations, asphaltenes contribute significantly to the oil's tendency to form water-in-oil emulsion.

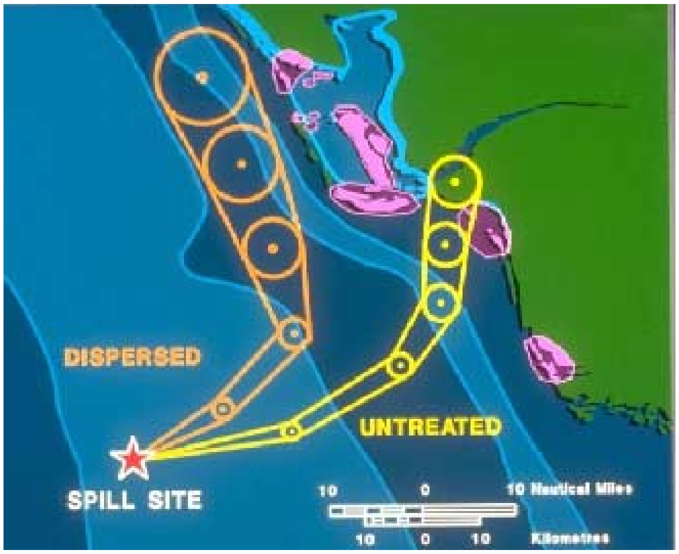
The refined oils of interest in this study are diesel oils, which are primarily used as fuel on the OCS platforms and on the vessels that serve the offshore industry. Diesel oil is simply a distillation product of crude oil that has had the very light and very heavy hydrocarbon fractions removed. Diesel oil does not contain asphaltenes and hence does not tend to emulsify when spilled, making the product a good candidate for dispersant use. This is discussed later.

2.1.2 The Main Spill Processes

When oil is spilled at sea it is subject to several so-called weathering processes. The processes of importance to dispersant use or dispersant effectiveness are drifting (advection), spreading, evaporation, natural dispersion of oil in water, and water-in-oil emulsification.

Drifting

Drifting or advection is the process of surface slicks moving away from the site of a spill by water currents and winds. The combination of residual current movements and wind-induced surface movements (whose velocities are about 3.5 percent of the wind velocity) determine the final slick drift. In nearshore marine waters, the movement of oil slicks is also affected by tidal currents, river outflows and long-shore currents. The process of spill advection does not have a major influence on dispersant effectiveness; rather, dispersant use has a major influence on oil fate. If the surface oil is not dispersed it will be influenced by wind (and water current) forces, and thus can be driven ashore by onshore winds. On the other hand, if the oil is dispersed, the movement of the oil droplets in the water will only be influenced by the water current. Hence, the trajectory of surface oil is different than the trajectory of the same oil dispersed. This has an influence on environmental impact considerations related to dispersant use.



Slick Spreading

The most notable feature of any marine oil spill is the surface spreading phenomenon. Numerous models are available for predicting oil spreading behavior and its dependence on oil properties and environmental conditions (Finnigan 1996). All models relate the properties of the oil (density, viscosity and interfacial tension) to its spreading on calm water. Most models today also include an oceanic diffusion term to describe spreading behavior in more realistic sea conditions. In addition, some models take into account the influence of pour point in the spreading process. The Apour point@ of an oil is the temperature below which the oil will not flow, and it increases as the spilled oil evaporates. Pour point is a major problem for many oils, but generally not for GOMR crude oils. Most of these will become highly viscous through emulsification well before the pour point of the spilled oil reaches the generally high water temperatures in the area.

The generally fast rate of oil spreading is demonstrated in Figure 2.1, which is a version of a figure first developed in the late 1970s (Mackay et al. 1980a) and still used extensively today.

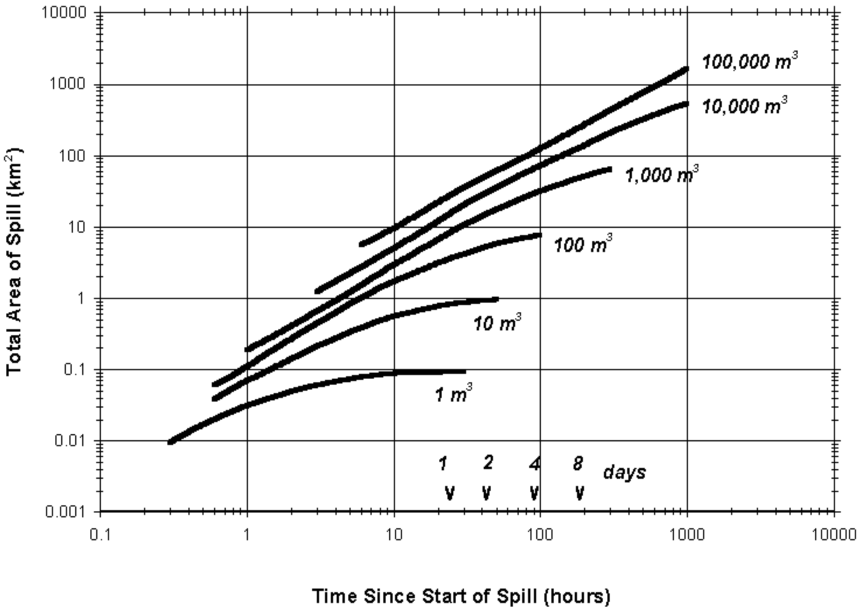


Figure 2-1 Total Area of Slick (thick + thin) versus Time

The figure can be used to show that for a spill of, say, 1000 m^3 (6300 barrels) the total slick area reaches about 10 km^2 in one or two days of spreading, and this is equivalent to an average slick thickness of 0.1 mm. This average thickness value of 0.1 mm is mentioned often in the dispersant literature in the 1970s and 1980s as the thickness to consider in the design and implementation of a dispersant response operation. Belief in the number led to the concept of a one-pass (carpet-sweeping-like) mode of dispersant application and to limitations in some jurisdictions on dispersant dosages allowed on spills based on this one-pass concept (Lindblom 1979,1981; Exxon 1992, 1994; Allen and Dale 1995).

The current expert view, and the one considered in most spill models in popular use today, is that marine spills do not spread uniformly as described above. Oil spills are now known to be composed of thick patches (usually thicker than 1 mm) that contain most of the spill's volume (the rule-of-thumb is that 90 to 95 percent of an oil spill's volume is contained in 5 to10 percent its area) and that these patches are surrounded by sheens (about 1 to 10 μm or 0.001 to 0.01 mm). The areas noted in Figure 2.1 represent the total area of thick patches and sheen.

Although the phenomenon of thick/thin spreading is widely accepted today, and there is much remote sensing and photographic imagery to support the notion of slicks being composed of thick and sheen portions, there is surprisingly little quantitative information available in the literature on the subject. Nonetheless, some well documented experimental spills have involved measurement of either thickness or volume/area (Mackay and Chau 1986, Lunel and Lewis 1993a, Lewis et al. 1995a, Walker et al. 1995, Brandvik et al. 1996) and these indeed show that oil spills at sea, even relatively small ones, do tend to stay relatively thick (> 1 mm) for reasonable periods of time.

This issue of slick thickness is of great importance in regard to dispersant effectiveness. It is now generally accepted in the U.S. (Scientific 1995) that the one-pass concept for dispersant application is not appropriate for dealing with the thick part of spills, and that the multi-pass approach that has always been used in the U.K. is the only possible way of completely dosing thick portions of marine spills when using aircraft application systems (Lunel et al. 1997).

Evaporation

Evaporation is one of the most important processes that affect the properties and therefore the behavior of spilled oil. The major effect on dispersant effectiveness is that evaporation losses advance the point at which spilled oil Aemulsifies@ or Agels@. This greatly increases the viscosity of the residual oil and its resistance to chemical or natural dispersion.

Evaporation is one the most intensively studied and predictable processes (Mackay 1984). It is known that the evaporation rate of an oil slick is controlled by: (1) the temperature of the oil and the air; (2) the surface area of the oil in contact with air; (3) the thickness of the oil; (4) wind speed; and (5) the concentration and vapor pressure of the individual components of the oil. Although there have been many studies of oil evaporation rates, they have all followed a similar approach of determining an overall Amass transfer coefficient@ as a function of environmental conditions (see for example, Nadeau and Mackay 1978 and Stiver and Mackay 1983). In these studies, the volume or mass fraction of oil evaporated is related to an exposure coefficient (combining time, oil volume and area, and the mass transfer coefficient to the atmosphere) and to the pressure-concentration behavior of the oil. The unique aspect of this approach is that it permits the results from a variety of laboratory evaporation experiments to be easily extrapolated to actual environmental conditions with a relatively high degree of confidence. Table 2-1 illustrates the results of this approach in predicting the evaporative loss from a 1 mm slick of unemulsified crude oil as a function of sea state.

Table 2-1 Evaporation of Light and Medium Crude Oil Slicks as a Function of Sea State (calculated using approach in Nadeau and Mackay 1978)

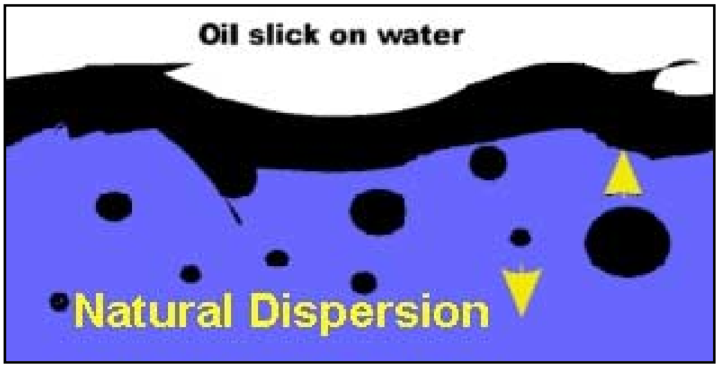
	Oil Loss (Percent)					
	Exposure Time = 6 h			**Exposure Time = 24 h**		
Sea State	**5°C**	**15°C**	**25°C**	**5°C**	**15°C**	**25°C**
Low (0 to 1)	16	21	28	23	32	38
Medium (2 to 3)	23	32	39	28	37	44
High (4 to 6)	26	35	42	29	38	45

Assumptions: Slick Thickness = 1 mm; Oil Density = .836 g.cm^{-3}

In the current study, oil well blowouts are a major concern and focus. Spills associated with above-surface or platform-based blowouts tend to evaporate much faster than conventional batch spills because the oil discharged into the air is first shattered into tiny droplets which present a much larger oil/air surface area for evaporation. Slicks from subsea blowouts that originate at the seabed also tend to evaporate quickly because they are often very thin to begin with and, again, present a large surface area for oil evaporation. Both these cases are discussed later in more detail in reference to specific GOMR oils.

Natural Dispersion

The dispersion of oil into the water by natural forces is an important process controlling the long-term fate of oil slicks at sea. In conjunction with evaporation, this process reduces the volume of oil on the water surface, thereby influencing the potential extent of surface and shoreline contamination. The idea behind chemical dispersion is to greatly increase the natural rate of oil dispersion by reducing the cohesion of the oil. If spilled oil on water has a relatively high rate of natural dispersion, it will be more amenable to chemical dispersion than oils that are viscous and normally resistant to natural dispersion.



In slick dispersion, oil droplets are dispersed from the slick into the water by oceanic mixing. The larger of these droplets, which are buoyant, resurface quickly and rejoin the slick. The smaller droplets remain in suspension in the water column. The lighter, more water-soluble hydrocarbons partition from these droplets into the water phase. Clouds of the entrained dissolved and particulate oils then spread horizontally and vertically by diffusion and other long range transport processes. When chemical dispersants are used, the process tends to produce a much higher proportion of the very small droplets that tend to stay in permanent suspension in the water column.

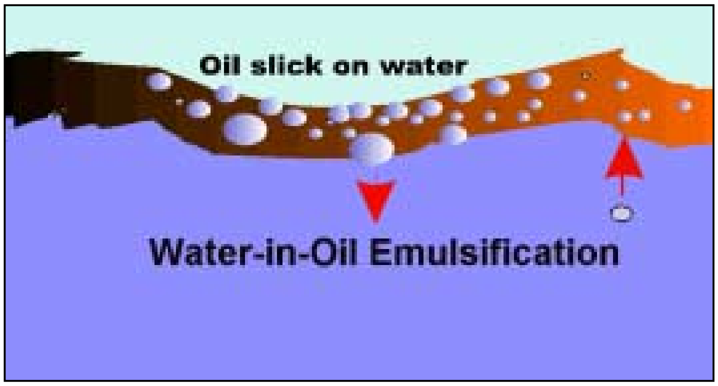
Although natural dispersion is a poorly understood process, it is known that oil/water interfacial tension, oil viscosity, oil buoyancy and slick thickness each inversely affect the ability of a particular oil to disperse naturally. Sea state is also an important factor controlling the rate and amount of dispersion. Even light, non-viscous oils do not rapidly disperse under calm conditions. On the other hand, even the heaviest, emulsified oils can disperse over a period of time in heavy seas with frequent breaking waves.

The net dispersion rate of oil from a slick into the water will vary greatly depending on the properties of the spilled oil and mixing energy. In experimental spills, oil concentrations measured in the water beneath the slicks have ranged from several hundred ppb to as much as several ppm

(McAuliffe et al. 1981, Lichtenthaler and Daling 1985, Lunel 1994a, 1995, Lewis et al. 1995a, Brandvik et al. 1995).

Emulsification

When most crude oils are spilled at sea, they tend to form water-in-oil emulsions. Emulsification occurs in the presence of mixing energy such as that provided by wave action. During emulsification, seawater is incorporated into the oil in the form of microscopic droplets. This water intake results in several undesirable changes to the oil. First, there is a significant increase in the bulk volume of the oil (usually up to a 4- or 5-fold increase), greatly increasing the amount of oily material that can contaminate shorelines and biological resources. Secondly, there is a marked increase in fluid viscosity. The much higher viscosities greatly inhibit the chemical or natural dispersion of oil.



The mechanisms and rates of the emulsification of oils spilled at sea are poorly understood. Through some mechanism, the mixing energy associated with waves causes small water droplets to become entrapped in the oil layer. Several theories have been advanced about the main chemical mechanisms involved in the process (Bobra 1990, 1991, Walker et al. 1993). Most experts believe that precipitates of asphaltenes and resins in the oil act as surface active agents to stabilize the water droplets in the forming emulsion. Without such stabilizing agents the small water droplets in the oil layer would tend to coalesce into larger droplets which would sink through and leave the oil phase. In any case, emulsification inhibits dispersion because the process greatly increases oil viscosity. Spills of some crude oils will start to form emulsion within a few minutes of environmental exposure, and will form a highly viscous and stable emulsion within hours. This has been recorded many times during actual and experimental spills. On the other hand, a few crude oils and most refined petroleum products do not easily emulsify at all. Results from field trials in the mid-1990s off the U.K. and Norway (Lunel and Lewis 1993a, Walker and Lunel 1995, Lewis et al. 1995a, Brandvik et al. 1995) indicate that modern dispersants are relatively effective against weakly-formed or freshly-formed emulsions and in fact actually seem to Abreak@ such emulsions; that is, their presence tends to promote the separation or the Acreaming@ of the oil and water phases.

Without question, oil spill emulsification is the most important process that affects spill dispersion and dispersant effectiveness. It is also (along with natural dispersion) one of the most difficult process to model or predict on a spill-specific basis. Except perhaps for a few oils that have been tested extensively, it is virtually impossible to predict when a particular crude oil will start to emulsify once spilled in a particular environment, and to predict, once the emulsification process begins, how long it will take for the spilled oil to form a Astable@, highly viscous emulsion.

Nonetheless, modelers of spill behavior have to deal with the problem of spill emulsification because it is such an important process. The usual tactic is to take advantage of a laboratory test, called the Mackay-Zagorski Test (Mackay and Zagorski 1982) that was developed to measure (1) an oil=s tendency to form an emulsion and (2) the stability of the emulsion once formed. The test provides some indication of an oil=s emulsifiability, but does not predict rates of spill emulsification in the field.

2.1.3 Oil Spill Types and Influence on Behavior

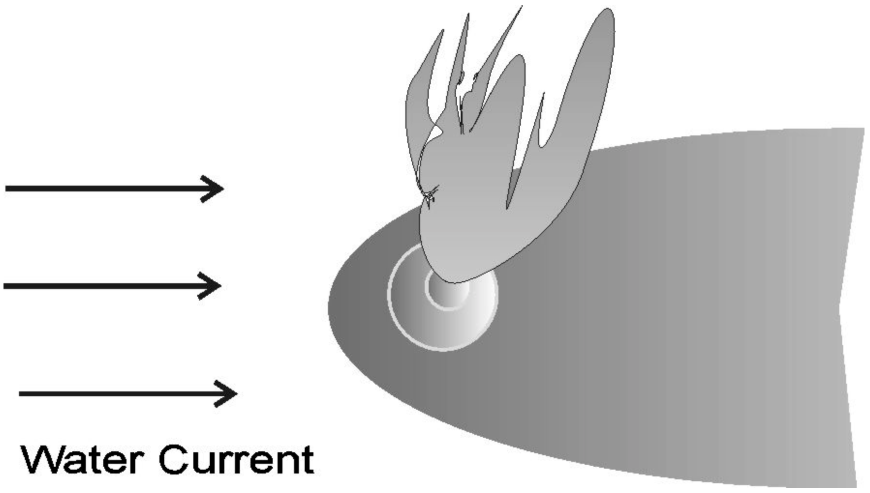
Several possibilities exist for the release of oil in the offshore environment. Oil can be discharged from a damaged tanker over a relatively short time-frame as a single “batch” of oil. A tanker can also release oil from a small rupture over an extended period of time either in a stationary or moving situation. A pipeline failure can lead to the release of oil and/or gas at the seabed with the subsequence rise of oil to the surface. A production or exploration well can be breached at the seabed and oil and gas will rise to the surface or a well can be breached at the surface and oil can “rain down” on the water’s surface. Each of these spill types results in a unique initial oil slick configuration that can greatly affect the oil’s short and long-term behavior.

Oil released from a ruptured tanker, either in batch or continuous form, usually reaches the water surface in a thick and relatively small area. Once on the water, the competing processes of evaporation, emulsification, dispersion, and spreading affect the behavior and properties of the oil slick. The general behavior of batch spills is familiar, and is not discussed in detail here. Suffice to note that large batch spills are relatively slow to evaporate because they tend to be thick initially. The opposite is true for blowout spills. Blowout spills behave differently in other ways as well, and, because they are infrequent and unfamiliar, they are discussed in some detail.

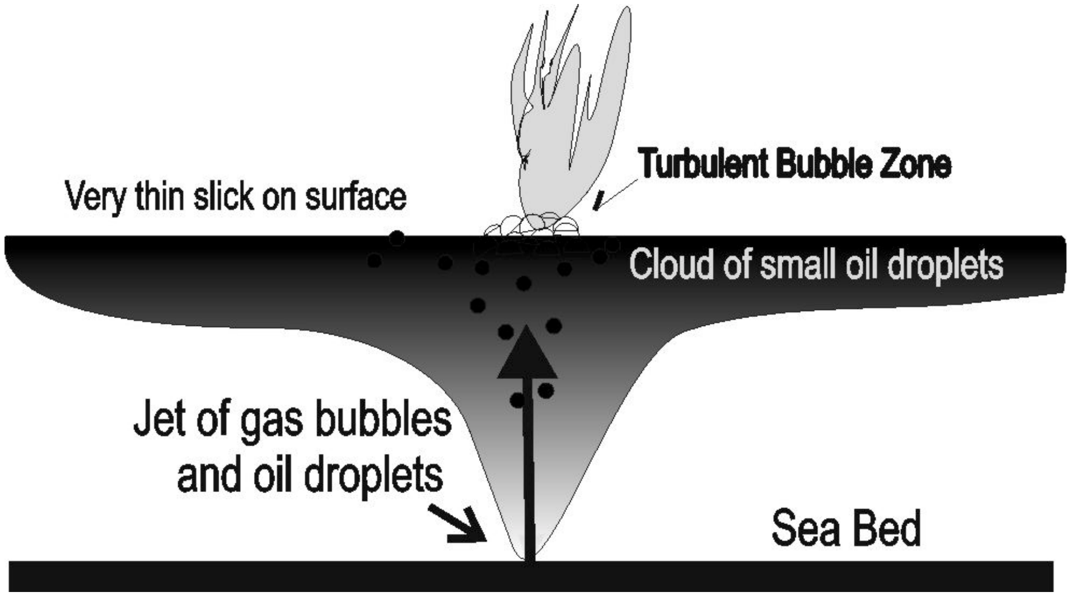
There are two basic kinds of offshore oil well blowouts. The first is a subsea blowout in which the discharging oil emanates from a point on the sea bed and rises through the water column to the water surface. An example of this kind of oil well blowout was the 1979 Ixtoc 1 blowout in the Bay of Campeche, Mexico (Ross et al. 1979). The other possibility is an above-surface blowout in which the platform maintains its position during the accident (because it is undamaged or bottom-founded) and the oil discharges into the atmosphere from some point on the platform above the water surface, and subsequently falls on the water surface some distance downwind. Examples of this kind of oil well blowout are the 1977 Ekofisk blowout in the North Sea (Audunson 1980) and the Uniacke blowout on the Scotian Shelf in 1984 (Martec, 1984), both of which were well recorded scientifically.

Shallow Water Subsea Blowouts

Oil-well blowouts generally involve two fluids, namely crude oil and natural gas. The volume ratio of these two fluids is a function of the characteristics of the fluids and the producing reservoir. The natural gas provides the driving force for an uncontrolled blowout. As the well products flow upwards, the gas expands, finally exiting at the well-head at very high velocities. At this point the oil makes up only a small fraction of the total volumetric flow. At the sea bed the high velocity of gas exiting the well-head generates a highly turbulent zone that causes the oil to fragment into small droplets. As the gas rises, oil and water in its vicinity are entrained in the flow and carried to the surface. In the surface zone, the rising water and oil flow away from the center of the plume in a radial layer. This radial flow spreads the oil faster than conventional oil spreading or convection thus resulting in a relatively wide, but very thin, initial slick. At the surface the oil takes on a hyperbolic shape when subjected to a natural water current, with its apex pointed up-current. Figure 2-2 depicts the characteristics of a shallow well blowout.



Subsea Blowout (gas on fire): Top View



Subsea Blowout: Side View

Figure 2-2 Top And Side Views of a Subsea Blowout with the Gas on Fire

Subsea Blowout Behavior in Deep Water (>300 m)

Unfortunately, little is known about the subject of deep-well blowouts. A deep-water oil spill experiment took place off the coast of Norway in the summer of 2000, and the analysis will improve our present understanding. A report to MMS in October 1997 (SL Ross 1997a) summarizes the main issues associated with deepwater blowouts, and the following is abstracted from that. Much of the discussion is either theoretical or based on limited bench-scale experimentation.

There are two processes that, under certain conditions, can reduce or eliminate the strong pumping action caused by the rising gas bubbles from a subsea blowout and thus dramatically change the behavior of the subsea blowout. The high pressure and low temperatures present at the sea floor in deepwater situations may cause the natural gas released at the sea bed to combine with water to form a solid, ice-like substance known as gas hydrate. The gas volume may also be depleted through dissolution into the water as it rises through the water column from great depths; this is a less significant process than gas hydrate formation and is not discussed further.

The pressure required for hydrate formation depends on the ambient temperature. Experiments have identified the thermodynamic conditions suitable for hydrate formation. At water pressures equivalent to water depths greater than about 900 m, the hydrate crystals form extremely fast and gas bubbles immediately collapse into large flakes of hydrates. Gas released at depths of about 750 meters will also be completely converted to hydrates, although at a somewhat slower rate due to the formation of a layer of hydrate crystals on the bubble surface.

The strong buoyant gas plume evident in a shallow blowout will be lost if the gas is completely converted to hydrates. Oil droplets will rise due to their buoyancy alone under these circumstances. The movement of the oil droplets will now be affected by cross currents during their rise due to the absence of a strong bubble plume. This will result in the separation of the oil droplets based on their drop size. The large diameter oil drops will surface first and smaller drops will be carried further down current prior to reaching the surface. Oceanic diffusion processes will result in additional separation of the oil drops due to their varying residence times in the water column. The final at-surface oil distribution will depend on the oil drop size distribution, the vertical water velocity profile and oceanic diffusion processes. This makes the prediction of the surface slick characteristics very difficult since little is known about the likely oil drop size distribution that might be created during such a release and vertical water velocity profiles and oceanic diffusion processes are not generally known in sufficient detail for this purpose. However, the surface slicks from these deep-water blowouts will likely be thin due to the separation and lateral diffusion of the oil droplets as they rise to the surface. The initial slick likely will be very long and narrow with thicker oil accumulating near the source where the largest oil drops will surface.

In view of the uncertainties of the behavior of very deepwater blowouts, a less rigorous approach has been taken in analyzing these spills.

Above-Surface Blowouts

In a surface blowout from an offshore platform, the gas and oil exit the well-head at a high velocity and the oil is fragmented into a jet of fine droplets. The height that the jet rises above the release point varies depending on the gas velocity, oil particle size distribution, and the prevailing wind velocity. The fate of the oil and gas at this point is determined by atmospheric dispersion and the settling velocity of the oil particles. The oil will "rain" down, with the larger droplets falling closer to the release point. If the gas is blowing through the derrick or some other obstruction, oil droplets will agglomerate on the obstruction(s) and increase in diameter. During their time in the air the droplets will evaporate very quickly due to the oil’s high temperature and the droplets high surface area-to-volume. As a result of this evaporation, the oil’s physical properties will change significantly by the time the oil reaches the water’s surface.

As sea water passes under the area of falling oil it will be Apainted@ by the falling oil and an accumulation of oil over the width of the fallout zone will occur. Changing wind and water current directions will affect the ultimate distribution of the oil on the water surface in the fallout.

Pipeline Discharges

Pipelines can carry either a mixture of gas and oil (”live” pipelines) or simply crude oil. Ruptures from “live” pipelines will behave like short-term blowouts. “Crude only” pipeline spills will result in surface slicks similar to surface tanker releases because the oil will quickly rise to the surface above the rupture and form relatively thick slicks.

2.1.4 Modeling Oil Spill Fate and Behavior

As discussed above, the major processes that determine the behavior of oil spilled on water are evaporation, spreading, natural dispersion into the water column, and the formation of water-in-oil emulsions. These processes are interrelated and must be considered together to arrive at an accurate estimate of an oil spill's likely behavior. That is the purpose of oil spill behavior models, of which there are several available internationally. Most are similar in many ways because they use similar mathematical algorithms in the structure of the models. For convenience in this study we use the model developed by S. L Ross Environmental Research. A description of the SL Ross Oil Spill Model (SLROSM) is available on the internet at the web site www.slross.com. At this location a demonstration model can be downloaded and examined.

The spreading model relies on the work of Fay (1971) and Mackay et al. (1980a) but includes modifications to account for oil viscosity changes and the development of a yield stress in the oil (i.e., pour point). Longer term spreading takes into account oceanic diffusion processes according to relationships developed by Okubo (1971). Evaporation models use the work of Stiver and Mackay (1983) with modifications developed by S.L. Ross and Mackay (1988). Natural dispersion is modeled using either Audunson's (1980) natural dispersion model modified to account for oil density, viscosity, interfacial tension and pour point or Delvigne’s (1985, 1987) oil entrainment model. In this project Delvigne’s algorithms were selected for the modeling. Emulsification is modeled using the relationship developed by Mackay and Zagorski (1982) with modifications by Bobra (1989) and SL Ross and Mackay (1988). Atmospheric dispersion and fallout of oil from surface blowouts is modeled using the methods described by Turner (1970). The rise of oil droplets from deep-well blowouts has been modeled, outside of the SLROSM model, using equations for the terminal velocity of a “falling” particle as provided by Perry and Green (1984).

SLROSM estimates the movement of slicks through the vector addition of the local surface water current and 3% of the prevailing wind speed. Wind forecasts are entered by the user for each spill scenario of interest based on the best available data. Surface water currents are provided, in map form, that identify the spatial variation in the water velocities. If surface water currents vary with time, such as in a tidal situation, a number of map sets can be used to represent the variation. The model is given a "schedule" of the time histories for the use of the appropriate map at a given time in the life of the spill. An option also exists to enter a pre-defined spill trajectory and bypass the internal trajectory calculations. This is useful if it is desirable to use another model's trajectory prediction with our oil behavior models.

A body of information on the potential trajectories of oil spills in the Gulf of Mexico has already been compiled by MMS in the form of Oil-Spill Risk Analyses (OSRA). OSRA are conducted routinely in connection with proposed lease sales (e.g., Price et al. 1997, 1998). We have used this extensive OSRA database in developing spill trajectories in this study.

The Oil-Spill Risk Analyses conducted by MMS are formal assessments of risk of contamination and damage that might result from accidental spills associated with proposed offshore oil developments. In each analysis, the risk of contamination of a section of the coastal zone or oil-exposure of a specific resource is considered for hypothetical spills originating from specific offshore locations. Each analysis consists of three parts, as follows.

1. The first part addresses the probability of spills. Probabilities are estimated based on historical rates of spills from OCS platforms and pipelines and are based on the volumes of oil produced or transported. For any given project, spill probabilities are based on the volume of oil to be produced or transported over the production life of a project and the historical spill rates from similar operations in the U.S.

2. The second deals with the potential trajectories of spills. This portion of the analysis consists of running a large number of hypothetical trajectories. Analyses are conducted on spills launched from specific locations. In each run, the trajectory is a consequence of the integrated action of

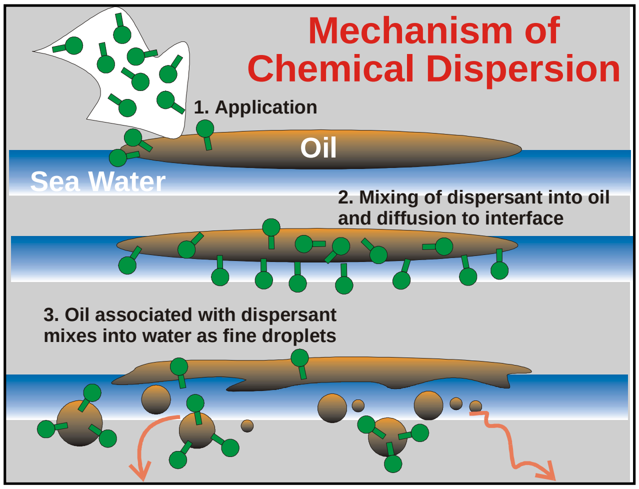
temporally and spatially varying winds and ocean currents. Details of the derivation of the winds and current fields are given in Price et al. 1997, 1998. The output is in the form of a conditional probability that the oil spill will contact a specific segment of shoreline or environmental resource within a certain travel time.

3. The third part deals with the combined probabilities of occurrence and trajectory. The combined probability is the likelihood that a spill, greater than a given volume, might occur over the period of the project and might contact a given receptor.

The process is described in detail in Price et al. (1997, 1998).

In the present study the conditional probability output from OSRA have been used to identify 1) the segments of shoreline at risk from spills from specified launch sites and 2) the approximate lengths of time required for spills to reach shore from the launch sites. Output from Price et al (1998) were used in analyses of Destin Dome spills and Price et al. (2000), were used for the remainder. Details of the use of this output are described, as appropriate, in later sections.

2.2 How Dispersants Work



When spilled on water, oil exhibits a cohesiveness or resistance to break up. This cohesive strength is due to the interfacial tension or contractile skin between the oil and water. A chemical dispersant sprayed onto an oil slick acts at the oil-water interface to reduce this interfacial tension. This action promotes the break-up of the oil film into droplets that disperse into the water phase. If the droplets are small enough they will have little buoyancy and will be carried away and diluted by normal ocean current and movement.

Surface active agents (surfactants) are the key components of a chemical dispersant. These compounds contain both a water compatible and an oil compatible group. Because of this molecular structure, the surfactant locates at the oil-water interface, reduces the interfacial tension, and thereby enables the oil slick to break up into finely dispersed oil droplets. Mackay and Hossain (1982) estimated that a concentration at an oil/water interface of 1 volume of dispersant per 500 volumes of oil will cause a 20-fold reduction in interfacial tension, say, from 20 dynes/cm to 1 dyne/cm. Since manufacturers recommend that dispersants be applied at a ratio of 1 volume of dispersant to 20 volumes of oil, the implication is that only a few percent of the dispersant is being effective at any time, most being present in the bulk of the oil and thus remote from the interface.

Despite the great decrease in interfacial tension, some mixing energy is needed to promote movement and dispersion of the fine oil droplets into the water column. This energy can be supplied either by the natural motion and currents of the sea or by mechanical means such as work boats. The greater the available energy, the less dispersant is required.

A dispersant formulation also contains a solvent. Since many of the surface agents used in oil spill dispersant formulations are viscous, some form of solvent is necessary to reduce viscosity so that the mixture may be properly applied by conventional spray equipment. In addition, the solvent may act to depress the freezing point for low temperature usage and to enhance the mixing/penetration of the surfactant(s) into more viscous oils. In general, present day surfactants have demonstrated very low toxicity. In addition, these current formulations have substituted dearomatized hydrocarbons or aqueous solvents, resulting in very low toxicity dispersant formulations as compared with early formulations.

By their very nature, present-day dispersants include active ingredients that are more soluble in water than in oil. So the dispersant must be applied directly to the oil ; otherwise the chemical will be lost to the water phase. Even when applied directly to the oil the chemicals will leach into the water, but the rate at which this happens is not well understood. Most products contain so-called “anionic” surfactants, like sulphosuccinates, in combination with “non-ionic” surfactants, like sorbitan ester surfactants (the SPANS® family of surfactants) and polyethoxylated sorbitan ester surfactants (the TWEEN® family). Recent studies on the subject (Knudsen et al. 1994, Hokstad et al.

1996) indicate that anionic surfactant compounds will rapidly leach into water, but that the rate of leaching of the non-ionic compounds is uncertain and dependent on a number of factors. Clearly, the leaching process is a complicated one, and more research is needed in the area. Until more information becomes available, it can be assumed that certain components of modern dispersant products will gradually leach from a layer of crude oil into the underlying water column and negatively affect the dispersibility of the oil. This suggests that an oil spill cannot be dosed in relatively calm conditions with the expectation that the dispersant will remain with the oil and become effective when sea states and mixing energies increase.

The surface of droplets generated from a slick treated with dispersant are initially Acoated@ with surfactant molecules, oriented in such a way that coalescence between droplets is prevented when droplets approach each other or collide. Also, freshly treated oil slicks and their dispersed droplets tend not to stick to surfaces that untreated oil would normally stick to. Thus the oil is initially prevented from wetting and adhering to bird feathers, beach sand, and the like. This is the theory. In practice, because the surfactants are more soluble in water than oil, as noted above, and the surfactants come into contact with much more water than oil during oceanic mixing, the surfactants are probably lost to the water quickly.

Much is said in promotional literature on dispersants about the benefits of chemically dispersed oil droplets not sticking to things and not coalescing with each other (thus reducing the oil's chances of rising back to the surface). This probably only has benefits at the early stages of the dispersant-use process. The truly important benefit of dispersing oil spills is the breakup of the mass of oil into droplets and *their subsequent dilution in the water column.* The droplets separate from each other so quickly after entering the water column that contact between droplets becomes highly improbable; so their tendency to coalesce or not upon contact is a non-issue.

The fact that chemical dispersants are lost to the water phase has one particularly good benefit: the oil left on the surface, poorly dosed or not, reverts to a product that can either be treated again with dispersants (S.L. Ross 1985) or mechanically recovered even with devices that rely on the principle of oleophilicity [oil sticking to surfaces] (Strom-Kristiansen et al. 1996).

2.3 Main Factors Influencing Dispersant Effectiveness

2.3.1 Definition of Dispersant Effectiveness

One of the most important questions to consider in assessing the feasibility of using dispersants on GOMR spills is whether the spills will actually disperse when treated with chemical dispersant. Will the spills treated with dispersant tend to break up and mix into the water column, or will they resist the process and remain on the surface as a cohesive mass? If there is some dispersant effectiveness, will it be high or low?

ADispersant effectiveness@ as defined here is a measure of how effective the application of dispersant might be on a targeted part of a slick. It is not to be confused with dispersant Aoperational efficiency@ (discussed in Chapter 5) which relates to operational factors such as the availability of sufficient stockpiles of chemicals, suitable and sufficient application platforms, a fast response capability, and an intelligent application and monitoring program.

Also, Adispersant effectiveness@ as used here means the effectiveness of the dispersant under field conditions, rather than laboratory conditions. Unfortunately, there is little quantitative information on the effectiveness of dispersants when used in the field. Most quantitative information comes from a number of laboratory tests, which are poor simulators of dispersant-use in the field and of oceanic mixing conditions. The five most popular laboratory tests today (Swirling Flask, Labofina, IFP, MNS and Exdet B see Nordvik et al. 1993) have different designs and produce different results for identical dispersant/oil combinations. The view among experts is that, although the results from any laboratory test can be useful in providing relative values of dispersant effectiveness between dispersant/oil combinations, they should not be trusted to predict absolute dispersant effectiveness values in the field.

This leaves the results of past field experiments as the main source of useful dispersant effectiveness information. Unfortunately, there is a lack of good data in this arena as well. This is because (1) there have been only a handful of open-ocean trials; and (2) there are no acceptable surface-sampling or remote sensing methods available for measuring a spill=s overall thickness or volume on the ocean=s surface, and no acceptable methods for determining total volume of dispersed oil in the water column. At least one of these measures is needed to quantitatively estimate oil dispersibility or dispersant effectiveness in the field.

Despite these problems, oil spill experts are not hesitant to say that certain spills are likely to be highly dispersible chemically and others are likely not to be. In the former category are freshly spilled, light to medium gravity oils in a medium wind condition or higher. In the latter category are spills of highly viscous oils and oils with very high pour points. The experts= confidence is based on (1) knowledge about actual light-oil spills that naturally dispersed at sea; (2) the known resistance to dispersion of highly viscous oil spills even in rough sea conditions; (3) anecdotal and qualitative information from actual spill responses where dispersants were used; (4) dispersant field trials under ideal conditions where chemical dispersants were clearly effective; and (5) many years of experience in the laboratory with scores of oils and dozens of chemical products.

2.3.2 Simple Approach for Assessing Dispersant Effectiveness

On the basis of the above factors, oil spill experts at the International Tanker Owners Pollution Federation in the mid-1980s developed a simple approach for estimating dispersant effectiveness. The approach is based primarily on the fresh-oil density of the spilled oil (ITOPF 1987). This variable was used in the correlation because, when a marine spill happens, the properties of the spilled oil are usually not known except for the density of the oil or its API gravity. The ITOPF approach has been used extensively by API (1986) and Regional Response Teams (RRTs) in the U.S. (for example, see RRT Region IV FOSC Pre-Approved Dispersant Use Manual, January 10, 1995). Table 2-2 provides an indication of how the method works.

Ignoring the problem of high-pour-point oils for the moment, the table indicates that oils that have a fresh-oil API gravity of 18° or greater should be chemically dispersible[1]. This method is intuitive and is indeed very simple, but in any case only makes sense for predicting the dispersibility of fresh,

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API gravity of 18° = Specific Gravity of 0.95

Table 2-2 Oil Dispersibility as a Function of API Gravity and Pour Point

Dispersibility Factor[a]	Oil Gravity and Pour Point	Oil Description
1	API Gravity over 45°	•Very light oil •No need to disperse •Oil will dissipate rapidly
2	API Gravity 35°- 45°	•Light oil •Relatively non-persistent •Easily dispersed
2W	API Gravity 35°- 45° Fresh Oil Pour Point >40°F	•Light Oil •Very difficult to disperse if pour point of fresh oil is greater than water temperature
3	API Gravity 17°- 34°	•Medium density oil •Fairly persistent •Dispersible while fresh and unemulsified
3W	API Gravity 17°- 34° Fresh Oil Pour Point >40°F	•Medium Density Oil •Fairly persistent if pour point of fresh oil is less than water temperature •Not dispersible if pour point of fresh oil is greater than water temperature
4	API Gravity less than 17° OR Fresh Oil Pour Point greater than 75°F	•Heavy or very high pour-point oil •Very difficult or impossible to disperse

a. The lower the number the higher the dispersibility
b. API gravity = ([141.5/Specific Gravity] - 131.5). The higher the API gravity the lighter the oil.

unemulsified oil. The dispersibility of spilled oil after some weathering time on the surface is another matter. As discussed earlier, when a crude oil is spilled it begins to evaporate immediately and to emulsify with water. This emulsification greatly increases the oil=s viscosity and greatly diminishes its dispersibility. Unfortunately, the rate of emulsification as a function of oil type and weather factors is presently impossible or very difficult to predict accurately due to lack of knowledge, and that is why the process must be monitored during a spill and why dispersant effectiveness in the field can only truly be determined during the response itself.

In summary, predicting dispersant effectiveness in the field for a given oil spill situation is not an easy and mechanical process; rather the process is inexact and based on a range of both objective and subjective thinking. The following sections work their way through this thought process.

2.3.3 Problems in Obtaining High Dispersant Effectiveness for Spills at Sea

It is known from a handful of experimental spills in the field that a non-viscous oil, when thoroughly pre-mixed with dispersant, and spilled on the ocean under average sea conditions, is likely to completely disperse from the surface and will do so relatively quickly compared with the same oil if left untreated (Lichtenthaler and Daling 1985, Delvigne 1985, 1987, Fingas 1985, Sørstrøm 1986). This provides the strongest possible evidence that chemical dispersants have the potential for being 100 percent effective on spills at sea. There are problems in realizing this with actual spills, however. This is because chemical addition to accidental marine spills takes place after the oil is on the surface and not before, and achieving good contact and mixing between the applied dispersant and the oil is very difficult at this stage. It is clear that applying the dispersant in the proper amounts, in the proper way and at the proper time is crucial in ensuring that the chemical has an opportunity to do the job that it is capable of doing.

Nichols and Parker (1985) and later Fingas (1985, 1988) analyzed the results of about a dozen field trials that were conducted over a ten-year period to evaluate dispersant effectiveness. In these trials, a total of 107 test spills were laid out including 23 control spills used to establish comparisons (Fingas 1988). Dispersant effectiveness values that were reported numerically had an average of 20 to 30 per cent. This value is not dismal by mechanical recovery standards, but one might wonder why values were not higher considering that most experiments were designed to simulate best-case conditions, including the use of unemulsified and relatively non-viscous oils. The main reason is that the experiments with the poor results involved poor initial dispersant/oil contact and mixing and quick loss of the dispersant to the water phase. (Here Amixing@ means the mixing of the dispersant with the oil, and not the mixing of the treated spill into the water column.) Some of the factors that caused poor chemical/oil mixing were not known at the time, but are now, as discussed below.

Dosage Control

As discussed in Section 2.2.2 above, until the mid-1980s most specialists still considered that marine oil spills spread uniformly and reached an average thickness of about 0.10 mm in several hours of spreading. So, dispersant application systems and plans were designed to spray dispersant onto such slick thicknesses to achieve a dispersant-to-oil ratio of 1 in 20, and this is equivalent to about 5 gallons of dispersant for every acre of slick (0.10 mm thick). Today it is known that slicks invariably are composed of a very thick portion in a relatively small area surrounding by a much larger area of very thin sheen. It is clear that if the entire slick is sprayed uniformly, the thicker portion will be vastly underdosed and the sheen greatly overdosed. This happened in most of the field trials noted above. It certainly happened in a well-documented field trial that was conducted in Norway in 1985, as discussed by Mackay (Mackay and Chau 1986, Chau and Mackay 1988) and summarized in Table 2-3.

Table 2-3 Illustration of Over-Under-Dosing for the 1984 Norwegian Experimental Spill[1] assuming 40 µm Diameter Dispersant Drops

	Thick Slick	Sheen	Overall
Slick Volume (m^3)	9.72	.28	10
Slick Area (m^2)	4510	27,690	322,200
Slick Thickness (mm)	2.16	0.01	.31
Fractional Areas	0.14	0.86	
Dispersant Applied (m^3)	0.133	0.311	.444
Dispersant Fractions Applied	0.3	0.7	
Oil to Dispersant Ratio	73.0	.89	22.5

1. Reference: Lichtenthaler and Daling 1985
Source of Table: Mackay and Chau 1986 (also in Chau and Mackay 1988)

Notice that the dispersant-to-oil ratio for the thick portion of oil (representing the vast majority of oil spill volume) was only 1 in 73. This is much less than the recommended 1 in 20. Therefore, the results of the trial were bound to be less than ideal. On the other hand, the dispersant-to-oil ratio for the sheen was almost 1 in 1, representing an excessive dosage and waste of product for so little oil. Many contingency plans, field guides and decision systems (e.g., Allen and Dale 1995) still consider spills to have uniform thickness, and dispersant spraying plans are based on this wrong assumption.

Oil Viscosity and Water-in-Oil Emulsification

Much work has been done to evaluate dispersant effectiveness as a function of oil type and condition (see, for example, Fingas et al. 1994, 1995a, 1995b). The singular most important factor that causes poor dispersant effectiveness in the field seems to be the viscosity of the spilled product at the time the chemical is applied; if the viscosity is extremely high, the dispersant will not penetrate and mix with the mass of oil. The applied chemical will simply "roll off" the oil and be lost to the water phase.

For spilled oils that are highly viscous to begin with, such as heavy bunker oils and extremely heavy and viscous crude oils, it is has been understood for some time that attempts at chemically dispersing the spill will prove futile. Not as well understood is the process of water-in-oil emulsification and its effects on dispersant effectiveness. Almost all crude oils emulsify and become viscous, and the evidence seems to suggest that the process can start early in a spill=s history and, once started, can proceed rapidly (Bobra 1990, 1991). The process is responsible for the largest hindrance to effective dispersant-use of any process or any factor. The effect is shown in Figure 2-3a and Figure 2-3b, both of which show the drop in dispersant effectiveness as the oil viscosity increases by virtue of evaporation and emulsification (noted in Figure 2-3a by the letter "W", which represents the percentage of water in the emulsion). Notice that in the cases shown, dispersant effectiveness drops sharply as the viscosity increases and becomes almost zero when the viscosity increases beyond 1000 to 10,000 cP. It is important to note the difference due to oil type and, as mentioned earlier, that newer dispersant products on the market, such as Corexit 9500, may be effective at higher viscosities than noted here.

It should perhaps also be noted that results of studies done to evaluate viscosity effects (for example, Martinelli and Cormack 1979, Martinelli and Lynch 1980, Bocard et al. 1984, Bocard and Castaing 1986, Desmarquest et al. 1985, Daling and Brandvik 1991) have shown only a weak correlation, if any, between dispersant effectiveness and viscosity when the viscosity is generally low, say in the 1 to 100 cP range. In fact, most studies show that the dispersant effectiveness is lower for oils with very low viscosity compared to oils with medium viscosity up to about 100 cP, and then decreases dramatically thereafter (Daling and Brandvik 1991).

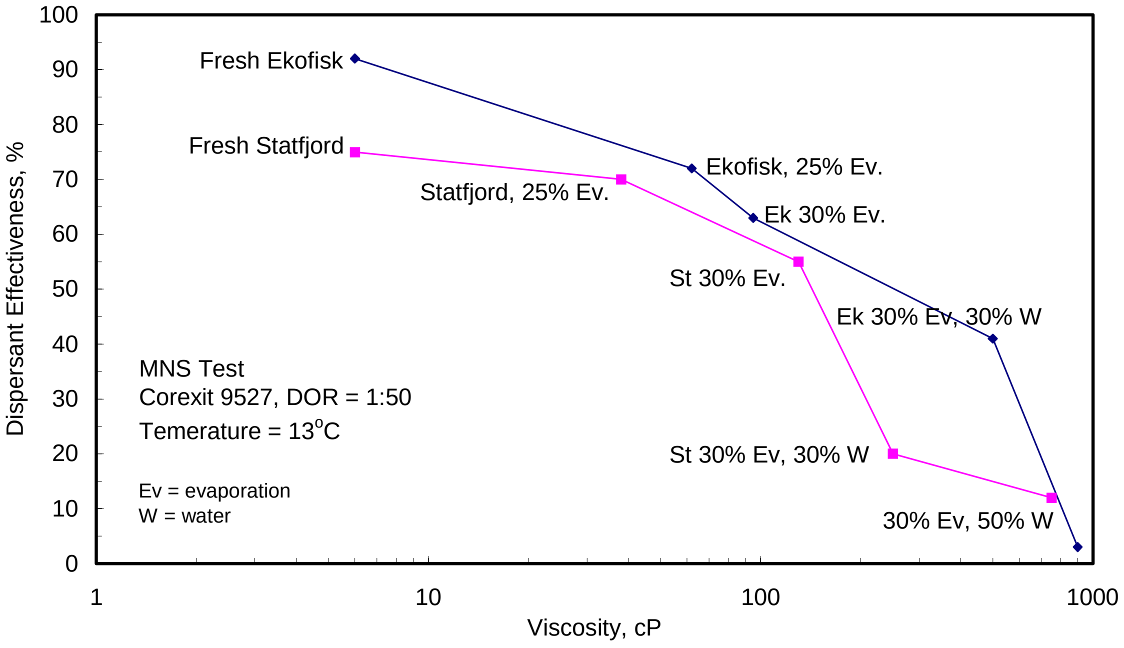


Figure 2-3a Effect of Viscosity on Dispersant Effectiveness (after Daling 1986)

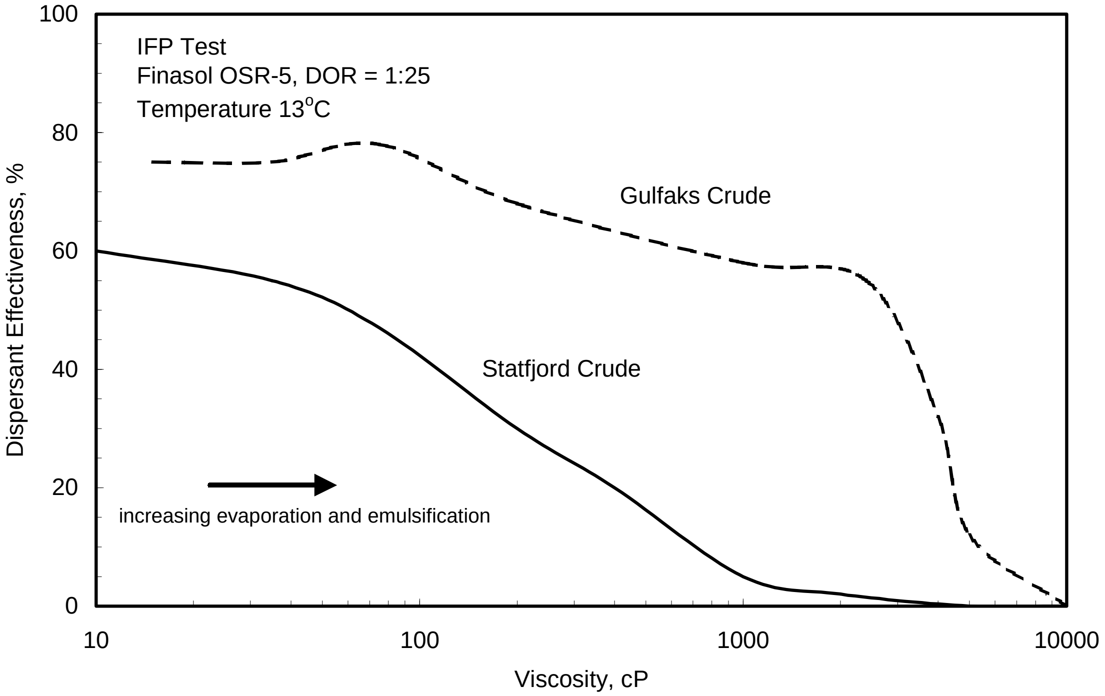


Figure 2-3b Effect of Viscosity on Dispersant Effectiveness (after Daling and Brandvik1991)

Finally, it should be noted that, although the emulsification process has been studied intensively (for example, see Fingas et al. 1995, 1996 and 1997) and is fairly well understood in general terms, how the process proceeds for specific oils is poorly understood; hence, predictions and modeling of the process become a very difficult matter.

Herding and Dispersant Drop Size

The phenomenon of slick Aherding@ has been recognized for many years and, yet, in most dispersant-use plans that exist in the U.S., it is not emphasized as a problem to avoid during the application of dispersant and to be aware of during the monitoring phase of operations. Dispersants, by their nature, have a higher spreading force than does oil. This means that a thin slick of oil surrounded by a layer of dispersant will be herded into a narrow ribbon of oil. This will happen if the dispersant misses its target of oil and falls on the water in proximity to the oil. As viewed from the air, the ribbons of oil thus formed are barely visible, so the operations looks as if the dispersant was very effective in clearing oil off the surface. The water will continue to look clear until the dispersant on the surface is naturally mixed into the water phase, and the oil re-spreads on the surface. This might take about 15 minutes (Fingas 1985). This herding phenomenon has fooled observers into thinking that the dispersant has worked, whereas the opposite has occurred. One indication that dispersants are working is seeing the coffee-colored cloud of dispersed oil in the water column. Lunel (1994a,1995) has indicated, however, that dispersion can occur without the appearance of such a cloud.

Another way herding occurs is if applied dispersant droplets crash through the slick to the underlying water surface and start herding the oil at that time. This will happen if the dispersant droplets are much larger than the slick thickness. For example, if the dispersant droplet has a diameter of, say, 0.50 mm and the slick thickness is 0.10 mm, the dispersant drop will likely break through the slick and cause it to herd (Chau and Mackay 1988). This is problem enough, but the worst of it is that the first few droplets of a dispersant application will immediately and greatly reduce the area of oil slick and increase the water surface area so that subsequently falling droplets will miss the oil entirely, fall on water, and gradually enter the water column. This problem can be avoided by ensuring that the dispersant droplets are always smaller than the thickness of the targeted oil.

There are limits to the droplet size, however, because dispersant droplets having diameters smaller than about 0.2 mm are easily lost to the atmosphere through drift (for example, a 0.10 mm droplet falling through a height of 30 feet in a 15 knot wind will drift about 1000 feet). Because of this problem of drift, the recommended dispersant drop size for applying dispersant from either aircraft or work boats is in the vicinity of 500μm (0.5 mm) (Gill 1981, Mackay et al. 1980b, 1981).

This leads to the conclusion that only relatively thick slicks (>> 0.5 mm) should be targets for dispersant treatment. This is usually not a serious problem because the thick portions of oil spills are usually in the range of a millimeter, or even much more if the response is rapid. For smaller spills where the thicknesses are less, herding will likely be a problem. Herding was certainly a major problem in several of the above-noted field experiments conducted in the 1980s when thick-thin spreading and the problem of herding were not well appreciated. These dispersant-effectiveness experiments were predestined to fail because the experimental slicks were intentionally designed to be very thin (in the 0.1 mm range).

Sea Energy

Sea energy is of obvious importance to the dispersion of marine oil spills: simply put, the more mixing the better (Fingas et al. 1992, 1993). This nicely complements the other two approaches to marine oil spill control, mechanical recovery and *in situ* burning, both of which work best under calm conditions. It is generally believed (with little evidence) that not much sea energy is needed to effect chemically-induced dispersion if the oil spill is properly dosed. This is because the dispersant greatly reduces the interfacial tension between the oil and water, meaning that very little energy is required to mix the oil into the sea. Some dispersant-use proponents suggest that dispersants should be applied to spills even in calm conditions because the oil will be inhibited from forming an emulsion and will be ready to be dispersed when the weather turns worse, during which time it may be much more difficult and even impossible to treat the spill properly. There is merit to this idea, but more study is needed to determine how quickly the dispersant might leach out of the oil and into the water during such periods of calm.

Dispersant Type – Corexit 9527 versus Corexit 9500

There are many products on the market that claim to be effective oil spill dispersants, but most have been shown to be relatively ineffective in laboratory tests and, in any case, are not available in large quantities on an emergency basis. Within the U.S. only dispersants that are listed on the EPA National Contingency Plan Product Schedule can be legally sprayed. (See Section 5.2.2 for a list of approved chemicals.) Of the products on the list only Corexit 9527 and Corexit 9500 are stockpiled in large quantity. Corexit 9527 was one of the first of the modern concentrate dispersants to be developed and has been available for more than 25 years. Recently, a new product has been developed to replace Corexit 9527. It is called Corexit 9500. According to the manufacturer, Corexit 9500 contains the same surfactant chemicals in the same amounts as in its forerunner, but the water-miscible, glycol-based carrier in Corexit 9527 has been replaced by a low-toxicity, hydrocarbon carrier. The product was reformulated for two reasons. First, the more oleophilic solvent enhances the penetration of the dispersant into heavier, more viscous oils. Second, the new solvent in Corexit 9500 allows the product to be used with a lower level of personal protective equipment. A component of the solvent phase of Corexit 9527, namely 2-butoxyethylene, obliges dispersant workers to wear protective clothing and respiratory protection gear, which proved cumbersome in tropical climates. The newer product does not require these protective items.

There is a growing body of information suggesting that Corexit 9500 is generally more effective than Corexit 9527. Figure 2-4 summarizes the results of laboratory tests, in which the effectiveness of Corexit 9500 was compared to that of Corexit 9527 against a broad range of crude oils using the Swirling Flask Test (see details of test in Nordvik et al. 1993). In the figure, Corexit 9527 and 9500 have equal effectiveness for oils whose results fall on the 1x1 line. Corexit 9500 is more effective than Corexit 9527 for all points above the 1x1 line; the opposite is true for points below the line. It is seen that Corexit 9500 tends to yield generally higher indices of effectiveness than Corexit 9527 for the same type of crude oil. These results, produced by Environment Canada at the Emergencies Science Division (ESD) Laboratory in Ottawa are similar to those produced by Blondina et al. in California using a modified version of the Swirling Flask Test (Blondina et al. 1999). Of the 31 experiments in which Blondina et al. tested Corexit 9527 and Corexit 9500 at the same salinity on the same oil, Corexit 9500 was more effective than Corexit 9527 in about 75 % of the cases.

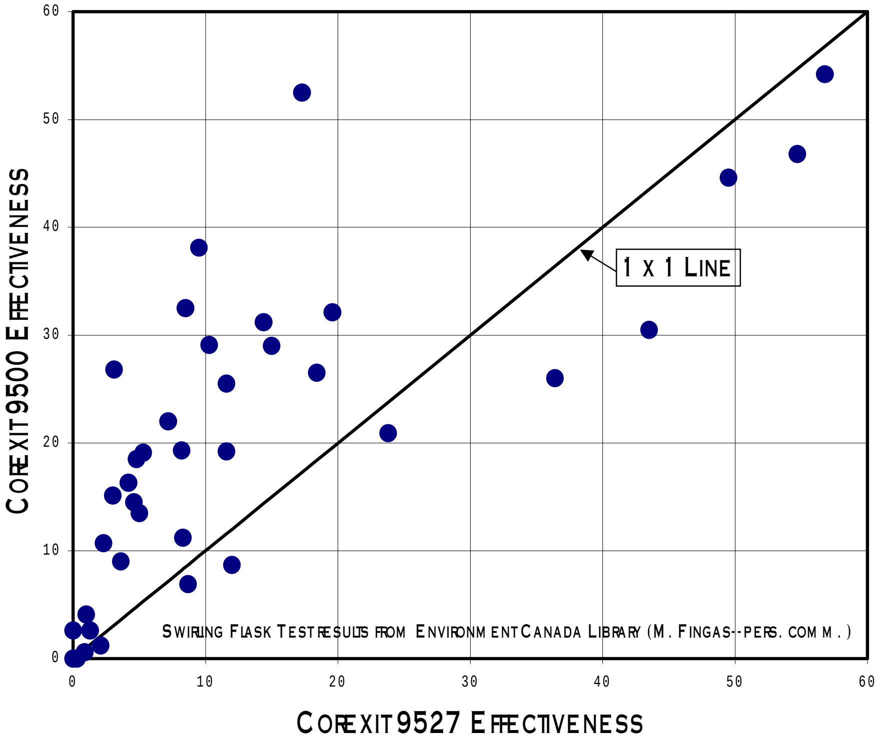


Figure 2-4 Comparison of Corexit 9500 to Corexit 9527

Method of Application: Neat versus Water-Diluted Dispersant

In the early days of dispersant use, dispersants were applied from vessels equipped with spray gear. The dispersant was diluted with water prior to spraying (usually in a concentration of about 1 part dispersant to 10 parts water) in order to produce the right drop size for treating thin slicks. In operations today aircraft apply the dispersant in undiluted form. Recently, however, an interest has developed in using ship-based systems again (Major et al. 1993, 1994; Major and Chen 1995; Lunel et al 1995; Ross 1998; Chen 1999). There are two approaches: the first is to use a separate system for applying dispersant in neat form and the second is to use a standard fire monitor system in which the dispersant is educted into the main water flow to deliver the dispersant in the form of diluted droplets. Recent test-tank work (SL Ross, 2000) with Corexit 9527 and Corexit 9500 on one oil (Alaska North Slope(ANS) crude) seems to indicate that the effectiveness Corexit 9527 is similar if the dispersant is applied in neat form or diluted form (both with the same dispersant-to-oil ratio), but that the effectiveness of Corexit 9500 is diminished when applied in diluted form. The results suggest that Corexit 9500 should not be pre-mixed with water prior to application, as would be the case when using conventional fire monitor systems. At the time of writing further research is proceeding to determine if the results with ANS crude apply to other oils as well (SL Ross *in progress)* .

Temperature

There is a general misconception that temperature, *per se*, is a general problem in dispersant effectiveness, and that dispersants should not or can not be used in cold climates. This is not true. Temperature simply increases the viscosity of the spilled oil. The viscosity of the spilled oil will become higher at low temperatures, but perhaps not too high for effective chemical dispersion (Ross 2000). In any case, none of this has serious relevance to the Gulf of Mexico situation.

Salinity

Blondina et al. (1999) were the first to make a thorough study of the effectiveness of Corexit 9500 relative to that of Corexit 9527 over a range of water salinities. They measured the effectiveness of the two dispersants against nine crude oils and Bunker C at a range of salinities using a modified Swirling Flask Test procedure. They found that Corexit 9500 was significantly more effective than Corexit 9527 on most oils at most salinities, although in a few cases the opposite was true. Both products showed the greatest effectiveness at higher salinities and were less effective at low salinities. In general, however, Corexit 9500 maintained a higher level of effectiveness over a wider range of salinities. Results for four oils are shown in Figure 2-5 (after Blondina et al. 1999).

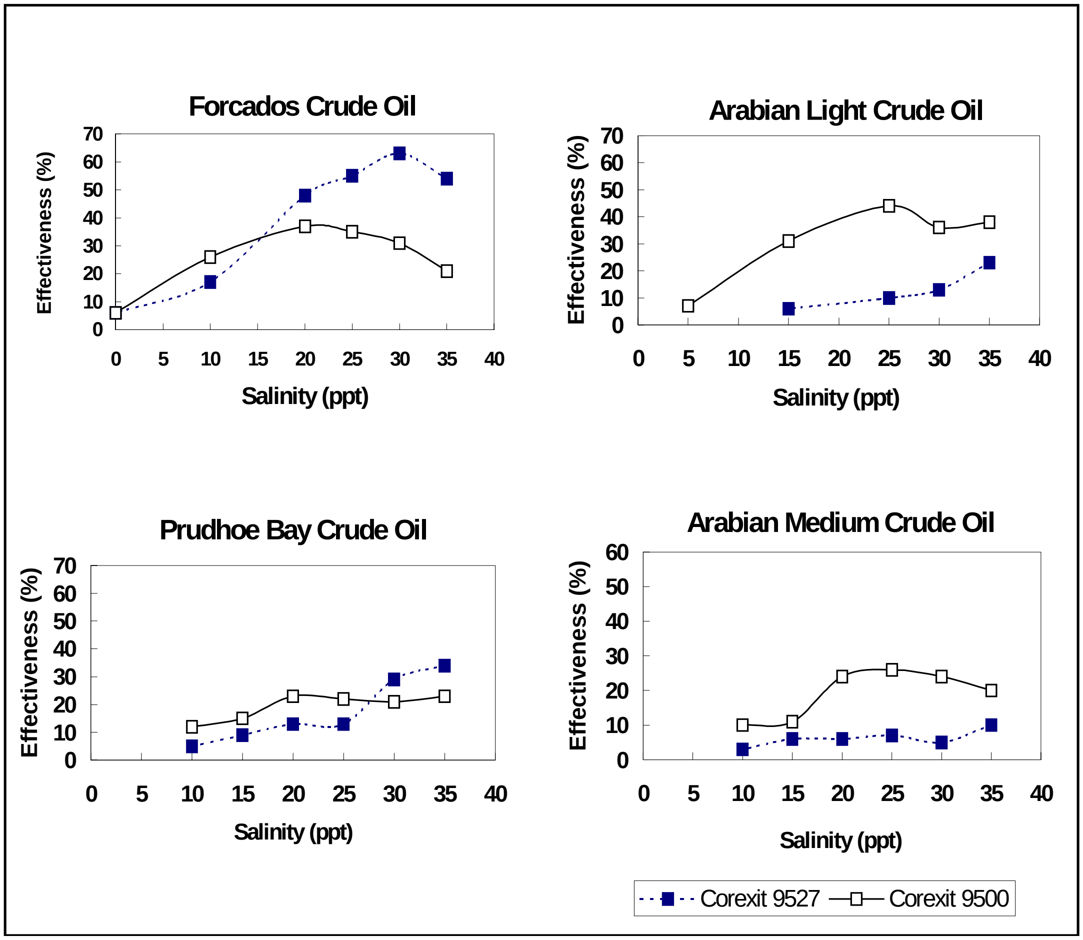


Figure 2-5 Mean Effectiveness of Corexit 9527 and 9500 on Four Crude Oils

2.4 European Field Experience with Dispersants in the 1990s

Most of what is discussed above on dispersant effectiveness is based on laboratory and test-tank studies. However interesting these studies may be, the ultimate question remains: How effective are dispersants when used in the field under real spill conditions? This nagging question started to produce good answers following results from experimental spills in Europe from 1991 to 1995 and from activities at the *Sea Empress* tanker spill off Wales in 1995. The scientists involved made breakthroughs in measuring dispersant effectiveness in the field more exactly than ever before. Although these spills involved oils other than those produced in the Gulf of Mexico and several dispersant products not available in the U.S., the results of are of importance to the present study and are summarized below. The experimental spills are discussed first and the *Sea Empress* is discussed second.

Several of the field trials involved experiments with so-called "demulsifiers" or "emulsion breakers" These class of chemicals are designed to "break" emulsions, that is, to cause water droplets in an emulsion to coalesce and separate from the oil; the effect produces a sharp decrease in spill viscosity. The main attraction of demulsifiers at one time (SL Ross 1985, Walker and Lunel 1995) was the idea that they could be used as the first step in a dispersant operation, not to disperse the oil but to "buy time" and keep the oil from emulsifying and becoming too viscous for subsequent treatment with chemical dispersion. Interest in the idea dropped considerably when it was realized that present-day dispersant products already exhibit strong demulsifying properties, as suggested below in the review of one of the field experiments.

For a much more detailed review and discussion of all the European offshore experiments trials, see SL Ross (1997b).

2.4.1 Experimental Spills

Seven trials took place during the period of 1991 to 1995, each involving either several large spills in the size range of 10 m^3 to 20 m^3 (63 barrels to 126 barrels) or continuous discharges with flowrates of 25 to 50 L per minute (6.6 to 13.2 gallons per minute). The first two trials involved emulsion breakers exclusively and are not reviewed here (for details on these see McDonagh and Colcomb-Heiliger 1992, Lunel and Lewis 1993a and Lunel 1993). The main features and results of the remaining five experiments are now discussed chronologically.

Spraying of Dispersant, September 1993, North Sea off U.K.

Two 20-tonne slicks of a 50:50 mixture of Marine Fuel Oil (MFO) and Gas Oil (GO) were released at sea (Lunel 1994a). One of the slicks acted as the control while the other was sprayed with dispersant Dasic Slickgone NS (with a DOR of 1:10) The wind speed during the experiment varied between 5 and 10 m/s. Although no attempt was made after the trial to estimate dispersant effectiveness quantitatively, the following results were found:

$ The remote sensing imagery indicated that the treated slick dissipated after 8 to 9 hours;

$ Surface sampling of the emulsion indicated that there was a reduction in water content and viscosity immediately following treatment with dispersant, and this was consistent with the rapid spreading of the treated slick observed by the remote sensing over the same period of time; and

$ Monitoring of the subsurface oil concentrations of the control and treated slick showed that at all times the volume of oil dispersed below the treated slick was as much as 16 times greater than below the untreated slick.

Spraying of Demulsifier and Dispersant, August 1994, North Sea off U.K.

In August, 1994, two large (15 m^3) experimental oil slicks were released in the North Sea in winds averaging 5m/sec (Walker and Lunel 1995). After weathering for about 25 hours, each was sprayed with a 400 L demulsifier solution from an aircraft; one hour later one of the slicks was sprayed with 2000 L of dispersant.

The thick and thin parts of each spill were determined as a function of time using IR imagery. Continuous flow fluorometry was used to determine the concentration of oil at various depths beneath the slicks, both before and after spraying operations.

The results showed that the water content of the both spills dropped from between 60 and 65% before spraying to between 40 and 50% after the demulsifier application. For the first spill these levels did not reduce over the next 6 to 7 hours. For the second spill, after the dispersant had been applied, the water content dropped significantly to between 10 and 20%, and remained constant until sampling ceased. This suggests that the dispersant was causing demulsification. Such behavior has been noted and has been attributed to similar chemicals used in both demulsifiers and dispersants before (Lewis et al. 1994, 1995a, 1995b; Lunel 1995; Lunel and Lewis 1993a, 1993b; Lunel et al. 1997; Walker and Lunel 1995).

In terms of the sub-surface oil concentrations, the study showed that the combined demulsifier / dispersant operation resulted in a five- to 10-fold increase in volumes of oil dispersed compared to an untreated slick, but not the 15- to 30-fold increases observed in other trials (Lunel 1994b) when dispersant was used alone. This suggested that the demulsifier was somehow inhibiting the potential of the dispersant, but this was left open to question.

Spraying of Demulsifier and Dispersant, June 1994, North Sea off Norway

An offshore sea trial involving two spills, each containing 20 m^3, was carried out in the Norwegian sector of the North Sea in June 1994. The main purpose was to study the weathering behavior of Sture Blend crude oil and to study the effects and operational factors involved in the aerial application of dispersant. The following are the results from the trial as abstracted from two separate research papers on the experiment (Lewis et al. 1995a, Walker and Lunel 1995).

\$ Water-in-oil (w/o) emulsification of Sture Blend crude oil began almost immediately when the oil was discharged on to the sea surface. The water content of the w/o emulsion was 55% (by volume) 15 minutes after discharge. Initially, the emulsion was very unstable and rapidly broke down to its oil and water components when removed from the sea surface and allowed to stand in static conditions.

\$ The distribution of oil residue and w/o emulsion within the total area of an oil slick was very uneven. The majority of the volume of oil was contained within a very small fraction of the total area. In less than perfect viewing conditions, it was very difficult to visually identify the thickest areas. Aerial IR/UV remote sensing techniques were very useful in identifying these areas.

\$ Dispersant treatment at low dose rates, estimated as 1:300 to 1:700 (dispersant to emulsion) in the thicker emulsion areas of the slick de-stabilized the emulsion that had been formed and led to increased oil spreading and an enhanced rate of natural dispersion. Dispersion occurred when the oil residue was at a temperature 5 to 15C° lower than its pour point, indicating that pour point is not a good indicator of the feasibility of using dispersants.

$ In contrast to some previously reported chemical dispersion field trials (Lichtenthaler and Daling 1985), the dispersion process was relatively slow, but the rate of dispersion was significantly enhanced compared to that of the control slick. The enhanced rate of dispersion persisted and it took several hours to remove all of the oil from the surface. Slow and continuous dispersion has also been observed in some previous field trials (Bocard et al. 1987 and Lunel 1994a). The dispersant treated slick was totally removed from the surface about 4 hours after the second treatment, while the control slick persisted for a total of 30 hours, after which it was treated with dispersant.

$ Based on the measured oil concentration in the water depth down to 5 meters under both slicks, the enhanced dispersion rate for the slick treated with a low dosage of Corexit 9500 can be estimated to be approximately ten times higher than for the untreated slick.

Spraying Dispersant on Steady-State Discharges, 1993, 1994, 1995, U.K.

Lunel (1994a) explains the problems of using batch spills for dispersant effectiveness trials at sea, and proposes that the best solution is to use a continuous, steady-state discharge so that replicate measurements can be made for both surface oil properties and oil concentrations in the water column. In the set-up, used for field experiments in 1993, 1994 and 1995, a discharge vessel, moored in a tidal current, releases oil at a constant rate laying a carpet of oil approximately 1 meter wide and 1 mm thick. The surface oil and the subsurface dispersed plume is carried downstream by the tide. The oil is then treated with dispersant over the entire width of the carpet of oil using spray equipment mounted 2 meters further downstream. A sampling vessel is used to cross the steady-state plume at a point downstream of the discharge vessel to obtain subsurface oil concentrations. After making one transect, the sampling vessel can turn around and repeat the transect at the same distance downstream, again and again. In this way replicate samples are collected, and the four-dimensional problem normally encountered with batch spill experiments is converted to a two dimensional process by fixing the time after treatment and the spreading along the tidal axis.

Some of the dispersant effectiveness results of the studies are presented in Table 2-4. These apply to a wind regime of 6 to 10 m/s. Also shown are the relative rates of dispersion for the various combinations. This is possible since the rates of oil dispersion into the water column were at steady state for the first 30 minutes after treatment using the continuous release experimental technique. It is seen that when the medium Fuel Oil was treated with the dispersant OSR-5, the oil dispersed ten times faster than the same oil untreated.

Table 2-4 Percentage Dispersed and Relative Rate of Dispersion

Oil-Dispersant	Percentage Dispersed	Relative Rate
MFO-OSR-5	30	10
MFO-Corexit 9527	26	9
MFO-Slickgone NS	17	6
MFO-Control	3	1
Forties-Slickgone NS	16	3
Forties-Control	5	1

The three major conclusions from these studies by Lunel et al. are that:

1. There is a clear ranking in the percentage of oil that different dispersants will disperse in the field. Although this ranking has been well documented for laboratory tests this is the first set of field data where this ranking has been quantified;

2. Dispersant type is the most significant factor affecting the percentage of dispersed oil, but smaller differences do exist for the two different oil types;

3. The tested dispersants increased the rate of dispersion by six- to 10-fold compared with natural dispersion in the case of MFO and three-fold in the case of Forties (Forties was not tested in the field with Corexit 9527 or OSR-5).

In the experiments conducted by Lunel et al. in July 1995 the MFO-GO emulsion that was initially discharged had a water content of 60% and a viscosity of about 2000 cP. In the absence of treatment the viscosity of the emulsion on the sea surface rose to 3540 cP. However, treatment with the dispersant product Corexit 9500 not only prevented this increase in emulsion viscosity but also broke the emulsion. One sample collected had a viscosity of 650 cP at $10s^{-1}$.

Thus, in addition to the loss of surface oil due to the dispersion effects of the chemical dispersant, there is an emulsion-breaking effect which results in a low viscosity emulsion that can spread on the sea surface and disperse "naturally" over time. These combined effects reduce the persistence of the emulsion on the sea surface. This is illustrated in figures provided in the 1996 Lunel paper.

2.4.2 *Sea Empress* Spill in 1995

Activities and Observations

On February 15, 1995 the tanker *Sea Empress* grounded at the mouth of Milford Haven, Wales, spilling 72,000 tonnes (19 million gallons) of Forties Blend crude oil and 370 tonnes of Heavy Fuel Oil. This spill is of particular interest because a major component of the response to the spill involved the application of dispersants. Semi-quantification of the effectiveness of the dispersant operations was made possible through a monitoring program mobilized at the initial stages of the response and subsequently carried out by the National Environmental Technology Centre (NETCEN) of AEA Technology (Lunel et al. 1997). The decision making at the incident was aided by the fact that the spilled crude oil, Forties Blend, has been used extensively in field trials in the North Sea. As noted earlier, these field trials showed that (1) Forties Blend forms emulsions readily and that in the absence of treatment these emulsions can be relatively persistent; and (2) Forties Blend tends to be amenable to treatment both by dispersants and demulsifiers.

In response to the grounding, the UK national contingency plan was activated and two surveillance aircraft, equipped with Side-Looking Airborne Radar (SLAR) and downward-looking Video, IR, and UV cameras, were deployed to fly over the vessel to estimate the extent of the spill. Seven DC3 dispersant aircraft were loaded with dispersant and flown to the scene in readiness to begin spraying operations at first light, if required. Predictions of where the major areas of oil contamination were to move and the likely weathering state of the oil were provided by an oil spill model used by the national government. The combination of remote sensing and predictive modeling was used throughout the incident to help plan response operations.

The bulk of the 72,000 tonnes of Forties Blend crude oil was released over the 4-day period from 12:00, 18th February to 18:00, 21st February. Table 2-5 provides a rough estimate of the volumes of oil released and the timing and amounts of dispersant application.

The dispersants used in decreasing order of volume sprayed were: Finasol OSR-51, Dasic LTSW, Dasic Slickgone NS, Dispolene 34S, Superdispersant 25, Enersperse 1583, and Corexit 9500. It was not possible to gather data at the spill on the relative effectiveness of the different dispersants. Around 400 tonnes were applied using the DC3 spray aircraft. This operation was supplemented on February 21 and 22 by an ADDS-pack system from OSRL (Oil Spill Response Limited) which applied approximately 45 tonnes of dispersant.

Table 2-5 Estimates of Oil Volumes Discharged and Dispersant Used at the *Sea Empress* Spill

Date (February)	Time (GMT)	Estimate of oil released (tonnes)	Date (February)	Dispersant application (tonnes)
15	20:00 - 22:00	2,000		
16			16	2
17	20:00 - 23:00	5,000	17	2(+2 demulsifier)
18	10:00 - 13:00	2,000	18	29 (+6 Demulsifier)
18	21:00 - 24:00	5,000		
19	10:00 - 13:00	8,000	19	57
19	22:00 - 01:00	20,000		
20	10:00 - 13:00	15,000	20	110
21	00:00 - 02:00	10,000	21	179
21	11:00 - 14:00	5,000		
			22	67
TOTAL		72,000	TOTAL	446 (+8 Demulsifier)

Source: Lunel et al. 1997

According to Lunel (1997) a notable feature of the spray response was the effective targeting achieved by the use of remote sensing aircraft positioned above the spray aircraft to direct the spray pattern. This operation is well tried and practiced in the UK and allowed the DC3 aircraft in particular to hit ribbons of oil as narrow as 10 to 20 m.

The response on 16 February was mainly restricted to at sea recovery operations inside the Haven as the majority of the oil slick was close to shore and in shallow waters which prohibited the use of dispersants. One test spray of dispersant (2 tonnes) was carried out at 14:20 on 16 February. As a result of visual observations from the remote sensing aircraft it was reported that the dispersant were not being effective in dispersing the surface oil, and subsequent sampling of the surface oil carried out from a surface vessel showed indeed that the oil had started to emulsify.

On the basis of the results from small test sprays on the 17th, and because of previous success in field trials with demulsifiers and dispersants on emulsions of Forties, permission was given for a larger area to be sprayed with 2 tonnes of dispersant and two tonnes of demulsifier. After the application at 09:08, the remote sensing aircraft reported that the oil was turning a milky color, but not dispersing as fast as had been expected. At this time, relatively small patches of emulsion (20 to 30 tonnes) were being driven out to sea and were breaking up. It was therefore decided that further spraying was not required at this stage.

On 18 February, there was another release of oil, estimated at 2,000 tonnes, between 10:00 and 13:00. A trial spray was carried out at 10:20 and at 10:59 the remote sensing aircraft reported that the spray had been successful and permission was given for full scale spraying. Throughout the incident, application of dispersant to the freshly released Forties Blend was highly effective and resulted in clearly visible plumes of dispersed oil.

Between 19-22 February the dispersant application and monitoring of the dispersed oil concentrations were coordinated to give an indication of the effectiveness of the dispersant in real-time. Flow-through-fluorometry techniques, developed for the field experiments discussed above, indicated that the dispersant operation was enhancing the rate of natural dispersion for the freshly-released oil and even for the weathered oil.

On the evening of 18 February there was a new release of oil at low water between 22:00 and 24:00, the size of the release is estimated at 5,000 tonnes. This was followed at low water on the 19

February, by a large release of oil, estimated at 8,000 tonnes, between 10:00 and 13:00. At 09:01 permission was sought and granted to begin spraying. All seven DC3 spraying aircraft were deployed until operations finished at approximately 15:50.

As expected, the dispersants were most effective on the oil just emerging from the grounded tanker. Therefore, the priority targets for dispersant application were slicks of this freshly spilled oil. Once these had been successfully treated with dispersant, larger patches of more weathered oil further offshore were then approached. These patches probably resulted from oil released at low tide during darkness, and thus escaped immediate treatment.

As emphasized by Lunel et al. (1997) the strategy used generally in the UK for applying dispersant, and the strategy used at the *Sea Empress* spill, is for remote sensing planes to direct spray aircraft to areas of thickest oil and for the spray aircraft to repeatedly pass over the region of thickest oil until the surface oil has been dispersed. The limits for dispersant-to-oil ratio (DOR) are set by an estimate of the volume dispersant required to treat the volume of surface oil, rather than trying to set an average application of, say, 5 to 10 gallons per acre, based on an estimate of the average thickness of the slick. In reality, for a major spill such as the *Sea Empress*, logistical limitations mean that it is unlikely that the optimum dosage of 1:20 will ever be exceeded. Lunel provides an example to explain the reasoning behind this strategy, as follows. The estimated 8,000 tonnes of oil released on 19 February was treated with 57 tonnes of dispersant. Assuming that 30% of the oil evaporated within the first 2 hours, this translates to a DOR of 57 : 5,600 or 1 : 100. Given the uncertainty in volumes of oil released, Lunel estimates that the actual dispersant to oil ratio was between 1:50 and 1:150. Even at this very low dose rate the dispersant resulted in an effective dispersion; little of the surface oil that had been released between 10:00 and 13:00 remained when the dispersant operation was stopped at 15:50.

Lunel summarizes the NETCEN reports between 19-22 February as follows:

$ Fluorometry showed that natural dispersion of the fresh oil was taking place when the oil was first released from the *Sea Empress*. For example, on 20 February typical concentrations at 1 m were 3 ppm (with localized maxima up to 10 ppm). However concentrations measured further down in the water column at 4 to 5 m depth were typically less than 0.5 ppm. This trend of high oil concentrations near the sea surface with little depth penetration is typical of the natural dispersion process (Lunel 1994a, Lunel 1995, Lewis et al. 1995, Brandvik et al. 1995). The oil concentration gradient with depth indicates that, in the prevailing 30 to 40 knot winds, oil was being transported into the water column as large Asuspended droplets@ which rise back to the surface to reform a surface slick. Certainly before the commencement of the spraying operation on the 20 February the surface slick of fresh oil close to the tanker was millimeters thick.

$ The dispersant spraying operation substantially increased the concentration of dispersed oil, penetrating to 4 m. This, combined with the dramatic reduction of the volume of surface oil, showed that the dispersant operation was successful when applied to the fresh oil being released from the *Sea Empress*. By way of illustration, on the 20 February oil concentrations at 4 to 5m depth were elevated to 3 ppm immediately following the application of dispersant. After the dispersant application these levels of 3 ppm were uniformly mixed over the entire depth range of measurement (surface to 5 m). This feature of elevated oil concentrations being measured through a depth greater than is observed for natural dispersion is again consistent with field trials carried out on dispersant effectiveness using Forties Blend crude oil (Lunel and Lewis 1993a, Walker and Lunel 1995).

$ Once the Forties oil had emulsified the natural dispersion process slowed down significantly. For example, the oil concentrations measured on 21 February at both 1 m and 4 m were well below 1 ppm under the weathered oil slick.

$ The first application of dispersant to the emulsions tended to break the emulsion while subsequent additions increased the concentrations of dispersed oil. This was consistent with previous trials in the North Sea with Forties when the dispersant operation was successful in breaking the water-in-oil emulsion and then dispersing it.

Lunel advises that it is important to recognize that while remote sensing in the absence of oil concentration measurements cannot provide a clear picture of the effectiveness of dispersant, neither can oil concentration measurements in the absence of remote sensing reveal the whole picture. Part of a successful operation is the judgement of when to stop treating a particular patch of oil. In the case of the fresh oil emerging from the *Sea Empress*, the situation was clear: the oil was basically a coherent surface slick, and dispersant operations reduced its thickness until only sheens remained. In the case of the weathered oil, the main problem, identified through remote sensing, was the patchiness and low surface coverage of emulsion (i.e., around 30% coverage of the water surface). This low coverage meant that, even though there was a significant volume of emulsion remaining at sea, it was not possible to achieve efficient application of the dispersant. When this point was reached in the response to a given patch of oil, the dispersant operation was terminated.

Oil Budget

About 59,000 tonnes of Forties crude oil cargo was transferred to the Texaco refinery once the Sea Empress had been brought alongside a jetty in Milford Haven. The oil budget considered here, therefore, refers to the 72,000 tonnes of Forties crude which was spilt at sea. The majority of the 370 tonnes of HFO impacted the shoreline in and around Milford Haven.

Lunel suggests an overall oil budget on the 29 February (when beach cleanup operations had removed the majority of the bulk oil from accessible sites) as shown in Table 2-6. The assumptions and calculations made in assembling the table are described below:

Table 2-6 Proposed Oil Budget for the *Sea Empress* Spill

	Considering dispersant operation deployed at the *Sea Empress*	**Estimate in the absence of dispersant use**
Recovered at sea	3%	10%
Impacting the shoreline	7%	40%
Evaporated	40%	40%
Dispersed	50%	10%

Oil recovered at sea - 3%: Approximately 4,000 tonnes of water-in-oil emulsion, with an average water content of 50% was removed at sea by skimming operations. This accounts for 3% of the oil. The wind speeds were above 30 knots for much of the initial stages of the response. This puts into context the 3% of the oil recovered by mechanical recovery, when previous experience indicates that 10% recovery is the best that can be achieved for spills of this magnitude (Scientific 1995). The best conditions for skimming operations were on 21 & 22 February and 25 & 26 when wind speeds were below 10 knots, the upper limit for effective mechanical recovery operations. On the 21 & 22 February the dispersant and mechanical recovery operations were often operating in the same part of the slick. The mechanical recovery teams did not report any loss of efficiency in the skimming operation as a result of dispersant use. On this basis, Lunel hopes that this incident will Adispel the myth that dispersant use and mechanical recovery are mutually incompatible.@

Oil impacting the shoreline - 7%: Lunel presents substantial detail defending this number with reference to sampling programs and surveys during the spill, and the like. This is not presented here. In any case, it is noted that, of the 72,000 tonnes, only about 2% was recovered from the shoreline (2,500 tonnes of liquid emulsion of 20% oil reprocessed at the refinery; 3,500 tonnes of oiled waste at 10% to landfarm; 7,800 tonnes of oiled sand at 5% oil to landfarm).

Evaporation - 40%: Forties Blend oil is a relatively Alight@ North Sea crude oil, and 40 to 45% is estimated to have evaporated up to the period of 29 February. This was the prediction of an oil spill model that has been extensively calibrated against experimental oil spills in the North Sea, a large number of which involved Forties Blend. Due to the rough sea conditions and the emphasis on measurements of dispersed oil concentrations, only 8 surface emulsion samples were taken at sea. The evaporative loss of all these samples, which represent between 6 and 24 hours after release, was between 35% and 45%.

Dispersion - by difference = 50%: Fluorometry measurements at sea suggested dispersant application to be successful particularly when applied to the fresh oil being released near the *Sea Empress*. But it is impossible to determine volume of oil dispersed by such measurements; it must be deduced. Thus, if 40% of the spill was evaporated, 3% was recovered at sea, and 7% impacted the shoreline, then by difference 50% of the oil is likely to have dispersed.

Lunel thus believes that, if dispersants had not been used at the *Sea Empress* incident, 72,000 to 120,000 tonnes of emulsion would have impacted the south Wales coastline, instead of the estimated 10,000 to 15,000 tonnes that actually did.

Conclusions

Lunel (1997) concludes that, as a result of the grounding of the *Sea Empress*, 72,000 tonnes of Forties Blend oil was released into the environment making this incident among the 20 largest oil spills of all time. With up to 45% evaporating the potential was for 40,000 tonnes of oil to come ashore. Since Forties Blend oil rapidly emulsifies to produce a 70% water-in-oil emulsion, this could have translated into 130,000 tonnes of emulsion impacting the South Wales coastline if dispersants and mechanical recovery had not been used.

Fortunately, the result of the combined dispersant and mechanical recovery operation was that only around 10,000 to 15,000 tonnes of emulsion impacted the shoreline. The mechanical recovery operation accounted for around 2,000 tonnes of oil (4,000 tonnes of emulsion) while it is estimated that 36,000 tonnes of oil was dispersed.

3. Gulf Of Mexico OCS Oils and their Likely Dispersibility

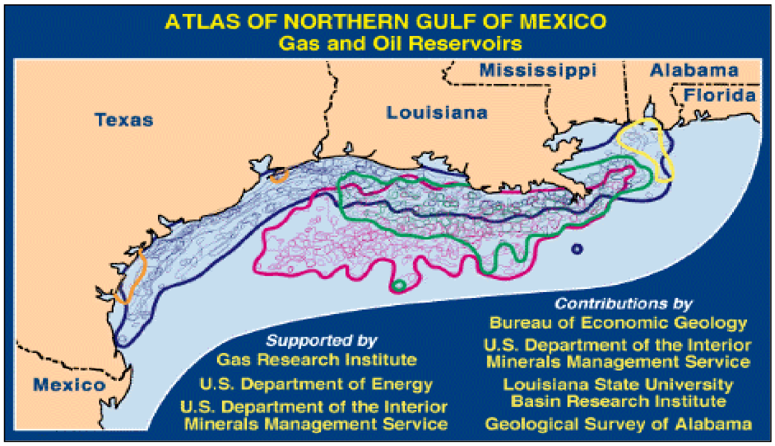
3.1 Introduction

In responding to an oil spill when physical recovery is the only cleanup option, the properties and weathering characteristics of the spilled oil are of minor concern because skimming systems can handle most oils however viscous. This is not the case for the technique of chemical dispersion. Here the spilled oil at the time of treatment must have relatively low viscosity. Dispersants are known to be ineffective on oils that are highly viscous to begin with or on spilled oils that become highly viscous after some weathering. In dispersant-use planning for a given area, it therefore becomes important to “know your oils” and to know their weathering characteristics, their viscosity and their probable dispersibility. This is a challenge in the GOMR area because there are about 5000 wells working in the area, so there are about 5000 distinct oils to consider.

MMS maintains a database on GOMR oil reservoirs which includes data on oil types. Unfortunately, the database is of limited value in evaluating the issue of spill dispersibility because the only oil property provided is API gravity or oil density. As discussed in the previous chapter, oil density by itself correlates only roughly to spill dispersibility. It is known that very high-density oils are usually very viscous and highly resistant to chemical dispersion, and that very low-density oils are usually non-viscous and very dispersible, but the dispersibility of spilled oils that have densities between these extremes is impossible to predict without further information. Such information includes the viscosity of the spilled oil when fresh as well as the viscosity of the spilled oil as it weathers over time. These data can only be obtained by conducting weathering and spill-related tests in the laboratory on the oils of interest. Fortunately, such testing has been done with several GOMR oils and it is information from this testing that is particularly useful in assessing the dispersibility of GOMR oils, as discussed below.

3.2 Analysis of GOMR Oils as Provided in MMS Database

MMS maintains an atlas and comprehensive database on gas and oil reservoirs in the GOMR (it is available for download on the Web at www.gomr.mms.gov/homepg/gomatlas/atlas.html). The atlas is composed of two large-format folios that describe plays[2] of hydrocarbon reservoirs. The data in these atlases are summarized and organized by a geographic information system (GIS) linking map graphics and tabular data together in a digital environment. Digital data from the atlas series include (1) attribute data of reservoir pools, fields, and plays and (2) GIS files of the boundaries of fields and plays. Various engineering and production data on each play are averaged or summed and represented by a single record. Similarly, production and reserve data are listed on each field as a single record.



Graphic from www.gomr.mms.gov/homepg/gomatlas/atlas.html

These data sets are aggregated subsets of data from upcoming Gulf Atlas folios. For each of the 91 plays in the current atlas data set there are 20 fields of information, but for the purposes of this study only a few are of interest. Table 3-1 is a reduction of the data set to only 7 data fields showing all but 23 plays. The omitted plays each have cumulative oil productions of less than 100 Mbbl (100,000 bbl).

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[2] A play is a group of reservoirs genetically related by depositional origin, structural style or trap type, source rocks, and seals. Play boundaries enclose fields that contain sandstone-body reservoirs in that play and exclude fields that do not. A play may comprise one or many fields. Maps of GOMR plays are available at the web site noted in the above graphic.

Table 3-1 Characteristics of Oil and Gas Plays in the Gulf of Mexico

Play [a]	Play Code	Water Depth, Ft.	API Gravity	Cumulative Oil Prod.,[a] Mbbl	Cumulative Gas Prod., MMcf	Oil Reserves, Mbbl	Gas Reserves, MMcf
lm2p1c	25613	46	58.6	4230	107119	2406	573
lm4r2a	23221	50	53.8	1245	76843	479	1142
lm2f1a	25811	70	51.9	4038	395584	1082	321568
mm4r2a	19221	53	51.3	10097	125235	0	81854
lm4p2	23621	53	50.9	379	639696	0	37969
olp2a	28621	43	50.8	3579	173786	103	0
mm4a1a	19411	77	50.5	175	132532	78	51448
olp2b	28622	52	49.6	3668	521462	241	101930
lm1f1b	26812	28	48.7	5402	773399	1908	245305
mm7f1a	16811	14	48.3	6806	131844	4532	34880
lm1p2	26621	23	47.5	2582	144371	4253	5825
lm4r3	23231	47	47.2	2907	80200	1783	7783
lm4p4	23641	32	46.2	4751	68170	428	12120
lm2f1b	25812	38	45.1	10241	1029053	1510	119652
mm7r1b	16212	56	44.8	20153	1710201	3618	186101
olp3	28631	22	43.3	430	46385	0	0
lm2p1b	25612	33	42.5	32432	1906922	7872	261645
mm4a1b	19412	41	42.0	12124	354930	5265	37222
mm4p1	19611	47	41.7	165914	5585740	14723	1389064
mm9p1b	14612	26	41.0	95611	5961583	16096	475707
lm4p1	23611	54	37.2	30234	2155505	4704	531447
mm7a1c	16413	33	37.0	177	5432	0	0
um3a1b	11412	15	37.0	16206	152072	2503	41776
mm7p1b	16612	37	36.8	118075	6985219	19673	711554
mm9p1c	14613	32	36.6	6666	371846	17	28472
mpla1a	05411	111	36.6	577	490258	408	165158
mm4r1	19211	43	36.4	28657	932485	4394	165781
um3f1	11811	174	36.0	78952	487121	144825	410662
mm9f1b	14812	41	35.8	142572	469980	149250	890431
mm4f1	19811	29	35.2	25748	918218	9742	233595
lplp1	07611	140	35.1	1212546	13982044	154017	2503717
upla1	01411	211	35.0	76609	1929477	18995	687597
um1f1	13811	116	34.8	37230	590132	85355	556215
upp1	09611	133	34.7	768118	6924944	134904	1414010
uplp1	01611	266	34.7	207539	9901054	217134	1789892
mplp1	05611	212	34.6	601093	9813494	109667	1401402
um1p1b	13612	43	34.6	561850	8638904	58431	1113912
upf1	09811	467	34.0	345647	2521424	206443	1132219
lplf1	07811	367	34.0	690690	7159182	349769	2817637
lpp1b	10612	139	33.8	1104391	5606930	194924	1318613
um3r2	11221	77	33.2	68677	461195	14195	96302
uplf1	01811	603	32.5	91742	1029497	93724	746639
upa1	09411	55	32.3	150333	899724	12998	112229
um3p1b	11612	71	32.2	2126810	9356701	228633	1803694
lpf1	10811	263	32.0	37299	570753	76603	261511
mm9a1	14411	86	31.7	832	19571	0	1699
lpa1	10411	121	30.3	502254	1174816	119455	120583
mplf1	05811	605	30.1	53959	432691	62417	706928
uplc1	01011	209	30.0	23122	2849	16878	2991
mm9a3a	14431	11	29.0	665	65	58	0
um3a1c	11413	16	28.8	50153	120359	12	6739
lpla1	07411	63	28.7	315487	1738470	28870	224517
um1ap1	13011	29	28.0	49636	394286	23890	297552
mpla1b	05412	61	22.8	17574	58055	5632	4848
um1p1a	13611	148		632	67741	2049	34605
mm9rap1b	14012	87		143	37067	65	9757
mm9p1a	14611	152		1809	242348	527	117308
mm9f1a	14811	58		2478	45559	39	4118
mm7rapf1a	16011	183		5201	1620713	2209	537572
mm7rapf1b	16012	103		195	75031	26	11684
mm7p2	16621	77		424	75764	319	94831
mm7f1b	16812	62		1219	15670	453	6055
lm4r1	23211	114		611	161038	437	144764
lm4a1	23411	166		395	154089	433	171394
lm4f1	23811	113		165	7870	48	1759
lm2p1a	25611	96		2799	481895	1810	620395
lm1p1	26611	25		516	34566	1703	133795
lm1f1a	26811	89		6699	1112504	2759	311972
TOTALS				9952169	120391661	2627773	27872116

a. Excludes 23 plays, each of which produced less than 100Mbbls of oil

The data column of particular interest is API gravity, and the table is sorted with respect to this variable. It is seen that the great majority of API gravity values are relatively high, meaning that GOMR oils are relatively light. (Remember that the gravities noted are average values for each play and thus do not represent the entire range of API gravities encountered in the GOMR.) There are very few plays that on average contain relatively heavy oils. Ignoring other influencing factors (such as an oil's pour point and emulsifiability), this means generally that GOMR oils are likely to be chemically dispersible.

There is sufficient information in the atlas database to calculate and plot the distribution of API oil gravities on the basis of oil and gas fields (371 in total) and lease areas (22 in total). Figure 3-1 shows a plot of API gravity (right ordinate) and cumulative oil produced to date (left ordinate) versus the 22 lease areas. The average for all is 32.9°. This is equivalent to a specific gravity of 0.861. Compared to crude oils from other parts of the world, GOMR oils do appear to be relatively light, and this is a favorable fact insofar as dispersant effectiveness is concerned. Considering the ITOPF simple approach for estimating oil dispersibility (see section 2.3.2 in Chapter 2), GOMR oils on average would have a dispersibility factor close to 2. This indicates that the oils on average are relatively non-persistent and readily dispersible. (This assumes that the effect of pour point is negligible, which is a reasonable assumption; it also ignores the effect of emulsification, which is not reasonable. Both these factors are discussed later).

3.3 Analysis Of Gulf Oils That Have Undergone Spill-Related Testing

The above suggestion regarding the possible dispersibility of GOMR must be viewed cautiously because, to repeat, more than API gravity information is required for evaluating the chemical dispersibility of crude oil spills and for modelling the behavior of spills. What is usually needed is information on oil composition (as measured by distillation data), pour point data, and the tendency of the oil to emulsify as a function of evaporation. Regrettably, such data are not available for the hundreds of GOMR oils. However, over the past few years MMS has funded a number of "oil spill analysis" projects which have included GOMR oils (MMS 1996, 1998, 1999; SL Ross 1998, 1999b). About thirty GOMR crude oils have been tested thoroughly, mostly in

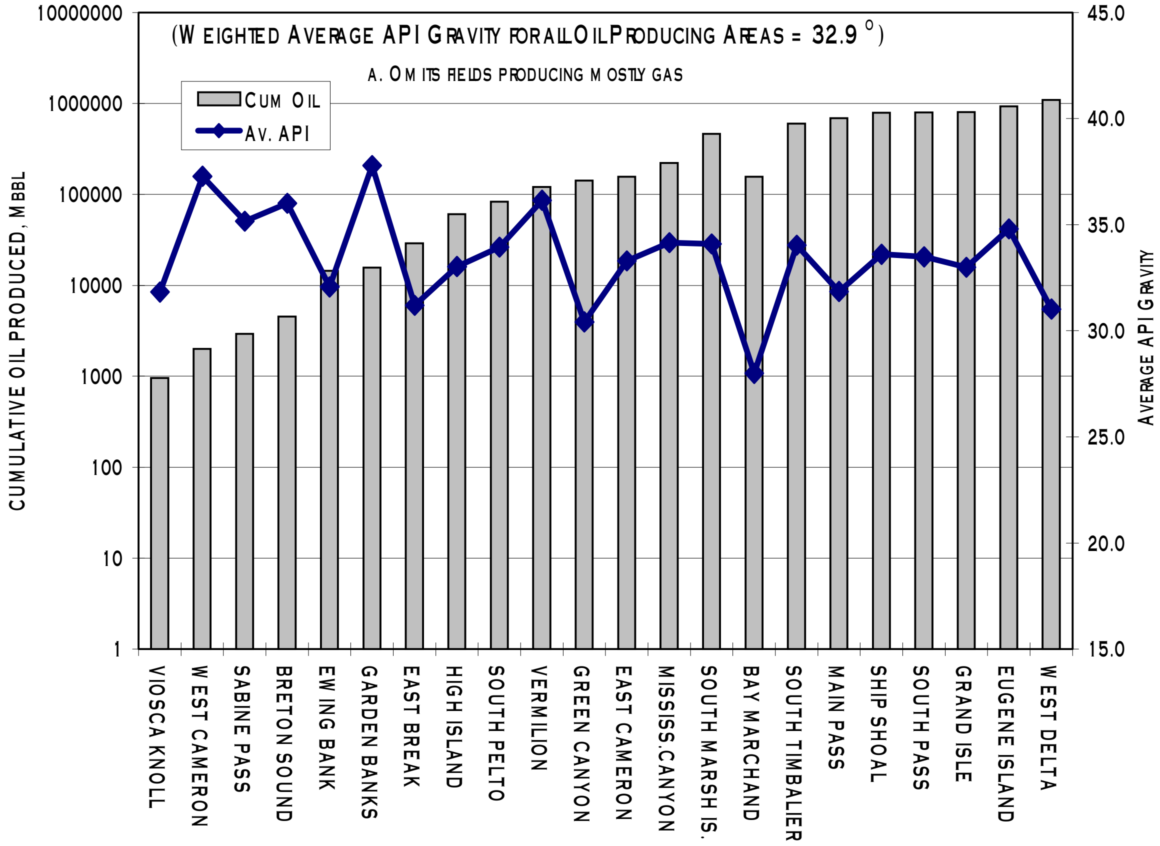

Figure 3-1 API Gravity and Cumulative Oil Production for OCS-GOM Lease Areas[a]

Environment Canada's Emergencies Science Division (ESD) Laboratory.[3]. The data supply the necessary input for current oil spill behavior models including the SL Ross Oil Spill Model (discussed in Chapter 2, Section 2.2.3) and ADIOS (Automated Data Inquiry for Oil Spills), the oil spill model maintained by NOAA[4]. A list of the oils that have been thoroughly tested is provided in Table 3-2[5].

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[3] See Environment Canada's web site http://www.etcentre.org/divisions/esd/english/esd.html for databases on crude oils.

[4] See NOAA's latest model at the web site http://response.restoration.noaa.gov/software/adios/adios.html

[5] The crude oil noted in the table as West Delta 143 was sampled in December 1998 from Equilon Pipeline Company's processing facility West Delta (WD 143) after processing. After processing the oil flows on pipeline segment 10553 to BM3. The Main Pass 69/225 crude oil was sampled on October 6, 1998 from the Shell pipeline terminal, located 30 miles south of Venice, LA. The terminal is located on the 60-mile pipeline between Main Pass 225 and Main Pass 69 (segment 11015) and carries oil from the VK 826 processing facility (SL Ross 199b).

The most important factor in the table is the oil's tendency to form emulsion because it is this process that dramatically drives up the spilled oil's viscosity and drives down its dispersibility. It is seen in Table 3-2 that there is a wide range of values for this factor — from a tendency to form emulsion immediately, to a tendency to form emulsion only after the oil has evaporated by 50%, and finally to a tendency to never form emulsion.

It is impossible to determine how representative these 28 oils are of all GOMR oils. The weighted-average API gravity of the 12 oils in the table for which oil reserve volumes are available in the GOM Atlas database is 32.1°. This is close to the average noted in Table 3-1 and in Figure 3.1. In this sense the oils may be representative of all oils. Also, the oils were selected for analysis for reasons other than the study of dispersant-use, so one could consider the oils listed in Table 3-2 to be a random selection of GOMR crude oils and are in this sense representative of all crude oils in the area. We will assume that to be case.

Table 3-2 GOMR Oils That Have Undergone Comprehensive Spill-Related Testing

Oil Identifier Field and Block	API Gravity	Fresh Oil Pour Point °F	Oil Viscosity @ 60°F at Various Weathered (Evaporated) States			Emulsion Formation Tendency[c]
			0%	~ 15%	~ 25%	
Green Canyon 65*	20	-18	177	800	4250	yes @ 0 %
Mississippi Canyon 807 (1998)*	28	-29	41	491	3454	yes @ 0%
West Delta 143	29	?	32	-	1572	yes @ 6 %
Mississippi Canyon 807 (1999)*	28	?	33	404	2237	yes @ 8%
Viosca Knoll 826 #2	31	?	17	84	186	yes @ 15%
Mississippi Canyon 72	32	-18	16	34	195	yes @ 18%
Green Canyon 109	27	-33	39	225	690	yes @ 22 %
Green Canyon 205	29	?	26	157	543	yes @ 23%
Garden Banks 387*	30	-38	29	181	579	yes @ 23%
West Delta 30*	23	-9	1180	-	1350	yes @ 24 %
Viosca Knoll 826 #1	32	25	16	132	325	yes @ 24%
Main Pass 69/225	34	?	13	-	118	yes @ 25 %
South Pass 49*	29	?	23	-	146	yes @ 30 %
South Pass 93	33	5	19	23	32	yes @ 34 %
Viosca Knoll 990*	38	?	7	12	31	yes @ 35%
South Pass 60	36	16	1	22	41	yes @ 38 %
Garden Banks 426*	39	-8	6	13	34	yes @ 38%
Green Canyon 184*	39	-47	5	11	31	yes @ 38%
South Pass 67	16	16-55?	39	-	110	yes @ 45 %
Main Pass 37	39	27	7	16	36	yes @ 50 %
Ship Shoal 239*	26	5	34	70	74	yes @ 50 %
Main Pass 306*	33	-63	9	19	54	no
Eugene Island 43	37	32	13	36	65	no
Eugene Island 32*	37	45	10	16	21	no
Mississippi Canyon 194*	35	-40	7	15	21	no
Ship Shoal 269	39	-44	5	7	18	no
South Timbalier 130	35	-17	7	10	19	no
West Delta 97	50	-17	1		1	no

Oil reserve information is available for these oils in the GOM Atlas

a. The percentage value refer to the amount of oil evaporation that must occur to start the emulsification process.

3.4 Modeling and Categorizing Representative GOMR Crude Oils

It was proposed above that GOMR crude oils, on the basis of their API gravities alone, might be reasonably dispersible. The objective now is to determine whether this remains to be the case when the emulsification process is taken into account.

The first step in the exercise is to divide the 28 oils in Table 3-2 into four categories of "emulsion formation tendency" ranging from highly emulsifiable oils to oils that do not emulsify. The second step is to conduct modeling (using the SL Ross Oil Spill Model) on selected oils in each category, considering 1000-bbl and 10,000-bbl batch spills in the Gulf under average environmental conditions. The end-result of the exercise is shown in Table 3-3 (see end of section).

It is seen that four of the 28 oils (14%) are considered highly emulsifiable and will have a very narrow "window of opportunity" for dispersing with chemical dispersants. These are called Hi-E oils in this study. They are defined as oils that will start to emulsify after 0% to 10% of the spill has evaporated. Consider the example of crude oil from Mississippi Canyon 802 (1998). A 1000-barrel spill of this oil will begin to emulsify immediately once exposed to the marine environment and will reach a viscosity of 2000 cP in only 3 hours. In 9 hours it will have a viscosity of 20,000 cP. Assuming the viscosity cut-off point for effective use of dispersants is in this range (it depends on the type of dispersant and oil—there is uncertainty on this), there is very limited time available for a dispersant response to the spill.

The next category is for so-called Av-E oils (29% of total). These are oils that will start to emulsify after 11 to 29% of the spill has evaporated. Considering Garden Banks 387 crude oil to be representative of this class of oils, it is seen that there is a relatively narrow time-window for effective dispersant response, but still significantly more time available than the Hi-E oils, namely, 33 to 72 hours depending on the selected spill size and viscosity cut-off value. The situation becomes very good for the third category of Low-E oils (32% of total). These are oils that will start to emulsify after 30 to 50% of the spill has evaporated. Here the "window of opportunity" for effective dispersant use becomes wide, and one has 141 to 267 hours (6 to 11 days) to respond to the spill (considering a spill of Green Canyon 184 crude oil).

Finally, the situation is ideal for the final category of No-E oils (25% of total). These crude oils do not emulsify regardless of the extent of evaporation, and there is an unlimited amount of time for using dispersant effectively on these spills if needed. This class of oils would also include diesel oils.

In summary, the opportunity for using dispersants effectively on the example oils shown in the table is significant. Only the Hi-E oils are a serious problem and these represent only 14% of the total. The remaining 86% offer a reasonable chance of being good targets for a dispersant response program.

It can be concluded that, if the oils in Table 3-3 can be considered representative of all GOMR oils, there is a general opportunity of using dispersant on spills involving GOMR crude oils. Indeed, both Low-E oils and No-E oils, representing 57% of all spill possibilities, are excellent candidates for responding with dispersants. There is much time available for dispersing such spills before the oils become too viscous.

This conclusion speaks of GOMR crude oil spills in general. No two spills are alike, of course, and there will be exceptions to the general statement. The 1000-bbl and 10,000-bbl spills used in this analysis are just examples; the dispersant-use time window will vary greatly as a function of spill size, spill type and environmental conditions (e.g., wind speed). The following chapter now looks at eight specific oil spill scenarios in the Gulf and analyses the dispersant-use possibilities in great detail. In these scenarios four model oils are selected for study. These are the ones highlighted in Table 3-3. Although the specific model oils have real crude oil names, to avoid confusion they will be given generic names (Hi-E Oil, Av-E Oil, etc.) in the following modeling exercise.

Table 3-3 GOMR Crude Oils That Have Undergone Spill-Related Testing

Crude Oil Name	API Gravity	Fresh Oil Pour Point °F	Oil Viscosity @ 60°F at Various Weathered States			Emulsion Formation Tendency	Size of "Window of Opportunity" for Successful Dispersant Use	Hours for Oil to reach Specified Viscosity in 6 m/s (12 kt) winds					
			0%	~ 15%	~ 25%			1000 Barrel Batch Spill			10,000 Barrel Batch Spill		
								2000 cP	5000 cP	20,000 cP	2000 cP	5000 cP	20,000 cP
HIGHLY EMULSIFIABLE OILS (Hi-E Oils) (Emulsion forms at 0 to10 % spill evaporation)													
Green Canyon 65	20	-18	177	800	4250	yes @ 0 %	very narrow	3.3	5	11	3.9	6	15
Miss. Canyon 807 (1999)	28	?	33	404	2237	yes @ 8%	very narrow						
Miss. Canyon 807 (1998)	28	-29	41	491	3454	yes @ 0%	very narrow	3.2	4	9	3.7	5	12
West Delta143-BM3	29	?	32	-	1572	yes @ 6 %	very narrow	5	7	30	5.9	9	54
MEDIUM EMULSIFIABLE OILS (Av-E Oils) (Emulsion forms at 11 to 29 % spill evaporation)													
Green Canyon 205	29	?	26	157	543	yes @ 23%	narrow						
Green Canyon 109	27	-33	39	225	690	yes @ 22 %	narrow	33	35	45	53	55	72
Garden Banks 387	30	-38	29	181	579	yes @ 23%	narrow	15.5	17	28	23	25	45
West Delta 30	11-23?	-9	1180	-	1350	yes @ 24 %	narrow	67	68	73	109	111	117
Mississippi Canyon 72	32	-18	16	34	195	yes @ 18%	narrow						
Main Pass69 to225	34	?	13	-	118	yes @ 25 %	narrow						
Viosca Knoll 826 #1	32	25	16	132	325	yes @ 24%	narrow						
Viosca Knoll 826 #2	31	?	17	84	186	yes @ 15%	narrow						
SLOWLY EMULSIFIABLE OILS (Low-E Oils)(Emulsion forms at 30 to 50+ % spill evaporation)													
Garden Banks 426	39	-8	6	13	34	yes @ 38%	wide	48	52	246	78	82	>360
Green Canyon 184	39	-47	5	11	31	yes @ 38%	wide	141	143	162	234	236	267
Main Pass 37	39	27	7	16	36	yes @ 50 %	wide	disperse@117			disperse@186		
Ship Shoal 239	26	5	34	70	74	yes @ 50 %	wide						
South Pass 49	29	?	23	-	146	yes @ 30 %	wide						
South Pass 93	33	5	19	23	32	yes @ 34 %	wide						
South Pass 67	16	16-55?	39	-	110	yes @ 45 %	wide						
South Pass 60	36	16	1	22	41	yes @ 38 %	wide	40	45	215	65	69	360
Viosca Knoll 990	38	?	7	12	31	yes @ 35%	wide						
OILS THAT DO NOT EMULSIFY (No-E Oils) (Emulsion does not form)													
Main Pass 306	33	-63	9	19	54	no	very wide	341	>360	>360	>360	>360	>360
Eugene Island 43	37	32	13	36	65	no	very wide	306	>360	>360	>360	>360	>360
Eugene Island 32	37	45	10	16	21	no	very wide	231	>360	>360	>360	>360	>360
Mississippi Canyon 194	35	-40	7	15	21	no	very wide	disperse@117			disperse@197		
Ship Shoal 269	39	-44	5	7	18	no	very wide						
South Timbalier 130	35	-17	7	10	19	no	very wide						
West Delta 97	50	-17	1		1	no	very wide						

4. Oil Spill Scenarios

4.1 Basic Considerations

The overall objective of the study is to conduct an assessment of the operational and environmental factors associated with the use of chemical dispersants to treat oil spills from GOMR facilities. In most cases, the assessment will depend on the spill situation. In order to take this into account, a number of spill scenarios were selected by an MMS oil spill project team to reflect the range of possibilities associated with OCS installations. Specifically, the spills of interest are:

a. batch (or instantaneous) spills of various size from platforms or vessels;
b. large and small subsea oil well blowouts in shallow and deep waters;
c. large and small above-surface (platform-based) oil well blowouts; and
d. subsea pipeline spills.

The main factors that will influence the feasibility of using dispersants on specific spills include:

1. The characteristics of the spill, which are determined by spill type (e.g., batch spill vs. continuous spill); spill size; oil type and properties; and water depth (for subsea blowouts only). Spill behavior is also influenced by temperature and wind speed;

2. The environmental impacts of using or not using dispersants, which are determined by the characteristics of the spill, its trajectory, its location with respect to shoreline and resources at risk, and the time-of-the-year of the spill (which affects resource vulnerability); and

3. The dispersant response capability, which is determined by the availability, amount and location of response systems (including dispersant product and application platforms); the characteristics of the spill; and its distance from the base of operation.

Considering that there are many scenario possibilities and there is a need to restrict the number to a manageable level, the following approach has been adopted. First, eight basic scenarios are selected that are not set in any particular location in the Gulf and do not occur at any particular time of year. These are presented and explained, and then they are “moved” to various locations to assess the effect of the relocations on dispersant response capability and environmental impact.

Because the basic scenarios are location- and season-independent, they are developed using average temperature, wind and water current data. There is an obvious variation in these parameters across the Gulf and over the seasons, but the variation will not greatly affect the behavior of spills, at least in comparison to the effects of the other variables (spill type, spill size, oil type, etc.).

As noted earlier, because of major uncertainties in the behavior of deepwater blowouts, a less rigorous approach has been taken in analyzing them in this study.

4.2 Fixed Environmental and Other Conditions

For all scenarios:

- the water and air temperature is fixed at 23°C. This is the likely temperature in late fall. It also is the average of the summer mode and winter mode temperatures;
- the residual water current is fixed at 15 cm/s; and
- the wind speed is fixed at 6 m/s.

For the blowout scenarios:

- the Gas-to-Oil Ratio (GOR) is fixed at 60 (unitless) or 336 ft^3 / bbl;
- for the above-sea release the discharges are assumed to occur through 4-inch (inner diameter) pipe and 20 meters above the water; for the sub-sea blowouts the discharges are assumed to flow through six-inch (inner diameter) pipe;

- the water depth for deep subsea blowouts (Scenario No. 8) is fixed at 2300 metres, and for the shallow water subsea blowouts (Scenarios No. 6 and 7) the depths considered are 35, 50 and 150 meters[6].

4.3 Model Oils

Four model crude oils are used in the scenarios as discussed in Chapter 3. These range from an oil that does not emulsify (presenting a very wide time window for effective dispersant use) to an oil that emulsifies quickly (presenting a very narrow time window for effective dispersant use). The names and properties of the model crude oils are shown in Table 4-1. Also shown is an oil called "Destin Dome CIS Diesel". Environment Canada recently tested this oil, so good oil property data are available for it. MMS requested that it be used as the model diesel oil in the exercise. The oil seems to have typical diesel oil properties.

4.4 List of Selected Scenarios and Analysis Approach

Eight basic scenarios are chosen for analysis as shown in Table 4-2. The objective in this chapter is to describe the behavior of the scenarios in concise, quantitative terms, starting with relatively small and simple spills (Scenarios 1 and 2) and ending with a very large and complex spill (Scenario 8). The subsea pipeline spills are not analyzed as a separate category because an instantaneous spill from a pipeline carrying gas-free or “dead” oil, will behave as a batch spill, and a spill from a pipeline carrying “live” oil, that is, both gas and oil, will behave as a small subsea blowout.

The scenarios are first varied to demonstrate the importance of certain parameters that affect spill behavior and dispersant effectiveness. After this, one spill within each basic-scenario set is selected for use in Chapters 5 and 6 for the assessments of dispersant logistics and environmental impact.

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[6] These water depths cover off the range of actual depths at the hypothetical shallow-water blowouts studied in Chapters 5 and 6, namely, 37m, 46m, 52m, 101m, and 132 m.

All spill behavior modeling work is done with the SL Ross Oil Spill Model (SLROSM) which is briefly described in Section 2.1.4 of Chapter 2. Because there are so many scenario variations, attempts are made to describe the spills as succinctly as possible, focusing on the characteristics of the spills that affect the dispersant application operation and possible impacts; for a more general and basic description of batch spills and blowout spills, please see Chapter 2.

Table 4.1 Four Model GOMR Crude Oils and Destin Dome Diesel Oil

Oil Name	API Gravity	Oil Viscosity @ 60°F at Various Weathered States			Emulsion Formation Tendency	Size of "Window of Opportunity" for Successful Dispersant Use	Hours for Oil to reach Specified Viscosity in 6 m/s (12 kt) winds					
		0%	~ 15%	~ 25%			1000 Barrel Batch Spill			10,000 Barrel Batch Spill		
							2000 cP	5000 cP	20,000 cP	2000 cP	5000 cP	20,000 cP
Hi-E Oil Highly Emulsifiable Oil	28	41	491	3454	yes @ 0%	very narrow	3.2	4	9	3.7	5	12
Av-E Oil Medium Emulsifiable Oil	27	39	225	690	yes @ 22 %	narrow	33	35	45	53	55	72
Lo-E Oil Low Emulsifiable Oil	39	5	11	31	yes @ 38%	wide	141	143	162	234	236	267
No-E Oil Does Not Emulsify	37	10	16	21	no	very wide	231	>360	>360	>360	>360	>360
Destin Dome CIS Diesel	32	5	6	-	no	unlimited	Disperses at 6 hrs @ 3.5 cP			Disperses at 12 hrs @ 5 cP		

% refers to volume evaporated

Table 4-2 GOMR Spill Scenarios

#	Spill Description	Spill Volume	Model Oil[a]	Comments
1	Batch Spill	(1a) 2000 bbl and (1b) 20,000 bbl	(1a) Diesel (1b) No-E Oil	Demonstrates the large dispersant-use *time window* for diesel spills and spills of crude oils that do not emulsify.
2	Batch Spill	20,000 bbl	(2a) Lo-E Oil (2b) Av-E Oil (2c) Hi-E Oil	Could be tank rupture on platform or "dead crude" pipeline spill. Shows the effect of oil type on *time window*, as compared to Spill#1.
3	Batch Spill	100,000 bbl	(3) Hi-E Oil	Could be worst-case FPSO spill or shuttle tanker spill.
4	Surface Blowout, average rate, short duration	20,000 bbl = 5000 BOPD[b] x 4 days	(4a) Lo-E Oil (4b) Av-E Oil	Demonstrates the fast initial evaporation of oil in air, and its effect on *time window*.
5	Surface Blowout, high flow rate	1,400,000 bbl = 100,000 BOPD x 14 days	(5a) Hi-E Oil (5b) Av-E Oil	Extremely large spill that will challenge all countermeasures methods for Hi-E oils and even Av-Oils and lighter.
6	Subsurface Blowout, shallow water, low flow	20,000 bbl = 5000 BOPD x 4 days	Av-E Oil (6a) 35 m deep (6b) 50 m deep (6c) 150 m	Shows the differences between same-sized batch spill (Spill#2) and surface blowout (Spill#4). Could also represent Alive crude@ pipeline spill.
7	Subsurface Blowout, shallow water, high flow	100,000 bbl = 7200 BOPD x 14 days	Av-E Oil (7a) 35 m deep (7b) 50 m deep (7c) 150 m	Worst-case, but more manageable than surface blowout (Spill#5) because no fast initial evaporation in air.
8	Subsurface Blowout, deep water, high flow	9,000,000 bbl = 100,000 BOPD x 90 days	(8a) HI-E Oil (8b) Av-E Oil	Represents worst-case blowout in deep water, and 90 days to drill relief well

c. Model oils defined in Table 4-1.

4.5 Scenario Modeling Results

The modeling results of importance to the logistics of a dispersant operation, for spill scenarios 1 through 7, are summarized in Table 4-3. Because of major uncertainties regarding the behavior of deepwater blowouts, no attempt has been made to model these spills mathematically. The data in the table for the rest of the scenarios can be read as follows.

The first three rows in of data for each scenario present the basic characteristics of the spill. The emulsification tendency of the oil spilled is provided along with basic release information.

The time at which the oil reaches two “cutoff” viscosities are the next pieces of information reported. The viscosity of the oil or emulsion in a slick is the main factor that determines whether or not dispersants are likely to work if properly applied. It is believed that the maximum oil viscosity that can be treated by modern dispersants is in the range of 5000 to 20,000 cP. The table shows approximately how much time would be available to complete a dispersant operation if the cut-off viscosity were 5000 cP or if it were 20,000 cP. A dash is placed in this space for those scenarios where the cutoff viscosities are never reached (scenarios 1a, 1b, 2a and 4a). For these scenarios, the total time that the surface slick is likely to survive on the surface before naturally dispersing becomes the window of opportunity for dispersant application.

The time taken for the surface slick to be completely lost (due to natural dispersion, evaporation etc.) is the next row of data presented in Table 4-3. This is followed by a number of rows of data that describe the thickness of the thick oil portion of the slicks over time. An estimate of the oil thickness is critical to the planning of a dispersant operation as it determines the quantity of dispersant required per unit area of slick. The thicknesses reported have been used to assess the logistical requirements for each scenario and in the estimation of possible impact to surface resources in the vicinity of the spill.

The widths of the thick oil portion of the slicks, at various times in the slicks life, are the next data reported. These widths are also needed to assess the logistical requirements of a dispersant operation.

Table 4-3 Spill Scenario Modeling Result Summary

	Spill Scenario Identifier (refer to Table 4-2 for full description of scenario)															
	1a	1b	2a	2b	2c	3	4a	4b	5a	5b	6a	6b	6c	7a	7b	7c
Spill Info																
Emulsification Tendency	No	No	Lo	Av	Hi	Hi	Lo	Av	Hi	Av	Av	Av	Av	Av	Av	Av
Volume Spilled (bbl)	2000	20,000	20,000	20,000	20,000	100,000	20,000	20,000	1,4000,000	1,4000,000	20,000	20,000	20,000	100,000	100,000	100,000
Discharge Rate (BOPD)	batch	batch	batch	batch	batch	batch	5000	5000	100,000	100,000	5000	5000	5000	7200	7200	7200
Viscosity (cP)																
Time to Visc.>5000 cP (hr)	-	-	-	55	5	5	-	10	2.3	22	4	3.5	2.5	4.3	4.0	2.9
Time to Visc.>20000 cP (hr)	-	-	-	96	12	15	-	15	5.2	36	6	5.5	4.3	7	6.2	4.9
Slick Thicknesses (mm)																
Time to Loss of Slick (hr)	42	119	113	>720	>720	>720	15	>720	>720	>720	414	306	111	576	432	177
Time to < .05 mm (hr)	40	112	110	290	>720	>720	12	>720	>720	>720	24	27	36	30	33	45
Initial Thickness	20	20	20	20	20	20	0.65	0.80	7.2	8.4	0.12	0.09	0.05	0.15	0.12	0.067
At 6 Hours	2.0	4.1	4.6	6.8	11	13.8	0.23	0.40	4.0	1.9	0.06	0.047	0.024	0.082	0.063	0.032
At 12 Hours	1.25	3.0	3.4	5.1	10	13.0	0.1	0.35	3.6	1.3	0.057	0.045	0.022	0.077	0.060	0.030
At 48 Hours	-	1.1	1.4	2.6	8.2	11.2	0.1	0.31	2.5	0.9	0.050	0.038	0.017	0.068	0.050	0.024
When Viscosity at 5000 cP	-	-	-	2.5	11	13.0	-	0.36	5.0	1.0	0.063	0.049	0.025	0.084	0.065	0.034
When Viscosity at 20000 cP	-	-	-	2.4	10	12.7	-	0.34	4.1	0.95	0.061	0.047	0.024	0.08	0.063	0.032
Slick Widths (m)																
Initial Width	140	450	450	450	450	1005	37	36	66	66	300	373	677	340	422	765
At 6 Hours	420	890	820	735	550	1104	45	43	86	133	300	373	677	340	422	765
At 12 Hours	480	990	915	825	566	1118	48	44	89	150	300	373	677	340	422	765
At 48 Hours	-	1150	1090	1003	600	1166	-	46	90	165	300	373	677	340	422	765
At Loss of Slick or 720 hrs	550	1180	1136	1063	730	1386	49	51	90	180	300	373	677	340	422	765
Naturally Dispersed Oil (top 10 metres)																
Time when < 5ppm (hr)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Time when < 1 ppm (hr)	54	138	140	66	-	-	-	-	-	-	-	-	-	4	4	-
Time when < 0.1 ppm (hr)	153	396	396	210	15	33	9	5	-	39	18	18	24	21	23	30
Peak Concentration (ppm)	2.86	4.6	3.8	2.4	0.3	0.3	0.27	0.2	0.04	0.65	0.9	0.94	0.75	1.08	1.08	0.91
Time Peak Reached (hr)	12	21	21	18	3	3	3	3	1.3	6	2.8	2.5	2.6	3	3	2.9

The final data presented in Table 4-3 are dispersed oil concentrations that have been estimated as a result of natural dispersion of the slicks. The elapsed times from oil release to the point where the concentration in the water is likely to drop below 5, 1 and 0.01 ppm are reported (also in the top 10 metres). These "cutoff" concentrations were selected because they represent lethal toxicity limits for adult, juvenile and eggs and larvae life stages of many marine organisms. This information is used in oil impact evaluations in Chapter 6. The peak oil concentration and time to peak concentration are also reported to provide a picture of the time history of the dispersed oil concentration and magnitude.

The following observations can be made about the specific results presented in Table 4-3.

Batch Spills: Scenarios 1 through 3

The windows of opportunity for the use of dispersants for the batch spill scenarios 1a, 1b and 2a are determined by the amount of time available prior to the loss of the surface slick by natural dispersion and not by an increase in the oil's viscosity due to emulsification. This is due to the low tendency of the oils used in these scenarios to form emulsions. The decision to chemically disperse these type of spill would depend on the presence of surface animals in the vicinity of the spill and/or the time that it might take for the surface oil to reach shoreline resources.

Emulsion viscosities for the Hi-E batch spills (scenarios 2c and 3) will exceed chemically dispersible levels within about 10 to 15 hours. Because of this small time window, it will be difficult to mount a dispersant operation for these spills. On the other hand, the Av-E oil batch spill (scenario 2b) is an obvious candidate for dispersant use because it is relatively persistent (> 30 days)—and, thus, a threat to even distant shorelines—and yet it does not emulsify quickly (96 hours), allowing ample time to implement a spraying operation.

The thickness of all of the batch spills at 6 to 12 hours after release range from 2 to 14 mm. This is relatively thick oil that would require multiple spray passes from aircraft application systems or relatively high capacity vessel-based spray systems to achieve proper dosage. The widths of the thick oil portions of these slicks will range from about 500 meters to a kilometer during dispersant operations.

Peak in–water oil concentrations in the 2 to 4 ppm range are predicted for the No-E, Lo-E and Av-E scenarios due to the relatively rapid natural dispersion of these oils. Much smaller peak concentrations (0.3 ppm) are predicted for the Hi-E oils due to their rapid emulsification that retards the natural dispersion processes.

Above Sea Blowouts: Scenarios 4 and 5

The primary difference between the above sea blowout results and the batch spills of similar oil and total spill volume is the initial thickness and widths of the oil slicks and the long-term release characteristics of the blowouts. The thick oil portions of the lower-flowrate blowouts of scenario 4 will only be about 50 meters wide and will be less than 1 mm thick. The slicks of the high flow rate above sea scenarios (5a and 5b) will be about 100 to 150 m wide and 1 to 4 mm thick.

The Lo-E oil again will disperse quickly (within 15 hours) but because of the smaller initial oil thickness it will likely generate much lower in-water oil concentrations (less than 0.3 ppm) than the batch spills.

The oil from an Av-E oil, lower flow, blowout (4b) will emulsify relatively rapidly (10 to 15 hours), as it did in the batch spills, but because this spill is continuous and lasts over a period of 4 days it will be possible to mount a spraying operation to treat the freshly released oil during daylight hours. Much of the oil released overnight will also remain treatable the next day because of the 10 to 12 hour window of opportunity for this scenario. Even though the initial oil thickness is small for this spill, the spill is predicted to last for a long time (> 30 days) due to the formation of emulsion and therefore this spill is an obvious candidate for chemical dispersion.

The Hi-E oil of scenario 5a emulsifies very quickly and provides a window of opportunity for dispersant application of only about 5 hours. Much of the oil that is released overnight during this blowout will not be amenable to effective dispersant treatment the next day. The fresh oil released from this high flow rate scenario will be relatively thick (2.5 to 4 mm) and narrow (<100m) making it a good candidate for vessel-based dispersant application as long as the dispersant is applied very close to the source. Dispersed oil concentrations from the natural dispersion of this spill will be very low due to the rapid emulsification of the oil.

Scenario 5b has the same high flow rate as 5a but the lighter oil (Av-E) results in a longer window of opportunity for dispersant application (up to 36 hours). This oil will spread somewhat more than the Hi-E oil of 5a (150 m thick oil width) and will have smaller oil thicknesses (1 to 2 mm). This scenario is also a good candidate for dispersant use as the slicks will survive a long time if left untreated (> 30 days) but dispersants should be effective on all of the oil, even that discharged over night.

Subsea Blowouts: Scenarios 6 and 7

In these scenarios the a, b and c designations refer to the different release depths of 35, 50 and 150 m, respectively. As the release point gets deeper the surface slick becomes wider (increasing from approximately 300 m to 750 m) and thinner (decreasing from about 0.15 mm to .05 mm) . The higher flow rates of scenario 7 increase the slick widths and thicknesses somewhat, but not radically. The window of opportunity for dispersant application in these scenarios is between 4 to 7 hours. Because these spills are all continuous releases, the fresh oil emanating from the blowout site during the day will be treatable as long as it can be dosed within about 6 hours of its release. However, much of the oil released overnight will not be chemically dispersible the following morning. The dispersant application system used to apply the dispersant will have to be designed to properly dose the relatively thin slicks (50 to 120 micrometers) that result from these blowouts.

The peak dispersed oil concentrations from these subsea blowouts will be on the order of 1 ppm.

5. Analysis of Logistics and Operational Efficiency Factors

5.1 Introduction

This chapter deals with the operational factors that control the effectiveness of dispersant operations in dealing with spills from offshore MMS-regulated facilities in the Gulf of Mexico. Even if dispersant products are highly effective and the spilled oils are dispersible when fresh, the responders' ability to apply sufficient dispersant to treat all of the spilled oil within the available time window will be controlled by a number of factors, including:

(1) availability of dispersant product;
(2) characteristics of platforms (payload, pump rate, speed);
(3) spill conditions (e.g., type of spill, behavior of the oil, distance offshore);
(4) ability to identify thick oil areas and position spray equipment accordingly;
(5) availability of effectiveness monitoring; and
(6) weather and daylight hours.

The objective is to (a) analyze the effect of each of these factors on operations; (b) assess the current level of dispersant capability in the Gulf, as tested against the spill scenarios developed earlier in the report; and (c) evaluate modifications to existing systems that might improve the capability in a cost-effective manner.

There are several types of dispersant application platforms available for use in the Gulf of Mexico and many spill scenarios to consider. A major challenge in the study was organizing and analyzing the many platform/spill combinations. To assist in this regard, several numerical logistics models were developed specifically for the project and programmed in MS Excel format.

The chapter contains four sections:

1) Setting — briefly describes conditions in the Gulf area that influence operational efficiency;

2) Weather and Daylight Conditions — describes the degree to which weather and day length conditions in the Gulf of Mexico area influence dispersant response;

3) Delivery Capacity — uses the output of logistic models to describe the capacity of GOM dispersant response resources to treat hypothetical spills under a range of conditions; and

4) Targeting and Monitoring — describes certain quality assurance activities that are applied at the point of dispersant spraying that can maximize the efficiency of dispersant application.

5.2 Setting

5.2.1 Spill Conditions

Specific spill scenarios and spill locations have been selected for analysis to determine the capabilities and limitations of existing dispersant response platforms in the Gulf of Mexico.

Spill Scenarios. The spill scenarios in Table 5-1 are selected to aid in considering the response limitations of dispersants and spraying platforms. The scenarios and the fate of oil in each have been described in detail earlier in this report and are summarized only briefly here. These scenarios include both batch and continuous spills (blowouts) with a broad range of spill volumes and oil types (having different tendencies to form emulsion). Because batch and continuous spills pose such drastically different problems for responders, they are treated separately.

Spill Locations. The location of a spill controls a number of aspects of spill impact and response, including: a) the environmental risk it poses and the net environmental benefit offered by dispersants; and b) the logistics challenges faced by responders. The launch points identified in Table 5-2 and Map 5-1, cover the entire oil-producing area in the Gulf, from Texas to the Destin Dome area off Florida. They include shallow nearshore sites, sites in deep, offshore waters and sites in mid-shelf areas. These launch sites influence at least two aspects of this logistic analysis: (a) the length of time required for oil slicks to reach the shoreline and therefore the time available for on-water remediation (Table 5-3); and b) the distance from a responder’s base of operations to the spill.

Table 5-1 Summary of oil spill scenarios and spill conditions

Scenario Number	Spill Type	Spill Volume, barrels	Discharge Rate and Duration	Oil Type[a]
1a	Batch	2000	instantaneous	diesel
1b	Batch	20000	instantaneous	No-E
2a	Batch	20000	instantaneous	Lo-E
2b	Batch	20000	instantaneous	Av-E
2c	Batch	20000	instantaneous	Hi-E
3	Batch	100,000	instantaneous	Hi-E
4a	Blowout	20000	5000 BOPD x 4 days	Lo-E
4b	Blowout	20000	5000 BOPD x 4 days	Av-E
5a	Blowout	1,400,000	100,000 BOPD x 14 days	Hi-E
5b	Blowout	1,400,000	100,000 BOPD x 14 days	Av-E
6a	Blowout	80,000	20,000 BOPD x 4 days	Av-E
6b	Blowout	80,000	20,000 BOPD x 4 days	Av-E
6c	Blowout	80,000	20,000 BOPD x 4 days	Av-E
7a	Blowout	100,000	7200 BOPD x 14 days	Av-E
7b	Blowout	100,000	7200 BOPD x 14 days	Av-E
7c	Blowout	100,000	7200 BOPD x 14 days	Av-E
8a	Blowout	9,000,000	100,000 BOPD x 90 days	Hi-E
8b	Blowout	9,000,000	100,000 BOPD x 90 days	Av-E

a. See Chapter 4 for definitions

Table 5-2 Spill launch sites

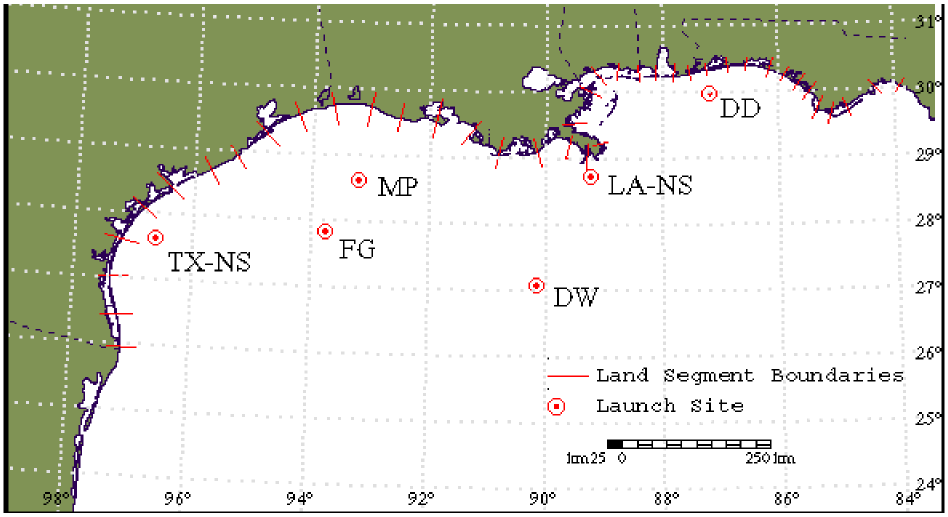
Nominal Location	Abbreviation	Lat. (deg)	Long. (deg)	Location on Map
Texas - Nearshore	TX - NS	27.619	96.624	A
Louisiana - Nearshore	LA - NS	28.725	89.25	B
Midpoint	MP	28.614	93.214	C
Flower Gardens	FG	27.837	93.761	D
Deepwater Site	DW	27.083	90.166	E
Destin Dome	DD	29.980	87.18	F

Table 5-3: Length of time required for slicks from various launch points to reach shore[a]

	Time to Shore (days)			
	Summer		Winter	
Scenario	25 percentile [b]	50 percentile[c]	25 percentile	50 percentile
Texas-Nearshore	1	2	3.5	6
Destin Dome[d]	5.5	9	4	7
Mid-Point	5	7	15	29
Flower Gardens	16	23	22	30+
Louisiana - Nearshore	7	30+	10	30+
Deepwater Site	30+	30+	30+	30+

a. Based on Price et al (2000)
b. Time at which conditional probability of shoreline contact ≥ 25%
c. Time at which conditional probability of shoreline contact ≥ 50%
d. Based on Price et al (1998)

Map 5-1 Locations of spill launch sites and shoreline segments



5.2.2 Response Resources

This section summarizes the availability and logistics characteristics of response resources currently available to responders in the Gulf of Mexico area.

Dispersant Products. A major limiting factor in dispersant operations can be the quantity of dispersant available. Within the U.S., only dispersants that have met the approval criteria set by the U.S. Environmental Protection Agency and that are listed on the EPA National Contingency Plan Product Schedule[7] can be legally sprayed. The most recently published NCP Product Schedule (December 1999) included the following products:

- Corexit 9527
- NEOS AB 3000
- MARE CLEAN 200
- Corexit 9500
- DISPERSIT SPC 1000

Of these, only Corexit 9527 and Corexit 9500 are stockpiled in large quantity within the U.S. The product, U.S. Polychemical DISPERSIT SPC 1000, has only recently been added to the list and is not yet widely available in product stockpiles. The remaining two products NEOS AB 3000 and MARE CLEAN 200 have never been stockpiled in quantity in North America despite having been on the NCP Product Schedule for many years.

The dispersant stockpiles in North America are summarized in Table 5-4. The values are approximate because quantities change constantly. The amount of dispersant available in the GOM area is 182,610 gallons. At least a portion of the remaining 222,290 gallons of dispersant could be made available for use on spills in the Gulf, as shown.

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[7] See http://www.epa.gov/oilspill/ncp/dsprsnts.htm

Table 5-4a Stockpiles of dispersant in the Gulf of Mexico area and elsewhere in North America (a,b)

Organization	Location of Dispersant	Type of Dispersant	Amount (Gallons)	Comments
Within the Gulf of Mexico				
LOOP, Inc. New Orleans, LA Cindy Gardner-LeBlanc (504)363-9299	Houma, LA	COREXIT 9527	33,600	
Clean Gulf Associates (c) New Orleans,LA Dick Armstrong - (504)593-6700 Frank Palmisano - (504)580-0924	Sugarland, TX (Nalco/Exxon) Houma, LA (ASI)	COREXIT 9500 COREXIT 9527	28,985 5,665	
Marine Industry Resources-Gulf (MIR-G) Jim O'Brien - (504) 368-9845	Houma, LA (Airborne Support,Inc.)	COREXIT 9527	16,000	
Airborne Support, Inc. Houma, LA Howard Barker - (504)851-6391	Houma, LA	COREXIT 9500 COREXIT 9527	2,000 4,470	
Nalco/Exxon Energy Chemicals(d) Contact: Garner Environmental Services Deer Park, TX Mike Nadeau or Reese Majoue (800)424-1716 or (281)930-1200	Sugarland, Texas	COREXIT 9500 COREXIT 9527	27500 2750	Nalco/Exxon can produce approximately 44000 gallons of dispersant per day under emergency conditons
National Response Corporation Houston, TX David Kendall (713)-977-9951	Cameron, LA Leeville, LA, Vessel Morgan City, LA	COREXIT9527 COREXIT9527 COREXIT9527 COREXIT9527 DISPERSIT SPC 1000	440 440 220 440 220	

Table 5-4a Stockpiles of dispersant in the Gulf of Mexico area and elsewhere in North America (a,b)

Organization	Location of Dispersant	Type of Dispersant	Amount (Gallons)	Comments
Outside Gulf of Mexico Area				
Alyeska Pipeline Service Company Anchorage, AK Mark Delozier - (907)834-6901	Anchorage, AK Valdez, AK	COREXIT 9527 COREXIT 9527	56,000 4,000	No apparent restriction on availability
Clean Islands Council/State of Hawaii Honolulu, HI Kim Beasely - (808)536-5814	Honolulu, HI	COREXIT 9527 COREXIT 9500 COREXIT 9500	3,080 4,180 30,000	
Clean Caribbean COOP Ft. Lauderdale, FL Paul Schuler - (954)983-9880	Pt. Everglades, FL Pt. Everglades, FL Trinidad	COREXIT 9527 COREXIT 9500 COREXIT 9500	4,070 25,300 990	Availability of stockpile for use outside of Caribbean Area - 50% of stockpile to COOP members - 25% available to non-members - 100% available if replaced within 48 to 72 hours
Marine Spill Response Corp. Edison, NJ Austin Smith - (732)346-2450	Lyndon, NJ	COREXIT 9527	24,640	
CISPRI (CIRO) Cook Inlet, AK Doug Lentsch - (907)776-5129	Nikiski, AK Nikiski, Ak Anchorage, Ak	COREXIT 9527 COREXIT 9550 COREXIT 9527	9,295 2,255 11,275	
Clean Seas COOP Carpenteria, CA Darrel Waldron - (805)684-3838	Carpenteria Carpenteria (COOP Member Use Only)	COREXIT 9527 COREXIT 9527	9,000 11,000	
Clean Bay COOP Concord, CA Steve Ricks - (925)685-2800	Martinez, CA Richmond, CA (Chevron)	COREXIT 9527	15,015	
Clean Coastal Waters Long Beach, CA Sean Torkleson - (562)432-1415	Long Beach (CCW Yard), CA	COREXIT 9527	6,545	

Table 5-4a Stockpiles of dispersant in the Gulf of Mexico area and elsewhere in North America (a,b)

Organization	Location of Dispersant	Type of Dispersant	Amount (Gallons)	Comments
Outside Gulf of Mexico Area				
Clean Sound COOP, Inc. Everett, WA Roland Miller - (425)744-0948	Blaine, WA	COREXIT 9527	6,270	
Delaware Bay COOP Lewes, DE Eugene Johnson - (302)645-7861	Slaughter Beach, DE	COREXIT 9527	1,650	
Clean Harbors Lyndon, NJ Dennis McCarthy - (908)862-7500	Lyndon, NJ	COREXIT 9527	1,375	
U.S. Polychemical Corporation Chestnut Ridge, NY Robert Bergman - (914)356-5530	Chestnut Ridge, NY	DISPERSIT SPC 1000	0	U.S. Polychemical can produce approximately 44000 gallons of dispersant per day under emergency conditons

(a) Prepared on 12 September 2000. Note that dispersant quantities and contact information change from time to time. The authors have made every effort to ensure that information is accurate as of the date of preparation, bu information reported here must be regarded as approximate and should be updated on a regular basis.

(b) Adapted and updated from material provided by MSRC August 2000.

(c) A portion of Clean Gulf and LOOP dispersant is stored at Airborne Support, Inc., Houma, LA (504)851-6391

(d) Garner Environmental Services is the distributor for Nalco/Exxon

Table 5-4b Locations of certain types of dispersant spraying equipment

Organization	Location of Equipment	Description and Quantity	Comments
Within the Gulf of Mexico Area			
Airborne Support, Inc. Houma, LA Howard Barker - (504)851-6391	Houma, LA	DC-4 Custom Aircraft Spray System x 1 2xDC-3 Custom Aircraft Spray System x 1	
National Response Corporation Houston, TX David Kendall (713)-977-9951	Cameron, LA Leeville, LA, Vessel Morgan City, LA Morgan City, LA	1 x fm-type spray system, 13-60 gpm capacity, neat (a) 1 x fm-type spray system, 13-60 gpm capacity, neat 1 x fm-type spray system, 13-60 gpm capacity, neat 1 x fm-type spray system, 13-60 gpm capacity, neat 1 x fm-type spray system, 60-240 gpm capacity, educted vessel speeds 5 to 20 knots	
Clean Gulf Associates (a) New Orleans,LA Dick Armstrong - (504)593-6700 Frank Palmisano - (504)580-0924	Huoma, LA	1 x vessel-based system, fm-type, diluted, maximum flow rates 30 gpm dispersant, 150 gpm water; payload up to 49 drums dispersant; speed 24 kts, maximum	
LOOP, Inc. New Orleans, LA Cindy Gardner-LeBlanc (504)363-9299	Houma, LA	3 x vessel based systems	
Emergency Aerial Dispersant Consortium Tynan, TX Ed Rosenberg (512)-547-9928	Tynan, TX Mer Rouge, LA Mer Rouge, LA Rosenberg, TX Rosenberg, TX	2 x AT-802 2 x AT-802 2X 500-GALLON CAPACITY TURBINE AIRCRAFT 1 x AT-802 2 x AT-502	

Table 5-4b Locations of certain types of dispersant spraying equipment

Organization	Location of Equipment	Description and Quantity	Comments
Dispersant Systems Outside Gulf of Mexico Area: High Capacity Systems Only			
Alyeska Pipeline Service Company Anchorage, AK Mark Delozier - (907)834-6901	Anchorage, AK	2 x ADDS Packs	No apparent restriction on availability
Clean Islands Council/State of Hawaii Honolulu, HI Kim Beasely - (808)536-5814	Honolulu, HI	1 x ADDS Pack	
Clean Caribbean COOP Ft. Lauderdale, FL Paul Schuler - (954)983-9880	Pt. Everglades, FL Pt. Everglades, FL	1 x ADDS Pack (Property of MIR-G)	
Oil Spill Response Limited London, United Kingdom David Neilson 44-20-7724-0102	Southampton, United Kingdom	1 x ADDS Pack	
East Asia Response Limited Singapore, Singapore Ms Alicia Ching 65-266-1566	Singapore, Singapore	1 x ADDS Pack	
Emergency Aerial Dispersant Consortium Tynan, TX Ed Rosenberg (512)-547-9928	Rigby, Idaho Rigby, Idaho Coolidge, AZ Coolidge, AZ	1 x AT-802 2 x AT-502 3 x AT-802 1 x AT-502	
US Coast Guard District 8 Marine Safety Division 504/589-6255 or CDR Ed Stanton, Gulf Strike Team (334)-441-6601	CG Air Station Mobile, AL CG Air Station, Clearwater, FL Other Gulf Coast Facilities	The US Coast Guard can provide C-130 aircraft to deploy the ADDS Pack.	
USAF 910 AIRLIFT WING (ASAFR 757 AIR WING), Vienna, Ohio LT COL Mike Deckman (330)-609 -1258 (commanding officer) or LT COL Marty Davis (330)-609 -1531	Vienna, OH	C-130-based aerial dispersant spraying capability	
(a) A portion of Clean Gulf and LOOP dispersant is stored at Airborne Support, Inc., Houma, LA		(504)851-6391	

In addition to the stockpiles already in place, the manufacturers of Corexit 9500 and Polychem Dispersit SPC 1000 claim to be capable of producing approximately 44,000 gallons (=800x55-gallon drums) per day on an emergency basis.

Response Resources. Another key component of the dispersant response system is the spraying platform used to apply dispersants. The logistics characteristics of dispersant application platforms currently available in the Gulf area are listed in Table 5-5. These are used in Section 5.4 to estimate the capabilities of these platforms to respond to different spill scenarios. A few key features of the platforms are mentioned here.

1) **C-130/ADDS Pack.** The C-130 aircraft, equipped with the ADDS Pack (Airborne Dispersant Delivery System) has the greatest overall dispersant delivery capacity of any existing platform. This is by virtue of its high payload, spray rate, swath width and transit speed. At present, its main drawback in the Gulf of Mexico is that start-up times may be lengthy. Spraying would not begin until the morning of the second day of the spill, in most cases.

2) **DC-4.** This platform is modeled after the dedicated dispersant spraying aircraft owned by Airborne Support Incorporated of Houma, LA. This aircraft has the greatest delivery capacity of any dedicated aircraft application system currently available in the U.S. The key feature of this system is that it operates on a “firehouse” basis, meaning that it is dedicated to the task of dispersant spraying and is in a constant state of readiness. Its start-up time is one hour or less.

3) **DC-3.** This platform is also modeled after the dedicated dispersant spraying aircraft owned by Airborne Support Incorporated of Houma, LA. This aircraft has the second greatest delivery capacity of the dedicated aircraft systems. This system also reports a start-up time of one hour or less.

Table 5-5 Characteristics of dispersant spraying platforms in the Gulf of Mexico

Application System	Payload, US gal	Pump Rate, US gpm	Swath Width, feet	Average Transit Speed, knots	Average				
					Start-up Time, hours	Spray Speed, knots	Re-Posit. Time, min	Re-Supply Time, hours	Range
C-130/ADDS-pack	5500	600	100	214	24	140	2	1	7 hours
DC-4[a]	2000-2500	500	100	214	1	157	2	1	
DC-3	1200	185	100	151	1	150	2	1	
Agtruck AT-802	800	120	80	200	4	140	0.5	1	200 miles
Agruck AT-502	500	120	80	200	4	140	0.5	1	200 miles
Helicopter	250	79	80	90	1	50	0.5	0.25	1.75 hours
Vessel A[b]	900	118	350	5	1	7	2	1	
Vessel D[c]	20,000	60	175	25	1	25	2	1	

a. Values reported in the literature for aircraft logistic characteristics such as payload are somewhat variable. For the DC-4 payload values range from 2000 to 2500 gallons. The value used in calculations is at the upper end of this range, 2500 gallons. It must be recognized that the payload of the existing DC-4 platform in the Gulf of Mexico area is somewhat lower than this at 2000 gallons.

b. Modeled after NRC Vessel "Jim G", 2X450 gal tank capacity, single nozzle application s system, 2 eductor units with 1000 gpm (1 to 12 % dispersant), and a throw of 175 feet.

c. Modeled after new portable single-nozzle spray system developed by National Response Corporation and mounted on one of their new crew-cargo vessels. System characteristics are as follows (A. Woods, pers. comm.):
- Payload – capacity is up to 20,000 gallons in the form of up to 10 x 2000-gallon DOT marine-portable tanks;
- Pump rates – variable at 12, 25, 40, and 60 gallons per minute;
- Swath width – range of nozzle varies with pump rate up to 70 feet @ 60 gpm, with one system on each side. Allowing for the 35’ beam of thevessel, swath width is 140’;
- Vessel speed – maximum speed is 25 knots

4) **Cessna AT-802 (Agtruck).** These are small, single engine aircraft that are purpose-built for aerial spraying. In the U.S. a group of operators have organized to offer a dispersant spraying service using this aircraft. A number of these are available in the Gulf area. These operators guarantee a start-up time of four hours or less. These have a lesser payload capacity than certain of the larger aircraft, but this deficiency is somewhat compensated for by availability of multiple platforms. These have a somewhat more limited range over water than the large, multi-engine aircraft.

5) **Helicopter.** Helicopters equipped with spray buckets have the advantage of availability. They are limited by their small payload and limited range. They have the advantage of high maneuverability and a capable of being re-supplied near a spill site, which greatly increases their operational efficiency.

6) **Vessels.** There are a number of vessel systems currently available in the Gulf area. These systems vary widely in terms of their operational capabilities, specifically their payloads, pump rates and swath widths, as illustrated in Table 5-6. In general, the relatively low payloads of most vessels severely limit their capabilities. However, the recent addition of larger, high speed crew-cargo vessels, equipped with portable dispersant spray systems and deck-mounted marine portable tanks have greatly improved the response capability of this group, as illustrated below.

Table 5-6 Logistic characteristics of existing vessels in Gulf of Mexico

Application System	Payload, US gal	Pump Rate, US gpm	Swath Width, feet	Maximum Speed, knots
Vessel A[a]	900	118	350	7
Vessel B[b]	2000	10	60	7
Vessel C[b]	12000	10	60	7
Vessel D[c]	20,000	60	175	25

a. Modeled after NRC Vessel "Jim G".
b. Modeled after LOOP responder vessels.
c. Modeled after new portable single-nozzle spray system developed by National Response Corporation and mounted on one of their new crew-cargo vessels. System characteristics are detailed in Table 5-5.

5.2.3 Influence of Day Length, Weather, and Oceanographic Conditions

Dispersant operations may be limited by day length, weather, and oceanographic conditions. This section summarizes these conditions and assesses the extent to which these conditions might hamper dispersant operations within the study area.

Day Length and Visibility. Day length and visibility exert strong influence over dispersant operations because all dispersant operations involve aircraft, either as platform or spotter. Some of the spraying platforms are aircraft and spraying operations involve low-altitude flying. Also, the spraying phase of the operation must be directed by an airborne controller. As such, spraying operations are possible only when conditions permit VFR flying, that is, during the hours of daylight with visibility greater than 0.5 miles and ceiling height greater than 1000 feet.

Information concerning day length, ceiling height and visibility within the study area are summarized in Table 5-7. Day length at this latitude varies little with season, range from 10.2 to 13.9 hours. For purposes of this study, day lengths have been assumed to be constant at 12 hours.

The data concerning ceiling height and visibility conditions given in Table 5-8 show that conditions are suitable for VFR flying and therefore suitable for dispersant operations in excess of ninety percent of the time in spring, summer and autumn in all areas. Conditions are suitable in winter more than eighty percent of the time.

Wave Height and Wind Speed. Both mechanical recovery and vessel-based dispersant use are sensitive to sea state or significant wave height. Dispersants require that there be at least some mixing energy in the form of waves so their effectiveness might be in question under conditions of complete calm. On the other hand, they will be limited by excessive wind and waves. The data in Table 5-9 show that work boats and single-engine aircraft can operate at wind speeds up to 21 knots, helicopters to 27 knots, and large, fixed-wing aircraft to winds of 30 knots. The wind speed data below suggest that wind speeds in both nearshore and offshore areas of the Gulf of Mexico are generally suitable for all platforms (less than 21 knots) more than ninety percent of the time. They are suitable for helicopters and large fixed-wing aircraft virtually 100 percent of the time.

Table 5-7 Hours of daylight at northern and southern limits of study area

Location	Jan 1	Apr 1	Jul 1	Oct 1
New Orleans, LA	10.2	12.4	13.9	11.8
Corpus Christi, TX	10.4	12.4	13.7	11.8

Table 5-8 Frequency of ceiling height and visibility conditions within the study area[a]

Visibility	Jan	Apr	Jul	Oct
Corpus Christi, Tx				
Percent Frequency<0.5 nm Ceiling	2.2	1.5	0.1	0.1
Percent Frequency <1000 feet	19.6	16.6	3.3	7.4
New Orleans, La				
Percent Frequency<0.5 nm Ceiling	0.5	0.3	0.1	0.2
Percent Frequency <1000 feet	14.2	9.0	5.0	7.8
Pensacola, Fl				
Percent Frequency<0.5 nm Ceiling	1.3	0.5	0.1	0.1
Percent Frequency <1000 feet	13.7	8.0	4.2	7.5
a. U.S. Naval Weather Service Command (1975)				

Table 5-9: Wind and sea state limitations for dispersant application systems[a]

	Approximate Upper Limit for Safe and Effective Spraying Operations		
Application System	Beaufort Scale	Wind Speed (knots)	Significant Wave Height (ft)
Work boats (Tugboat type)	3-5	7-21	1-9
Single-Engine Airplanes	5	17-21	6-9
Medium-Sized Helicopters	5-6	17-27	6-17
Large,Multi-Engine Airplanes	7	30-35	17-23
a. Exxon (1994)			

The information on wave height given in Table 5-10, show that there is adequate mixing energy for dispersant use virtually all of the time outside of the summer months. It is noteworthy that at the offshore station, waves are reported to be calm almost twenty percent of the time. Several factors must be borne in mind in selecting countermeasures for use in these periods of relative calm. First, dispersant effectiveness is directly proportional to the level of mixing energy, so that at very low mixing energy effectiveness is likely to be very low. Also, it is unlikely that dispersant that is applied during periods of calm will remain mixed with the oil until sea states increase. However, experience in this area is very limited, so for the present a pragmatic approach to dispersant use is suggested; that is, try dispersants and monitor the outcome. In this connection, it is important to recognize that at low sea states, the rate of emulsification is also drastically reduced, so that the spilled oil may still be dispersible when sea states increase at the end of the calm period. Second, low sea states are the ideal conditions for using mechanical containment and recovery methods and these methods should be considered for both small and large spills. For small spills, mechanical methods may be sufficient to completely handle the spill, and may obviate the need for dispersants. For larger spills, mechanical methods may not be adequate to treat the entire spillage, but their use can reduce the overall amount of dispersant needed and the amount of oil dispersed into the water column. This may be significant if the dispersed oil cloud poses a significant threat to a valued resource.

Temperatures. Average water temperatures in the Gulf of Mexico vary somewhat with location and season, but generally range from to 20 to 30 ^{0}C, as seen in Table 5-11. Water temperature can be important in dispersant planning because when sea temperatures (and temperatures of oil slicks) are below the pour point of the fresh oil, the oil becomes semi-solid and dispersants are ineffective. Fortunately, most oils produced in the Gulf have pour points much lower than the ambient temperatures, as mentioned in Chapter 3.

Table 5-10 Wave height and wind speed conditions in the study area[a]

Parameter	Jan	Apr	Jul	Oct
Off Freeport, Tx (28.7 N 95.3 W)				
Significant Wave Height				
Percent Frequency calm	n.d.(2)	n.d.	n.d.	n.d.
<3 feet	n.d.	n.d.	n.d.	n.d.
<6 feet	n.d.	n.d.	n.d.	n.d.
Mean Wind Speed (kts)	12.8	12.8	10.9	12.7
Percent Frequency calm	1	<1	1	<1
<21	88	92	98	93
<27	97	99	100	98
<34	100	100	100	100
Offshore Alablama (29.3 N 87.5 W)				
Significant Wave Height				
Percent Frequency calm	0	4	7	1
<3 feet	71	71	96	76
<6 feet	91	95	100	98
Mean Wind Speed (kts)	11.7	10.6	7.1	10.5
Percent Frequency calm	1	1	5	1
<21	93	98	100	99
<27	99	100	100	100
<34	100	100	100	100
Offshore Gulf of Mexico (25.9 N 89.7 W)				
Significant Wave Height				
Percent Frequency calm	<1	2	18	<1
<3 feet	56	63	94	64
<6 feet	85	94	99	94
Mean Wind Speed (kts)	13.4	12.0	7.6	12.0
Percent Frequency calm	<1	<1	3	<1
<21	87	91	98	95
<27	98	99	100	99
<34	100	100	100	100

a NOAA (1990)

Table 5-11 Sea and air temperature conditions within the study area[a]

Parameter	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
Off Freeport, Tx (28.7 N 95.3 W)				
Mean Temperature, Air (°C)	11.4	19.8	28.2	24.8
Mean Temperature, Water (°C)	12.8	19.5	29.2	25.6
Off Alabama (29.3 N 87.5 W)				
Mean Temperature, Air (°C)	15.4	19.1	28.0	24.4
Mean Temperature, Water (°C)	20.3	20.6	29.4	27.2
Offshore Gulf of Mexico (25.9 N 89.7 W)				
Mean Temperature, Air (°C)	20.5	23.0	28.6	26.0
Mean Temperature, Water (°C)	23.5	23.4	29.3	27.4
a. NOAA (1990)				

5.3 Dispersant Delivery Capacity

Some of the most critical factors limiting the operational effectiveness of dispersant operations are the logistic limits of the spraying platforms, that is, the payload, speed, pump rate, and availability of the vessels and aircraft that spray dispersants. This section examines the performance variation among platforms currently available in the Gulf of Mexico area. Capabilities have been assessed by estimating the theoretical performance of each platform in a number of hypothetical, but realistic spill scenarios. The measure of performance is the ability of the platform to spray dispersant on spills within an available time window. Spraying ability has been calculated using simple numerical models. The logistical and computational problems associated with blowouts differ greatly from those of batch spills, so these are treated separately.

5.3.1 Batch Spills

Batch spills are spills in which all of the spilled oil is released at once, resulting in a single batch or slick of oil, within which all of the oil weathers approximately uniformly.

5.3.1.1 Method and Assumptions in Logistics Modeling for Batch Spills

Modeling Method. The performance of different dispersant application platforms have been estimated using simple spreadsheet models which calculate the ability of the platforms to transport dispersant to spill sites from their bases of resupply and spray them on the target slicks. Dispersants are applied in a series of sorties in which a loaded spray platform departs its base, travels to the spill site, sprays its dispersant, returns to base, is re-supplied with dispersant and fuel and then continues the sortie cycle. The platform executes one sortie after another until either the oil has been fully treated and dispersed or has become too viscous to be dispersible. The spreadsheet model keeps track of the length of time required for each sortie, the amount of dispersant applied in each scenario and changes in the amount and properties of oil present. The duration of each sortie, a critical element in these calculations, is a function of three variables as follows.

1) Transit time**.** The time required for the platform to travel from its base of operations to the spill site. It is a function of distance and transit speed.

2) Spraying time**.** Time required for spraying dispersant includes both the actual time spraying and the time needed to reposition between spraying passes. It is a function of the payload, dispersant pumping rate, spraying speed and the length, width and thickness of the slick, as well as the repositioning time.

3) Resupply time**.** Time required to resupply with dispersant and fuel between sorties.

Modeling Assumptions. The following assumptions were used in the logistic modeling.

1) Start-up Time**.** This is the time required to prepare the platform to respond and to actually depart for the spill site. Start-up times are platform-specific, as previously discussed. All platforms are assumed to have a start-up time of one hour. This is reasonable for some, but not others. The operational implications of differences in start-up time between platforms are dealt with in the discussion.

2) Dispersant Effectiveness**.** Operational measures of dispersant effectiveness reported in the literature range from 75 parts oil dispersed per 1 part dispersant sprayed to as little as 1:1. These are values based on actual spills and field trials. For purposes of this study, it has been assumed that the intrinsic effectiveness of the dispersant is 1:20. That is that twenty volumes of oil are dispersed for each volume of dispersant that is sprayed.

3) Viscosity Limit for Dispersant Effectiveness**.** There is no single point at which weathered oil becomes completely resistant to chemical dispersion. One accepted rule of thumb is that dispersibility is largely determined by viscosity, and that the transition point between dispersibility and non-dispersibility lies in the range of 2000 to 20,000 cP, depending on the dispersant used, oil type and other factors. For purposes of this study we have assumed that the viscosity threshold for dispersibility is 5000 cP.

It is important to note that the oil types in this study become highly viscous because the oil emulsifies and not because the oil itself becomes highly viscous through evaporation. It is the viscosity of the emulsion that is the problem, not the viscosity of the oil in the emulsion. In subsequent tables in this report where data are presented on the “oil remaining on the surface” after a certain period of time, in all cases this refers to the volume of oil contained in the emulsion that has formed. The volume of the emulsion can be several times larger than the volume of the oil itself.

Grouping of Scenarios. For purposes of discussion, the spill scenarios are divided into three groups, based on the behavior of the oil.

1) Low Emulsifying Spills**.** These spills (Scenarios 1a, 1b and 2a) involve oils which do not emulsify or which emulsify very slowly (Lo-E, No-E oils). They do not form highly viscous stable emulsion before the oils dissipate completely, within a few hours or days, by natural means , as summarized in Table 5-12. In the present study, low emulsifying spills from the six selected launch points in the Gulf of Mexico pose very little risk of shoreline contamination because they dissipate before they reach the shoreline. Scenario 2a is analyzed below as being representative of these scenarios.

2) Medium Emulsifying Spills**.** These kinds of spills (e.g., Scenario 2b) involve oils which emulsify at a moderate rate (Av-E oils), forming highly viscous, stable emulsions. The slicks can become highly persistent, lasting for many days. The Scenario 2b spill, if not dispersed, poses a serious threat of shoreline contamination from all launch sites, with the possible exception of the Deepwater offshore spill location. Fortunately, the spill requires several days to emulsify to high viscosities, thus providing a lengthy time window in which to mount dispersant operations.

3) High Emulsifying Spills**.** These spills (Scenarios 2c and 3) involve oils which emulsify quickly to form highly viscous, stable emulsions. These slicks are highly persistent and pose a serious threat of shoreline contamination for all spills from all launch sites, with the possible exception of the Deepwater offshore spill location. Oils in scenarios 2c and 3

become resistant to dispersion within only a few hours after being spilled and offer only a very brief time window for dispersant operations.

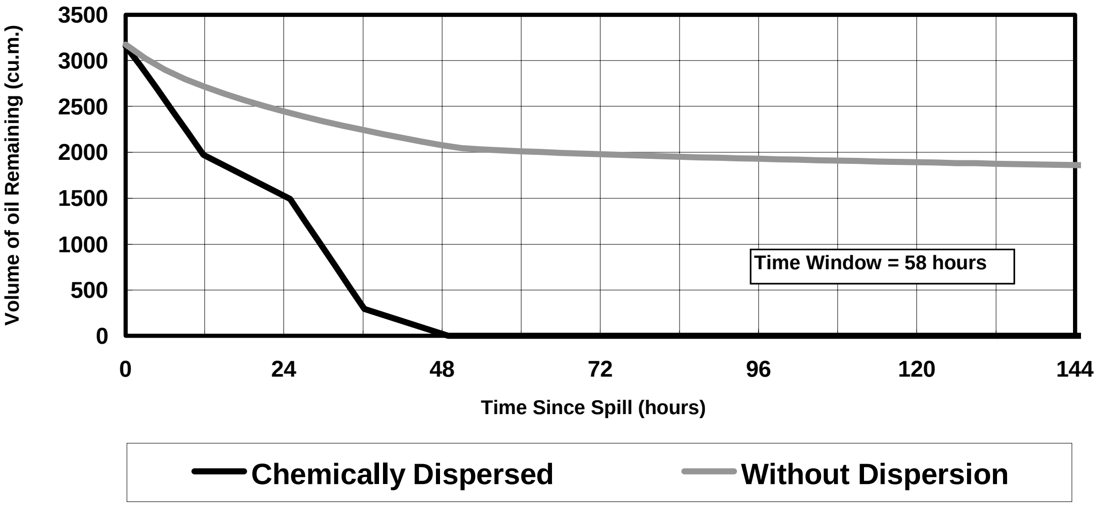
5.3.1.2 Response Capabilities for Batch Spills

The estimated response capabilities of dispersant spraying platforms are assessed here, starting with the case of medium emulsifying spills.

Response to Medium Emulsifying Spills

The capabilities of the platforms can be seen most clearly in spills of this group (Scenario 2b), which emulsify slowly and have a lengthy time window for dispersant operations. The persistence of the spill if left untreated and the impact of a dispersant operation using a single DC-4 application system are compared in Figure 5.1.

Figure 5.1 Fate and Persistence of Oil:
Scenario 2b - DC-4 at 30 n.miles from base



This scenario involves a batch spill of 3180 m^3 (20,000 barrels) of Av-E oil. If left untreated, the slick initially dissipates relatively quickly, losing approximately 66% of its volume through weathering over the first 48 hours. The 1080 m^3 of oil that remains at this point has become highly emulsified and viscous, and persists for many, many days. In the chemically-treated case, the volume of the spill declines more quickly than the untreated spill during the first 12-hours. This reflects the effect of dispersant spraying during the 12 hours of daylight on the first day. The rate of dissipation is slower during the subsequent 12 hours of darkness when dispersant operations are suspended, but increases again when dispersant operations begin at dawn on the second day.

Operations continue until all of the oil is dispersed early on the third day. In this hypothetical spill of 3180 m^3 (840,000 gallons) of oil, the DC-4 system delivers 113 m^3 (30,000 gallons) of dispersant to the spill in 12 sorties over 3 days. The slick is fully dispersed, with approximately 2260 m^3 of the spilled oil being chemically dispersed and the remainder dissipating through evaporation and natural dispersion.

Table 5-13 summarizes the results of all logistic simulations with all platforms in Scenario 2b. In this scenario, the performance of each platform is reflected by the amount of oil remaining at the end of the dispersant application time window (the 72-hour mark in this scenario). The general dispersant delivery/spraying capacities of these platforms are compared in Table 5-14. The performances of each platform are described below.

1) C-130/ADDS Pack. A single C-130/ADDS Pack can fully treat this spill within the time window at all three operating distances (assuming a start-up time of one hour). Even allowing for a more reasonable startup time (delay in startup until the morning of the second day), this platform has sufficient delivery capacity to deal fully with this spill. Based on this simulation, the C-130/ADDS Pack can deliver and spray from 42 to 83 m^3 (11000 to 22000 gallons) of dispersant per 12-hour day in 2 to 4 sorties at operating distances of 30 to 300 nm (Table 5-14).

2) DC-4. The DC-4 system appears to have the capacity to deal with this spill at the shorter operating distances, but falls short at the 300 mile distance, due to its smaller payload than

Table 5-13 Performance of platforms on low emulsifying batch spills. Example- scenario 2b

Platform[a]	Operating Distance n.mi.	Volume of Oil Remaining, m^3						
		0 hours	24 hours	48 hours	72 hours	96 hours	216 hours	720 hours
No Dispersion		3180	2446	2078	1979	1930	1790	1518
C-130 with ADDS Pack	30	3180	1240	0	0	0	0	0
	100	3180	1680	0	0	0	0	0
	300	3180	2127	291	0	0	0	0
C-130/ADDS Pack with 24-hour start-up time	30	3180	2446	272	0	0	0	0
	100	3180	2446	702	0	0	0	0
	300	3180	2446	1093	0	0	0	0
DC-4	30		1971	295	0	0	0	0
	100		2162	666	0	0	0	0
	300		2068	1131	465	416	276	4
DC-3	30		2068	1246	767	719	579	307
	100		2219	1548	1146	1097	957	685
	300		2294	1700	1449	1400	1260	998
DC-3; 2 units	30		1689	413	0	0	0	0
AT-802	30		2022	1169	707	658	518	246
	100		2143	1412	1120	961	821	519
AT-802; 3 units	30		1645	0	0	0	0	0
	100		2014	378	0	0	0	0
Helicopter	30		2256	1643	1355	1306	1166	894
	100		1879	886	257	208	68	0
Helicopter, 3 units	1		1879	886	257	0	0	0
Vessel A	30		2378	1942	1843	1794	1449	1177
	100		2378	1942	1843	1794	1449	1177
Vessel A at 1 n. mi.	1		1901	920	344	295	155	0
Vessel D	30		1885	174	0	0	0	0
	100		7167	456	0	0	0	0
	300		2446	989	839	790	739	467

a. Results reflect a single unit operating at maximum efficiency with a one-hour start-up time, unless otherwise noted. It is recognized that for a large spill operators would in all likelihood use more than one platform operating concurrently in order to increase the overall delivery capacity.

Table 5-14 Dispersant spraying capacity of platforms at a distance[a]

Platform	Operating Distance n. mi.	Number of sorties per day	Payload, m^3	Volume of dispersant sprayed per day, m^3	Volume of oil dispersed per day[b], m^3
C-130/ADDS Pack (c)	30	4	20.8	83.2	1664
	100	3	20.8	62.4	1248
	300	2	20.8	41.6	832
DC-4 (d)	30	5	7.5	37.8	750
	100	4	7.5	30.3	606
	300	3	7.5	22.7	454
DC-3 (e)	30	5	4.6	23.1	462
	100	3	4.6	13.9	277
	300	2	4.6	9.2	185
AT-802	30	7	3.0	21	420
	100	5	3.0	15	300
Helicopter	1	30	0.9	27	540
	30	11	0.9	9.9	198
Vessel A	1	9	3.4	30.6	612
	30	2	3.4	6.8	136
	100	1	3.4	3.4	68
Vessel D	30	1	75.7	60.6	1211
	100	1	75.7	60.6	1211
	300	0.5	75.7	30.3	605.5

a. Based on response a batch spill of 3180 m^3 (20,000 barrels).
b. Assuming 20 volumes of oil are dispersed per 1 volume of dispersant sprayed.
c. ADDS Pack specifications as per Biegert Aviation: Maximum Reservoir Capacity = 5500 gallons (20.8 cu. m.), Recommended Capacity = 5000 gallons (18.9 cu.m.).
d. Values reported in literature for payload of DC-4 range from 2000 to 2500 gallons (7.5 to 9.5 cu.m.). Value used here is 2000 as per ASI, Huoma, LA.
e. Values in literature for payload of DC-3 range from 1000 to 1200 gallons. Value used here is 1200 gallons, as per ASI, Huoma, LA.

the C-130. The DC-4 can deliver and spray from 29 to 48 m^3 (7600 to 12600 gallons) of dispersant per 12-hour day in 3 to 5 sorties at operating distances of 30 to 300 nm (Table 5-14).

3) DC-3. A single DC-3 system cannot deal fully with this spill. It reduces the spill volume by nearly 60 percent at the 30-mile operating distance, but has only a modest impact at the longer distances. However, two DC-3 spray systems appear to have the capacity to treat the spill within the time window at an operating distance of 30 miles. A single DC-4 can deliver and spray from 7 to 19 m^3 (2000 to 5000 gallons) of dispersant per 12-hour day in 2 to 5 sorties at operating distances of 30 to 300 nm (Table 5-14).

4) The performance of a single Agtruck AT-802 appears to be similar to that of the DC-3 at the shorter distances. The AT-802 cannot be used at longer distances due to limitations in range. It appears that three AT-802 units working together can deal fully with this spill at the shorter operating distances. A single AT-802 can deliver and spray from 15 to 21 m^3 (4000 to 5500 gallons) of dispersant per 12-hour day in 5 to 7 sorties at operating distances of 30 to 100 nm (Table 5-14).

5) The helicopter, due to its small payload, can disperse only a portion of this spill, even at the shortest operating distance of 30 miles. The limited range of helicopters prevents them from operating at longer distances from the spill. The helicopter, however, has the advantage of being able to be re-supplied from an offshore base near the spill. This improves the platform performance, but not enough to completely disperse this spill within the time window. A single helicopter can spray from 9 to 27 m^3 (2000 to 7000 gallons) of dispersant per 12-hour day in 11 to 30 sorties at operating distances of 1 to 30 nm (Table 5-14).

6) The Vessel A system can disperse only a small portion of this spill, even at the short operating distance of 30 miles. The vessel's slow transit speed limits it to only one sortie per day. This combined with a small payload of 3.4 m^3 (900 gallons) of dispersant means that this platform can treat only a very small proportion of the spill within the time window. Re-supplying this platform at scene can greatly increase it performance allowing it to complete

up to nine sorties within the window of opportunity (or approximately 30.7 m^3 [8100 gallons] of dispersant per day). Although this allows the platform to greatly reduce the volume of oil present, it is not sufficient to completely disperse the spill. Significant improvements to the vessel's capability could be effected by greatly increasing the vessel's dispersant storage capacity. This is discussed later.

The high capacity Vessel D system can fully disperse this spill at both the 30- and 100-mile distances. This performance is due to enhancement of all of the logistically critical aspects of performance including payload, vessel speed, pumping rate and swath width. The vessel cannot fully treat the spill at the 300-mile distance, because even at top speed of 25 knots the vessel requires 24 hours to perform the round trip to base for re-supply. Therefore at this distance its effective delivery capacity is reduced to less than one-half of its payload per day.

The differences in logistic performance among platforms and the effect of operating distance on performance are summarized in Table 5-14. Using the 30-mile response distance as a common denominator, this summary shows that dispersant delivery capacities of these platforms vary by a factor of 12, between the lowest, Vessel A, at 6.8 m^3 of dispersant sprayed per day, to the C-130 ADDS Pack at 83.2 m^3 per day. In other words, 12 vessels similar to Vessel A would be required to deliver as much dispersant in a day as one C-130/ADDS Pack. Similarly, the C-130/ADDS Pack can deliver as much dispersant as 1.4 Vessel D systems, two DC-4s, four DC-3s, four AT-802s, and nine helicopter systems. Since both helicopter and vessel systems have the advantage of being re-supplied at the spill site, thus avoiding the necessity of traveling to their base of operations, their performance can be improved by factors of 2.7 (helicopter) and 4.5 (vessel).

One of the vessels considered here, Vessel A, was typical of the type of vessel available for dispersant spraying in the Gulf until recently. The new larger, faster vessels with very high potential payloads have only recently been added to the responder fleet. These new vessels invite responders to reassess the use of vessels for dispersant application in the Gulf, particularly for spills from MMS-OCS facilities.

It is important to note that a number of AT-802 aircraft units are available for immediate response in the Gulf area, and these could be used in a coordinated fashion to achieve the delivery capacity needed in a large spill. On the other hand, only a few of the large fixed-wing platforms are available. Only one each of the DC-4 and DC-3 systems are currently available through Airborne Support Inc. of Houma, LA. Although a number of C-130 Hercules aircraft are available from various sources, only two ADDS Pack spray systems are available in the continental U.S. Obviously, the small number of large, fixed-wing systems could be used in combination to respond to a large spill.

The distance between the base of re-supply and the spill site has an important effect on performance. By increasing the operating distance from 30 miles to 100 miles, as would be the case in responding to spills in mid-shelf areas, the capacities of platforms are reduced to 50 to 75 percent of their capacities at 30 miles. In addition, the helicopter system would not be an option for responses at 100 miles because its range is too limited. By further increasing the operating distance to 300 miles, as would be the case in responding to offshore spills in the Gulf, delivery capacities of platforms are further reduced to 40 to 60 percent of their capacities at 30 miles. The vessel-based and AT-802 systems are not useful at a distance of 300 miles. This 600-mile round-trip is beyond the 500-mile range of the AT-802. Also, this round-trip could not be performed by any existing response vessel in 24 hours given their top speed of 5 to 7 knots.

A number of considerations must be borne in mind in connection with the above logistic modeling. First, the performance characteristics of all platforms depend, in part, on the size and shape of the slick. This determines the numbers of times that the platform will need to reposition itself during the spraying operation. Efficiencies will be lower for smaller spills where platforms will spend a greater proportion of their time repositioning.

Second, the above assumes a start-up time of one hour for all platforms. This will be reasonable for certain platforms, such as the ASI DC-4 or the vessel-based system, but not for non-dedicated platforms like the C-130 or the Agtruck AT-802. Members of the EADC[8] are bound by contract to have a start-up time of no more than 4 hours, so their performance on the first day must be corrected

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[8] The Emergency Aerial Dispersants Consortium is an organization, based in Tynan, Texas, whose members are AT-802 aircraft operators trained and available to apply dispersants.

accordingly. At present in the Gulf area there are no dedicated C-130/ADDS Pack systems. At least two ADDS Pack spraying units are available in the area, but it appears few C-130 Hercules aircraft are available on a commercial basis to fly them. Many hours or even days may be required to locate suitable aircraft to fly the ADDS Pack. Arrangements are in place to involve the USCG in this work. Even though this process can be initiated quickly, it appears that many hours will be needed to reconfigure the USCG aircraft, install the ADDS Pack and fly to the spill site. A conservative estimate of the start-up time of for the C-130/ADDS Pack would be the morning of the second day. It is useful to recognize, however, that if a DC-4 system were to begin responding at the start of Day 1 and a C-130/ADDS system were to begin on the morning of Day 2, the C-130 would catch up with the DC-4 by the end of Day 2 (see Table 5-13).

Response to Low Emulsifying Spills

Spills involving non-persistent oils (Scenarios 1a, 1b, and 2a,), dissipate quickly, by natural means, within a few hours or days. As illustrated in Figure 5.2 and Table 5-15, when these spills are treated with dispersants, their persistence is further reduced, but the net change in the persistence of these spills is small compared to spills involving medium or high emulsifying oils.

Response to High Emulsifying Spills

The two spills in this category (Scenarios 2c and 3) emulsify very quickly and are undispersible within 7 hours. This time window is too short to allow any platform to fully treat even the smaller of these. Figure 5.3 illustrates the impact of dispersant application by C-130/ADDS Pack on oil persistence in Scenario 2c. In this case, the C-130/ADDS Pack can complete two sorties within the 7-hour time window, applying 41.6 m^3 and dispersing more than 800 m^3 of oil. This leaves over 1500 m^3 of viscous persistent oil on the sea surface at the end of the operation. The results of model runs with other platforms are summarized in Table 5-16. These show that all other platforms perform less well than the C-130 /ADDS Pack. In many cases, the time window is so short that oil is undispersible by the time the spray platform arrives on scene, and increasing the number of units does little to increase the response capability. A notable exception is the hypothetical case of a response using three C-130s (see Figure 5.4). This however, is highly unrealistic for several reasons.

It is interesting to note that three helicopter units operating from a base near the spill yielded a performance similar to that of a single C-130 operating from a distance of 30 miles. This highlights the potential value of staging dispersant resources, even low capacity ones like helicopters or vessels, near potential spill sites.

The results of Scenario 3 are similar to Scenario 2c, except that even a smaller proportion of the spill can be treated. dissipation is slower during the subsequent 12 hours of darkness when dispersant operations are suspended, but increases again when dispersant operations begin at dawn on the second day.

Figure 5.2 Fate and Persistence of Oil:
Scenario 2a: DC-4 at 30 n.mi. from Base

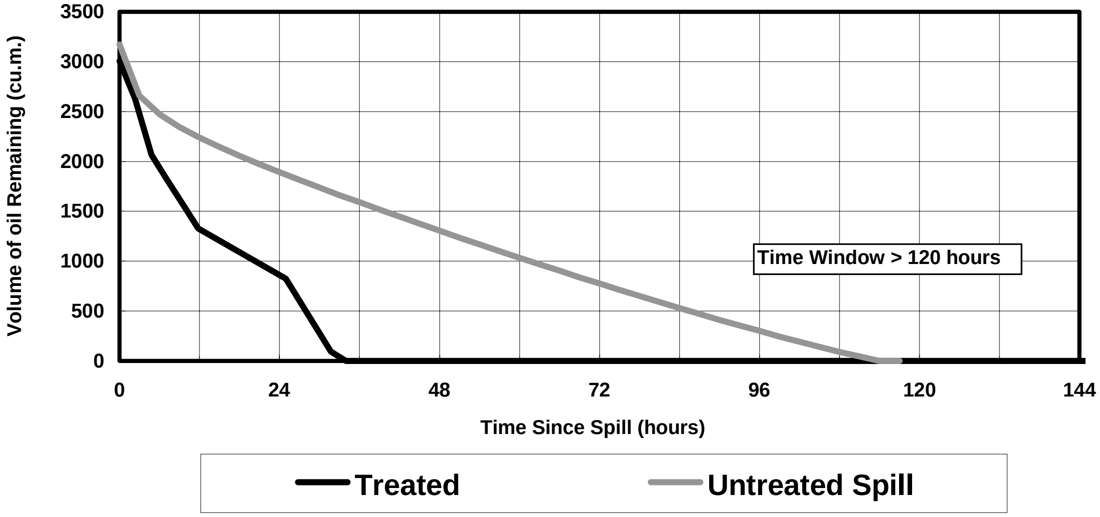


Table 5-15 Performance of platforms on batch spills of low emulsifying oils. Example- scenario 2a

Platform[a]	Operating Distance n.mi.	Volume of Oil Remaining, m^3						
		0 hours	24 hours	48 hours	72 hours	96 hours	216 hours	720 hours
No Dispersion		3180	2254	1734	1230	726	0	0
C-130 with ADDS Pack	30	3180	589	0	0	0	0	0
	100	3180	1031	0	0	0	0	0
	300	3180	1466	0	0	0	0	0
DC-4	30	3180	1316	0	0	0	0	0
	100	3180	1507	38	0	0	0	0
	300	3180	1661	645	0	0	0	0
DC-3	30	3180	1870	901	0	0	0	0
	100	3180	1928	1166	360	0	0	0
	300	3180	2290	1729	1225	721	0	0
Agtruck AT-802	30	3180	1831	837	0	0	0	0
	100	3180	1957	1075	208	0	0	0
	300	3180	2073	1442	757	71	0	0
Helo/Helibucket	30	3180	2046	1325	594	0	0	0
	100	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	300	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Vessel A	30		2057	1855	1283	711		
	100		-	-	-	-	-	-
	300		-	-	-	-	-	-
Vessel A at 1 n. mi.	1		1868	805	0	0	0	0

a. Results represent a single unit operating with a one-hour start-up time, unless otherwise noted.

Figure 5.3 Fate and Persistence of Oil:
Scenario 2c: C-130 with ADDS Pack
at 30 n.mi. from Base

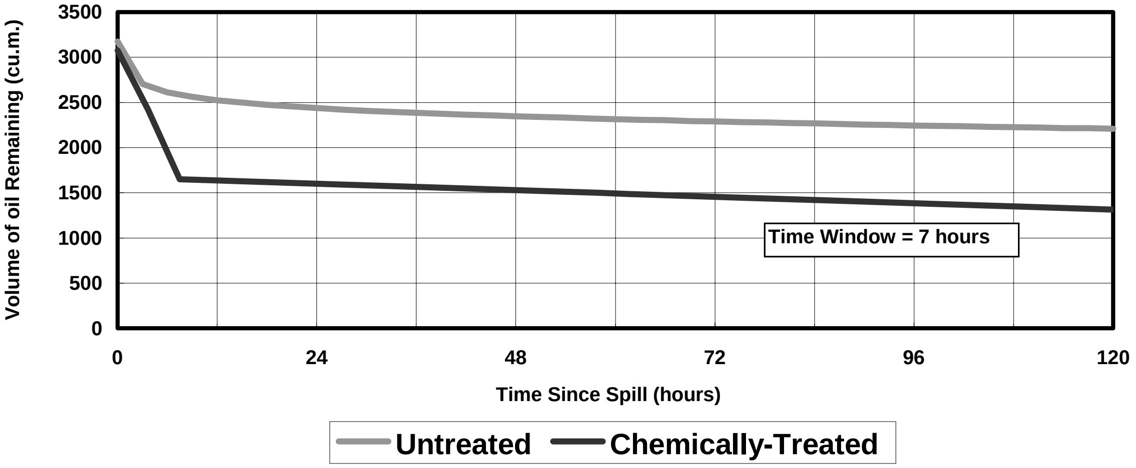


Figure 5.4 Fate and Persistence of Oil:
Scenario 2c: C-130 with ADDS Pack
at 30 n.mi. from Base (3 units)

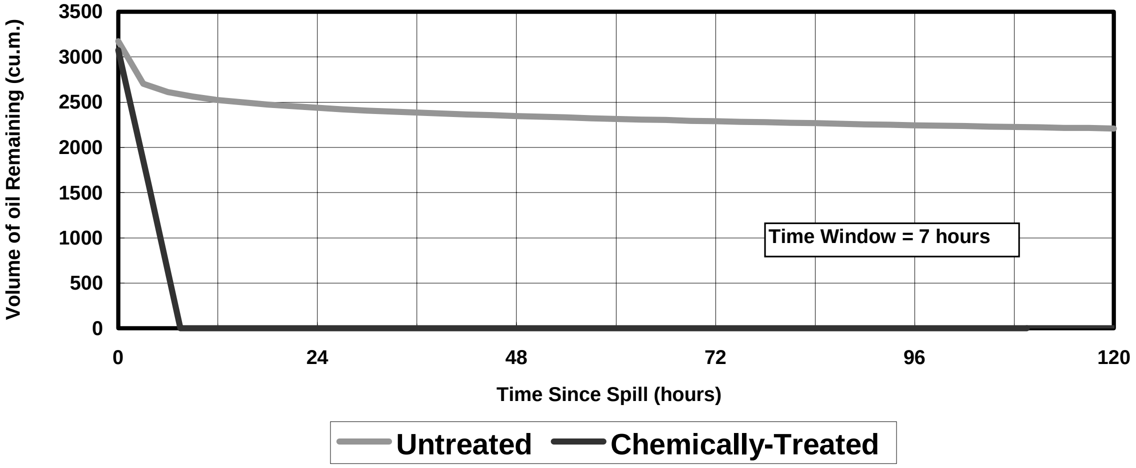


Table 5-16 Performance platforms on batch spills of high emulsifying oils. Example- scenario 2c

Platform[a]	Operating Distance n.mi.	Volume of oil remaining, m^3						
		0 hours	24 hours	48 hours	72 hours	96 hours	216 hours	720 hours
No Dispersion		3180	2438	2346	2289	2245	2097	1716
C-130 with ADDS Pack	30	3180	1638	1521	1449	1372	1017	916
	100	3180	1638	1521	1449	1372	1017	916
	300	3180	2246	2154	2097	2053	1905	1524
C-130/ADDS Pack- 24-hour start-up time	30	no effective dispersion						
DC-4	30	3180	1966	1863	1808	1764	1616	1235
	100	3180	2060	1968	1910	1865	1718	1338
	300	3180	2281	2157	2099	2054	1908	1527
DC-3	30	3180	2286	2194	2134	2093	1945	1564
	100	3180	2285	2193	2140	2092	1943	1563
	300	3180	2363	2271	2214	2170	2022	1641
AT-802	30	3180	2198	2106	2049	2005	1853	1476
	100	3180	2258	2166	2109	2065	1917	1536
	300	3180	2378	2686	2229	2185	2037	1656
AT-802; 3 units	30	3180	1718	1626	1569	1525	1397	996
Helicopter	30	3180	2325	22332	2176	2132	1984	1603
	1	3180	2136	044	1987	1943	1795	1414
Helicopter; 3 units	30	3180	2097	2005	1948	1904	1756	1375
	1	3180	1530	1438	1381	1337	1190	809
Vessel A	30,100,300	no effective dispersion						
Vessel A at 1 n. mi.	1	3180	2165	2073	2016	1972	1824	1443

a. Results represent a single unit operating with a one-hour start-up time, unless otherwise noted.

5.3.2 Blowouts

5.3.2.1 Main Considerations

A blowout is a continuous discharge of oil from a platform. Blowout slicks differ in several respects from batch spills and present different challenges for responders. In a blowout, oil is discharged continuously from a point source and the resulting slick is moved away from the spill site by winds and currents. The slick can be visualized as a long, narrow ribbon of oil, stretching away from the spill site, breaking up into patches until it finally dissipates through weathering and spreading. Treating blowout slicks with dispersants involves certain tactical considerations including the following.

1) Blowout slicks, shaped as long, narrow swaths, can be sprayed longitudinally, in a series of long passes. For this reason treating blowouts may require less repositioning than with batch spills and therefore may require less spraying time.

2) Oil from different parts of a blowout slick are of different states of weathering. Freshly discharged oil near the spill site may be dispersible, while oil at a distance from the spill site that has been discharged hours earlier, may already be weathered, emulsified and undispersible. The overall effectiveness of a dispersant operation may depend on the degree to which the operation is successful in dispersing the spilled oil while it is still fresh and preventing it from weathering to the point of its becoming undispersible.

3) Blowout slicks, especially those from subsea blowouts, initially can be thinner and cover much greater areas than batch spills. This has several implications for spill response. The thinner slicks may weather and become heavily emulsified more quickly than the thicker ones. Thin slicks may require lower than usual application rates (and therefore lower pumping rates) in order to avoid overdosing. Lower pumping rates, while spraying over larger areas, means longer spraying times and lower operational efficiency.

5.3.2.2 Blowout Spill Model

A number of blowout scenarios are considered in evaluating the capabilities of different spraying platforms. As with the batch spills, the scenarios cover a range of spill and response conditions, including: spill volume; spill duration; emulsion tendency; and distance from base of resupply.

Blowout scenarios have been categorized differently from batch spills. Batch spill scenarios were grouped only according to the emulsifying behavior of the oils. In blowout spills, the scenarios have been categorized according to the speed with which emulsification takes place in the scenario, regardless of the properties of the oil. This is because the rate of emulsification in blowout spills is controlled by both the emulsification tendency of the oil and the conditions of the spill. A summary of the persistence of the oil in blowout scenarios is presented in Table 5-17.

Similar to the batch spills, there are three basic kinds of oils considered in the blowout scenarios that relate to the oil's potential for emulsifying. One category involves low emulsifying oils in which the oil dissipates completely before it becomes highly emulsified and viscous (e.g., Scenario 4a).

The next category involves medium emulsifying oils in which the oil emulsifies slowly, taking more than 12 hours to become highly viscous and resistant to chemical dispersion (Scenario 5b).

The final category involves spilled oil that emulsifies quickly and becomes highly viscous in less than 12 hours. This group includes Scenarios 4b, 5a, 6a, 6b, 6c, 7a,7b and 7c. In the following analysis most attention is devoted to this category.

Table 5-17 Persistence of oil in blowout scenarios

Scenario Number	Spill Conditions	Emulsion Tendency	Time on surface to reach viscosity > 5000 cP, hours	Volume of Oil Persisting at End of Blowout, bbl (m^3)[b]		
				0 hours[a]	24 hours	96 hours
4a	Surface blowout, 5000 BOPD x 4 days = 20,000 bbl	Lo-E	>15	627 (99.8)	0	0
4b	Surface blowout 5000 BOPD x 4 days = 20,000 bbl	Av-E	11	14,467 (2300)	11,322 (1800)	7548 (1200)
5b	Surface blowout 100,000 BOPD x 14 days =1,400,000 bbl	Av-E	23	880,342 (139,959)	862,585 (137,136)	827,493 (131,557)
6b	Subsurface blowout 5000 BOPD x 4 days = 20,000 bbl	Av-E	4.5	9636 (1532)	8925 (1419)	6661 (1059)
7b	Subsurface blowout 7200 BOPD x 14 days = 100,000 bbl	Av-E	4.5	32,613 (5185)	30,833 (4902)	25,468 (25,468)
8	Subsurface blowout, Deepwater 100,000 BOPD x 90 days = 9,000,000 bbl	Av-E	uncertain			

a. This is the time after the end of the blowout.

b. b. This oil is part of an emulsion, which can have four times the volume of the

5.3.2.3 Method of Logistics Modeling for Blowout Spills

As was done with the batch spills, the performance of different dispersant spraying platforms is evaluated using simple spreadsheet models. However, the logistics model for blowout spills is far more complicated.

As was done with the batch spills, the quantity of dispersant sprayed during each sortie and the time required for each sortie is computed. The start-up times, transit times, spraying times, re-supply times and the volume of dispersant sprayed per sortie are tracked on a sortie-by-sortie basis. Since the spill is ongoing, the volumes of oil that are spilled and the amount that becomes undispersible during each sortie interval are tracked, as well as the amounts lost to weathering and chemical dispersion. The assumptions described above regarding start-up times, dispersant effectiveness, and viscosity limits for effective dispersion apply to the blowout spills as well.

5.3.1.4 Response Capabilities for Blowout Spills

Response to Low Emulsifying Spills

Only Scenario 4a applies to this kind of oil. The oil spilled in this scenario is not persistent, dissipating completely within 24 hours after the discharge ceases, even without chemical dispersion. The oil is not persistent enough to travel any distance from the spill site, so these spills pose environmental risks only in the immediate vicinity of the spill. Most spraying platforms are capable of delivering enough dispersant to completely disperse slicks from these spills in a single sortie. However, chemical dispersion does little to alter the already low persistence of this oil and so this scenario is not discussed further.

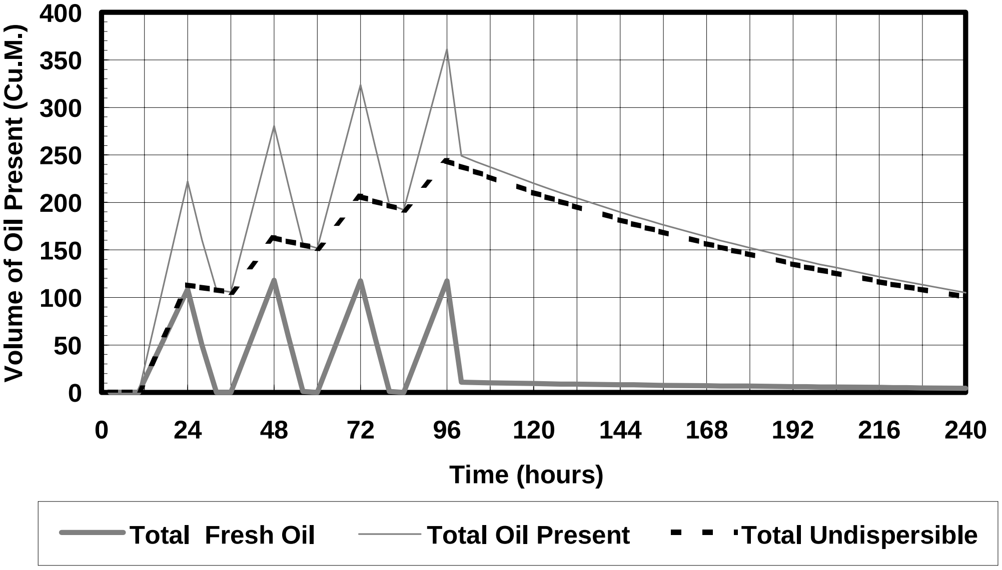
Response to High Emulsifying Spills

The scenarios involving high emulsifying oils are the most interesting and edifying. These spills emulsify in less than 12 hours due to the combination of emulsifying tendency and spill conditions. Scenario 4b is the simplest of these scenarios and is discussed first.

In Scenario 4b (surface blowout discharging Av-E oil at 3180 m^3/day) the oil becomes heavily emulsified to the point of being undispersible within 10 hours after discharge. A total of 3180 m^3 (20,000 bbl) of oil is spilled over four days at a rate of 33.1 m^3/hr (208.3 bbl/hr). In the absence of treatment, 2300 m^3 (72%) of this oil remains on the sea surface at the end of the spill, in the form of highly emulsified, persistent oil. This emulsified oil dissipates only slowly.

Figure 5.5 illustrates the way in which the model handles the fate of oil and the effect of dispersant application during a blowout spill. In this case, the spraying involves a DC-4 and the spill site is 30 miles from its base. The figure shows that on the first day of the spill, the spray platform disperses all of the oil discharged. However, when spraying operations are suspended overnight the spilled oil accumulates on the sea surface. By dawn of Day 2, a portion of the oil spilled overnight has weathered to the point of being undispersible. On Day 2, the DC-4 system is capable of treating any overnight oil that remains dispersible, as well as all of the fresh oil discharged during the day. For the duration of the spill, the DC-4 treats all of the dispersible oil discharged during the day, but quantities of undispersible oil accumulate each night. When the discharge ceases after 4 days, a total of 250 m^3 of weathered, undispersible oil remains. This represents approximately 10% of the emulsified oil that remained at the end of the spill in the untreated case. The dispersant operation has reduced the volume of persistent oil remaining at the end of the spill from 2300 m^3 to 250 m^3.

Figure 5.5 Fate and Persistence of Oil
Scenario 4b: DC-4 at 30 miles



The simulated performance data for all platforms in Scenario 4b are summarized in Table 5-18. When platforms are compared over a common operating distance of 30 miles, the platforms with smaller payloads (e.g., helicopter, vessel) are less effective overall than the larger platforms (e.g., DC-4, or large vessel "D"), in that they leave a larger amount of emulsified oil at the end of the spill (see the 120-hour column in Table 5-18).

However, the differences between effectiveness of large and small platforms are less pronounced in the blowout spill than in the batch spill of the same size and oil type (Scenario 2b). Also, unlike the batch spill, the operating distance has less influence on the efficiency of the larger platforms (DC-4, C-130), although it does on the smaller platforms. This is shown in Table 5-19 Part A. In a blowout with a relatively low discharge rate, like Scenario 2b, the payload of a large spray platform, like the DC-4, exceeds the volume needed to treat the oil discharged during the sortie. That is during most if not all sorties that sprays only a portion of its load and returns to base with some dispersant still on board. This is not the case for the smaller platforms. Similarly, the additional time needed to travel to more distant spills does not diminish the efficiency of the larger platforms because the larger platforms have excess payload capacity on every sortie and can compensate for the longer duration of each sortie at greater distances by spraying a larger proportion of their payload on each sortie. This suggests that during small blowout spills, the larger platforms need carry only a fraction of their payload.

The large vessel "D" also has excess capacity and is efficient for this spill at distances of 30 and 100 miles. It is, however, highly inefficient at the 300-mile distance. With a payload of 20,000 gallons, this platform has more than enough payload to treat all of the oil discharged in a single day, but not enough for two days' spillage. As a result the vessel must return to base nightly for re-supply, even though its tanks are nearly one-half full. At the 30- and 100-mile distances, the vessel can complete the round-trip to base for re-supply each day and still have enough time to treat any overnight discharge that remains dispersible, as well as all of the oil discharged during the daylight hours. The vessel is inefficient in the 300-mile distance because even at a speed of 25 knots, it would require more than on full, 24-hour day to complete the 600-mile round-trip to base for re-supply. At a distance of 300-mile it would begin spraying only on the morning of the 2nd day; would not spray

Table 5-18 Effectiveness of platforms on high emulsifying blowout spills. Example scenario 4b.

Platform[a]	Operating Distance, n. mi.	Volume of oil remaining , m^3			
		96 hours[b]	120 hours	192 hours	720 hours
No Chemical Dispersion		2300	1800	1200	30
C-130 with ADDS Pack	30	270	230	140	0
	100	325	275	165	0
	300	325	275	165	0
DC-4	30	370	250	130	0
	100	470	380	210	0
	300	470	380	210	0
Agtruck AT-802	30	950	600	380	0
	100	1200	850	520	20
Helicopter	1	720	480	280	0
	30	1350	1240	680	20
Vessel A	1	780	460	280	0
	30	1520	1240	720	20
Vessel B					0
	1	361	252	141	0
	30	361	252	141	0
	100	361	252	141	0
	300	1979	1687	1113	20

a. Results represent a single unit operating with a one-hour start-up time, unless otherwise noted.
b. Time is from the start of the blowout. This blowout lasts 96 hours in total.

Table 5-19 Dispersant spraying characteristics of platforms in selected blowout spills (4b and 6b)

Platform	Operating distance, n. mi.	Sorties per day	Payload, m^3	Average volume sprayed per sortie, m^3	Maximum pump rate, m^3/min.	Observed pump rate, m^3/min.	Volume of dispersant sprayed per day, m^3
Part A: Scenario 4b							
C-130	30	9	20.8	4.09	2.27	2.27	36.8
	100	6	20.8	5.82	2.27	2.27	43.9
	300	4	20.8	9.30	2.27	2.27	37.2
DC-4	30	9	7.5	4.00	1.89	1.89	36.0
	100	6	7.5	5.63	1.89	1.89	33.7
	300	4	7.5	7.5	1.89	1.89	30.0
Agtruck AT-802	30	9	3.03	3.03	.45	.45	27.3
	100	6	3.03	3.03	.45	.45	18.2
Helicopter	1	35	0.95	0.95	.30	.30	33.25
	30	13	0.95	0.95	.30	.30	11.96
Vessel A	1	8	3.41	3.41	.45	.45	27.3
	30	1	3.41	3.41	.45	.45	3.41
Vessel D	1	1	75.7	39.7	.22	.22	39.7
	30	1	75.7	39.7	.22	.22	39.7
	100	1	75.7	39.7	.22	.22	39.7
	300	0.5	75.7	75.7	.22	.22	75.7
Part B: Scenario 6b							
C-130	30	6	20.8	4.09	2.27	.39	29.6
	100	5	20.8	5.82	2.27	.39	28.8
	300	3	20.8	9.30	2.27	.39	23.3
DC-4	30	5	7.5	4.00	1.89	.44	29.3
	100	5	7.5	5.63	1.89	.44	28.3
	300	6	7.5	8.97	1.89	.44	23.1
Agtruck AT-802	30	7	3.03	3.03	.45	.32	21.2
	100	5	3.03	3.03	.45	.32	15.5
Helicopter	1	19	0.95	0.95	.30	.11	18.1
	30	12	0.95	0.95	.30	.11	11.4
Vessel A	1	6	3.41	3.41	.45	.07	20.46
	30	1	3.41	3.41	.45	.07	3.41

on the 3rd day at all because it would be in transit and would spray again on the 4th day. These inefficiencies could be overcome by re-supplying this platform at sea.

It is important to emphasize that, as far as the larger platforms are concerned, the fact that weathered oil still persists at the end of the spill (as in this scenario), does not indicate that the dispersant spray system does not have the capacity to treat the oil. On the contrary, the larger platforms have more than enough capacity to treat a blowout of this rate. The weathered, persistent oil that remains at the end of the spill is oil that is spilled at night when dispersant operations are suspended and weathers to an undispersible state before dispersant operations are re-initiated at dawn. In these cases, adding additional platforms cannot increase the effectiveness of the operation.

The result of this scenario suggests that for blowouts of low discharge rate, it may be cost-effective to respond with smaller platforms matching the platform capacity to the demands of the spill.

Scenario 6b is a 5000 BOPD subsea blowout of Av-E oil lasting 4 days. The spill is similar in many respects to Scenario 4b, except that in Scenario 6b the slick is much wider and thinner than in 4a. One important observation from an environmental and operational perspective is that a much larger amount of the spill persists after the dispersant operations in 6b (see Table 5-20) than in 4b. There are two causes for this. First, the 6b slick is much thinner (0.04 to 0.08 mm) than the 4b slick (0.4 to 0.8 mm). It is so thin that it would be greatly overdosed with dispersants by all platforms, even the aircraft, if they were to use their maximum spray settings, as was done in 4b. Therefore, in Scenario 6b the pump rates have been reduced, by 50 to 80 percent, depending on the platform, to yield a suitable dispersant application rate (See Table 5-19 Part B). The net effect is an increase in spraying time, a reduction in sorties per day, and thus a reduction in volume of dispersant sprayed in all cases. Second, the 6b slick emulsified much more quickly than the 4b spill, reaching the 5000 cP threshold within 4.5 hours, as opposed to 11 hours in the 4b scenario. The more rapid emulsification in Scenario 6b results in a greater proportion of the oil discharged overnight becoming undispersible, leading to a larger amount of viscous, persistent oil being present at the end of the spill. Both factors clearly contribute to the lower operational efficiency in dispersing this spill.

Table 5-20 Operational effectiveness of platforms on blowout spill, scenario 6b

Platform[a]	Distance, n. mi.	Volume of oil remaining at during spill, m^3			
		96 hours[b]	120 hours	192 hours	384 hours
No Chemical Dispersion		1532	1419	1059	100
C-130 with ADDS Pack	30 100 300	841 904 813	728 793 702	368 433 314	0 0 0
DC-4	30 100 300	880 938 844	772 825 731	412 465 371	0 0 0
Agtruck AT-802	30 100	875 1056	761 943	401 583	0 0
Helicopter	1 30	810 943	730 630	350 470	0 0
Vessel A	1 30	852 1512	748 1401	435 1241	0 0

a. Results represent a single unit operating with a one-hour start-up time, unless otherwise noted.
b. Time .from the start of the blowout. This blowout lasts 96 hours.

Scenario 7b is similar to 6b in some respects, but it is five times larger with a longer duration and greater discharge rate. The net result of the higher discharge rate and longer spill duration is greater amounts of persistent oil remaining at the end of the discharge in both the untreated and dispersant-treated cases (Table 5-21). Although the DC-4 and C-130 have the theoretical capacity to fully disperse all of the oil as it is discharged during the day, the amount of oil that is discharged overnight exceeds their capacity to catch up. Furthermore, because of the size of the spill, the effects of operating distance and difference in payload between the DC-4 and C-130 become evident.

Response to Medium Emulsifying Spills

This group of scenarios is includes those in which the oil requires longer than 12 hours to emulsify. Scenario 5b is the only one of this type in this study. It involves a very high discharge rate of 15,898 m^3 (100,000 BOPD) of Av-E oil for 14 days for a total discharge of 222,575 m^3 (1,400,000 barrels). It requires 18 hours for the oil to emulsify to an undispersible level. In the absence of chemical dispersion almost 140,000 m^3 of oil (in the form of a viscous emulsion) will have accumulated by the end of the blowout and this oil persists for many days (Table 5-17).

The discharge rate of this blowout greatly exceeds the capacity of even the largest spraying platform, so a single unit of even the largest platform can treat only a portion of the amount spilled daily. The remainder will weather and form emulsion that will persist long after the spill has ended . Table 5-22 shows that even the largest platforms are only partly effective in treating this spill. Also, as expected, effectiveness is a function of payload and operating distance. Table 5-22 also shows that, theoretically speaking, three C-130/ADDS Pack units could fully disperse this large spill. This delivery rate is unrealistically high, but the example is used to demonstrate that, unlike the Group C scenarios, Group B spills can be fully treated if the dispersant delivery rate is high enough. The difference is that the time window for Group B spills is longer than 12 hours. Under these conditions, all of the oil that is spilled over night will remain dispersible for at least a few hours past dawn, when dispersant operations can resume.

Table 5-21 Operational effectiveness of platforms on blowout spills, scenario 7b

Platform[a]	Distance, n. mi.	Volume of oil remaining at during spill, m^3				Sorties per day	Dispersant sprayed per sortie, m^3
		336 hours[b]	360 hours	432 hours	720 hours		
No Chemical Dispersion		5185	4902	4049	639		
C-130 with ADDS Pack	30	1297	1012	160	0	6	6.1
	100	1532	1247	394	0	5	7.5
	300	2555	2270	1417	0	3	9.1
DC-4	30	1897	1612	760	0	6	6.0
	100	1971	1665	834	0	5	7.0
	300	2714	2433	1580	0	3	8.9
Helicopter	1	1554	1271	418	nd [c]	23	0.95
	30	2695	2412	1558	nd	12	0.95
Vessel A	1	3370	3085	2232	nd	6	3.41
	30	4875	4620	3767	nd	1	3.41

a. Results represent a single unit operating with a one-hour start-up time, unless otherwise noted.
b. Time from the start of the blowout. This blowout lasts 14 days or 336 hours.
c. nd = no data

Table 5-22 Operational effectiveness of platforms on blowout spills, scenario 5b

Platform[a]	Distance, n. mi.	Volume of oil remaining at during spill, m^3			Sorties per day	Dispersant sprayed per sortie, m^3
		336 hours[b]	360 hours	408 hours		
No Chemical Dispersion		139959	137136	131557		
C-130 with ADDS Pack	30	94934	89709	82073	9	20.82
	100	109845	105164	96744	6	20.82
	300	124656	120908	113575	3	20.82
C-130/ADDS Pack, 3 units	30	9513	0	0	18	62.46
	100	51227	43795	42094	12	62.46
	300	80010	73518	69446	8	62.46
DC-4	30	119524	115444	107484	9	9.46
	100	126304	122646	115469	6	9.46
	300	130852	127473	120822	4	9.46

a Results represent a single unit operating with a one-hour start-up time, unless otherwise noted.
b Time from the start of the blowout. This blowout last 14 days or 336 hours.

Response to Deepwater Blowout

Although the behavior of the large, deepwater blowout scenarios (Scenarios 8a and 8b) is uncertain, it is clear that such spills present great operational challenges for several reasons. First, a spill of this large size would require at least 900 to 1300 barrels of dispersant per day to treat. This would exhaust the dispersant stockpiles in the Gulf Region within 3-4 days and all the stockpiles in the U.S. within 6 to 10 days. Dispersant manufacturers in the U.S. can produce dispersant at a rate of 44,000 gallons per day (1047 barrels per day), which would be just enough dispersant to treat this spill, if it were efficiently used. Second, these spills occur furthest from any base of operations. They are beyond the operating range of all but platforms the large, fixed-wing aircraft systems (DC3s and 4, C-130s). At this long distance, a spill of modest size, such as Scenario 2b, is beyond the capabilities of all systems, except the C-130/ADDS Pack system. Theoretically, the 100,000-BOPD spill would require, as a minimum, the combined efforts of the two DC-3s, the DC-4, the MIRG C-130/ADDS Pack, plus at least two of the C-130/ADDS Pack systems from outside the Gulf region. In practical terms, because of unavoidable operational inefficiencies, such as the need for maintenance and coordination far more logistics resources than these would be needed to fully treat a spill of this size.

5.5 Summary of Dispersant Delivery Capacity

1. In the batch spill scenarios the rate of emulsification exerts a very strong influence over dispersion efficiency. In scenarios involving oils that have little tendency to emulsify, the oil dissipates naturally within hours or days and the effect of dispersants is to reduce the persistence of oil only slightly. In scenarios involving oils with a high tendency to emulsify, the time windows are very short, approximately seven hours. For some platforms this allows time for one or two sorties at most, while for others the time window is too brief to complete even a single sortie. Most platforms had little impact on these scenarios. The systems with the largest payloads (e.g., C-130) reduced the volume of persistent oil present by a few tens of percentage points in only the smaller spill scenario (3180 m^3 scenario).

2. The impact of dispersants is most evident in scenarios with oils that do emulsify, but also do have a relatively long time window, up to 58 hours. In the smallest of these scenarios (Scenario

2b, 3180 m^3), the platforms with the highest delivery capacities (C-130 and DC-4) are capable of dispersing the entire spill, but the smaller platforms are not. When the capacities of all platforms to deliver dispersant over a 12-hour period and a 30-mile distance were compared to the C-130, their relative performances would be as follows: DC-4, 0.57 times the C-130, DC-3, 0.23; Agtruck AT-802, 0.25; helicopter,0.12; Vessel A, 0.08 and Vessel D, 0.73.

3. Both helicopter and vessel systems have the advantage of being capable of being re-supplied at the spill site, thus avoiding the necessity of traveling to their base of operations. By re-supplying at the spill site, their performance can be improved by factors of 2.7 (helicopter) and 4.5 (vessel). The performance of these platforms relative to the C130, when supplied at site would be 0.32 and 0.36, respectively.

4. The distance from the spill site to the base of re-supply influences performance. Increasing the operating distance from 30 miles to 100 miles reduces performance of most platforms to 50 to 75 percent of their capacities at 30 miles. By increasing the operating distance to 300 miles, delivery capacities are reduced to 40 to 60 percent of their capacities at 30 miles. The helicopter system could not be used for responses at 100 miles, nor the AT-802 at 300 miles because of range limitations.

5. Blowout spills present somewhat different logistic challenges for dispersant operations. As with batch spills, the effects of dispersant use on oil fate in blowouts depends on the properties and behavior of the oil. Blowouts of oils which do not emulsify or which emulsify very slowly, will disperse quickly by natural means and dispersants may not affect their persistence greatly. Other oils which emulsify relatively quickly, can be strongly affected by dispersant operations.

6. Blowouts which emulsify quickly cannot be fully dispersed because dispersant operations must be suspended at night and a portion of the oil that is spilled overnight will emulsify to undispersible levels. When a blowout and batch spill of identical size (3180 m^3) and oil type (Av-E) are compared, the batch spill can be fully dispersed, but the blowout can not because of the “overnight effect”. The more quickly the oil emulsifies, the greater the proportion that will become undispersible.

7. When surface and subsea blowouts of identical size and oil type are compared, dispersion of the subsea blowout is much less effective operationally than the surface blowout due to its larger width, smaller oil thickness and more rapid emulsification.

8. Payload and operating distance control overall operational effectiveness in blowout spills as in batch spills, but these influences are less evident when blowout rates are of the order of 5000 BOPD or less. At these discharge rates the larger platforms have excess capacity, and so their logistic advantage over the smaller platforms are less pronounced.

5.6 Targeting and Monitoring

Two additional challenges must be met to ensure that dispersant operations are efficient and that the most effective use is made of time and resources. These are: 1) targeting, that is, selecting the most appropriate part of the slicks to be sprayed; and 2) effectiveness monitoring, that is, verifying that the applied dispersant is indeed increasing the rate of dispersion of the slick. Both of these indispensable tasks require skill and the use of technology, as described below.

5.6.1 Targeting

Targeting refers to the task of assessing the slick and identifying the parts to be sprayed. This decision process has been largely ignored in the past because dispersant spraying strategies were based on the premise that spills spread to form large slicks of known, uniform thickness. Dispersant operations were assumed to involve spraying the large slick in a series of single passes in "carpet-sweeping" fashion, until all of the slick had been sprayed. However, more recent, practical experience has shown that slicks are not uniform in thickness, but rather are made up of relatively small, thick patches of oil surrounded by large areas of very thin sheen. The vast majority of the oil is contained in the thick patches. A rule of thumb is that the thick patches contain approximately 90% of the volume of the oil, but make up only 10% of the area. Indeed, the majority of the area of a slick may be made up of sheen containing only a small proportion of the volume of the slick.

It is critically important that dispersant spraying operations target the thick portions of slicks and avoid the thin portions for several reasons. First, sheens are so thin (only a few hundredths of a mm), that even a single spray pass, at an application rate of 5 to 10 gallons of dispersant per acre, will greatly overdose the sheen. In addition, the sheen is so thin that droplets of dispersant spray will pass completely through the sheen into the underlying water and will be lost without actually dispersing the slick. Both of these circumstances result in a waste of both valuable dispersant product and time.

The thick patches of oil can be distinguished from the sheen in at least two ways. The simplest method is by visual observation from the air by an experienced observer. This method may not be completely reliable under all conditions. A more dependable method is the use of airborne remote sensing using the UV/IR technique. This detection method detects the infra-red radiation being emitted by the slick patches of oil, the thin sheen and surrounding water. The thick patches can be distinguished from the water and sheen because they are warmer. These methods allow the thick patches to be distinguished from sheen, but they do not provide any information concerning slick thickness. A variety of UV/IR remote sensing systems are available and are in use for oil spill response planning purposes. Once the targets have been selected, the spraying platform is directed to them by marking them with suitable buoys or by identifying their position electronically.

5.6.2 Effectiveness Monitoring

In spill response, monitoring is conducted for a variety of reasons, but from an operational point of view the most critical is effectiveness monitoring. The objective of this is to establish whether dispersant application is being effective in increasing the rate of dispersion of the patch being treated. Even though a slick may be amenable to dispersion early in the spill, it may become resistant within a matter of hours or days through the processes of weathering and emulsification. Monitoring will establish whether the target patch of oil continues to be dispersible over time. When a patch of oil has clearly become resistant to chemical treatment, it is pointless to spend further time trying to disperse it, and the operation should move on to target another patch of oil or to change spill control strategies.

There are two approaches to effectiveness monitoring: 1) monitoring the rate of disappearance of the treated slick, and 2) monitoring the concentration of oil that has been dispersed into the water. The first approach involves observing the treated slick to determine whether or not it is disappearing more quickly than a similar, untreated one. This is done by observing the treated slick from the air, either visually or by remote sensing. At present, there does not appear to be an accepted, documented approach for this kind of monitoring. However, there appears to be agreement among practitioners that this type of monitoring is based on the judgment of a thoroughly trained and experienced observer (MacLeod 1995).

The second approach involves observing and/or measuring oil in the water under slicks. This is done either through visual observation from the air or by direct measurement of oil in the water using in-situ fluorometry. Visual observation involves looking for the presence of a “coffee-with-cream”-colored cloud of dispersed oil droplets in the water in the vicinity of the treated slick (Lunel 1997). This approach is not always reliable because the plume may or may not be visible depending on a variety of factors (e.g., lighting conditions). The more rigorous method involves directly measuring the concentration of oil under slicks before and during treatment. This method makes use of the differences in behavior between physically and chemically dispersed oil. When oil is being dispersed physically, the dispersed oil is present in the water in modest concentrations in the form of large droplets, which because of their buoyancy and large size, float very quickly to the sea surface and seldom mix deeper into the water column than one meter. In the chemically dispersed case, oil is present in higher concentrations in the form of very small droplets. The droplets do not resurface, but remain in the water and are mixed quickly down to a depth of several meters.

Practitioners utilize at least two approaches to monitoring. One approach relies on differences in the overall concentration of dispersed oil in the upper one meter of the water column under slicks. Oil concentrations are measured in the water under the slick before and after treatment. The treatment is considered to be effective if the concentration of dispersed oil under the treated slick is at least five times greater than under the untreated slick. This approach is used by responders in the U.S., as described in the protocols of “Special Monitoring of Applied Response Technologies” (SMART 2000). SMART is described more fully below. Another approach relies on differences in behavior between chemically treated and untreated oil. Oil concentrations in the water under slicks are measured simultaneously at two depths under the untreated and dispersed slick. Oil concentrations should be elevated at the one-meter depth in both cases. Treatment is considered ineffective if the oil concentrations decline sharply at depths below one meter, indicating that the oil droplets in the water column are large and are resurfacing quickly. Treatment is considered effective if oil concentrations are elevated to depths of three to five meters, indicating that the droplets present are small and readily mixed to greater depths (Lunel, 1997). Workers in the U.K favor this approach.

SMART or Special Monitoring of Applied Response Technologies program is a U.S. initiative to develop monitoring protocols for spill control technologies, such as dispersants. It is a collaboration of scientists and responders, the objective of which is to help provide managers with scientifically based information on spill conditions, in real time, to assist in managing the response. SMART is an ongoing process, with procedures being revised on a regular basis as advancements occur. At present, SMART calls for three levels of monitoring for dispersant operations:

Tier I is the most basic type of monitoring involves visual assessment of the rate of disappearance of the slick or the appearance of chemically dispersed oil in the water column. This approach is unreliable under certain conditions, so a more reliable though more involved approach (Tier II) is used whenever possible.

Tier II involves combining visual observations with measurements of the concentrations of dispersed oil in the water column under the center of the treated slick. The latter is performed using in-situ fluorometry and involves measuring the oil concentrations at a depth of one metre in the water column under the treated slick.

Tier III is a more involved procedure that verifies that the dispersed oil is indeed diluting as predicted. This procedure involves measuring dispersed oil concentrations and several depths and under different parts of the slick in order to collect information on transport and dispersion of oil in the water column.

6. Assessment of Factors Influencing Net Environmental Benefit

6.1 Introduction

This chapter discusses the environmental benefits and drawbacks of using dispersants to treat spills from offshore facilities in the U.S. Gulf of Mexico. The balancing of benefits and losses is necessary because dispersants do not remove the oil from the environment, but rather move it from the sea surface into the water. While this reduces the risks posed by the spill to species at the sea surface and at shorelines, it increases risks to in-water and seabed-dwelling species. Before using dispersants in any given spill, it is critical to consider whether their benefits outweigh their drawbacks, that is, whether they offer a net environmental benefit (NEB).

Section 6.2 that follows discusses methods for assessing the NEB of dispersant use and describes the many factors that influence it. Section 6.3 considers the environmental impacts of spills and the potential NEB associated with dispersant use in the Gulf, using the hypothetical spill scenarios described in earlier sections.

6.2 Methods for Assessing Net Environmental Benefit for Dispersants

The role of dispersants, like other countermeasures, is to reduce the environmental impact of oil spills. In any spill, the preferred method for ameliorating impact is recovering the spilled oil and removing it from the sea. Unfortunately, in most incidents, only a small proportion of the spill can actually be collected while the remaining oil escapes. This escaping oil poses an environmental threat to organisms and human-use resources at the sea surface (marine birds, hairy mammals, fishing gear), in intertidal areas (e.g., coastal marshes, amenity beaches) and in shallow sub-tidal habitats (e.g., juvenile shrimp). Dispersants can reduce these risks by removing the oil from the sea surface and moving it into the water where it can be diluted and degraded. However, this comes at the cost of increasing exposure to the in-water community (e.g., fish, crustaceans, mollusks, corals, sea grasses) to dispersed oil, thereby increasing the risk of damaging it. Depending on spill conditions, the overall risks posed by the dispersed oil may be less or greater than those posed by the untreated spill, so before dispersants are used, the NEB of their use must be considered.

The impact and NEB of spills are influenced by a variety of factors, such as the location of the spill, spill conditions and environmental conditions. Since practical experience with the effects of dispersant use is limited, some analysis is required to assess the NEB in any given situation. Decisions about the environmental merits of dispersant involve: a) estimating the potential damage caused by the untreated spill; b) assessing the degree to which this damage can be reduced by using dispersants; and c) finally, factoring in any damage that might be caused by the chemically dispersed oil to in-water resources. These assessments have proven simple in certain contexts and highly complex and challenging in others, as explained below.

Historically, assessments of the NEB associated with dispersant use have involved two basic approaches: 1) an intuitive approach for spills in deep, offshore waters; and 2) an analytical approach for others. The intuitive approach is based on a consensus among regulators and responders that dispersants pose little environmental risk when used in deeper, offshore waters. Generally speaking, dispersant use in waters farther than one to three miles offshore in waters greater than 30 to 60 feet deep pose few environmental risks under most circumstances. This is because 1) dispersed spills in these areas pose risks only to organisms in the upper water column (seabed dwellers are not at risk of direct exposure); and 2) in offshore areas, productivity in the upper water column is generally low and biota not abundant. Any minor risks that do exist are less than the well-known risks associated with allowing untreated spills to contaminate sensitive and productive littoral zones and shorelines. Thus the net environmental benefit of chemically dispersing spills in offshore areas is intuitively clear. This intuitive approach is the basis for dispersant pre-approval agreements for waters in many jurisdictions (IMO 1995; Region IV Regional Response Team).

A more rigorous, analytical approach is needed for assessing the NEB of dispersant use in shallow, nearshore waters, because dispersing oil in here can have far greater effects than in offshore areas. As a consequence, before planning to use dispersants in nearshore waters, it is necessary to rigorously assess the risks associated with using dispersants and not using them, to identify the approach that will result in the lesser overall environmental impact. This is done be estimating the potential impact of the untreated spill (and the reduction in impact that might result from dispersant use) and comparing it with the impact of the spill on the in-water community, if treated with dispersants. Common methods have been developed for these analyses including: Trudel (1984), Trudel et al. (1986), Trudel and Ross (1987), Trudel et al. (1989), Aurand et al. (1998) and Pond et al (2000). These methods all involve conducting analyses on a scenario basis. A series of realistic spill scenarios are analyzed for the impacts of both untreated and dispersed spills and the NEB is determined in each case. The damage resulting from the untreated and chemically dispersed spills is estimated by performing the following:

1) Assembling a list of important, local, spill-sensitive resources or Valued Environmental Components (VEC) upon which the impact of the spill is measured;
2) Estimating the fate and behavior of the spill itself, whether untreated or chemically dispersed, and estimating the exposures experienced by the VECs;
3) Identifying the effects and the potential area within which effects might occur (area-of-effect), based on the sensitivity of the VEC and the spatial distribution of the oil;
4) Identifying the amount of each VEC population that might be damaged by the spill based on its vulnerability to the oil and the spatial overlap of the VEC's distribution and the area-of-effect of the spill;
5) Estimating the length of time needed for the VEC population to recover from the damage; and
6) Assessing the relative value or importance of the potentially damaged resources.

The final step involves comparing the impacts of the untreated and chemically dispersed spills, in order to determine whether dispersants might yield a net environmental benefit.

The next few sections describe the VECs included in the analysis, the general method used in assessing net environmental benefit in each scenario, and the treatment of each of the critical factors influencing impact in both the chemically-dispersed and untreated cases.

6.2.1 Valued Environmental Components (VECs)

As explained above, in order avoid biasing the analysis of the net environmental benefit of dispersants; it is critical that every important resource that is threatened by either the untreated or the dispersed spills is included in the analysis. In the present study, the assessments of impact of untreated and dispersed spills are made using the many of the same groups of valued environmental components (VECs) that are used by MMS GOM OCS in their own environmental assessment process (as described in MMS GOM OCS Region 1997, 1998, for example). The groups of VECS used in the present analysis are listed in Table 6-1.

Table 6-1 Types of Oil-Sensitive Resources Considered in this Analysis

• Oil Sensitive Environments a) Coastal Barrier Beaches b) Wetlands c)Topographic Features (e.g., coral reefs) • Wildlife a) Marine Mammals b) Coastal and Marine Birds c) Marine Reptiles	• Finfish, Shellfish and Commercial Fisheries a) Finfish b) Crustaceans c) molluscs • Recreational Resources and Human-Use Features a) Recreational waterfronts b) National / State Parks, Wildlife Refuges, National Seashores

Information concerning the species present and their characteristics that determine susceptibility to oil spills has been derived from several sources including:

a) Texas Coastal Oil Spill Planning and Response Tool Kit (1999);
b) b) Gulf-Wide Information System; and
c) c) MIRG[9]/SLRoss system, as described in Trudel et al. (1989).

The following is a brief description of each of the groups of VECs included in this analysis.

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[9] MIRG is an oil industry planning group named Marine Industry Group (currently known as Marine Industry Response – Gulf)

6.2.1.1 Oil Sensitive Habitats

The substrates listed below are critical habitats for important biological communities in the Gulf. They are particularly sensitive to damage by either chemically dispersed or untreated oil. Damage to these habitats would have secondary impacts on the communities and species that they support.

a) Coastal Barrier Beaches

The coastal barriers of the western Gulf of Mexico consist of low, elongated coastal land masses composed of sand and other unconsolidated sediments. These provide habitats for a variety of wildlife species, including a number of endangered species. Oil spills themselves probably pose little direct threat to the stability of these features, but large spill cleanup operations can affect beach stability (MMS GOM OCS 1998). Coastal barrier beaches would not be affected by chemically dispersed oil, but chemical dispersion of oil slicks in offshore areas would prevent beach oiling.

b) Wetlands

Wetland habitats of the Gulf coast include fresh, brackish and saltwater marshes and forested wetland, including mangroves. These may be present as narrow coastal bands or broad expanses. These wetlands perform a number of critical functions in the region, one of which is to provide habitat and an energy source for a wide diversity of finfish, shellfish, and wildlife. Intertidal wetlands are notoriously vulnerable and sensitive to effects of oil slicks. Oil stranding in wetlands can kill or damage the above-ground portions of the plants. Depending on the level of oiling and the conditions of the oil and substrate, oil may penetrate into the substrate sufficiently to damage the root systems. The spills being considered in the present study originate well offshore and the dispersant operations to treat them take place well offshore. In scenarios, like scenarios 2b and 4b, in which dispersant operations can be effective in dispersing the majority of the spilled oil, coastal wetlands can be protected from the effects of oil slicks and are also unlikely to be exposed to either dispersants or chemically dispersed oil. Even in the unlikely event that the cloud of dispersed oil were to enter a wetland, the vegetation would probably not be damaged, because marsh plants are relatively insensitive to chemically dispersed oil (Baca and Getter 1984).

c) Offshore Hard-Bottom Communities

The shelf and shelf-edge in the Western Gulf contain a number of high relief topographic features that support hard-bottom communities in which the biological substrate is composed of corals, algae and sponges (e.g., Flower Garden Banks). These are important for a variety of reasons, the most important of which is that they are oases of relatively high biological productivity and diversity, supporting large numbers of commercially and recreationally important species in an area that is otherwise not particularly productive. These communities and their locations are described briefly in MMS GOM OCS (1998).

Untreated spills pose little threat to these communities because most occur at depths of several tens of meters (MMS GOM OCS 1998) or more while dangerously elevated concentrations of oil occur only within a few meters of the surface immediately under slicks. The vertical penetration of spilled oil into the water column under oil slicks has been studied by a number of authors. Cormack and Nichols (1977) reported that, under small experimental slicks, oil concentrations exceeding 1.0 ppm occurred in the upper 2 m. Below this, concentrations declined steeply to the low hundreds of ppb at 5 m and then to a few tens of ppb below 10 meters. The observations of McAuliffe et al. (1981) and Lichtenthaler and Daling (1985), also on small experimental spills, are consistent with this. Lunel et al. (1997) reported a similar pattern of distribution of oil under untreated slicks during the *Sea Empress* spill (Wales, 1996). Since in untreated spills, dangerously elevated concentrations of hydrocarbons generally do not occur below depths of 5 meters, while the shallowest of these offshore hard-bottom communities occur at depths of 15 meters or greater (MMS GOM OCS 1998), these spills pose very little threat to these communities.

Dispersant operations will cause elevated concentrations of oil in the upper water column. Clouds of dispersed oil with concentrations in the range of 1 to 10 ppm , with spikes to several tens of ppm, have been observed in the upper few meters of the water column under treated slicks (Cormack and Nichols 1977, McAuliffe et al. 1981, Lichtenthaler and Daling 1985, Lunel et al. 1995, Lunel et al. 1997. Lunel (1994b) determined that, unlike untreated oil, chemically dispersed oil was quickly mixed uniformly to a depth of up to five meters. McAuliffe et al. (1981) showed that this uniform mixing layer penetrated only to 5 to 6 meters in to the water column, with concentrations declining somewhat below this. A panel of experts concluded that, generally, it was unlikely that dangerously elevated concentrations of chemically dispersed oil would penetrate below 10 meters into the water column. These conditions may pose some risk of toxicity to the pelagic life stages of the hard-bottom species, if they are present in surface waters at the time of the spill. However, they pose little risk to the bottom-dwelling adult life stages even in the shallowest (15 to 20 m depth) of the communities.

6.2.1.2 Wildlife

a) Coastal and Marine Birds

The Gulf of Mexico supports dozens of species of coastal and marine birds, including a number of endangered species. Birds are of particular concern in the context of spills because some birds are highly sensitive to spilled oil and are the most common casualties of spills. Bird species can be divided into a number of subgroups, based on habits and certain of these subgroups, such as true seabirds, are far more susceptible to the effects of spills than others. Some of the resident species in the Gulf are present in large numbers year round and breed in the Gulf region, while others are migratory and are present for only part of the year. In short the risk posed birds by oil spills varies with species, location and season.

Seabirds are a diverse assemblage of species that spend all of their lives in or on salt water. Many members of this group are highly vulnerable to the effects of oil slicks because they spend considerable time sitting on the water where they are vulnerable to contamination by oil slicks. This group includes pelicans, cormorants, frigatebirds, gulls, terns, phalaropes and skimmers.

Waterfowl are a group that includes ducks, geese and swans. These species spend part of their time at sea and part on shore or inland. When at sea these species are similar to seabirds in terms of vulnerability to spills because they spend part of their time sitting on the water and are vulnerable to contamination by oil slicks. Most members of this group are migratory species and are present in the Gulf for only part of the year.

Waders or marsh birds are species that live in or around marshes and have long legs that enable them to wade in shallow marsh or coastal waters to forage for food. These species may be exposed to oil slicks, but are less vulnerable to effects because they are less likely to have oil contact their plumage. These include; herons; egrets; ibises spoonbills and cranes.

Shorebirds are species that are restricted to coastline margins, including beaches and mudflats. In the Gulf region there are more than 40 species, including species of oystercatchers, stilts, plovers and sandpipers. These species appear to be less vulnerable than seabirds to spills because their plumage is less likely to become contaminated with oil.

The sensitivity of coastal and marine bird species, particularly seabird species, to oil slicks is well known. However, their susceptibility to effects of chemically dispersed oil is less well understood. The limited amount of information available suggests that bird species will be largely unaffected by dispersant use, except perhaps if they are sprayed directly. In the present study this would be unlikely because, due to the nature of the spills being considered, dispersant spraying will almost invariably take place in offshore areas away from the most commonly used bird habitat.

b) Marine Reptiles

There are five species of sea turtle found in the Gulf of Mexico, including: loggerhead; green; hawksbill; Kemp's ridley and leatherback sea turtles. All are protected under the Endangered Species act. Sea turtle species are pelagic, spending most of their lives at sea. Adult females emerge periodically to nest on beaches. The geographic distribution of nesting activity varies with species. Most nest at some location within the Gulf, but only the Kemp's ridley and loggerhead nest in the western Gulf. The potential susceptibility of sea turtles to oiling is not well understood. There are accounts of turtles suffering sublethal effects as a result of exposure to oil (Vargo et al 1986, Lutcavage et al. 1995) , however, accounts of effects of on turtles during actual spills (e.g., Mignucci-Giannoni 1999) appear to be rare. Nesting females and hatchlings are probably most vulnerable to oiling during nesting season, if nesting beaches become oiled. In addition, nesting activity and survivorship of nestlings may be affected by shoreline cleanup activities. There is little evidence to suggest that pelagic turtles are susceptible to effects of chemically dispersed oil.

c) Marine Mammals

The marine mammals in the Gulf Mexico, include twenty-eight species of whales and dolphins and one species of manatee. The existing information concerning effects of oil spills on marine mammals show that hairy mammals (e.g., polar bears, otters, seals) are most sensitive to the effects of oiling. Bare-skinned mammals appear to be far less susceptible. Some sublethal effects have been observed, but neither mortalities nor other ecologically significant population effects can be linked to spills. There is little information available concerning the risks to mammals by chemically dispersed oil.

6.2.1.3 Finfish, Shellfish and Commercial Fisheries

The Gulf of Mexico supports a wide variety of finfish and shellfish species, many of which support highly valued commercial and recreational fisheries MMS GOM OCS (1998). The effects of untreated marine spills on fish populations and on commercial fisheries have been documented and the effects of hydrocarbons on fish and shellfish have been extensively studied (Law and Hellou 1999, National Research Council 1985). Under many conditions, fin-and shellfish populations do not suffer material damage during untreated spills (National Research Council 1985). Some pelagic eggs and larval life stages may be killed through contact with oil in the upper water column, but risks to a year class strength or the stock, as a whole, is generally very, very small. Adults and juveniles usually do not suffer toxic or significant sublethal effects except in the case of very large spills, such as the Amoco Cadiz or Exxon Valdez. More commonly, spills impact fisheries through local fishery closures due to the presence of oil slicks in fishing areas or the presence of spill-related hydrocarbon contamination in fish tissue (Law and Hellou 1999).

On the other hand, there is little information available concerning the effects of chemically dispersed oil on fish stocks and fisheries. Our knowledge in this area is based on only a very limited number of actual case studies involving dispersed spills (Smith 1968, Law et al. 1998) and extensive laboratory work (GESAMP 1993, National Research Council 1989, SL Ross 1997b, Trudel 1985). Chemical dispersion unquestionably increases the contamination of the water column and experimental studies have demonstrated that dispersed oil can be toxic to marine life under laboratory conditions (e.g., Shuba and Heikamp 1989, Singer et al. 1991, 1996). However, there is a growing body of information to suggest that chemically-dispersed oil may not cause mortality to in-water species under actual spill conditions, with the possible exception of the more sensitive species and larval life stages. The reason is that toxic thresholds for dispersed oil for most species are well above the concentrations likely to be encountered even in the upper water column under dispersing slicks (SL Ross 1997b). As with untreated spills, chemically dispersed spills will probably have their greatest effect on fisheries through closures due to the presence of contamination in the water or through closures or condemning of catches due to the presence of contamination in fish tissues.

The most important commercial fishery species in the study area and their relative values based on catch and dollar value of catch is given in Table 6-2.

The vulnerabilities of VECs that are sensitive to untreated spills (e.g., shorelines, shoreline habitat, parks, birds, turtles) are well represented in currently available information sources, such as TCOSPR 1999 and MMS 2000. It is important to recognize, however, that these information sources provide very little information concerning resources that are susceptible to chemically dispersed oil, namely fishery species and fisheries. For this reason the MIRG/SL Ross model supplemented with more recent data have been used in estimating risks to fisheries. This system and the associated natural resource database are described in Trudel et al. (1989). During the development of the MIRG/SL Ross oil spill impact assessment system for the U.S. Gulf of Mexico, representatives of state natural resource trustee agencies and regulatory agencies were asked to identify the resources that could be pivotal to oil spill management decisions. The agencies nominated seventy species of birds, mammals, reptiles, living habitats, amenities, fish and shellfish. The list of resources is given in Trudel et al. (1989). The groups of finfish, crustaceans and mollusks to which these species belonged are identified below.

Table 6-2 Annual Commercial Fishery Landings by Species and State, 1998 (a)

Resource	Florida West Coast		Alabama		Mississippi	
	Metric Tonnes	$	Metric Tonnes	$	Metric Tonnes	$
SHELLFISH/FISHERIES						
Brown Shrimp	250	1,793,724	4,751	22,523,437	4,676	16,924,297
White Shrimp	338	1,638,011	1,066	6,482,657	2,382	14,829,705
Pink Shrimp	9,553	48,249,355	1,234	5,474,950	119	634,720
Blue Crab	42	8,027,084	1,577	1,947,802	0	431,749
Eastern Oysters	692	2,416,591	154	783,499	0	0
Stone Crab	3,147	22,812,364	0	0	0	0
FINFISH/FISHERIES						
Menhaden	22	10,953	1,601	301,239	82,100	9,051,079
King Mackerel	612	13,332,622	0	0	0	0
Red Snapper	98	460,874	25	125,696	95	414,950
Black Drum	4	4,751	25	23,469	7	11,419
Florida Pompano	228	1,272,526	8	47,250	0	0
Spotted Seatrout	19	70,041	0	0	19	87,287
Crevalle Jack	302	342,023	0	0	0	0
Spanish Mackerel	112	147,584	99	134,161	0	0
Atlantic Croaker	9	45,348	19	8,667	0	0
Scamp Grouper	3	11,999	2	8,399	0	787
Sand Seatrout	10	15,939	22	26,077	12	14,777
Red Drum	0	0	0	0	14	51,123

a. From National Marine Fishery Service, Marine Fisheries Annual Landings Results

Resource	Louisiana		Texas	
	Metric Tonnes	$	Metric Tonnes	$
SHELLFISH/FISHERIES				
Brown Shrimp	22,743	54,985,093	25,180	120,236,809
White Shrimp	24,005	100,524,635	10,527	58,207,837
Pink Shrimp	10	54,075	699	3,960,738
Blue Crab	19,722	30,744,473	3,166	4,543,491
Eastern Oysters	5,831	30,994,392	1,559	8,282,479
Stone Crab	1	7,747	11	99,172
FINFISH/FISHERIES				
Menhaden	413,727	47,494,052	0	0
King Mackerel	382	851,083	148	318,892
Red Snapper	1,039	4,730,153	550	2,565,942
Black Drum	808	1,384,789	1,181	2,729,797
Florida Pompano	28	166,229	0	0
Spotted Seatrout	51	197,874	0	0
Crevalle Jack	0	0	0	0
Spanish Mackerel	2	2,308	0	0
Atlantic Croaker	6	6,541	18	200,197
Scamp Grouper	7	32,097	40	185,578
Sand Seatrout	14	25,259	0	0
Red Drum	2	5,725	0	0

a. From National Marine Fishery Service, Marine Fisheries Annual Landings Results

a) Crustaceans

The Gulf supports a wide variety of crusatcean species and members of this group, the brown, white and pink penaeid shrimps, are by far the most important commercial fishery species of any kind in the Gulf. The blue crab occurs throughout the Gulf and supports significant in most states. The stone crab is taken in important quantities only in Florida.

b) Finfish

The finfish species support fisheries throughout the Gulf, but are particularly important in Louisiana and Mississippi , where the Gulf menhaden is by far the most important species. In these states and in Texas, other estuary-dependant species, such as black drum are important, as are the shelf species, red snapper. The pelagic king mackerel dominates the Florida fishery.

c) Molluscs

A variety of molluscs are common in the northern Gulf in the area of this study area. However, the most common and economically important is the American oyster mollusks are particularly sensitive to contamination during spills, which commonly results in prolonged closures of fisheries.

6.2.1.4 Recreational Resources and Human Use Features

Human use features are common and widespread in the Gulf, and these are in danger of becoming contaminated during oil spills. They include: a) parks and protected areas; and b) recreational or amenity beaches.

a) Recreational waterfronts

Extensive stretches of the Gulf coast are made up of recreational sand beach. Contamination of these beaches with spilled oil or the cleanup activities, which follow spills, will render these beaches unusable for recreational purposes for the duration of the spill and cleanup.

b) National and State Parks, Wildlife Refuges, National Seashores

These installations combine conservation and recreation functions; with the emphasis on recreation varying from installation to installation. Those at risk from spill scenarios in this study all include recreational beaches. The potential impact of spills on the use and amenity value of these installations appears to be variable. MMS GOM OCS (1998) suggests, apparently based on experience in several major U.S. marine spills, that large spills can “severely impact” the recreational use of these installations. However, Freeman et al. (1985) and Sorensen (1990), cited in MMS GOM OCS (1998), suggest that, in some cases, pollution from spills in or near these installations can cause no significant effects on park use or a modest, short-term reduction in use (10-15 percent reduction in usership for one season).

6.2.2 General Method for Analyzing Spill Scenarios

The net environmental benefit of dispersant use was assessed by analyzing selected oil spill scenarios. For each scenario, estimates of environmental impact were formulated for the spill if left untreated and if it were chemically dispersed. Impact estimates were made considering all of the VECs identified above. The general approach is illustrated in Figure 6.1.

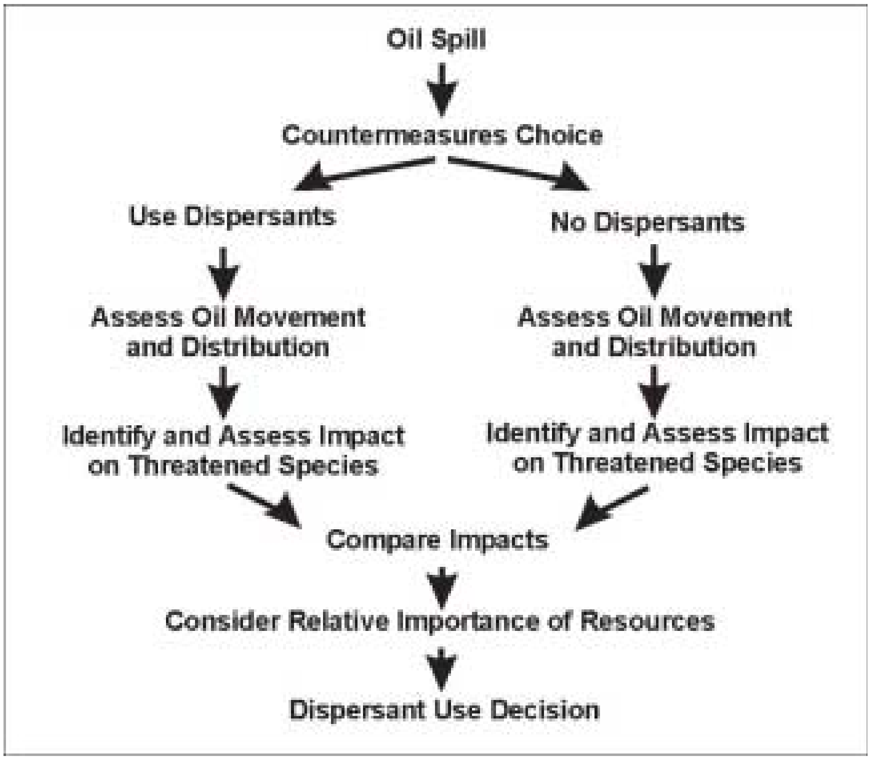


Figure 6.1 Flowchart of Method for Assessing Net Environmental Benefit

The procedure for assessing net environmental benefit in each scenario involves three steps, as follows.

Step 1. Identify the resources threatened by either the untreated and dispersed spill cases. This is based on:

a) the movement and fate of oil; and
b) the geographic distribution of oil-sensitive resources.

Step 2. Estimate the kind and amount of damage to each VEC that might result from untreated and chemically dispersed spills. This is based on:

a) the spatial extent of oil distribution and environmental concentrations of oil;
b) the sensitivity of each VEC to oil;
c) the spatial distribution of the target VEC stock; and
d) the vulnerability of various VEC life stages to oiling.

Step 3. Quantify the impacts of the untreated and dispersed spills and compare them to determine which approach yields the lesser overall environmental impact, that is which offers a net environmental benefit. This is based on:

a) the VECs at risk from the treated and untreated spills;
b) the level of acute damage suffered by each VEC;
c) the length of time required for each damaged VEC to recover to its pre-spill condition; and
d) the value placed on each VEC by the local human population.

The method for expressing the level of damage in a simple, unambiguous language is critical to this work. A number of approaches have been developed in the past for use in environmental impact statements (e.g. Beanlands and Duinker 1983) and in analyses of net environmental benefit (Pond et al. 2000, Trudel et al. 1983, 1987, 1989), but at present there is no standard method. Any method used must apply equally well to a wide variety of VECs using a common set of criteria. For purposes of this study, we have modified and updated a system developed earlier by MMS for preparing environmental impact assessments. It is important to recognize that while impact is, in fact, a continuous function, we have divided this continuum into five discrete categories for purposes of simplicity. The categories of impact have been defined based on: a) the definition of the target stock (regional versus local); b) severity and amount of damage to the stock; and c) the length of the recovery period. In order to aid the reader, words have been used (e.g., low, medium, high) to label the categories of impact, instead of letters or numbers. The definitions of the categories are given in Table 6-3.

Each of the critical factors in determining impact is described briefly in the following sections.

Table 6-3 Definitions of terms used to quantify impacts (a)

	Level of Impact				
Valued Environmental Component (VEC)	**Very High**	**High**	**Medium**	**Low**	**Very Low**
General Definition	Large proportion of a large target resource damaged, recovery period very long, if not indefinite.		Large proportion of local resource or small proportion of regional resource damaged, intermediate recovery time		Damage detectible, but negligibly small on a small, local resource, recovery period very short
Oil-Sensitive Environments					
Wetlands	0.25%/yr of the habitat within a physiographic unit OR 1000 ha/yr are permanently converted to other types	0.125%/yr of the habitat within a physiographic unit OR 500 ha/yr are permanently converted to other types	0.05%/yr of the habitat within a physiographic unit OR 200 ha/yr are permanently converted to other types	< 0.05% of the habitat within a physiographic unit OR 200 ha affected; recovery time are > 1year	< 0.025% of the habitat within a physiographic unit OR 100 ha affected; recovery time are > 1year
Offshore Hard-Bottom Communities	Complete loss or major changes in system elements; recovery time > 10 years	Substantial loss of system elements; recovery time 5 to 10 years	Measurable loss of system elements; recovery time 2 to 5 years	Measurable loss of system elements; recovery time < 2 years	Some detectible effects; recovery time <1 year
Highly Valued Species					
Endangered Species(includes all sea turtle species)	Measurable decline in numbers; duration > 2 generation	Measurable decline in numbers; duration 1 to 2 generations	Measurable decline in numbers; duration < 1 generation	Chronic, persistent sublethal effects	Transient sublethal effects
Cetaceans	Complete loss of regional population; recovery time > 3 generations	Measurable decline in regional population; recovery time 2 to 3 generations	Measurable decline in regional population; recovery time 1 to 2 generations	Measurable decline in regional population; recovery time < one generation	Mortality of few individuals

Table 6-3 Definitions of terms used to quantify impacts (a)

	Level of Impact				
Valued Environmental Component (VEC)	**Very High**	**High**	**Medium**	**Low**	**Very Low**
Coastal or Marine Birds, Finfish and Shellfish	Measurable decline in population; recovery time > 3 generations	Measurable decline in regional population; recovery time 2 to 3 generations	Measurable decline in regional population; recovery time 1 to 2 generations	Measurable decline in regional population; recovery time < one generation	Mortality of few individuals
Human-Use Resources or Features					
Commercial Fishery	Stock or regional fishery materially reduced; recovery time > 3 generations	Stock or regional fishery materially reduced for 1 or more generations	Stock or regional fishery reduced; recovery >1 generation; local fishery materially disrupted for more than 1 year.	Stock materially reduced for < 1 generation; regional fishery not affected; local fishery reduced for 1 peak operating season.	Transient sublethal effects only; stock and regional fisheries not materially reduced; local fishery disrupted for << 1 peak season.
Recreational Beach Use	Complete loss or major disruption in beach use and associated tourism on regional scale lasting > 1 year.	Substantial loss or disruptions in beach use and associated tourism on regional scale lasting > 1 peak use season.	Some substantial loss or disruption in beach use and associated tourism on regional scale lasting < 1 peak use season; OR substantial disruption on local scale lasting > 1 peak season.	Some interference with the quality of beaches on a regional scale, widespread cleaning may not be needed; or some localized, short-term disruptions to beach use; some localized cleanup required.	Interference with quality of beaches may be perceptible, but will not necessitate cleaning and will not materially disrupt recreational use.

a. Based heavily on U.S. Department of the Interior (1991)

6.2.3 Fate and Movements of Oil

The movement, fate and behavior of the untreated oil slick or the cloud of chemically-dispersed oil are key determinants of the impacts of spills. In the case of the oil slick, this involves the direction and speed of movement of the slick, its rate of spreading, and its rates of evaporation, dispersion and emulsification. In the case of the dispersed oil, this involves the movement and spreading of the cloud. These processes determine where the oil moves (and where effects will take place), the persistence of the oil, the size of the area affected, and the environmental concentrations of oil or hydrocarbons to which oil-sensitive resources will be exposed. These factors coupled with the toxic potency of the oil determines whether on not effects, occur, as well as the location and size of the area within which effects could occur.

The present study involved simulating the fate and movements of seven spill scenarios, including both batch spills and blowouts from each of six launch sites. In all cases the fate and movement of the spills were handled separately as follows.

6.2.3.1 Fate and Behavior of the Spills

The fate and behavior of untreated and chemically dispersed cases for all spills were simulated using the SL Ross oil spill model, SLROSM, as described elsewhere in this report. For the untreated batch spills, the discharge was assumed to be instantaneous and the fate and behavior of all of the oil were calculated for the spill as a single parcel. The persistence and spreading of the spill and changes in oil properties with time are summarized for the batch spills in Tables 4-1 and 4-3.

For the blowouts or continuous spill scenarios, the spill was modeled as a series of many discrete parcels of oil or spillets. The persistence, spreading and changes in oil properties with time were calculated for a single spillet and applied to all spillets (Tables 4-1 and 4-3). The cumulative environmental exposure from a blowout spill, such as the length of shoreline oiled and the level of shoreline oiling, was estimated by summing the effects of the spillets, as explained below.

For the chemically dispersed spills in both the batch and blowout spills, all of the oil dispersed on a given day was treated as a single parcel, which was dispersed instantaneously at the midpoint of the operating day. That is, if dispersant operations took place from 0600 to 1800 on a given day, dispersing 1500 m^3 of oil, then all 1500 m^3 were assumed to disperse instantaneously at the location of the spill as of 1200 noon. The resulting cloud of dispersed oil was spread and moved according to the SL Ross model. This had the effect of yielding a worst-case estimate of impact.

6.2.3.2 Movement of Oil

The environmental damage caused by a spill is strongly influenced by where it goes as a result of winds and currents. In this study the movements of oil slicks (batch spills) and spillets (blowout spills) were estimated using results of Spill Risk Analyses conducted by Minerals Management Service in conjunction with environmental impact analyses. Analyses for spills from the five launch sites off Texas and Louisiana, as well as the deep-water launch site were taken from Price et al. (2000). Analyses for the Destin Dome launch site were taken from the OSRA for the Destin Dome Development and Production Plan (Price et al. 1998). Both the transit time and the point(s) of contact with the shoreline were estimated using conditional probability data for spills from the respective launch sites.

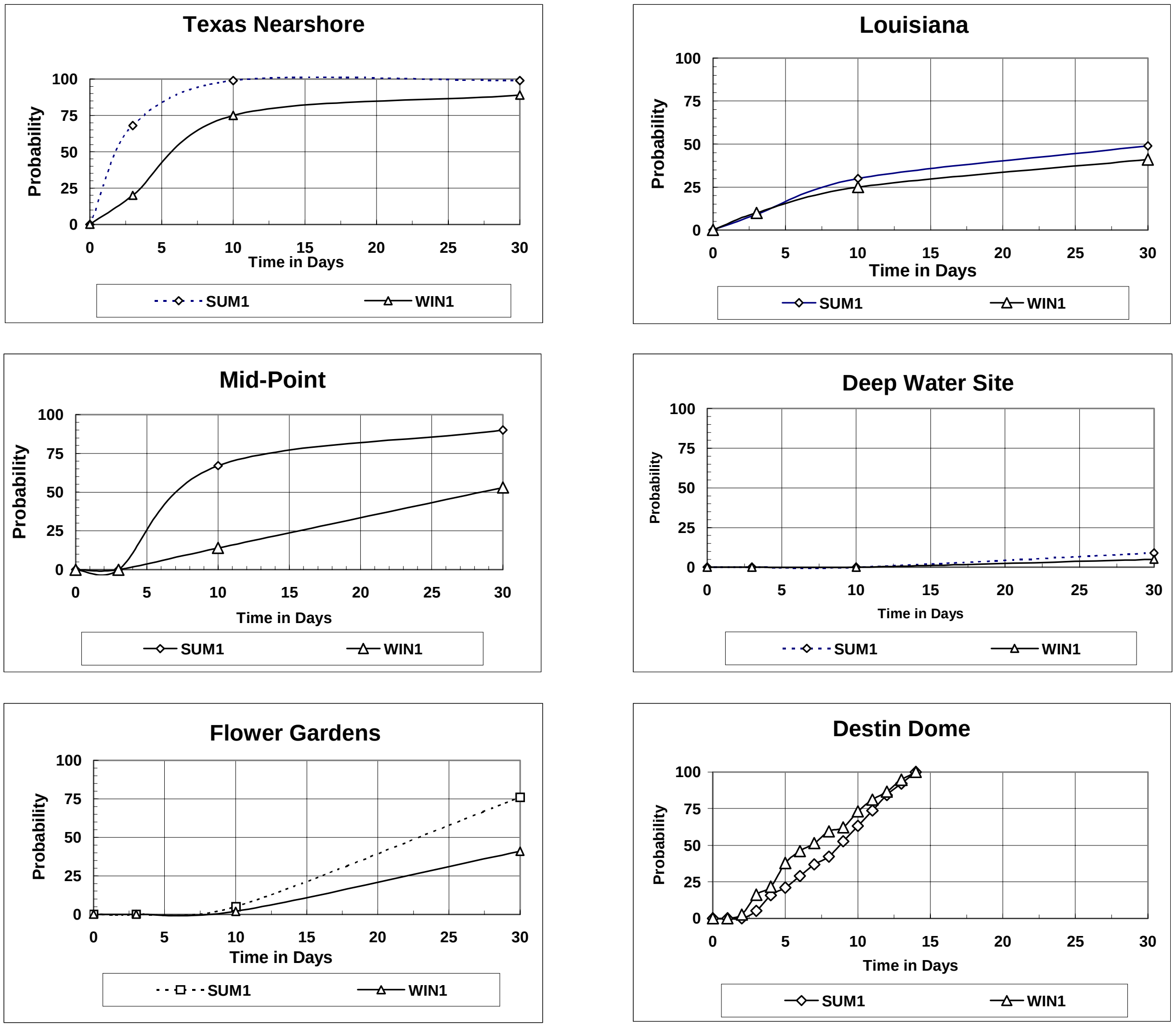
For batch spills, the point of contact with the shoreline was taken to be the midpoint of the segment with the highest conditional probability of contact (Figure 6-2). The time of transit from the spill site to the shoreline was taken to be median transit time based on the OSRA analyses, as illustrated in Figure 6-3. These also were based on conditional probabilities of contact with shorelines within specified periods of time from Price et al. (2000, 1998). The level of shoreline oiling was estimated using the volume of oil remaining at the time of contact and the Okubo width of the slick at the time the slick hit the shoreline, from the oil fate simulations in Section 4.5, above. This approach yields the most probable impact of the untreated spill rather than the worst-case impact. Thus the analysis of net environmental is based on comparing the most probable impact of the untreated spill vs. that of the dispersed spill.

Figure 6-2 Spatial distribution of conditional probabilities of shoreline contacts occurring within 30 days (a,b)

Launch Point	Season	Shoreline Segment																					Total Cond. Prob. 30 Days (c)	Total Length Oiled km (d)
		Segments in Central and Western Parts of the Gulf (e,f)																						
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19			
Texas NS	**Summer**	1	2	5	14	38	36	4	0	0	0	0	0	0	0	0	0	0	0	0	0		100	420
Texas NS	**Winter**	8.2	14	13	21	29	11	3.1	0	0	0	0	0	0	0	0	0	0	0	0	0		93	420
Mid Point	**Summer**	0	1.1	2.2	2.2	1.1	3.3	3.3	7.7	8.9	12	14	11	16	11	2.2	2.2	1.1	0	0	0		90	960
Mid Point	**Winter**	0	0	0	3.7	9.4	19	23	17	15	11	1.9	0	0	0	0	0	0	0	0	0		48	480
Flower Gardens	**Summer**	0	1.3	1.3	3.9	3.9	3.9	6.6	9.2	13	12	11	9.2	9.2	9.2	2.6	1.3	1.3	0	0	0		76	960
Flower Gardens	**Winter**	0	27	4.8	9.7	15	15	15	7.3	7.3	0	0	0	0	0	0	0	0	0	0	0		37	480
Louisiana	**Summer**	0	0	0	0	0	0	2	2	2	4	2	2	6	12	24	16	14	2	2	2		49	840
Louisiana	**Winter**	0	0	0	0	0	2	2	2	2	2	2	2	5	5	2	2	29	24	12	5		41	900
		Segments in Eastern Gulf (g)																						
Launch Point		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20		
Destin Dome	**Summer**	0	0	0	0	0	5.1	2.6	2.6	2.6	7.7	15	13	15	10	10	5.1	2.5	5.1	0	0	2.5	37	390
Destin Dome	**Winter**	0	0	0	0	0	2.7	0	0	0	2.7	8.1	14	22	24	19	5.4	2.7	0	0	0	0	37	240

a. Based on OSRA as explained in Section 6.2.3.2.
b. Conditional probability per segment / total conditional probabilites of shoreline contact within 30 days.
c. Total conditional probabilities for contact on all shoreline segments within 30 days
d. Shoreline length = number of segments x length of segments
e. From Price et al. (1997, 2000); segments approximately 60 km in length.
f. Segment 0 = International Land
g. From Price et al.1998, the OSRA for the Destin Dome development; segments approximately 30 km in length.

Figure 6-3 Estimated Time for Oil to Reach Shore from Launch Sites



In the case of blowout spills, spillet trajectories and the distribution and level of shoreline oiling were also based on conditional probability of shoreline contact within 30 days, as in Figure 6-2. The level of shoreline oiling in each segment was based on: a) the proportion of spillets contacting the segment; b) the volume of oil remaining per spillet at time of stranding; and c) the width of the segment. For the sake of simplicity the transit time for all spillets was taken to be the median transit time for all spillets (Figure 6-3).

6.2.4 Sensitivity of Valued Environmental Components

Sensitivity refers to the level of exposure to oil required to cause damage to a target resource. Spill management decisions take into account a wide variety of types of resources, as described above; these resources interact with oil in a variety of ways and suffer a range of effects. The types of effects and the exposure threshold for each vary from resource to resource. Values for effect thresholds for different resources and effects have been derived from published experimental work. Minerals Management Service has developed effect threshold values for untreated spills for its environmental impact assessment process, as described in MMS GOM OCS (1998). These values have been used whenever available. The effects and effect threshold values used in this study are described on a resource-by-resource basis in Table 6-4. In each scenario, the effect threshold information is combined with the oil fate information to determine the location and size of the area within which effects might be expected to occur. This "area-of-effect" is then combined with information about the spatial distribution of the appropriate target species to estimate the amount of a target resource that is affected by the spill.

Table 6-4 Effect thresholds used in estimating impact

Resource	**Untreated Oil**	**Chemically Dispersed Oil**
SENSITIVE ENVIRONMENTS		
Coastal Barrier Beaches	Oiling, *per se*, has no direct effect on these sand shores. However, Cleanup of large spills can affect beach stability.(MMS 1998, p IV-86)	No effect.
Wetlands	Short-term effects. Complete or partial mortality of the above-ground parts of plants, with complete recovery in less than one year. Exposure threshold is 0.01 l/m2 or 0.1 l/linear m of shore with a depth of effect of 1 m or less. Long-term effect. Complete or partial mortality of the below-ground parts of the vegetation. Loss of the root systems result in loss of stability of the substrate resulting in erosion. Recovery is many years. Exposure Threshold is 0.1 to l.0 l/m of shoreline.	No effect.
Live Hard-Bottom Communities (Offshore)	Complete or partial mortality of the coral species is expected to occur at exposure concentrations of 3 ppm of total petroleum hydrocarbons as physically dispersed oil.	Complete or partial mortality of the coral species is expected to occur at exposure concentrations of 3 ppm of total petroleum hydrocarbons as chemically-dispersed oil.
WILDLIFE		
Marine Mammals Note that only bare-skinned species are present in the Gulf of Mexico study area.	Given the rarity of accounts of impacts of spills on bare-skinned mammals, an exposure threshold for slicks of 10 mm in thickness has been used.	No effect.

Table 6-4 Effect thresholds used in estimating impact (cont.)

Resource	**Untreated Oil**	**Chemically Dispersed Oil**
Marine Reptiles	At sea - Adults. Exposure threshold for slicks is 5mm in thickness. At sea - Hatchlings and juveniles, exposure threshold is 0.5 mm At the shoreline - 1 l/m of shoreline is the threshold for hatchling and adults.	No effect.
Coastal and Marine Birds	Exposure threshold for contact of birds with oil slicks at sea. Exposure threshold is 0.1 mm for mortality for all birds.	No effect.
FINFISH, SHELLFISH AND FISHERIES		
Finfish	Effect threshold for mortality and other significant sublethal effects on adults and juveniles is 20 ppm as oil-water dispersion in ambient water. Organisms at depths greater than 3 m are invulnerable to untreated oil.	Effect threshold for mortality and other significant sublethal effects on adults and juveniles is 20 ppm as chemically-dispersed oil in ambient water. Organisms at depths greater than 10 m are invulnerable to chemically-dispersed oil.
Crustacea	Effect threshold for mortality and other significant sublethal effects on adults and juveniles is 10 ppm as oil-water dispersion in ambient water. Organisms at depths greater than 3 m are invulnerable to untreated oil.	Effect threshold for mortality and other significant sublethal effects on adults and juveniles is 10 ppm as chemically-dispersed oil in ambient water. Organisms at depths greater than 10 m are invulnerable to chemically-dispersed oil.

Table 6-4 Effect thresholds used in estimating impact (cont.)

Resource	**Untreated Oil**	**Chemically Dispersed Oil**
Bivalve Mollusca	Effect threshold for mortality and other significant sublethal effects on adults and juveniles is 10 ppm as oil-water dispersion in ambient water. Organisms at depths greater than 3 m are invulnerable to untreated oil.	Effect threshold for mortality and other significant sublethal effects on adults and juveniles is 10 ppm as chemically-dispersed oil in ambient water. Organisms at depths greater than 10 m are invulnerable to chemically-dispersed oil.
Eggs and Larvae of All Species	Effect threshold for mortality and other significant sublethal effects is 5 ppm total petroleum hydrocarbons. Organisms at depths greater than 3 m are invulnerable to untreated oil.	Effect threshold for mortality and other significant sublethal effects is 5 ppm total petroleum hydrocarbons as dispersed oil. Organisms at depths greater than 10 m are invulnerable to chemically-dispersed oil.
Fishery	Closure of a fishery for reasons of contamination of the environment OR tainting of the exploitable life stages: a) each NMFS fishing zone that is traversed by the untreated oil slick is assumed to be closed for a period of one month; and b) exposures to oil concentrations greater than 1 ppm in ambient water is assumed to cause tainting and results in the closure of the NMFS fishing zone for a period of one month.	Closure of a fishery for reasons of contamination of the environment OR tainting of the exploitable life stages b) exposures to oil concentrations greater than 1 ppm in ambient water is assumed to cause tainting and results in the closure of the NMFS fishing zone for a period of one month.

Table 6-4 Effect thresholds used in estimating impact (cont.)		
Resource	**Untreated Oil**	**Chemically Dispersed Oil**
RECREATIONAL RESOURCES		
Recreational Resources and Beach Use	Contamination at a level greater than 10 liter of oil per linear m of shoreline will require cleanup and will result in the closure of the affected region for 30 days. Contamination at a level greater than 1 liter of oil per linear m of shoreline will cause short-tem reduction in beach use.	No effect.
Parks	The use of land-based park facilities are assumed to be unaffected by oil contamination of their shores, as per MMS 1998 p IV-144.The contaminated portions of marine parks or underwater parks are assumed to be unusable for as long as visible oil slicks persist.	The contaminated portions of marine parks or underwater parks are assumed to be unusable for as long as measurable concentrations of oil (100 ppb) persist.

6.2.5 Vulnerability and Spatial Distribution of Valued Environmental Components

Untreated and chemically-dispersed oil spills cause dangerous exposure conditions only in localized areas and only in a limited portion of the marine environment, such as the sea surface and the upper part of the water column. The impact of a spill is strongly determined by: 1) whether or not oil-sensitive resources occupy the parts of the environment that are contaminated by oil and 2) how much of each resource at risk lies within the "area-of-effect@ caused by the spill.

Vulnerability refers to whether or not a resource occupies the part of the marine environment where toxic conditions occur. Untreated spills cause toxic conditions as follows.

1. Oil slicks pose risks to organisms at the sea surface placing at risk targets that inhabit the sea surface such as sea birds, marine mammals, sea turtles and fishing activity.

2. Oil stranded on a shoreline poses risks to organisms in the intertidal zone placing at risk resources like coastal marshes and bathing beaches.

3. Physically dispersed oil poses risk to organisms in the upper one or two meters of the water column, placing at risk the young pelagic life stages of species, such as corals and commercially important finfish species. On the other, hand physically dispersed oil poses little risk to species that live at depths deeper than 3 or 4 meters.

Chemically-dispersed spills cause toxic or contaminating conditions in the upper 5 to 10 meters of the water column and so pose risks to young life stages in the upper water column, demersal or benthic species if dispersants are used in shallow water, and commercial fishing activity. Dispersed spills do not pose risks to resources that live deeper than 10 meters.

In short, if an oil spill threatens a resource, the resource is at risk from the spill only if it occupies a part of the environment that is contaminated by the spill.

The second factor covered here—spatial overlap between the area-of-effect of a spill and the area of distribution of a target resource—is straight forward. The "area-of-effect" of the spill is the area within which exposure conditions are sufficient to cause an effect. If a resource is broadly distributed, such as the brown shrimp, an oil spill is likely to contact only a very small proportion of the stock and the impact will be very small. On the other, if the area of distribution of a resource is relatively small, such as the pelagic foraging areas of local Brown Pelican stocks on the coast of Texas, there is potential for contaminating a large portion of the area with an oil spill and causing a large impact.

6.2.6 Recovery Potential

A critical consideration in dispersant decision-making is the speed with which resources can recover after they are damaged by a spill. Recovery rates vary with the type of resource, type of extent of injury. Phytoplankton populations can be expected to recover quickly, within days after being damaged by a spill. A lightly oiled section of coastal marsh might require from a few months to a year or more to recover, provided only the above-ground portions of the plants were affected. A stand of red mangrove might require many years to recover if a large proportion of the adult trees are killed by a spill. Recovery times for different resources in this study are summarized in Table 6-5.

Table 6-5 Time Required for Recovery from Significant Damage for A Range of ResourceTypes

Valued Environmental Resource	**Recovery Time**				
	Weeks	**Months**	**One Year**	**Several Years**	**Many Years**
Recreational waterfronts (a)	▨	▨			
Wetlands		▨	▨	▨	
Commercial Fishing (b)		▨	▨	▨	
Crustaceans (shrimp, crabs)			▨	▨	
Finfish (drums, croaker)				▨	
Molluscs (oysters, scallops)				▨	
Coastal and Marine Birds (terns, skimmers)				▨	▨
Sea Turtles					▨
Marine Mammals (whales, dolphins)					▨

a. Provided oiled beaches are cleaned up.

b. Provided disruption is caused by closure or contamination of the stock.

6.2.7 Relative Importance of Valued Environmental Components

All of the factors considered above deal with actual damage to resources. When assessing net environmental benefit , it is important to recognize that stakeholders do not place equal value or importance on all environmental components and their valuation should be taken into account. There is no single accepted approach or formula for rating the relative importance of sources. In general, criteria include such factors as economic, ecological, social and moral factors, but criteria and relative values vary from place to place.

In the present treatment it has not been possible to make fine distinctions in value among resources. Instead we have used our experience in workshops on this subject and have valued certain resource types namely: oil-sensitive habitats (e.g., coastal marsh); endangered species; and economic resources (e.g., commercial fisheries, recreational bathing beaches) more highly than others (e.g., non-endangered shorebirds).

6.2.8 Assessing Net Environmental Benefit

The final step in the analysis of a spill scenario is to compare the potential impacts of the untreated and chemically dispersed cases in order to determine whether chemical dispersion offers a net environmental benefit in this case. The approach taken here was to list all of the resources at risk from the spill, in either the untreated or chemically dispersed cases, based on the above. The level of risk to each resource was estimated using the criteria in Table 6-3 and the information on the exposure to oil and the sensitivity, vulnerability, spatial distribution and recovery potential of each resource. This information was tabulated as in example Table 6-6 below.

. **Table 6-6** Example Summary of Environmental Risks for a Spill Scenario:
Batch Spill 2b Launched from Texas Nearshore Site in Summer

Valued Environmental Component (VEC)	Impact of Treatment	
	Untreated Case	Chemically-Dispersed Case
SENSITIVE HABITAT		
Coastal Marsh	Low	No Effect
WILDLIFE		
Brown Pelican (E/F)(a)	Medium	No Effect
Least Tern (E/F)	Medium	No Effect
Royal Tern	Very Low	No Effect
Piping Plover (E/F)	Medium	No Effect
Snowy Plover	Very Low	No Effect
Peregrine Falcon	Very Low	No Effect
MARINE REPTILES		
Kemp=s ridley Sea Turtle (E/F)	Low	No Effect
Leatherback Sea Turtle (E/F)	Low	No Effect
Loggerhead ST	Low	No Effect
FINFISH, SHELLFISH AND FISHERIES (b)		
White Shrimp	Very Low	Very Low (Low)
Brown Shrimp	Very Low	Low (Medium)
Atlantic Croaker	Very Low	Low
SHORELINES		
Sand Scarps, Sand Beach	4km	0
HUMAN USE FEATURE		
Amenity Sand Beach	Medium	No Effect
Padre Island Nat. Seashore	Very Low	No Effect

a. F/E = Endangered Species Federally
b. All impacts are on fisheries. Target fisheries are those landing catches in Texas

From the tabulated information in Table 6-6 it was possible to determine:

1. the potential damage to VECs from the untreated spill;
2. the degree to which this damage could be ameliorated through dispersant use; and
3. the potential increase in damage to any resources resulting from dispersant use.

This information was recorded and conclusions were drawn about the net environmental benefits or drawbacks of dispersant use in this scenario and any uncertainties associated with the assessment.

6.3 Analysis of Factors Influencing Net Environmental Benefit

This section considers the net environmental benefits of dispersant use for specific spill scenarios and launch sites in the Gulf Mexico. For each spill scenario, the environmental impact has been estimated for both the untreated and chemically dispersed cases, and the two impacts have been compared to determine whether dispersant use might reduce the overall environmental impact of the spill and yield a net environmental benefit. Combinations of launch sites and spill conditions have been selected to consider the influence of important variables, such as spill location, distance from shore; spill type (i.e., batch spill versus blowout) and season.

Overall, this project involves a bewildering combination of spill scenarios and launch sites, but for purposes of simplicity, the various combinations of spill conditions and launch sites can be divided into three groups, based on risk of shoreline contamination (Table 6-7—at end of section) as follows.

Spills that dissipate naturally. This group includes all of the spills that dissipate naturally offshore, causing no shoreline oiling or impact in the nearshore and intertidal zones. Included are spills of No-E or Low-E oils, which either do not emulsify or emulsify only slowly. These dissipate quickly in scenarios 1a, 1b, 2a and 4a for most launch points. It also includes smaller spills of persistent oils that take place well offshore, such as scenarios 6b and 7b for the launch points farthest offshore (Table 6-7).

Spills that could reach shore, but can be fully dispersed offshore. This group includes emulsifiable spills that would persist to reach shore if left untreated, but that emulsify slowly enough to allow dispersant operations to fully disperse the spills at sea. This group includes scenarios 2b and 4b for all launch points, as well as 6b and 7b for the launch points nearest to shore.

Spills in which dispersant operations do little to reduce the amount of oil reaching the shoreline. This group includes spills that emulsify quickly, resulting in considerable oil arriving at the shoreline. In these spills emulsification is so rapid that dispersant operations do little to diminish the amount of reaching shore. This includes moderate sized spills, which emulsify quickly, such as scenario 2c. It also includes very large spills of emulsifying oils in which the amount of oil spilled greatly exceeds the amount that can be dispersed within the time window. This includes scenarios 3 and 5.

Much of the analysis that follows is based on the middle group of spills above, that is, spills that could reach shore if untreated, but which can be fully treated near the spill site. This analysis offers the clearest view of the environmental tradeoffs. There is no formal analysis presented for the other spill groups, but they are mentioned in the discussion that follows the scenario analysis sections.

Five spill scenarios are fully analyzed:

1. Spill 2b launched from Mid-Point in summer (MP/2b/Summer) should present the simplest decision-making problem because dispersion takes place well offshore where risks should be low.

2. Spill 2b launched from Texas Nearshore in summer (Texas/2b/Summer) involves the launch point that is nearest to shore.

3. Spill 2b launched from Destin Dome in summer (Destin Dome/2b/Summer) is the only launch site in the Eastern Gulf, and has been included to examine the effects of spill location.

4. Spill 2b launched from Texas Nearshore in winter (Texas/2b/Winter) considers the effect of season.

5. Spill 4b launched from Texas Nearshore in summer (Texas/4b/Summer) considers the differences between batch spills and blowouts.

In the following sections the tables and figures for each scenario are placed at the end of the section.

Table 6-7 Summary of Levels of Shoreline Oiling

Launch **Site**	**Time To Shore (a)**	**Scenario**										
		1b	**2a**	**2b**	**2c**	**3**	**4a**	**4b**	**5a**	**5b**	**6-50**	**7-50**
SPILL SUMARY												
Total Volume	bbls	20,000	20,000	20,000	20,000	100,000	20,000	20,000	1,400,000	1,400,000	20,000	100,000
	m^3	3,180	3,180	3,180	3,180	15,898	3,180	3,180	222,575	222,575	3,180	15,898
Flow Rate & Duration	bbl/d x d	NA	NA	NA	NA	NA	5000X4	5000X4	100,000/14	100,000x14	5000X4	7200x14
Oil Type		No-E	Lo-E	Av-E	Hi-E	Hi-E	Lo-E	Av-E	Hi-E	Av-EA	Av-E	Av-E
Persistence	days (hours)	4.8(117)	4.6(111)	30(>720)	30(>720)	30(>730)	0.6 (15)	30(>720)	30(>720)	30(>720)	12.6(306	18(432)
Emulsion Time (b)	hours	>117	>111	58	7	7	>12	11	3	23	4.5	5
TEXAS NS-SUMMER												
Volume (m^3) (c)	2(48)	1165		2078	2346	11936	0	1947	166249	152288	1253	6773
Length of Shore Oiled, (m) (d)		4162		4162	4162	4162		420000	420000	420000	420000	420000
Max Conc (m3/m) (e)		279		499	563	2344	0	12.3	1053	964	7.9	42.9
Avg Conc (m3/m) (f)		279						4.6	395	362	2.9	16.1
TEXAS NS-WINTER												
Volume (m^3) (c)	6(144)	0	0	1861	2177	11247	0	1749	100840	135106	877	50279
Length of Shore Oiled, (m) (d)				15053	15053	15053		420000	420000	420000	420000	420000
Max Conc (m3/m) (e)		0	0	123	145	747	0	8.4	487	653	4.2	24.5
Avg Conc (m3/m) (f)								4.1	240	321.6	2	12

Table 6-7 Summary of Levels of Shoreline Oiling (Continued)

Launch **Site**	**Time To Shore (a)**	**Scenario**										
		1b	**2a**	**2b**	**2c**	**3**	**4a**	**4b**	**5a**	**5b**	**6-50**	**7-50**
MID-POINT-SUMMER												
Volume (m^3) (c)	7(168)	0	0	1675	1951	10521	0	1510	48148	116363	0	1919
Length of Shore Oiled, (m) (d)				18028	18028	18028		960000	960000	960000	960000	960000
Max Conc (m3/m) (e)				102	119	618		4.4	236.2	343.2	20.1	12.4
Avg Conc (m3/m) (f)								1.8	94.6	137.5	0.8	5
MID-POINT-WINTER												
Volume (m^3) (c)	29 (696)	0	0	1518	1716	9900	0	1152	31796	102306	0	0
Length of Shore Oiled, (m) (d)				98949	98949	98949		480000	480000	480000	480000	480000
Max Conc (m3/m) (e)				15.3	17.3	100		5.2	143.1	460.3	0	0
Avg Conc (m3/m) (f)								2.4	66.2	213.1	0	0
DESTIN DOME-SUMMER												
Volume (m^3) (c)	9(216)	0	0	1790	2097			1669	754002	128078	642	4139
Length of Shore Oiled, (m) (d)				24191	24191	24191	0	390000	390000	390000	390000	390000
Max Conc (m3/m) (e)				74	8608	453		8.6	377	661.7	3.3	21.4
Avg Conc (m3/m) (f)								4.3	193.3	328.4	1.6	10.6
DESTIN DOME-WINTER												
Volume (m^3) (c)	6(144)	0	0	1861	2177	11247	0	1709	100840	135106	877	5080
Length of Shore Oiled, (m) (d)				15053	15053	15053	0	13.7	806.7	108.1	7	40.6
Max Conc (m3/m) (e)				123	144	747		7.1	420.2	562.9	3.6	21.2
Avg Conc (m3/m) (f)												

Table 6-7 Summary of Levels of Shoreline Oiling (Continued)

Launch Site	**Time To Shore (a)**	**Scenario**										
		1b	**2a**	**2b**	**2c**	**3**	**4a**	**4b**	**5a**	**5b**	**6-50**	**7-50**
FLOWER GARDENS- SUMMER												
Volume (m^3) (c)	23(552)	0	0	1590	1828	10186	0	1331	38155	108554	0	0
Length of Shore Oiled, (m) (d)				72516	72516	72516		960000	960000	960000	960000	960000
Max Conc (m3/m) (e)				21.9	25.2	140		2.9	82.7	235.2	0	0
Avg Conc (m3/m) (f)								1.4	39.7	113.1	0	0
FLOWER GARDENS-WINTER												
Volume (m^3) (c)	30(720)	0	0	1518	1716	9900	0	1152	31796	102306	0	0
Length of Shore Oiled, (m) (d)				98949	98949	98949		480000	480000	480000	480000	480000
Max Conc (m3/m) (e)				15.3	17.3	100		5.2	143.1	460.3	0	0
Avg Conc (m3/m) (f)								2.4	66.2	213.1	0	0
LOUISIANA-SUMMER												
Volume (m^3) (c)	30(720)	0	0	1518	1716	9900	0	1152	31796	102306	0	0
Length of Shore Oiled, (m) (d)				98949	98949	98949		1140000	1140000	1140000	1140000	1140000
Max Conc (m3/m) (e)				15.3	17.3	100		4.6	127.2	409.2	0	0
Avg Conc (m3/m) (f)								1	27.8	89.7	0	0
LOUISIANA-WINTER												
Volume (m^3) (c)	30(720)	0	0	1518	1716	9900	0	1152	31796	102306	0	0
Length of Shore Oiled, (m) (d)				98949	98949	98949		900000	900000	900000	900000	900,000
Max Conc (m3/m) (e)				15.3	17.3	100		5.5	153.6	494.4	0	0
Avg Conc (m3/m) (f)								1.3	35.3	113.7	0	0

Table 6-7 Summary of Levels of Shoreline Oiling (Continued)

Launch	**Time To**	**Scenario**										
Site	**Shore (a)**	**1b**	**2a**	**2b**	**2c**	**3**	**4a**	**4b**	**5a**	**5b**	**6-50**	**7-50**
DEEPWATER-SUMMER												
Volume (m^3) (c)	30(720)	0	0	1518	1716	9900	0					
Length of Shore Oiled, (m) (d)				98949	98949	98949						
Max Conc (m3/m) (e)				15.3	17.3	100						
Avg Conc (m3/m) (f)												
DEEPWATER-WINTER												
Volume (m^3) (c)	30(720)	0	0	1518	1716	9900	0					
Length of Shore Oiled, (m) (d)				98949	98949	98949						
Max Conc (m3/m) (e)				15.3	17.3	100						
Avg Conc (m3/m) (f)												

a. Median length of time rquired for oil slick or spillet to travel from the spill site to the nearest shoreline (See Figure 6-3)

b. Estimated length of time required for oil to become fully emulsified under given conditions.

c. Volume of oil remaining when oil strands on shore

d. Length of shoreline oiled. For batch spills, equals width of slick at time of stranding. For blowouts, total width of all segments oiled (see Figure 6-2)

e. Maximum concentration = maximum level of shoreline oiling. For batch spills, equals volume/length of shore oiled. For blowout spill, equals (volume x proportion of oil stranding in segment receiving highest proportion of hits)/ width of segment.

f. Average oil concentration of oil on shore. For blowout spills only, equals (volume)/(number of segments oiled x width of segment)

6.3.1 Analysis of Spill Scenarios

6.3.1.1 Scenario Mid-Point/2b/Summer

This spill is a case in which a large proportion of the oil would reach shore if the spill were left untreated, but in which dispersion could be accomplished well offshore.

The MP/2b/Summer spill is a batch discharge of 3180 m^3 of Average-E oil. Under average summer wind conditions the slick would move northward. If left untreated, it would require four or more days to reach the nearest point of land and could strand at some point within segments 9 to 12. (Figure 6-2, 6-3, Map-6-1). For purposes of this analysis it has been assumed that the oil strands near Galveston Bay in segment 9, near 94^0 28' 30"W; 29^0 29' 00"N. At the point of stranding, an amount of 1935 m^3 of the oil persists, resulting in contamination of an 18-km length of shoreline at a level of 102 m^3 of oil per meter of shoreline (See Table 6-7). As discussed in Chapter 5, this spill could theoretically be treated fully with dispersants within 48 hours after the spill, within 28 km of the spill site. All dispersant spraying would take place at distances greater than 74km from land, over depths of 20 to 40 m.

The results of the impact analysis are provided in Tables 6-8a, b, and c. Table 6-8a summarizes the information concerning VECs at risk from this spill, based on the TCOSPR Toolkit (1999) and Table 6-8b summarizes the corresponding output of the MIRG/SL Ross model. The information concerning impact of untreated and dispersed spills from both of these sources are combined and summarized in Table 6-8c. The combined results can be summarized as follows.

In the untreated case, this spill threatens to contaminate an 18-km section of shoreline at an average level of 102 liters of oil per linear meter of shoreline. This level of contamination would require cleanup. This shoreline segment is also an amenity beach; this level of contamination and the associated cleanup activities would certainly disrupt its use as a recreational resource for at least many weeks. The level of impact for this recreational resource is LOW, because it is localized and of relatively short duration. The effective use of dispersants offshore would reduce the level of shoreline oiling to a negligible level and reduce the level of impact to NO EFFECT.

The untreated case would also pose a risk to local marine and coastal birds, including at least three endangered species: brown pelicans, least terns and piping plover. Only the local area would be affected, but the amount of oil involved would be sufficient to cause at least some mortalities among the more vulnerable species (e.g., pelicans, terns, skimmers). Risks to the less vulnerable shorebird species are less certain. The levels of risk to wildlife are modest and should be rated as VERY LOW. However, because some endangered species are at risk, the level of risk to these species is rated as MEDIUM. The effective use of dispersants offshore would eliminate this impact.

The oil slick traverses coastal areas inhabited by a number of finfish and shellfish species. While the spill poses very little risk of mortality to these stocks, the presence of oil slicks on the water will cause localized, short-term disruptions in fishing activities for several very important species, including shrimp and menhaden. These effects are small and are rated as VERY LOW.

Dispersing the spill offshore might offer some protection to the white shrimp and menhaden fisheries in the shallow nearshore areas and the impacts on these would be reduced to NO EFFECT. Dispersing the spill would raise the potential impacts on the brown shrimp fishery. Although there appears to be little risk of mortality to the stock, the cloud of dispersed oil and the possibility of contamination of the catch might result in closure of the fishery or condemnation of catches. This problem might persist for weeks to months, until it could be demonstrated that the habitat and fish tissues are free from spill-related contamination.

Net Change in Environmental Impact. On balance, the net effect of using dispersants appears to be positive. Dispersing offshore keeps the oil out of the nearshore area and thereby reduces the risks to: 1) the wildlife, including the endangered species; 2) the recreational beach; and 3) the nearshore fisheries for white shrimp and menhaden. These benefits appear to clearly outweigh the cost of the temporary disruption to the brown shrimp fishery, despite the fact that this fishery is by far the most lucrative in the state. Therefore, there would be a net environmental benefit associated with dispersant use in this offshore spill scenario.

Map 6-1 Movement of Untreated and Chemically Dispersed Spills: Scenario Mid-Point/2b/Summer

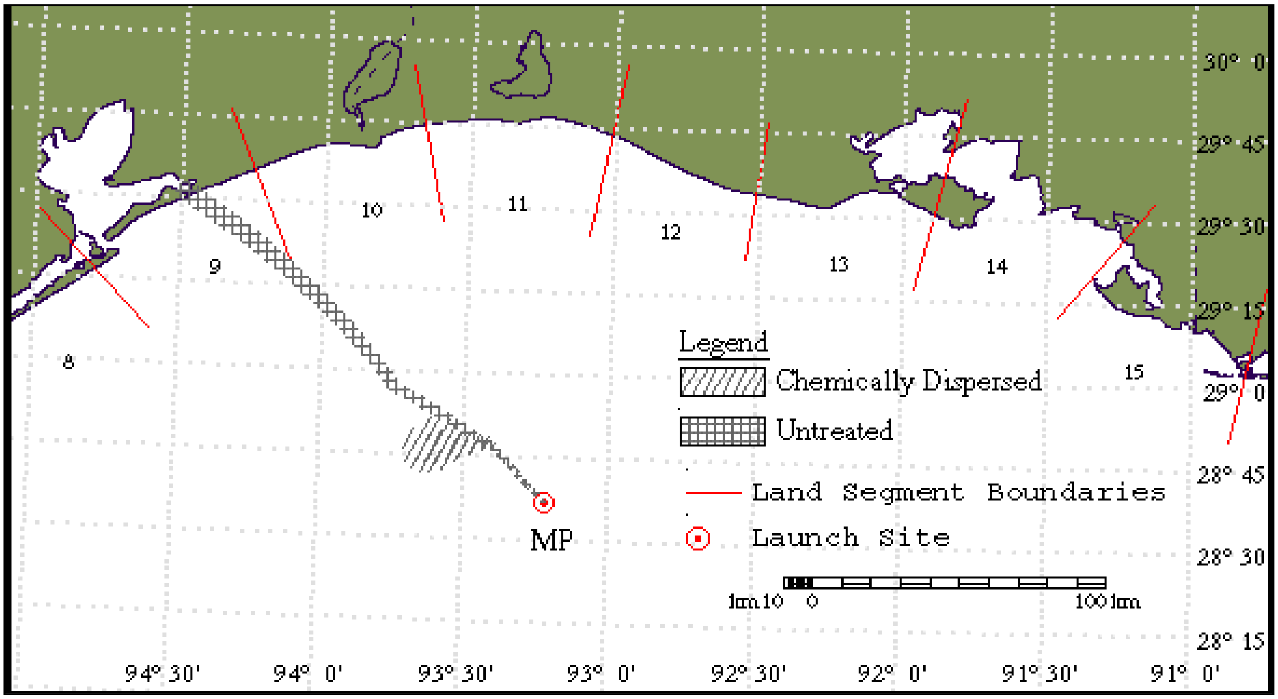


Table 6-8a Oil-Sensitive Resources at Risk from Untreated Spill:
Midpoint/2b/Summer (from TCOSPR 1999)(a)

Valued Environmental Components	**Shoreline Segments** **Caplen (b) 11 km**	 **High Island 13 km**	 **Mud Lake 13 km**
SHORELINES (km)			
Marsh Salt/Brackish	0	0	0
Exposed Tidal Flat	0	0	0
Rip Rap	0	0	0
Mixed Sand/Gravel	11	13	13
Steep Scarps, Sand	0	0	0
Steep Scarps, Clay	0	0	0
Exposed Walls,etc	0	0	0
SENSITIVITY POLYGONS			
High			
B. Pelican (F/E)	B.Pelican (c)	B.Pelican (c)	B. Pelican, foraging
Least Tern	Least Tern (c)	Least Tern (c)	Least Tern
Piping Plover	Piping Plover (c)	Piping Plover (c)	Piping Plover
Medium & Low	none	none	none
HUMAN USE	amenity beach	amenity beach	amenity beach
BIRDS-Coastal Species			
Brown Pelican F/E (d)	Brown Pelican F/E	Brown Pelican	Brown Pelican
Black Skimmer	Black Skimmer	Black Skimmer	Black Skimmer
Gulls	Gulls	Gulls	Gulls
Sandwich Tern	Sandwich Tern	Sandwich Tern	Sandwich Tern
Least Tern F/E	Least Tern F/E	Least Tern F/E	Least Tern F/E
Royal Tern	Royal Tern	Royal Tern	Royal Tern
BIRDS-Waders	Waders	Waders	Waders
Shorebirds	Shorebirds	Shorebirds	Shorebirds
Piping Plover	Piping Plover	Piping Plover	Piping Plover
Willet	Willet	Willet	Willet
Ruddy Turnstone	Ruddy Turnstone	Ruddy Turnstone	Ruddy Turnstone
Black-Bellied Plover	Bl-Bellied Plover	Bl-Bellied Plover	Bl-Bellied Plover
Sanderling	Sanderling	Sanderling	Sanderling
BIRDS-Offshore Species			
Franklin Gull	Franklin Gull		Franklin Gull
MARINE MAMMALS			
Bottlenosed Dolphin	Bottlenosed	Bottlenosed Dolphin	Bottlenosed Dolphin
MARINE REPTILES			
Loggerhead Sea Turtle			Sea Turtle, Loggerhead
Kemp's ridley Sea Turtle			Sea Turtle, Kemp's
FINFISH			
Spanish Mackerel	Spanish Mackerel	Spanish Mackerel	Spanish Mackerel
Menhaden	Menhaden		Menhaden
Tarpon	Tarpon	Tarpon	Tarpon
Mullet	Mullet		Mullet
Red Drum	Red Drum	Red Drum	Red Drum
Fl Pompano	Fl Pompano	Fl Pompano	Fl Pompano
Crevalle Jack	Crevalle Jack		
Sharks	Sharks		Sharks
Southern Kingfish	Southern Kingfish	Southern Kingfish	Southern Kingfish
Catfish, Hardhead			Catfish, Hardhead
Kingfish, Gulf			Kingfish, Gulf
SHELLFISH			
White Shrimp	White Shrimp	White Shrimp	White Shrimp

a. From Texas Coastal Oil Spill Planning and Response Toolkit Atlas, 1999.
b. Name of Map, distance is length of Gulf of Mexico shoreline.
c. Refer to Mud Lake section for description
d. F/E = Federal Endangered Species

Table 6-8b
Impacts of Dispersed and Untreated Cases:
Scenario Midpoint/2b/Summer (from MIRG/SLRoss)

Valued Environmental Component (a)	Untreated (b,c)	Overall Dispersed
SHELLFISH/FISHERIES		
Brown Shrimp	0 (0.2, 0.4)	0 (1.0 2.0)
White Shrimp	0 (0.04 0.3)	0.04 (0.03 0.03)
Blue Crab	0 (0.8)	0.01 (0.01 0.01)
FINFISH/FISHERIES		
Kingfish, Southern	0 (0 0.6)	0 (0 0.6)
Atl. Croaker	0 (0 0.5)	0 (0 0)
Snapper, Red	0 (0 0)	0 (0.01 0.01)
Pompano, Florida	0 (0 3.8)	0.03 (0 0.03)
Southern Flounder	0 (0 0.3)	0 (0.08 0)
Mackerel, Spanish	0 (0 0)	0.01 (0.01 0)
Menhaden	0 (0.3 0)	0 (0 0)
MARINE BIRDS		
Tern, Least (Texas)	0.02	0
Tern, Royal (Gulf)	0.01	0
Pelican, Brown (Texas)	0	0
Piping Plover (W. Gulf)	0	0
sanderling (Gulf)	0.02	0
Skimmer, Black (W. Gulf)	0.1	0
Gull, Laughing (Texas)	0.2	0
Turtle, Leatherback (West Atlantic)	0.1	0
SENSITIVE SHORELINES/HABITAT		
Amenity Beach	6.7	0
PROPERTY		
none		
SHORELINES		
Marsh		
Mangrove		
Amenity Beach km	6.7	0
Non-Amenity Beach	0	0
Tidal Flast	0	0
Tidal flat / Mangrocwve	0	0
Stoney Waterfront	0	0
Rocky Shore	0	0
Wall	0	0
	0	0
LEVEL OF OILING (l/m)	102	0

a. Name in brackets identifies the population or stock affected.
b. Values in brackets are net reduction in annual yield to the Louisiana and Texas commercial fisheries, respectively.
c. Based on output of MIRG/SL Ross Oil Spill Impact Assessment Model for the Culf of Mexico (Trudel et al. 1989)

Table 6-8c Summary of Environmental Risks: Mid Point/2b/Summer		
Valued Environmental Component (VEC)	**Treatment Option**	
	Untreated	**Chemically-Dispersed**
SENSITIVE HABITAT		
none	none	none
WILDLIFE		
Brown Pelican (E/F)(a)	Medium	No Effect
Least Tern (E/F)	Medium	No Effect
Royal Tern	Very Low	No Effect
Black Skimmer	Very Low	No Effect
Laughing Gull	Very Low	No Effect
Piping Plover (E/F)	Medium	No Effect
Sanderling	Very Low	No Effect
MARINE REPTILES		
Kemp=s ridley Sea Turtle (E/F)	Low	No Effect
Leatherback Sea Turtle (E/F)	Low	No Effect
FINFISH, SHELLFISH AND FISHERIES (b)		
Brown Shrimp	Very Low	Low
White Shrimp	Very Low	Very Low
Menhaden	Very Low	No Effect
Spanish Mackerel	No Effect	No Effect
Drum	No Effect	No Effect
Red Snapper	No Effect	No Effect
SHORELINES		
Sand/Gravel Beach	18 km	
HUMAN USE FEATURE		
Amenity Sand/Gravel Beach	Low	No Effect
a. F/E = Endangered Species Federally b. All impacts are on fisheries. Target fisheries are those landing catches in Texas		

6.3.1.2 Scenario Texas NS/2b/Summer

This scenario was selected because the spill takes place closer to shore than any other and therefore poses the greatest risk of interacting with the shallow nearshore environment.

This is a batch spill of 3180 m^3 of Average-E oil. Under average summer wind conditions, this spill would move northward and if left untreated reaches land very quickly, within 2 to 3 days, stranding at some point within segments 3 to 5 (Figure 6-2, 6-3, Map 6-2). For purposes of this analysis, it has been assumed that the oil strands in Segment 5, on Matagorda Island near San Antonio Bay near $96^0$34' 50" W; $28^0$15'06" N. At this point 2078 m^3 of oil persists, oiling a stretch of shoreline 4.1 km long at a concentration of 499 l/m (Table 6-7). As described above, this spill could be theoretically fully treated within 48 hours after the spill, within a distance of 40 km from the spill site. The spill site lies at a distance of 42 km from the nearest point of land, in 50m+ deep water. If dispersant operations are completed within 48 hours, spraying would initially take place in deep, offshore waters (pre-authorized zone), but operations on the second day will take place in or near the shallow waters.

Data concerning the environmental risks derived from TCOSPR (1999) and the MIRG/SLRoss Model are summarized in Table 6-9. The untreated spill threatens to oil a 4-km stretch of shoreline at a level of 499 l/m of sandy shoreline. This contamination would require cleanup. The shoreline is an amenity beach. This level of oiling, coupled with the associated cleanup activities would render this portion of the beach, as well as adjacent sections unusable for a period of weeks during a portion of the peak season. The level of impact for this recreational resource is LOW. This section of shoreline is also a part of the Matagorda Island State Park and National Wildlife Refuge. Shoreline oiling may also reduce visitation to the park causing a LOW impact for this feature as well. However, MMS GOM OCS (1998) suggests that the potential impact of shoreline contamination on overall park visitation might be very minor and short-lived, so that this impact might be as low as VERY LOW. This uncertainty over the potential impact of the spill on park usage must be recognized in assessing NEB. In either case, however, the effective use of dispersants offshore would prevent oiling and would eliminate this effect.

The untreated slick would pose a risk to local marine and coastal birds, including three protected species: brown pelican, least tern and piping plover. Only the immediate local area would be affected, but the amounts of oil and conditions of the slick are such that at least some individuals would be killed. Because some mortalities to endangered species can be expected, the level of risk is MEDIUM. The effective use of dispersants offshore would eliminate this effect and reduce the level of impact to NO EFFECT.

The trajectory of the slick traverses the habitat of all five local species of endangered or protected sea turtles. The portion of the range of each species involved is very small and the threat to sea turtles from oil are uncertain. Moreover, although this time of year is the breeding season for these turtles, sensitivity information indicates there is no nesting activity that takes place on or near the threatened segments of the coast. However, as these turtles are endangered or protected, the level of risk is changed from being VERY LOW to LOW. The risk would be reduced by dispersing the slick near the spill site, thereby minimizing the potential for contact between oil slicks and turtles.

The slick trajectory also traverses areas inhabited by a number of finfish and shellfish species. The spill poses little risk of mortality to these stocks, but the presence of oil slicks will cause localized, short-term disruptions of fishing activities. These effects will be brief and localized and are rated as VERY LOW. Dispersing the spill in the offshore will offer some protection to the white shrimp fishery that takes place near shore. However, using dispersants near the spill site will result in elevated levels of contamination in the upper water column in areas where brown shrimp are fished. Dispersants may increase the impacts on the brown shrimp fishery by increasing the areal extent and duration of the closure of the local fishery. Although the effects of dispersion are brief and localized, the spill occurs in a highly productive shrimp fishing area during an important part of the shrimp fishing season. As a result the level of risk is rated as LOW.

Net Change in Environmental Impact. The net effect of using dispersants may be positive, but the decision is not clear cut. Using dispersants near the spill site keeps the oil out of the coastal zone and reduces the risks to: 1) the wildlife, including the endangered or protected species; 2) the recreational beach and wildlife refuge; and 3) the nearshore fisheries for white shrimp. These benefits may outweigh the cost of the temporary disruption to the brown shrimp fishery. However, this decision will depend on the relative values placed on the resources by the local human population. The complexity of the judgment is heightened in this particular scenario because the shrimp fishery is by far the most economically important fishery in Texas (Table 6-2) and this spill takes place both near the peak in the fishing season in a very productive fishing zone. However, the decision might still favor dispersants because of two arguments; first, the shrimp fishery might be closed whether dispersants are used or not, so this lessens the importance of this factor as an argument against dispersants; and second, the impact of the dispersed oil on the fishery will be short-lived, a few months at most, while the damages to wildlife may have long-lasting consequences. The uncertainty surrounding the impact of the spill on visitation at the Matagorda Island State Park/NWR could influence this decision, in that the greater the potential impact of the untreated spill, the greater the NEB of dispersant use.

Map 6-2 Movement of Untreated and Chemically Dispersed Spills: Scenario Texas NS/2b/Summer

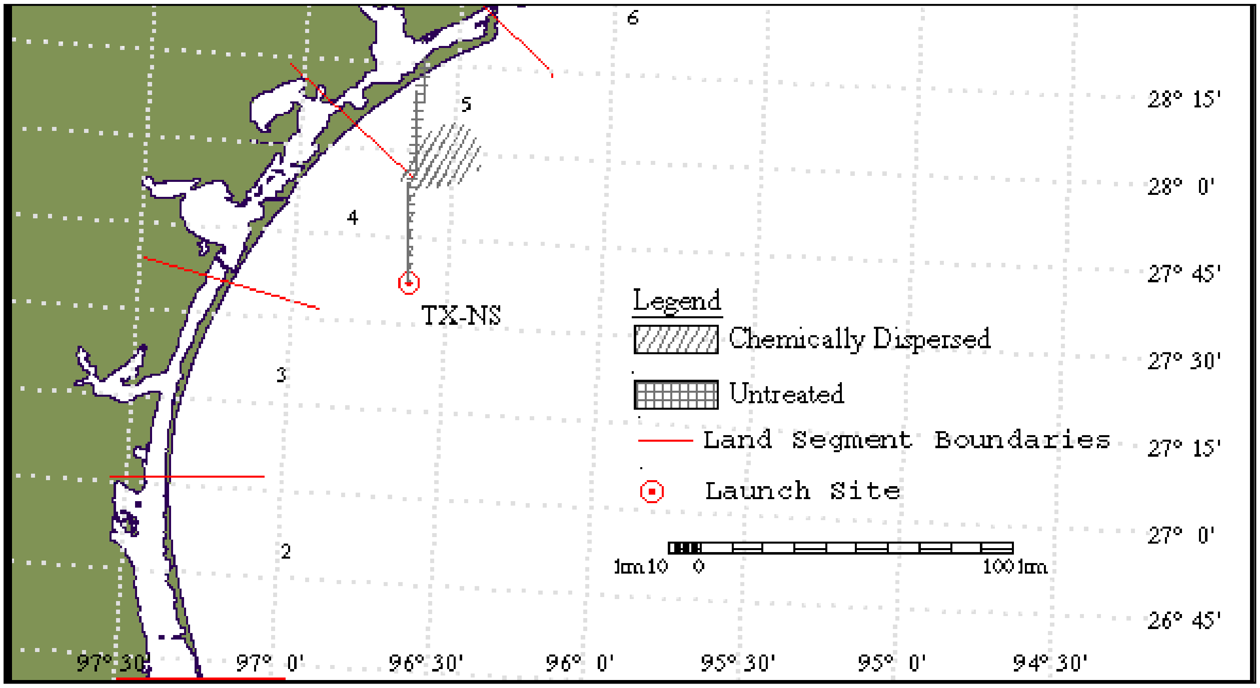


Table 6-9 Summary of Environmental Risks: Texas Nearshore, Scenario 2b, Summer

Valued Environmental Component (VEC)	**Treatment Option**	
	Untreated	**Chemically-Dispersed (a)**
SENSITIVE HABITAT		
none	None	none
WILDLIFE		
Brown Pelican (E/F)(a)	Medium	No Effect
Least Tern (E/F)	Medium	No Effect
Royal Tern	Very Low	No Effect
Black Skimmer	Very Low	No Effect
Piping Plover (E/F)	Medium	No Effect
Sanderling	Very Low	No Effect
Snowy Plover	Very Low	No Effect
Peregrine Falcon	Very Low	No Effect
MARINE REPTILES		
Kemp=s ridley Sea Turtle (E/F)	Low	No Effect
Leatherback Sea Turtle (E/F)	Low	No Effect
Hawksbill Sea Turtle (E/F)	Low	No Effect
Green Sea Turtle (E/F)	Low	No Effect
Loggerhead Sea Turtle (T/F)	Low	No Effect
FINFISH, SHELLFISH AND FISHERIES (b)		
White Shrimp	Very Low	Very Low (Low)
Brown Shrimp	Very Low	Low (Medium)
Atlantic Croaker	Very Low	Low
SHORELINES		
Sand Scarps, Sand Beach	4km	0
HUMAN USE FEATURE		
Amenity Sand Beach	Low	No Effect
Matagorda Island SP/NWR	Very Low - Low	No Effect

a. F/E = Endangered Species Federally, T/F=Threatened Federally
b. All impacts are on fisheries. Target fisheries are those landing catches in Texas

6.3.1.3 Scenario Destin Dome/2b/Summer

All of the scenarios in this analysis, except this one, involve spills that strand on the barrier islands off the Texas coast. This scenario has been included to consider the environmental issues in a different part of the Gulf.

This is a batch spill of 3180 m^3 of Average-E oil. Under summer winds, this spill would move NE and would land, on average in 9 days, stranding at some point within segments 5 to 17 (based on Price et al. 1998) (Figure 6-2, 6-3, Map 6-3). For purposes of this analysis, it has been assumed that the oil strands in Segment 10, near the entrance to Mobile Bay and the eastern end of Mississippi Sound. At this point 1790 m^3 of oil persists, oiling a stretch of shoreline more than 24 km long at a concentration of 74 l/m (Table 6-7). The spill could be dispersed 48 hours after the spill, within a distance of 28 km of the spill site. The spill site lies at a distance of 33 km from the nearest point of land, in 46m+ deep water. If dispersant operations are completed within 48 hours of the time of the spill, spraying would take place in offshore waters (pre-authorized zone) further than 28 km from shore in depths of 20 to 30 m. The resulting cloud of dispersed oil would be carried westward.

Data concerning the environmental risks derived from the Gulf-Wide Information System and the MIRG/ SLRoss Model are summarized in Table 6-10. The oil from the untreated spill will strand on the barrier islands and within Mississippi Sound. Since the oil will enter the sensitive Mississippi Sound system, the impacts of the untreated spill can be expected to be greater than those seen in any of the Western Gulf spills. The spill will contaminate several tens of kilometers of sand beach and coastal marsh at a level of 79 m^3 of oil per meter of shoreline. This contamination would require cleanup. The shoreline is an amenity beach. Oil contamination and cleanup activities would render this and adjacent portions of beach unusable for a period of weeks during a portion of the peak season. The level of impact for this recreational resource is LOW. The oil-threatened marsh and oyster reef are both important habitat features. The marsh is highly sensitive and is likely to suffer, at least, mortality of vegetation, with recovery taking several years. This a small portion of the marsh in the Mobile Bay-Mississippi Sound-Chandeleur Sound system, but it is an extensive amount of habitat from a local perspective, so the impact level is set at MEDIUM. The likelihood of damage to the oyster reef is less and risks are rated at VERY LOW. There are risks of mortality to a number of wildlife species, including at least two endangered bird species. There are also risks to a number of fisheries. The most notable are the risks to the inshore shellfish species, oysters and crab. Oil could be prevented from entering the bay system and the risks could be reduced to NO EFFECT by dispersing the oil in open coastal waters near the spill site.

Dispersing the spill offshore, near the spill site will result in localized contamination of the surface waters. The dispersed oil is unlikely to cause mortality to adult fish and shellfish in the area, but it may result in a temporary loss of fishing opportunity for shrimp and finfish fishing in the area outside Mobile Bay. This disruption may be brief, lasting from weeks to months. The impacts on these shrimp and finfish fisheries are rated as VERY LOW to MEDIUM, depending on the species.

Net Change in Environmental Impact. The environmental benefits of keeping the oil out of the Mississippi Sound system are clear. Dispersing the oil in the open coastal waters protects important habitat, inshore fisheries and wildlife. The potential cost of dispersion to the commercial fishery would be considerable and cannot be overlooked. However, these short-term costs to the fisheries are clearly outweighed by the environmental gains.

Map 6-3 Movement of Untreated and Chemically-Dispersed Spills: Destin Dome/2b/Summer

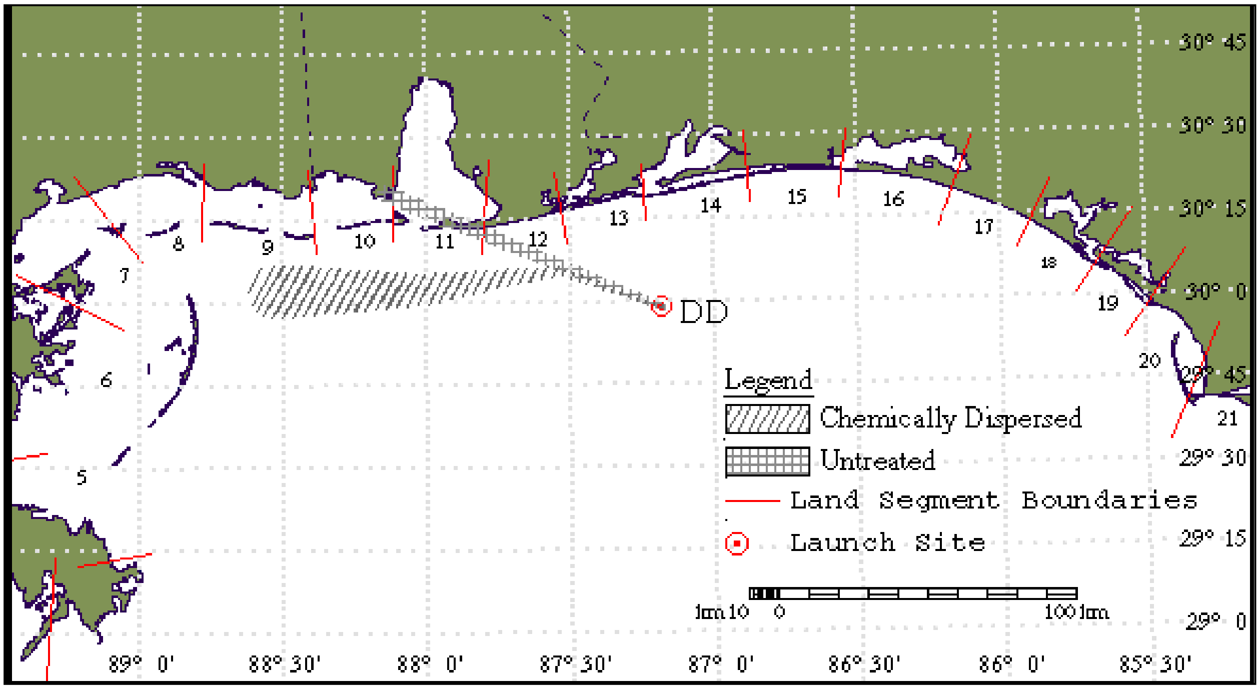


Table 6-10 Summary of Environmental Risks: Destin Dome/2b/Summer		
Valued Environmental Component	**Treatment Option**	
	Untreated	**Chemically-Dispersed**
SENSITIVE HABITAT (a)		
Coastal Marsh (Mobile-Chandeleur)	Medium	No Effect
Oyster Reef (Mobile-Chandeleur)	Very Low	No Effect
WILDLIFE (a)(b)		
Brown Pelican (E/F)	Medium	No Effect
Least Tern (E/F)	High	No Effect
Royal Tern	Very Low	No Effect
Black Skimmer	Very Low	No Effect
Laughing Gull	Very Low	No Effect
Sanderling	Very Low	No Effect
MARINE REPTILES		
Leatherback Sea Turtle (E/F)	Low	No Effect
FINFISH, SHELLFISH AND FISHERIES (c)		
Oyster	Very High	No Effect
Blue Crab	Low	No Effect
Sea Trouts/Drums	Low	Low
Brown Shrimp	No Effect	Medium
White Shrimp	Very Low	Very Low
Menhaden	Very Low	Medium
SHORELINES (km)		
Sand Beach	20.7	0
Coastal Marsh	7.9	0
HUMAN USE FEATURE		
Amenity Sand/Gravel Beach	Low	No Effect

a. Brackets indicate population or stock
b. F/E = Endangered Species Federally
c. All impacts are on fisheries. Target fisheries are those landing catches in Mississippi and Alabama

6.3.1.4 Scenario Texas/2b/Winter

This scenario is included in order to consider the effect of season on impacts and benefits by contrasting it to scenario Texas/2b/Summer, analyzed above.

In this winter batch spill of 3180 m^3, winds would move the spill to the west, rather than to the north and if left untreated the slick would reach land, within 6 days, stranding within segments 2 to 4 (Figure 6-2, Map 6-4). We assume that the oil strands at the margin of Segments 2 and 3, on Padre Island off Baffin Bay near 97°20' W; 27°14'30"N. At this point 1861 m^3 of oil strands on shore, oiling a stretch of shoreline 15 km long at a concentration of 123 l/m (Table 6-7). This spill could be fully treated within 48 hours after the spill, within 28 km of the spill site, while the spill was still more than 25 km from the nearest point of land, in waters 20 to 60m deep.

The untreated winter spill threatens to contaminate a 15-km stretch of sandy shoreline at a level of 123 l/m and would require cleanup (Table 6-11). The shoreline is an amenity beach and this oiling, coupled with the associated cleanup activities would render this portion of the beach and adjacent areas unusable for a period of weeks. The level of impact for this recreational resource is LOW. This shoreline is part of the Padre Island National Seashore. As discussed above in Scenario Texas NS/2b/Summer, there is considerable uncertainty concerning the potential impact of shoreline oiling on potential visitor traffic in the Park during the spill and cleanup. For this reason the level of impact is rated as VERY LOW to LOW.[10] The effective use of dispersants offshore would prevent oiling and would eliminate this effect.

The untreated slick would pose a risk to local wildlife. At this time of year the species at risk include some of the same species that are at risk during the summer months, but also includes some species that breed in more northern latitudes and winter in the south. The resources at significant risk include the protected species: brown pelican and piping plover, as well as other marine associated birds, waders and shore birds, including snowy plover, sanderling and laughing gull. The amounts of oil

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[10] In addition, it appears that the physical layout of the park, with access via only a single road, may mean that the spill and cleanup operations may completely prevent access to sections of the park south of the contaminated area. This would mean that a larger portion of the park would be inaccessible for a period of a few weeks and the impact would be LOW.

and conditions of the slick are such that a portion of the individuals present would be killed. However, because all of the species in question are broadly distributed throughout the area and since only the local area would be affected, the risks to non-protected species would be VERY LOW. Because of their protected status the risks to protected species are rated at MEDIUM. The effective use of dispersants offshore would prevent oil from reaching these species and reduce the level of impact to NO EFFECT.

The trajectory of the slick traverses the habitat of all five local species of endangered or threatened sea turtles. However, the distribution range of all of these species is very large and at this time of year all individuals are widely dispersed throughout their ranges. The portion of the range of each species involved with the spill is very, very small and the vulnerability of sea turtles to oil slicks is uncertain, so the risk of significant mortalities from this spill is probably small. However, as all of these turtles are endangered or threatened worldwide, the level of risk is taken to be LOW. Dispersing the slick near the spill site would reduce the risk.

The slick trajectory traverses offshore and coastal areas inhabited by a number of finfish and shellfish species. The presence of oil slicks can cause short-term disruptions to any fishing activity in progress at the time of the spill. These effects will be localized and of short duration, so risks to these fisheries are rated as VERY LOW. In this case the spill occurs at the low point of the fishing season for the shrimp fishery and, therefore, the level of risk to this fishery as a whole is less than VERY LOW. Dispersing the spill in the offshore will eliminate any risk to the inshore shrimp fishery.

Using dispersants in the near offshore will probably result in a temporary closure of the fishing zones involved, for as long as elevated levels of hydrocarbons are detectible in the water column. The resulting impacts on the brown shrimp fishery would be VERY LOW. One additional consideration in this connection is oil contaminating the shoreline and nearshore sub tidal area might serve as a source of contamination for nearshore shrimp fishing areas for some months until cleaned up. This untreated oil might disrupt the nearshore portion of the shrimp fishery locally for months after the spill, thereby increasing the impact of the spill somewhat.

Net Change in Environmental Impact. The net effect of using dispersants will be positive in this case. Dispersant use near the spill site keeps the oil out of the coastal zone and reduces the risks to: 1) the wildlife, including the endangered species; and 2) the recreational beach. Dispersant use still poses a risk to the shrimp fishery in the near offshore waters, but these effects small because these fisheries are less active at this time of year. In short, there is a net environmental advantage to using dispersants in this winter spill. The advantages of dispersant use are more clear cut in the winter spill because of the seasonality of the fishery.

Map 6-4 Movement of Untreated and Chemically-Dispersed Spills: Texas/2b/Winter

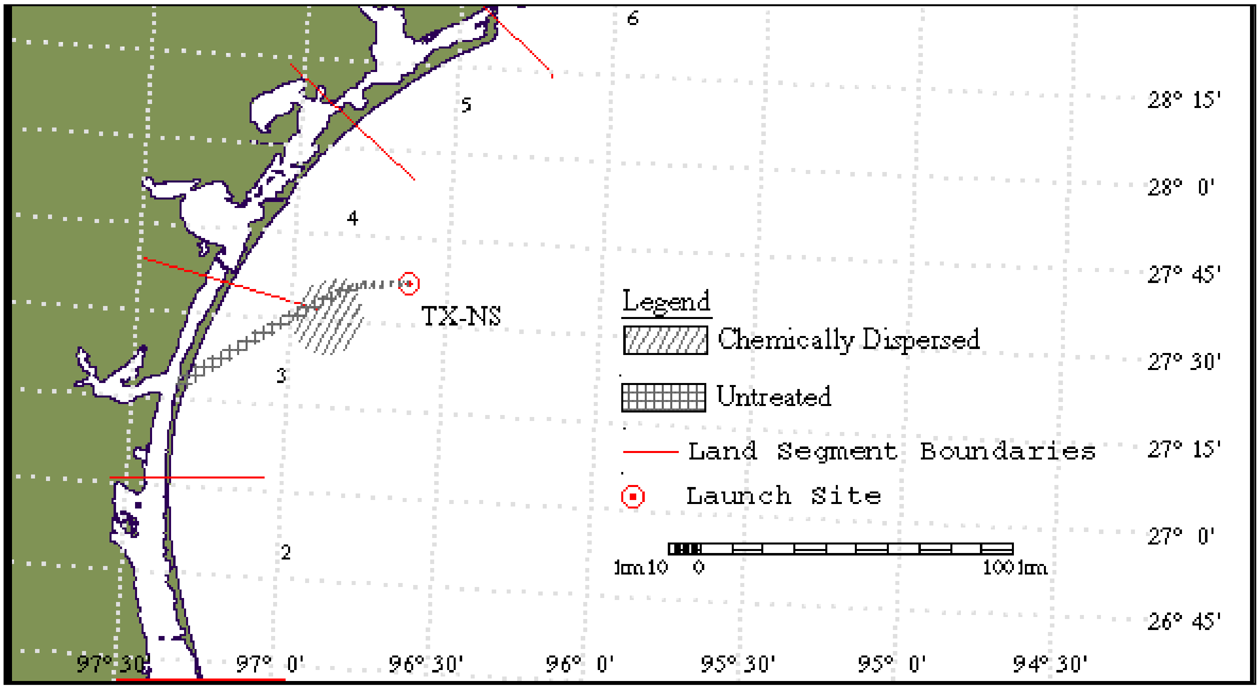

Table 6-11 Summary of Environmental Risks: Texas Nearshore, Scenario 2b, Winter

Valued Environmental Component (VEC)	**Treatment Option**	
	Untreated	**Chemically-Dispersed (a)**
SENSITIVE HABITAT		
none	none	None
WILDLIFE		
Brown Pelican (E/F) (a)	Medium	No Effect
Piping Plover (E/F)	Medium	No Effect
Snowy Plover	Very Low	No Effect
Loon	Very Low	No Effect
Sanderling	Very Low	No Effect
Laughing Gull	Very Low	No Effect
MARINE REPTILES		
Kemp's Ridley Sea Turtle (E/F)	Low	No Effect
Leatherback Sea Turtle (E/F)	Low	No Effect
Hawksbill Sea Turtle (E/F)	Low	No Effect
Green Sea Turtle (E/F)	Low	No Effect
Loggerhead Sea Turtle (T/F)	Low	No Effect
FINFISH, SHELLFISH AND FISHERIES (b)		
White Shrimp	Very Low	No effect
Brown Shrimp	Very Low	Low
Atlantic Croaker	Very Low	Low
SHORELINES		
Sand Scarps, Sand Beach	4km	0
HUMAN USE FEATURE		
Amenity Sand Beach	Low	No Effect
Padre Island Nat. Seashore	Very Low-Low	No Effect

a. F/E = Endangered Species Federally. T/F = Threatened Federally.
b. All impacts are on fisheries. Target fisheries are those landing catches in Texas.

6.3.1.5 Blowout Scenario Texas Nearshore/4b/Summer

This scenario is included in order to address differences between blowout spills and batch spills in terms of their overall impact and the net environmental benefit of dispersant use.

This scenario involves a blowout spill discharging 795 m^3 of Av-E oil per day over four days, for a total discharge of 3180 m^3. The spill is simulated as a continuous discharge of a series of small (0.8 m^3) spillets, each of which moves independently under wind and current conditions encountered at the time of discharge. According to the oil spill analysis in Price et al. (2000), under average summer wind conditions, these spillets would move in directions ranging from NW to SW, with the majority of the oil would reaching land quickly, within 2 to 4 days. Similarly, these spillets would contaminate shoreline segments 0 through 6 in the western Gulf to some degree, with most of the oil stranding on segments 3 to 5 (Figure 6-2, 6-3, Map 6-5)[11]. For purposes of this analysis, it has been assumed that the oil will strand in segments 2 to 5. A total of 1947 m^3 of oil will accumulate on shore and the average levels of shoreline oiling in these segments will be as follows: Segment 2 = 1.6 l/m; Segment 3 = 4.5 l/m; Segment 4 = 12 l/m; Segment 5 = 11 l/m. Clearly, according to this simulation, a far greater length of shoreline would become oiled by this blowout than by the batch spill of the same size (Section 6.3.1.2).

As described in section 5.3.1.4, this spill could be largely dispersed at sea, with all dispersant operations taking place within 10 km or less of the blowout site. The spill site lies at a distance of 42 km from the nearest point of land, in 50 m+ deep water. If dispersant operations are completed within 10 km of the spill site, spraying would take place in deep, offshore waters.

It is important to recall that the dispersant operation was not fully effective in treating the oil in this scenario. In fact, approximately 250 m^3 of crude oil escaped the dispersant operation without being chemically dispersed. Allowing for weathering, this would translate to approximately 150 m^3 of crude oil arriving at shorelines, or less than 10% as much as in the untreated case. On average, the resulting levels of shoreline oiling would be less than 1 l/m. These levels of shoreline oiling are too

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[11] In Price et al. (2000), Segment 0 represents International Land.

low to require cleanup and would pose little risk to even the most sensitive shorelines and species (Table 6-4).

Data concerning the environmental risks derived from TCOSPR 1999 and the MIRG/SLRoss Model are presented briefly in Tables 6-12a and 6-12b, respectively, and all of the information is summarized in Table 6-12c. The untreated spill threatens to contaminate a far larger area of nearshore water and shoreline and cause far more damage than the batch spill of similar size. The blowout contaminates over 100 km of shoreline at oil concentrations greater than 10 l/m of shoreline. This contamination would require cleanup. This oiling, and the widespread cleanup activity would disrupt recreational use of the beaches throughout the affected region for months during a high-use period. The level of impact for this recreational resource is MEDIUM. The sections of shoreline affected are part of Matagorda Island State Park/National Wildlife Refuge and Padre Island National Seashore. Large sections of the shore of these areas would become oiled and this would disrupt their use temporarily. The level of impact is rated as MEDIUM. (NOTE: It is important to recognize that these impacts are rated as "MEDIUM" because, although the disruption is very extensive, it is of relatively short duration (< 1 year)).

The untreated spill would pose a risk to marine and coastal birds, including three protected species—brown pelican, least tern and piping plover—over a wide area. Slick thicknesses and concentrations of oil in the nearshore foraging areas will be sufficient to cause mortalities. This would occur over a large area and would threaten a significant proportion of these local populations. For this reason the impacts on the endangered species are rated as VERY HIGH.

The trajectory of the slick traverses the habitat of all five local species of endangered or threatened sea turtles, but more importantly, this spill would contaminate sections of nesting beach for the Kemp=s Ridley sea turtle, the most endangered of the sea turtles, in or near nesting season. The risk to the Kemp=s Ridley sea turtle is rated as VERY HIGH. All of these risks would be reduced to NO EFFECT or at worst, VERY LOW, if the spill were dispersed at source.

As discussed above, dispersing the spill near its source would cause a disruption of the important brown shrimp fishery due to closure or contamination of catch. This impact would be very localized and temporary (weeks to months). Indeed, the area of contamination would be smaller than in the batch spill because dispersant spraying would take place within a much smaller area than in the batch spill. As a result, the impacts would be LOW. Although the overall impact is rated as LOW, the potential economic costs could be significant because: a) the shrimp fishery is very highly valued; and b) the spill occurs in a productive area at the height of the season.

Net Change in Environmental Impact. The environmental benefits of dispersant use in this scenario are overwhelmingly evident. The analysis suggests that the untreated blowout will contaminate a much larger area than the batch spill. The average levels of contamination are lower than in the batch spill (because the oil is spread over a much larger area), but levels of contamination in segments 4 and 5 are sufficient to cause significant effects and impacts. As a result, the impact of this untreated blowout will be far greater than the corresponding batch spill.

The risks associated with dispersing the blowout spill are different from those of the batch spill. On the one hand, the risks to the fisheries would be less in the blowout spill than in the batch spill, because in the blowout spill dispersants are sprayed further offshore and over a smaller area than in the batch spill, causing in a smaller area of contamination in an area of lesser risk. This is true even though the spraying takes place over a period of four days in the blowout vs. 2 days in the batch spill. On the other hand, the dispersant operation was not fully effective in the blowout scenario, because of the “overnight effect”, and as a result, a small proportion of the spilled oil came ashore. The resulting level of shoreline oiling was low, less than 1 l/m. This level is well below the threshold level needed to cause effects or to necessitate a disruptive, large-scale shoreline cleanup (Table 6-4, above). All things considered, therefore, there is a large environmental benefit to dispersing this blowout spill.

This situation may not always hold for all spills. Small blowouts that take place far offshore may cause only low levels of contamination (e.g., Scenario 4b at the Deepwater launch site). Even though large areas of shoreline contamination may be involved, the levels of contamination may be far too small to cause significant damage or to even be detectible. In these cases the environmental gains associated with dispersion may not be as great.

Map 6-5 Movement of Untreated and Chemically-Dispersed Spills:
Blowout/Texas Nearshore/4b/Summer

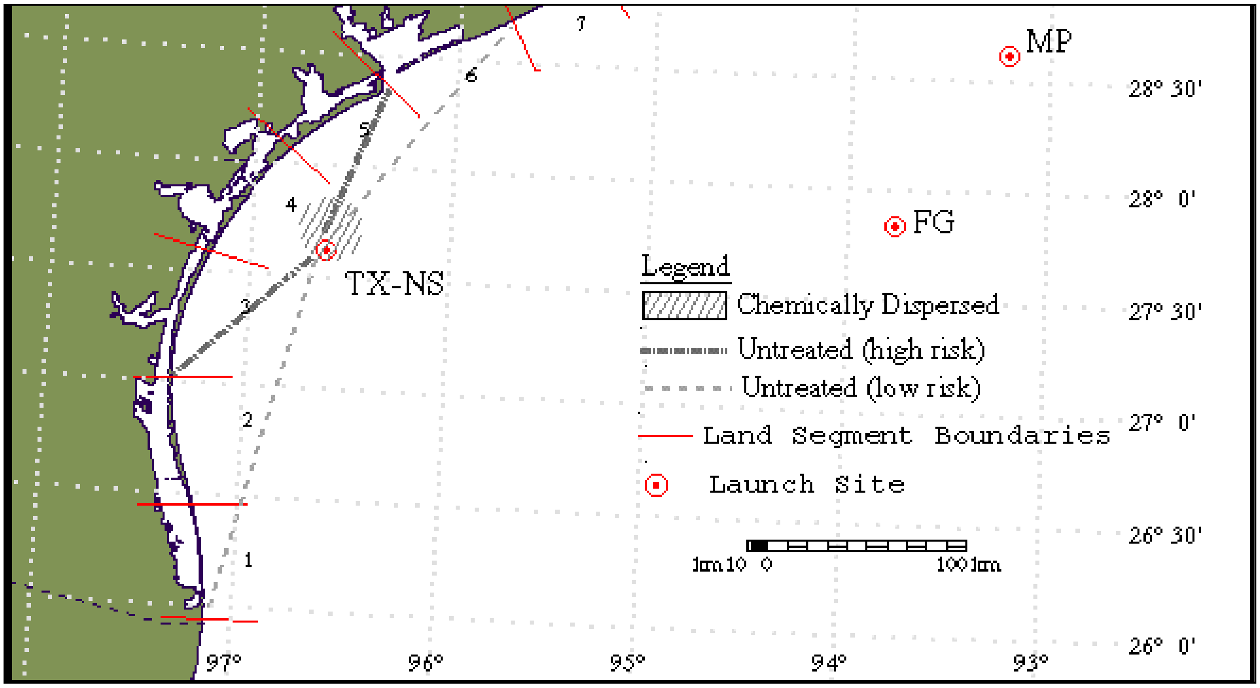

Table 6-12a Oil-Sensitive Resources at Risk from Untreated Blowout Spill: Texas/4b/Summer (from TCOSPR 1999)

Valued Environmental Components	E of Potr Cort'o	E of Yarb'o Pass	S Bird Is SE	S Bird Is	Pita Is.	Crane Is SW	Crane Is NW	Pt Aran's	Estes	Allyn Bight	St Chas Bay SW	St Chas Bay SE	P'ther Pt	P'ther Pt NE	Long Is	Pass Cav'o SW
MMS Shore Seg	3	3	3	3	3	3	4	4	4	4	4	5	5	5	5	5
SHORELINES (km)													15	5	9	15
Marsh Salt/Brackish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exposed Tidal Flat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rip Rap	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mixed Sand/Gravel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Steep Scarps, Sand	15 (bar)	15 (bar)	15 (bar)	15 (bar)	2.5	12	13	15	5	12	6	13	15	5	9	15
Steep Scarps, Clay	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exposed Walls,etc	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exposed Riprap	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0
Jetties	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pass	0	0	0	0	0	0	0	Aransas P	0	0	0	0	0	0	0	0
SENSIT'Y PY'GON																
HIGH	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
Birds (High)	X	X	X	X	X	X	X									
Terns	X	X	X	X	X	X										
Pelicans					X	X										
Waders	X	X	X	X												
Shore Birds	X	X	X	X	X	X	X									
Piping Plover	X	X	X	X	X	X	X									
Snowy Plover					X	X	X									
Wading Birds							X									
Reddish Egret							X									
Peregrine Falcon																
Sea Turtles						X	X									
Kemp's Ridley ST																
Loggerhead ST																
Green ST																
Fish																
MEDIUM	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
Birds (High)								X	X	X	X	X	X	X	X	X
Piping Plover								X	X	X	X	X	X	X	X	X
Brown Pelican										X	X	X	X	X	X	X
Snowy Plover										X	X	X	X	X	X	X
Least Tern										X	X	X	X	X	X	X
Terns								X	X							
Shore Birds								X	X	X	X	X	X	X	X	X
Wading Birds										X	X	X	X	X	X	X
Peregrine Falcon										X	X	X	X	X	X	X
Turtle Nesting (?)								X nest	X							
LOW	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Birds (High)																
Pelicans																
Other Birds																
HUMAN USE																
Matagorda Island SP/NWR												X	X	X	X	X
Padre Is NSS	X	X	X	X	X											

Table 6-12b Impacts of Dispersed and Untreated Cases: Blowout Spill Scenario Texas Nearshore/4b/Summer (from MIRG/SLRoss)

	Untreated Case(b)				**Summary (c)**		Case Dispersed (b,d)	
Resource (a)	Segment 2	Segment 3	Segment 4	Segment 5	**Untreated Overall**	**Dispersed Overall**	6 hr	30 hrs
Brown Shrimp	0 (0.7)	0 (1.6)	0 (1.1)	0 (1.9)	**0 (5.2)**	**0 (3.6)**	0 (3.6)	0 (3.6)
White Shrimp	0	0 (0.2)	0 (0.2)	0 (0.5)	**0 (0.9)**	**0.05 (0.05)**	0.01 (0.01)	0.05 (0.05)
Atl. Croaker	0 (0.1)	0 (0.6)	0 (0.4)	0 (0.5)	**0 (1.6)**	**0 (1.5)**	0 (1.5)	0 (1.5)
Black Drum	0 (0.6)	0 (2.2)	0	0	**0 (2.8)**	**0**	0	0
Reddish Egret (W. Gulf)	0	0.01	0.01	0	**0.02**	**0**	0	0
Sooty Tern	0	0.03	0.02	0.02	**0.03**	**0**	0	0
Tern, Least (Tx)	0	1.1	2.9	2.8	**6.8**	**0**	0	0
Tern, Royal (Gulf)	0.2	0.1	0.3	0.6	**1.2**	**0**	0	0
Frigatebird (gulf)	0.04	0.5	0.3	0.4	**1.24**	**0**	0	0
Brown Pelican	0	0	7.8	10.1	**17.9**	**0**	0	0
Sanderling (Gulf)	0.02	0.2	0.1	0.1	**0.42**	**0**	0	0
Skimmer, Black (W. Gulf)	0.08	0.6	0.4	0.5	**1.58**	**0**	0	0
Laughing Gull (Texas)	0.07	0.8	0.6	0.06	**1.53**	**0**	0	0
Bald Eagle (W. Gulf)	0	0	0.2	0.4	**0.6**	**0**	0	0
Kemp's Ridley ST	0.05	0.01	0.01	0.01	**0.08**	**0**	0	0
Turtle, Leatherback (W.Atl)	0.04	0.4	0.2	0.3	**0.94**	**0**	0	0
Shoreline								
Marsh	0	0	0	0	**0**	**0**	0	0
Mangrove	0	0	0	0	**0**	**0**	0	0
Amenity Beach km	4	42	12	18	**76**	**76**	76	76
Non-Amenity Beach	0	0	14	11	**25**	**25**	25	25
Tidal Flast	0	0	0	0	**0**	**0**	0	0
Tidal flat / Mangrocwwe	0	0	0	0	**0**	**0**	0	0
Stoney Waterfront	0	0	0	0	**0**	**0**	0	0
Rocky Shore	0	0	0	0	**0**	**0**	0	0
Wall	0	0	0	0	**0**	**0**	0	0
Level of Shore oiling l/m	1.6	4.5	12	11	**10+**	**<1**	<1	<1

a. Parentheses refer to name of population or stock.

b. Parentheses show reduction in annual yield to commercial fisheries.

c. Comparison of Untreated Overall vs. Dispersed Case Overall. Summary for Dispersed Case is Worst Case based on 6 hr and 30 hr values.

d. Values at 6 and 30 hr are impacts if

Table 6-12c Summary of Environmental Risks: Scenario Texas Nearshore/4b/SummerBlowout Spill

Valued Environmental Component (VEC)	**Treatment Option**	
	Untreated	**Chemically-Dispersed (a)**
SENSITIVE HABITAT		
none	none	none
WILDLIFE		
Brown Pelican (E/F)(a)	Very High	No Effect
Least Tern (E/F)	Very High	No Effect
Royal Tern	Medium	No Effect
Black Skimmer	Medium	No Effect
Piping Plover (E/F)	Very High	No Effect
Snowy Plover	Medium	No Effect
Peregrine Falcon	Medium	No Effect
MARINE REPTILES		
Kemp=s Ridley ST (E/F)	Very High	No Effect
Leatherback ST (E/F)	Low	No Effect
Hawksbill ST (E/F)	Low	No Effect
Green ST(E/F)	Low	No Effect
Loggerhead ST (T/F)	Low	No Effect
FINFISH, SHELLFISH AND FISHERIES (b)		
White Shrimp	Very Low	Very Low (Low)
Brown Shrimp	Very Low	Low (Medium)
Atlantic Croaker	Very Low	Low
SHORELINES		
Sand Scarps and Sand Beach	>100 km	0
HUMAN USE FEATURE		
Amenity Sand Beach	Medium	No Effect
Matagorda Is. SP and NWR	Medium	No Effect

b. E/F = Endangered Species Federally, T/F = Threatened Federally

c. All impacts are on fisheries. Target fisheries are those landing catches inTexas

6.4 Discussion of Net Environmental Benefit Analysis

The most obvious conclusion to be drawn from this work is that if dispersants are used to treat spills from MMS-regulated offshore facilities in the Gulf of Mexico, there will be a net environmental benefit in almost every case. The reason for this is that the launch sites considered in this study are all well offshore. In cases in which untreated oil slicks from these sites pose significant environmental risks, these can be ameliorated through dispersant use for the following reason. If spills from these sites are sprayed with dispersants within the fairly narrow time window required for effective dispersant use, the spraying will take place well offshore. The associated environmental risks from the dispersed oil will be very low or, if they are significant, they will localized, transient and less than the risks from the untreated spill.

The analysis of scenario Mid-Point/2b/Summer illustrated that there will be a net environmental benefit because the untreated spill posed some risks, but the dispersed case posed far fewer risks, in par because dispersant application occurred offshore. This situation is likely hold in many other locations in the Gulf, because many sections of the coast are at least as sensitive as in this scenario if not more so, while offshore areas are commonly insensitive to dispersed oil. One exception to this might be the offshore hard-bottom communities, such as the Flower Garden Banks. However, even the shallowest of these communities are probably at little risk if dispersants are used nearby. At a depth of 15+ meters, even the shallowest of these banks will be not be exposed to dispersed oil concentrations greater than a few hundreds of parts per billion, were dispersants to be used nearby. These concentrations are far less than those that have caused effects in toxicity experiments involving corals in the past (Ballou et al. 1989, Knap et al. 1983, Le Gore et al. 1989, Wyers et al. 1986)

The Texas/2b/Summer scenario illustrated that not all scenarios are as straightforward as Mid-Point/2b/Summer, because there may be drawbacks in using dispersants on spills from platforms that are relatively close to shore. In the Texas/2b/Summer case, the drawback involved the risk of significant losses to the local, highly lucrative shrimp fishery. Commonly, the risk to fisheries from dispersed oil is one of the greatest concerns of regulators and stakeholders. In this case, the importance of the interaction was amplified by the fact that the most valuable fishery in the state was involved and the spill occurred at a critical location and time. When faced with similar trade-offs in workshops, trustees have traditionally decided to accept the losses to the fisheries on the basis that these were temporary, while damage to habitat and wildlife was longer lasting. The analysis raised two additional issues. First, it is difficult to predict the magnitude of the potential impact of dispersant use on fisheries because fisheries losses result from regulatory closures not from biological effects. Closures are put in place during spill events by regulators, but to date, few jurisdictions have established written criteria for implementing closures during spills. As a result, it is difficult to predict how the spatial extent or the duration of closures will be determined and how large an impact closures might have. The second issue is that the dispersant decision may be influenced strongly by the relative values placed on the different resources involved. In the present project, we have assumed that decision-makers would elect to protect wildlife and habitat at the expense of fisheries. If the local human population places a higher value on shrimp fishing than on endangered species, then the assessment of net environmental benefit might not favor dispersants.

The Texas/2b/Winter scenario demonstrated that impacts and NEB may be influenced by the seasonal habits of the VECs.

The Destin Dome scenario demonstrated that there are important variations from place to place in the impact potential and NEB of dispersants. In the Gulf, coastal zones vary widely in terms of there sensitivity to untreated slicks, with conditions ranging from the sandy shores of the Texas barrier islands to the marshes and exposed bay systems of Louisiana and Mississippi. There are also spatial variations in the sensitivity of the offshore community to dispersed oil, but these differences appear to be less dramatic, especially across the broad expanse of open shelf in the Northern Gulf. This appears to confirm that, within the study area, there will be a net benefit of using dispersants on offshore spills; only the size of the benefit will vary from case to case. In short, while there may have been some uncertainty about the advantage of using dispersants on the spill from the Texas Nearshore launch site, there should be little uncertainty about using dispersants to keep oil slicks out of the marshes and open bay systems of the northern Gulf.

The blowout scenario illustrated that the impact of an untreated blowout spill can be far greater than that of a batch spill of a similar size and that the NEB of dispersant use may similarly be greater.

This is because, while the damage caused by a relatively small untreated batch spill will be concentrated in a relatively small, localized area, the oil from a continuous blowout spill can be spread over a larger area, causing greater and more widespread contamination and damage. On the other hand, when dispersants are used to treat a blowout, the contamination and damage that results are restricted to the immediate vicinity of the spill site to an even greater degree than in the case of the batch spill.

In this blowout scenario, the dispersant operation was not fully effective in dispersing all of the oil in the offshore. This allowed us to consider the question of "incomplete dispersion." In the present scenario, the dispersant operation using the C-130/ADDS Pack platform was successful in reducing the volume of oil arriving at the shoreline by over 90%. The amount of oil surviving the dispersant operation was small. It posed very little risk and dispersants still offered a net environmental benefit. This would not have been true if the operation had been far less effective, as in the case of: a) the present scenario if a less capable dispersant application platform had been used; b) a spill of similar volume, but with an oil that emulsified more quickly; or c) a much larger spill, such as 5a or 5b that greatly exceeded the logistics capabilities of even the largest platforms.

The NEB of dispersants may also be less for spills that are launched well offshore. It should be remembered that blowout scenarios 6b and 7b, launched from spill sites that are farther offshore, dissipated naturally at sea and would have had few impacts in the coastal zone. However, since the potential persistence of slicks cannot be predicted reliably, it may be prudent to not rely on offshore spills dispersing naturally before they reach the shoreline.

Realistically, no dispersant operation can be expected to be 100% effective. Therefore, decision-makers are faced with the problem of assessing the net environmental benefit of partially effective dispersant operations. Unfortunately, impact assessment models are not accurate enough to provide definitive conclusions in all cases. However, the following approach offers a partial, interim answer. For spills that are small enough to be easily treated by the available dispersant response capability, the amount of oil escaping treatment will be small enough to cause little or no impact. For spills that are only a few times larger than the upper limit of the dispersant capability, dispersants can yield a measurable reduction in the impact of the slick. According to the analyses of the present scenarios, the impact of the dispersed oil will be smaller than the impact of the reduction in the impact of the slick, so dispersants still offer a net environmental benefit. For very large spills, dispersion of a small proportion of the spill may not yield an appreciable reduction in impact, so that the question of net benefit is moot.

It is concluded that if dispersants are used to treat spills from MMS-regulated offshore facilities in the Gulf of Mexico, there will be a net environmental benefit in every case where there is a potential for shoreline oiling. The main reason is that the launch sites considered in this study are all offshore. If spills from these sites are dispersed in deep water, the environmental risks from the dispersed oil will be very low and less than the risks from the untreated spill.

7. Conclusions and Recommendations

7.1 Likely Dispersibility of GOMR Oils

There are only two publicly available sets of oil property data that are useful for attempting to predict the chemical dispersibility of GOMR oil spills. The first is an MMS data set on average density of oils in GOMR plays of hydrocarbon reservoirs. These data show that the thousands of oils produced in the Gulf are on average very light: the overall mean density is 33^{o} API gravity. This suggests that in general GOMR oils are likely to be dispersible. The other data set is a selection of 28 GOMR oils that MMS has thoroughly tested from a spill-behavior perspective. This data set shows that 86% of the selected oils will not emulsify quickly if spilled and will remain relatively non-viscous for a reasonable period of time. This means that the spills will likely be amenable to treatment with dispersants. Overall, the suggestion is that GOMR oil spills are good candidates for chemical dispersion. However, it remains impossible to predict the dispersibility of any particular GOMR spill, other than spills of the 28 oils already tested.

The chemical dispersibility of spills of GOMR oils could be better predicted if key information on the properties and spill-weathering characteristics of more oils were available, but generally this is not the case. GOMR oil property information is largely operator-confidential. There are three main ways to deal with this problem of uncertainty regarding spill dispersibility:

1. Identify high-risk GOMR oils (the ones most likely to be spilled) and test them thoroughly for spill behavior and dispersibility;

2. Expect all spills of GOMR oils to be treatable and dispersible and design response plans accordingly. During the response, monitor the situation and stop the dispersant operation if spill dispersion is not proceeding as expected; and

3. Have operators determine the dispersibility of their oils (through standard testing procedures) and have this information available, with proper protection of confidentiality, for contingency planning and spill response purposes.

There are advantages and disadvantages of the three options. The recommendation is to analyze and review these, and decide which is the most cost-beneficial planning strategy.

7.2 Response Analysis and Contingency Planning

In this study a wide range of oil spill scenarios were developed. The variables included: (1) spill type (blowout versus batch spill); (2) spill size; (3) oil type; and (4) spill location. A detailed analysis of the scenarios was performed with respect to dispersant-use logistics. The parameters that control the feasibility and success of a dispersant operation were identified and analyzed. The parameters included: (1) quantity and location of available dispersant; (2) type, availability, number and location of platforms for applying dispersant; (3) response time for platforms to arrive on scene; and (4) ability of platforms to remain and be re-supplied on site.

To analyze the various spill scenarios, the logistical options and the operational efficiencies associated with these, a spreadsheet program (in MS Excel) was constructed and used. The results are as follows:

1. Environmental conditions (winds, waves, visibility conditions) in the study area are amenable to dispersant effectiveness and operations.

2. The scenarios fall into three groups from the perspective of dispersant-use feasibility and net environmental benefits:

    a. Scenarios in which oils disperse very quickly, by natural means for which dispersant use would not appreciably speed up the dispersion rate or reduce the environment impact;

    b. Scenarios in which oils emulsify very quickly allowing little time for mounting a dispersant operation. In these scenarios dispersant use can do little to reduce the persistence of the spill and therefore influence the impact of the oil slicks;

   c. Scenarios in which spill sizes are appropriate and time windows are long enough to permit operations to disperse enough of the spill to greatly reduce the impact of the spill and potentially yield an net environmental benefit.

3. The results of the logistic analysis demonstrate that dispersant delivery capabilities, in terms of volumes sprayed per day varies greatly among spray platforms. In planning, it will be critical to match the capabilities of the platforms to the demands of the spill (type of spill, size of spill, distance offshore). In addition, it will be important to recognize that delivery capabilities estimated here are maximum theoretical values, and make no allowance for factors that will reduce the efficiency of operations, such as mechanical breakdowns, maintenance, or demands of coordinating dispersant spraying with other aspects of dispersant operations or other spill response activities. Actual delivery capabilities will be less than theoretical ones.

4. Under our study assumptions, the largest spill that can be fully treated by a single unit of the existing response platforms in the Gulf area is approximately 3180 m^3 for batch spills or 800 m^3 /day for 4 days for continuous spills. Of course somewhat larger spills could be treated with the coordinated use of a number of units and platform types. While some spills will fall into these categories, at present the behavior of any given spill cannot be accurately predicted. It is important to recognize that the results of the scenarios analyzed here were based on computer simulations and assumptions concerning dispersant effectiveness rates and rates of emulsification. Many of the processes involved cannot be estimated precisely enough to allow an accurate prediction of the effectiveness of a dispersant operation in advance. Rather, during an actual spill, it will be necessary to make decisions about the potential usefulness of dispersants and the effectiveness of dispersant applications based on direct real-time observations. For this reason, it will be necessary to have these monitoring capabilities in place if dispersants are to be used.

7.3 Net Environmental Benefits of Dispersant-Use

One very obvious conclusion to be drawn from this work is that, when spills from offshore platforms threaten to contaminate nearby shorelines and when these spills can be effectively dispersed, there will be a net environmental benefit in almost every case. The reason for this is that the launch sites are well offshore. If a spill from one of these launch sites is to be effectively treated it must be fully treated within a few kilometers of the spill site. Here the spill still lies in deep offshore waters where environmental risks of chemical dispersion are small and considerably less than the risks posed by the untreated spill. The scenarios analyzed in this study showed that the size of the impact and the net environmental benefit from dispersant use will vary with spill conditions (spill location, season, type of spill). However, in all cases the net environmental benefit will favor dispersant use.

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