Assessment of the Use of Dispersants on Oil Spills in California Marine Waters

by

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for

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Summary

Objective

This project is a comprehensive assessment of operational and environmental factors associated with using chemical dispersants to treat oil spills in California. The project addresses spills from both transportation and production sources. It addresses four subjects: a) amenability of produced and imported oils to chemical dispersion; b) time windows (TW) for chemical dispersion in California spills; c) operational logistic and feasibility issues in California; and d) net environmental benefits or drawbacks of dispersant use for California spills.

Review of Basics

The report begins with a review of the basics of (a) marine spill behavior, (b) chemical dispersants, (c) factors that control dispersant effectiveness, and (d) accounts of field trials and spills. The review shows that dispersants will be effective if: (a) the response takes place quickly while the spilled oil is unemulsified, relatively thick, and low in viscosity; (b) the thick portions of the spill are treated with state-of-the art chemicals at the proper dose; and (c) 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 California Oils

Three groups of oils are considered: a) crude oils produced in California OCS waters; b) oils imported into California ports; and c) fuel oils spilled from marine industrial activities (e.g., fuel tanks from ships, cargoes of small tankers). Understanding the properties of oils is important because dispersants work only if the spilled oil has a low viscosity at the time of treatment.

The 22 producing fields in the Pacific Outer Continental Shelf Region (POCSR) are summarized in Table S-1. Until recently, the properties of the oils produced were not known. In 1999, an MMS-sponsored study produced information useful in assessing the dispersibility of POCSR oils. Table S-1 shows that most POCSR oils are heavy— the average API gravity of all oils is 20.2^{o}. These values border on the range of oils that are considered to be difficult or impossible to disperse, suggesting that POCSR oils are not good candidates for chemical dispersion. However, a more thorough analysis, by modeling, was done to provide insight into this, as discussed in a later section.

Table S-1 POCSR Fields, Platforms and Oils

Oil Field Name	Platform Name	POCSR API Gravity(1)	MMS/EC Oil Catalog(2) Name	API Gravity	Average Annual Production 1996-2000(BBLS)(3)
Beta	Ellen Elly Eureka Edith	17.3 - 18.3	Beta	13.7	2,364,019
Carpinteria	Hogan Houchin Henry	24.2	Carpinteria	22.9	808,641
Dos Cuadras	Hillhouse A B C	24.3	Dos Cuadras	25.6	2,473,702
Hondo	Hondo Harmony	21.5	Hondo	19.6	13,938,138
Hueneme	Gina	20.9	Port Hueneme		222,569
Pescado	Heritage	21.5			11,968,537
Pitas Point	Habitat		Pitas Point	38	3,099
Point Arguello	Hidalgo Harvest Hermosa	22.2	Point Arguello Commingled Point Arguello Heavy Point Arguello Light	21.4 18.2 30.3	9,627,539
Point Pedernales	Irene	21.1	Platform Irene	11.2	3,294,989
Sacate					2,187,755(4)
Santa Clara	Gilda Grace	20.9	Santa Clara	22.1	1,145,562
Sockeye	Gail	21.6	Sockeye Sockeye Commingled Sockeye Sour Sockeye Sweet	26.2 19.8 18.8 29.4	1,735,719
			Platform Holly	11	

(1) From a table presented at a POCSR workshop, June 7, 2001. From samples taken between Jan, 99 & Oct, 99
(2) Jokuty,P.,S. Whiticar, Z. Wang, B. Fieldhouse, and M. Fingas,
A Catalogue of Crude Oil and Oil Product Properties for the Pacific Region, 264p 1999.
(3) Pacific Production Information and Data Available in ASCII Files for Downloading:
http://www.gomr.mms.gov/homepg/pubinfo/pacificfreeasci/product/pacificfreeprod.html
(4) Sacate shows up in the production files in 1999 with 0.25 MBbl and then in 2000 with 2.0 MBbls

The oils imported into California by tanker in 1999-2001 are listed in Table S-2. Two to three dozen crude oils were imported annually. By far, the most important oil is Alaska North Slope crude oil, representing 50% of each annual total. Some properties of the most important oils are summarized in Table S-3. Based on API gravity information, these oils appear to be dispersible when fresh, but modeling work is required to estimate their emulsion-forming tendency and TW for dispersants. Information needed for modeling is available for only five of the oils identified in Table S-3.

As far as refined products are concerned, information about types and amounts of fuels and other refined products was not available, so only diesel fuel was included in this analysis.

The general dispersibility of produced and imported oils identified above, was determined based on their tendency to form emulsion. The SL Ross Oil Spill Model (SLROSM) was used to estimate the time-dependent spill characteristics of 18 California oils for which oil property data are available. The modeling considered 1000-bbl and 10,000-bbl batch spills under average environmental conditions for California waters.

Table S-2 Summary of California Crude Oil Imports for 1999, 2000 and 2001

SUMMARY: OILS RANKED BY VOLUME (1999)			
Name of Oil	Volume (1000 bbls)	Fraction of Total	Cumulative Total
Alaska North Slope	188743	56.3%	56.3%
Oriente	28274	8.4%	64.7%
FAO Blend	26546	7.9%	72.6%
Basrah Light	21410	6.4%	79.0%
Arab Extra Light	9617	2.9%	81.9%
Arab Light	5657	1.7%	83.6%
Maya	9987	3.0%	86.6%
Escalante	8063	2.4%	89.0%
Arab Medium	5751	1.7%	90.7%
Minas	4774	1.4%	92.1%
Loreto	4637	1.4%	93.5%
Kuwait	3074	0.9%	94.4%
Oriente Lt.	3069	0.9%	95.3%
Sumatran Heavy	2664	0.8%	96.1%
Eocene	2482	0.7%	96.8%
Bintulu	1469	0.4%	97.3%
Dai Hung	1199	0.4%	97.6%
Isthmus	1196	0.4%	98.0%
Tapis Blend	1087	0.3%	98.3%
Lucula	869	0.3%	98.6%
Magellanes	749	0.2%	98.8%
Djeno Blend	723	0.2%	99.0%
Burgan	627	0.2%	99.2%
Seria Lt	584	0.2%	99.4%
Basrah Heavy	455	0.1%	99.5%
Lagomedio	384	0.1%	99.6%
Cano Limon	381	0.1%	99.7%
???? (Mexico)	347	0.1%	99.8%
BCF 24	262	0.1%	99.9%
???? (Malaysia)	244	0.1%	100.0%

SUMMARY: OILS RANKED BY VOLUME (2000)			
Name of Oil	Volume (1000 bbls)	Fraction of Total	Cumulative Total
Alaska North Slope	163233	47.7%	47.7%
FAO Blend	39955	11.7%	59.4%
Oriente	34941	10.2%	69.6%
Arab Medium	17083	5.0%	74.6%
Arab Light	9396	2.7%	77.4%
Maya	12863	3.8%	81.1%
Yemen	9802	2.9%	84.0%
Basrah Light	9507	2.8%	86.8%
Escalante	6993	2.0%	88.8%
Minas	4110	1.2%	90.0%
Arab Extra Light	4065	1.2%	91.2%
Eocene	2825	0.8%	92.0%
Barrow Island	2801	0.8%	92.9%
Tapis Blend	2526	0.7%	93.6%
Dai Hung	2367	0.7%	94.3%
Cossack	2345	0.7%	95.0%
BCF 24	2320	0.7%	95.7%
Kuwait	2161	0.6%	96.3%
???? (Mexico)	1995	0.6%	96.9%
Oriente Light	1921	0.6%	97.4%
Basrah Heavy	1787	0.5%	98.0%
Loreto	1494	0.4%	98.4%
Cano Limon	1237	0.4%	98.8%
Taching (Daqing)	835	0.2%	99.0%
Burgan	780	0.2%	99.2%
Bachaquero	694	0.2%	99.4%
Murban	423	0.1%	99.6%
Seria Light	414	0.1%	99.7%
Griffin	411	0.1%	99.8%
Bintulu	384	0.1%	99.9%
Champion Export	237	0.1%	100.0%
Dubai	54	0.0%	100.0%

SUMMARY: OILS RANKED BY VOLUME (2001*)			
Name of Oil	Volume (1000 bbls)	Fraction of Total	Cumulative Total
Alaska North Slope**	48091	49.7%	49.7%
Arab Medium	9092	9.4%	59.1%
FAO Blend	6531	6.7%	65.8%
Maya	6130	6.3%	72.1%
Arab Light	5325	5.5%	77.6%
Yemen	4149	4.3%	81.9%
Oriente	3527	3.6%	85.6%
Cossack	2566	2.7%	88.2%
Murban	2282	2.4%	90.6%
Escalante	2176	2.2%	92.8%
Arab Extra Light	1690	1.7%	94.6%
Seria Light	811	0.8%	95.4%
BCF 24	804	0.8%	96.2%
Vasconia	745	0.8%	97.0%
Minas	623	0.6%	97.6%
Lucula	560	0.6%	98.2%
???? (Australia)	433	0.4%	98.7%
???? (Congo)	399	0.4%	99.1%
Arab Heavy	332	0.3%	99.4%
Loreto	290	0.3%	99.7%
Jackson Blend	196	0.2%	99.9%
Cano Limon	75	0.1%	100.0%

*data for January to April 2001

**note: volume for Alaska estimated assuming 12% decline from 2000, which reflects trend of last five years

In above three charts, a total of ten oils (highlighted) represent 90% of the volume in a given period.

Table S-3 Some Fresh Oil Properties of Top Ten Oils Shipped to California, 1999-2001

Oil Type	Identifying Properties				Sufficient spill-test data for modeling purposes?
	API gravity	Sulfur content, %	Viscosity at 15°C, cP	Pour point, °C	
Alaska North Slope	26.8	1.15	17	-15	Yes
Arab Medium	30.8	2.4	29	-10	Yes
Maya	21.8	3.3	299	-20	Yes
Arabian Light	33.4	1.77	14	-53	Yes
Oriente	29.2	1.01	85	-4	Yes
Basrah Light	33.7	1.95	≈20	-15	No
Escalante/Canadon Seco	24.1	0.19	?	?	No
Arabian Extra Light	37.9	1.2	?	?	No
FAO Blend	31.0	3.0	?	?	No
Yemen	31.0	0.6	?	?	No

Based on the analysis, the 18 oils can be divided into three categories according to their "emulsion formation tendency" (Table S-4). Clearly, 12 oils are highly emulsifiable (called Hi-E oils) and have very narrow Time Windows (TW) for chemical dispersion. These include Arab Medium crude and Pt. Arguello crude that start to emulsify after 0% to 10% of the spill has evaporated. For both oils, 1000-barrel spills will reach a viscosity of 2000 cP within 4 hours of the spill, 5000 cP in 6 to 7 and 20,000 cP in 22 to 23 hours. Assuming the viscosity cut-off point for effective dispersant use is in the range of 5000 to 20,000 cP, the time available for response is less than 24 hours.

The next category of oils, called Av-E oils, will start to emulsify after 11 to 29% evaporation. ANS crude is representative of this class and has a TW of 38 to 67 hours.

The final category, called Low-E oils, will not emulsify regardless of evaporation, allowing an unlimited TW for dispersants. In this study there were only two these oils: a) diesel oil; and b) Pitas Point crude, a heavy gas condensate.

In summary, the opportunity for using dispersants effectively on the oils in this study is limited. Few of the produced oils are dispersible, but if the response is rapid, some success might be possible. The situation is different for the imported oils. Alaska North Slope crude, which represents 50% of imported oil, appears to be amenable to dispersion. Diesel oil, which tends to be spilled frequently, is also a good candidate.

Spill Scenario Modeling

In general, dispersant TWs vary with factors other than oil type (e.g., spill type, spill size, environmental conditions). To assess the TW issues, a spill modeling exercise was conducted using eighteen scenarios derived from California contingency plans.(Table S-5).

Table S-4 POCSR and Imported California Oils That Have Undergone Spill-Related Testing

Crude oil name	API Gravity	Fresh oil Pour Point °C	Oil Viscosity @ 15°C at various weathered states			Emulsion formation tendency	Size of "Window of Opportunity" for successful dispersant use	Hours for oil to reach specified viscosity in 5 m/s (10 kt) winds and at 15°C water temperature					
								1000 Barrel Batch Spill			10,000 Barrel Batch Spill		
			0%	~ 15%	~ 25%			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 % oil evaporation)													
Arab Medium	29.5	-10	29	91	275	Yes @ 0%	very narrow	4.2	6.4	22.0	4.9	7.7	39.0
Arab Light[a]	31.8	-53	14	33	94	Yes @ 0%	narrow[a]	10.0	36.0	Disp @41 hr	13.3	68.8	Disp @ 68
Hondo	19.6	-15	735	9583	449700	Yes @ 0%	very narrow	2.0	3.0	5.5	2.4	3.7	6.2
Hueneme	14.8	-9	4131	20990		Yes @ 0%	very narrow	0.0	0.5	1.9	0.0	0.5	1.9
Maya	21.8	-20	299	99390		Yes @ 0%	very narrow	1.6	2.3	4.8	1.8	2.6	5.1
Oriente	25.9	-4	85		6124	Yes @ 0%	very narrow	2.2	3.2	5.2	2.8	3.8	6.4
Pt Arguello Co-mingled	21.4	-12	533	41860	2266000	Yes @ 0%	very narrow	1.6	2.6	4.3	1.7	2.9	4.9
Pt Arguello Heavy	18.2	-4	3250		4953000	Yes @ 0%	very narrow	0.0	0.5	1.7	0.0	0.5	1.9
Pt Arguello Light	30.3	-22	22	183	671	Yes @ 0%	very narrow	4.4	6.9	23.0	5.1	8.1	42.0
Santa Clara	22.1	-3	304	1859	22760	Yes @ 0%	very narrow	2.6	3.8	6.6	2.9	4.4	7.9
Sockeye	26.2	-12	45	163	628	Yes @ 0%	very narrow	3.9	5.6	13.2	4.3	6.4	20.4
Sockeye Sour	18.8	-22	821	8708	475200	Yes @ 0%	very narrow	1.1	1.9	3.1	1.3	2.0	3.5
MEDIUM EMULSIFIABLE OILS (Av-E Oils) (Emulsion forms at 11 to 29 % oil evaporation)													
Alaska North Slope	26.8	-15	17	110	650	Yes @ 26%	narrow	37.9	39.7	43.3	60.7	62.2	66.7
Carpinteria	22.9	-21	164	3426		Yes @ 11%	narrow	5.6	6.6	8.9	8.3	9.5	12.0
Dos Cuadras	25.6	-30	51	187	741	Yes @ 11%	narrow	5.4	7.0	11.0	7.4	8.9	14.3
Sockeye Sweet	29.4	-20	20	39	321	Yes @ 17%	narrow	8.6	10.6	28.8	11.6	14.1	47.8
OILS THAT DO NOT EMULSIFY (No-E Oils) (Emulsion does not form)													
Diesel	39.5	-30	8	25	100	No	very wide	60.0	Disp @ 69 hr		101.0	Disp @ 111 hr	
Pitas Point	38.0	<-60	2		2	No	very wide	Disp @ 2.3 hr			Disp @ 3.5 hr		

a. Although Arab Light is a highly emulsifiable crude oil, the viscosity of its emulsion is estimated to be relatively low, explaining the "narrow" time window designation rather than "very narrow".

Table S-5 California Marine Oil Spill Scenarios

#	Spill Description	Spill Volume	Oil	Comments
Local Production Spill Scenarios				
1	Hermosa Platform -subsea blowout	1070 bopd for 30 days	Pt. Arguello Heavy	water depth of 184 m 480 scf gas / bbl oil, 14 knot winds, 14 °C
2	Hermosa -surface blowout	1070 bopd for 30 days	Pt. Arguello Heavy	480 scf gas / bbl oil, 14 knot winds, 14 °C
3	Hermosa Platform - batch	2217 bbl	Pt. Arguello Commingled	pipeline discharge, 14 knot winds, 14 °C
4	Hidalgo Platform -subsea blowout	973 bopd for 30 days	Pt. Arguello 4 a) Heavy 4 b) Light	water depth of 130 m, 14 knot winds, 14 °C, 763 scf gas / bbl oil
5	Hidalgo -surface blowout	973 bopd for 30 days	Pt. Arguello 5 a) Heavy 5 b) Light	763 scf gas / bbl oil, 14 knot winds, 14 °C
6	Hidalgo Platform - batch	500 bbl	Pt. Arguello 6 a) Heavy 6 b) Light	Pipeline discharge, 14 knot winds, 14 °C
7	Harvest Platform -subsea blowout	5000 bopd for 30 days	Pt. Arguello Heavy	water depth of 206 m, 14 knot winds, 14 °C, 1435 scf gas / bbl oil
8	Harvest Platform -surface blowout	5000 bopd for 30 days	Pt. Arguello Heavy	1435 scf gas / bbl oil, 14 knot winds, 14 °C
9	Harvest Platform -batch	292 bbl	Pt. Arguello Heavy	Pipeline discharge, 14 knot winds, 14 °C
10	Gail Platform -subsea blowout	882 bopd for 30 days	Sockeye crude	water depth of 225 m, 7 knot winds, 17 °C, 4071 scf gas / bbl oil
11	Gail Platform -surface blowout	882 bopd for 30 days	Sockeye crude	4071 scf gas / bbl oil, 7 knot winds, 17 °C
12	Gail Platform -batch	a) 2068 bbl b) 131 bbl	Sockeye crude	Platform vessels and piping, 7 knot winds, 17 °C
Vessel Spills				
13	Very Large Batch	250,000 bbl	13 a) ANS 13 b) Arab Med	Los Angeles area in Summer 5 knot winds 18 °C
14	Very Large Batch	250,000 bbl	14 a) ANS 14 b) Arab Med	San Francisco area in Spring 12 knot winds 11 °C
15	Large Batch	10,000 bbl	15 a) ANS 15 b) Arab Med 15 c) Diesel	Los Angeles area in Summer 5 knot winds 18 °C
16	Large Batch	10,000 bbl	16 a) ANS 16 b) Arab Med 16 c) Diesel	San Francisco area in Spring 12 knot winds 11 °C
17	Small Batch	3000 bbl	17 a) ANS 17 b) Arab Med 17 c) Diesel	Los Angeles area in Summer 5 knot winds 18 °C
18	Small Batch	3000 bbl	18 a) ANS 18 b) Arab Med 18 c) Diesel	San Francisco area in Spring 12 knot winds 11 °C

The common feature in the behavior of California production spills is the rapid emulsification and high persistence of the oils. The TW for dispersants in batch spills from production facilities, Scenarios 3, 6, 9 and 12, are 2 to 20 hours (Table 6a). Because of this small TW, it may be difficult to mount dispersant operations for these spills.

The primary differences between the above sea and sub-sea blowouts are the initial dimensions of the oil slicks. Slicks from subsea blowouts are initially much wider and thinner than surface blowouts and have TW of 0 to 2 hours. With lighter oils (e.g., Pt. Arguello Light and Sockeye crude oils), slicks from subsea blowouts are very thin initially (0.005 to 0.014 mm) and appear to disperse almost immediately by natural means. With heavier oils, slicks are somewhat thicker and emulsify almost immediately to an undispersible state. Even though these latter spills are all continuous releases, the oil emulsifies so rapidly that it is unlikely that dispersants will be effective even if applied within a few minutes after the oil surfaces. The picture is somewhat different for the above sea blowouts because the Av-E oils, like Sockeye Sweet, have somewhat longer TW, up to eight hours. However, the above sea blowouts of Hi-E oils emulsify almost immediately as they do in subsea blowouts.

For batch spills from ships, spills of three sizes (250,000, 10,000 and 3000 barrels) and three oil types (Alaska North Slope crude, Arab Medium crude and Diesel fuel) are considered. Diesel spills have not been considered for the largest spill volume. In the 250,000-barrel spill, the two crude oils differ markedly in their behavior. ANS crude oil has longer TW (104 to 166 hours) than the Arab Medium crude scenarios (8 to 22 hour) because of the delay in onset of emulsification (Table 6b). The TW for dispersants declines with spill volume for all batch spills. In 5-knot winds, the TWs for ANS spills are 166, 90 and 74 hours for the 250,000, 10,000 and 3,000 barrel spills, respectively. The same trend holds for different oil types and wind speeds. Diesel fuel spills are all amenable to dispersant use up to the time that they would naturally disperse since these spills will not form emulsions.

<u>Logistics and Feasibility of Operations</u>

Detailed analyses of dispersant logistics were conducted in order to assess the current level of dispersant capability in California as tested against the selected spill scenarios. The two factors that are most critical in this analysis are: a) the availability of dispersant resources; and b) the capability of various platforms to deliver and apply dispersant.

Inventory of Spraying Platforms. Only a limited amount of dispersant equipment is in place in California at present. In Southern California there two ship-based systems, and two Simplex helicopter bucket systems, all based in Carpinteria. There are no dispersant delivery systems in place in the San Francisco area, although Clean Bay Cooperative is in the process of acquiring a ship-based system. There is a considerable quantity of high capacity response equipment located throughout North America that can be cascaded to California in the event of a large spill. Realistically, however, these outside resources would be available for a California spill only on the second day of response or later. Operational features of the key platform types are as follows.

Table S-6a. Spill Scenario Modeling Result Summary: Local Production Facilities

	Spill Scenario Identifier (refer to Table S-5 for full description of scenario)															
	1	2	3	4a	4b	5a	5b	6a	6b	7	8	9	10	11	12a	12b
Spill Information																
Emulsification Tendency	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi
Volume Spilled (bbl)	32100	32100	2217	29190	29190	29190	29190	500	500	150000	150000	292	26460	26460	2068	131
Discharge Rate (BOPD)	1070	1070	batch	973	973	973	973	Batch	Batch	5000	5000	batch	882	882	Batch	batch
Viscosity (cP)																
Time to Visc.>5000 cP (hr)	0.0	0.0	1.8	0.0	-	0.0	2.0	0.17	4.7	0	0	0.17	-	4.6	7.0	5.6
Time to Visc.>20000 cP(hr)	0.01	0.0	3.1	0.01	-	0.0	3.5	1.0	22	0.01	0	1.0	-	8.9	12.4	9.6
Time to Loss of Slick (hr)	>720	>720	>720	216	0.16	>720	>720	>720	141	>720	>720	>720	0	>720	>720	>720
Time to < .05 mm (hr)	0	0	>720	0	0	1.0	>720	-	140	0	>720	>720	0	>720	>720	>720
Initial Slick Thickness	0.015	0.238	20	0.014	0.014	0.213	0.184	20	20	0.027	0.77	20	0.006	0.33	20	20
Thickness at 6 Hours	0.012	0.212	10.5	0.012	0	0.189	0.147	10.2	4.1	0.0222	0.71	8.9	0	0.26	6.4	2.8
Thickness at 12 Hours	0.012	0.208	9.6	0.011	0	0.185	.0142	9.3	3.6	0.0219	0.70	8.1	0	0.24	5.7	2.5
Thickness at 48 Hours	0.011	0.2	7.6	0.011	0	0.179	0.134	7.6	2.3	0.0206	0.67	6.6	0	0.23	4.6	2.1
Thickness when viscosity at 5000 cP	0.015	-	12.3	0.014	-	-	0.156	17.6	4.3	0.027	-	16.7	-	0.27	2.9	
Thickness when viscosity at 20000 cP	0.014	0.238	11.4	0.014	-	-	0.151	13.1	3.1	0.020	-	11.9	-	0.25	5.7	2.6
Initial slick width	527	28	150	504	504	28.5	30.0	71	71	1357	40	54	1682	22	145	36
Width at 6 Hours	527	28	200	504	0	28.5	30.0	97	143	1357	40	79	1682	23	245	91
Width at 12 Hours	527	28	207	504	0	28.5	30.0	100	149	1357	40	81	1682	24	256	95
Width at 48 Hours	527	28	226	504	0	28.5	30.0	107	164	1357	40	86	1682	25	274	98
Width at Loss of Slick or 720 hrs	527	28	259	504	0	28.5	30.0	107	171	1357	40	86	1682	25	279	98
Naturally Dispersed Oil (top 10 meters)																
Time when < 5ppm (hr)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Time when < 1 ppm (hr)	-	-	-	-	0.16	-	-	-	-	-	-	-	-	-	-	-
Time when < 0.1 ppm (hr)	-	-	-	-	12	-	-	-	12	-	-	-	24	-	-	-
Peak Concentration (ppm)	.00085	0.00084	0.0318	0.00083	1.05	0.00094	0.00865	0.0033	0.3	0.0008	0.0007	0.003	0.56	0.0058	0.07	0.04
Time Peak Reached (hr)	0.8	0.4	1.82	0.8	0.16	0.24	3.5	1.0	1.0	0.06	1.0	1.0	0.0	2.7	1.0	1.0

Table S-6b. Spill Scenario Modeling Result Summary: Vessel Spills

	Spill Scenario Identifier (refer to Table S-5 for full description of scenario)															
	13a	13b	14a	14b	15a	15b	15c	16a	16b	16c	17a	17b	17c	18a	18b	18c
Spill Info																
Emulsification Tendency	Av	Hi	Av	Hi	Av	Hi	No	Av	Hi	No	Av	Hi	No	Av	Hi	No
Volume Spilled (bbl)	250 k	250 k	250 k	250 k	10 k	10 k	10 k	10 k	10 k	10 k	3000	3000	3000	3000	3000	3000
Discharge Rate (BOPD)	batch	batch	batch	batch	batch	batch	batch	batch	batch	Batch	batch	batch	batch	batch	batch	batch
Time to Visc.>5000 cP (hr)	166	22	104	8	90	19	-	56	7	-	74	17	208	45	6	-
Time to Visc.>20000 cP (hr)	188	120	107	87	112	63	-	59	51	-	91	48	-	48	36	-
Time to Loss of Slick (hr)	>720	>720	>720	425	665	375	560	360	155	97	535	273	208	272	106	74
Time to < .05 mm (hr)	>720	>720	>720	420	650	375	255	350	150	90	520	271	204	270	105	73
Initial Thickness	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Thickness at 6 Hours	12.2	13.1	13.1	14.5	6.0	6.8	4.1	6.9	8.9	4.2	4.2	4.8	2.8	7.9	6.5	2.8
Thickness at 12 Hours	10.3	11.8	11.2	13.7	4.7	5.9	3.1	5.3	7.9	3.0	3.2	4.1	2.1	3.7	5.8	2.0
Thickness at 48 Hours	6.5	10.0	7.3	11.4	2.7	4.6	1.7	3.0	5.6	1.3	1.8	3.2	1.2	2.1	3.5	0.7
Thickness when viscosity at 5000 cP	4.1	10.9	5.4	14.1	2.0	5.4	-	2.8	8.7	-	1.53	3.9	0.025	2.1	6.4	-
Thickness when viscosity at 20000 cP	4.0	8.6	5.4	10.1	1.9	4.4	-	2.7	5.5	-	1.49	3.2	-	2.0	3.9	-
Initial Width	1457	1457	1457	1457	318	318	318	318	318	318	174	174	174	174	174	174
Width at 6 Hours	1716	1663	1654	1566	527	496	646	492	433	624	342	320	421	318	275	405
Width at 12 Hours	1846	1714	1760	1586	590	523	716	549	447	686	385	338	464	357	285	442
Width at 48 Hours	2272	1794	2081	1655	743	561	841	686	487	781	485	362	539	441	310	495
Width at loss of slick or 720 hrs	2769	2079	2411	1829	847	615	927	722	515	797	531	386	582	452	318	499
Time when < 5ppm (hr)	-					-				-	-		-	-	-	
Time when < 1 ppm (hr)	-		120	108	-	-				108	-		-	-	-	
Time when < 0.1 ppm (hr)	540	>720	>720	>720	665	48	260	216	300	288	48	17	108	96	170	168
Peak Concentration (ppm)	0.7	0.3	1.7	1.0	0.35	1.2	0.94	0.85	0.5	4.3	0.27	0.16	0.75	0.68	0.42	3.5
Time Peak Reached (hr)	24	12	24	84	12	6	12	6	36	6	6	6	6	6	6.4	6

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. In theory a single C-130/ADDS Pack system might be capable of fully treating all of the oil spilled in the blowout spills and all of the oil in the 10,000 bbl batch spills. Its main drawback in California is that at present the nearest ADDS Pack units are outside the state. As a consequence, start-up times may be lengthy and spraying is not likely to begin until the second day of the spill.

DC-4. This platform is modeled after the dedicated dispersant spraying aircraft owned by Airborne Support Incorporated (ASI) of Houma, LA. Its delivery capacity is approximately one-half of that of the C-130 ADDS Pack. Realistically, as with the ADDS Pack, the earliest this aircraft can begin spraying dispersant in California is probably the morning of the second day.

Cessna AT-802 (Agtruck). These are small, single engine aircraft that are purpose-built for aerial spraying. They are capable of having a fairly short start-up time, but have a smaller payload than the larger aircraft and have a more limited range. In the U.S., a group of operators have organized to offer a dispersant spraying service using this aircraft. None of these are available in California, although one operator in Arizona may currently be under contract to a California oil spill cooperative. Under many conditions, this platform too may not be available until the beginning of the second day. The advantage of this platform is that a number of these are available for use in a large spill.

Helicopter. Helicopters equipped with spray buckets have the advantage of availability. They are also highly maneuverability and are capable of being re-supplied near a spill site, which greatly increases their operational efficiency. However, they are limited by their small payload and range. Two are available in southern California.

Vessels. Globally speaking, ship-based systems vary widely in their operational capabilities (e.g., payloads, pump rates and swath widths). In general, the relatively low payloads and slow transit speeds 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. There are only two ship-based systems currently available in California and at least one more system is planned. Due to the slow transit speed of this type of platform, it is unlikely that systems from outside California would be available to respond to a spill, except in the event of a prolonged blowout spill.

Dispersant Products. The amount of dispersant available in California at the time of writing is 41,560 gallons (=989 barrels). Based on the 1:20 rule of thumb, this quantity would be sufficient for a 20,000-barrel spill. A quantity of 273,615 gallons (=6514 barrels) is held in North American stockpiles outside California, for a total volume of dispersants available to California operators of 315,175 gallons (=7504 barrels) of dispersant. At least a portion of the 6514 barrels could be made available for use on spills in California. Using the 1:20 rule of thumb again, the total North American stockpile of dispersant is sufficient for a spill of approximately 150,000 barrels.

Analysis of Logistics. Tanker spills may occur at any point in California's offshore waters; they may be of any size and may have short, medium or long TW. The present analysis suggests that ship- and helicopter-based dispersant systems may be adequate to deal with small tanker spills close to their bases of re-supply. In addition, they may be adequate to deal with mid-sized spills, provided the TW is long enough. However, these platforms are limited in their capability to respond to spills at a distance from their base of operations either because of slow transit speed or limited operating range. These limitations can be overcome in some circumstances by re-supplying them at or near the spill site. The small- to mid-sized spills that occur at considerable distance from the response centers appear to be well suited to the small, fixed wing aircraft, provided the TW is long enough to accommodate their slower startup time. Very large spills appear to require the delivery capacities of the large, fixed-wing platforms, such as the C-130/ADDS Pack system. However, at present, this system is useful only for spills with longer (several days) TW, given that the startup time is at least 24-hour. Spills of Hi-E oils, of the kind analyzed here (TW<24 hours), are amenable only to locally based resources that can respond within hours. The startup times of resources based outside California may be too long to be useful. The present analysis showed that when spills involve Hi-E oils, even the smaller spill scenarios described in the ACPs require multiple platforms in order to deliver dispersant within the TW.

Production-related spills in California appear to pose challenges for dispersant planners. Many of the spills analyzed here, including all spills of Hi-E oils and subsea blowouts appear to be poor candidates for chemical dispersion, either because of very rapid emulsification (short TW) or rapid natural dissipation. The above sea blowouts of Av-E oils appear to be good candidates for treatment using ship-based or helicopter-based systems because these systems can remain on-scene and deliver dispersants constantly when needed. Happily, discharge rates of worst-case blowouts described in contingency plans for California fields are low enough to be within the capacities of these systems.

It is important to reiterate that the performance of the ship-based system is limited by both their slow transit speed and small payload. In this analysis we have used the characteristics of systems that are currently available in California (payload =1000 gallons, transit speed 7 knots). Larger and faster vessels are currently in use elsewhere and can be developed in California.

Net Environmental Benefit of Dispersant Use

Scenarios were analyzed to determine the environmental risks associated with untreated and chemically dispersed spills in Southern California. The work focused on the area in Southern California where the MMS-regulated oil production facilities are located. A range of launch-points and spill conditions were considered, from which three scenarios were selected, located in the Santa Barbara Channel area. The three scenarios involved increasingly complex impact and decision-making problems. Environmental impacts were estimated using the general approach used in the earlier MMS dispersant technology study for the Gulf of Mexico.

Dispersants offer a net environmental benefit in all scenarios. The reason for this is that the launch sites for all spills are somewhat offshore, on the open coast where the spills pose little environmental risk, if they are chemically dispersed. On the other hand, if left untreated the slicks from these spills all move onshore where they pose a significant threat to a variety of resources. Hence impacts of the untreated spills were always greater than those of dispersed spills.

The scenario off San Miguel Island is the simplest of the scenarios and is typical of spills in areas outside the Santa Barbara Channel that threaten the islands. The net environmental benefit of dispersants is clear because the untreated spill threatens very significant damage to important wildlife in coastal waters off San Miguel Island, while chemical dispersion poses few, if any environmental risks. The dispersed oil poses little risk for two reasons: a) dispersion can be completed well offshore; and b) surface currents keep the dispersed oil offshore and carry it away from sensitive nearshore targets, such as the giant kelp forests.

The batch spill scenario off Port Hueneme in the Santa Barbara Channel is more complex in that it takes place near to shore and some dispersed oil is carried into shallow coastal waters. Net environmental benefit favors dispersants because there are important risks to wildlife and human use resources from the untreated oil, while risks from the dispersed oil are limited. The reasons for the low risk from the dispersed oil are as follows: a) the number of in-water resources threatened by the chemically dispersed oil are small compared to the untreated spill (as per the ESI maps); b) hydrocarbon exposure concentrations for in-water resources are relatively low and therefore the risk of toxicity is limited; and c) the species at risk from dispersed oil are widely distributed throughout Southern California, so only a small proportion of the total Southern California stocks are at risk in each case.

The scenario involving a blowout from platform Gail addresses two complicating factors: a) the complexity arising from a prolonged blowout spill that lasts many days vs. a instantaneous batch spill; and b) the problem of a dispersant operation that is less than 100% efficient.

Generally blowout spills pose somewhat different environmental threats compared to those from batch spills involving the same amount of oil. The differences arise because of dissimilarities in the fate and movements of spilled oil in the two spills. In principle, untreated and dispersed blowouts may cause larger or smaller impacts than the corresponding batch spills depending on the spill location and the nature of the receiving environment. In the present Platform Gail scenario, the impact of the untreated blowout is smaller than its corresponding batch spill, for several reasons. However, the impact of the dispersed spill is negligible, so dispersants still offer a NEB. This result is consistent with studies of similar offshore blowouts in other areas, such as the Gulf of Mexico. Therefore, despite the additional complexity of the blowout spill, it is clear that dispersants still offered a NEB, in this case.

In this scenario, dispersants are less than 100% efficient due to operational limitations and this too may influence the NEB issue. If dispersant operations were 100% effective, the net environmental benefit of dispersion would be clear. Dispersants would eliminate risks posed by the untreated spill without increasing the risk to in-water resources appreciably. However, the dispersant operation is only 75% efficient. In this case, a 75% reduction in the quantity of oil leaving the spill site is sufficient to almost eliminate shoreline oiling and to reduce or eliminate risks to living habitats, wildlife and invertebrates. So, in short, chemical dispersion, though only 75% efficient, still dramatically reduces the risks from the untreated spill, while not increasing the risks to in-water resources appreciably. Therefore dispersion, though only 75% effective, appears to offer a clear NEB.

In short, despite the additional complications of a blowout scenario and incomplete dispersion, dispersants offer a clear NEB in the case of the Platform Gail blowout spill. It must be borne in mind that this may not be true in all scenarios.

Based on this study, it is reasonable to conclude that for most marine spills of this size in this area, effective chemical dispersion of spills generally offers a net environmental benefit. This is certainly true for offshore spills, but also appears to be true for spills in shallower, nearshore waters, as well, with some possible exceptions.

The report contains a detailed list of conclusions and recommendations.

Table of Contents

1. Introduction

1.1 Study Rationale

The main objective of this study is to assess the operational and environmental factors associated with using dispersants to treat oil spills from Outer Continental Shelf (OCS) facilities in the Minerals Management Service (MMS) Pacific Outer Continental Shelf Region (POCSR). This follows a similar study of OCS spills in the Gulf of Mexico (SL Ross 2000). Whereas the Gulf of Mexico study was restricted to spills from offshore exploration and production facilities, this California study has been expanded to include spills from other sources such as oil tankers. Our goals are to help expedite dispersant-use decision-making and planning on a California-wide and agency-wide basis and to provide an information base for MMS and other agencies in revising dispersant regulations.

1.2 Study Approach

The study approach involves a detailed assessment of all factors associated with the use of chemical dispersants to treat California marine oil spills. 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 - 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 in California;
2. Define the existing knowledge base, highlighting significant developments and their implications; and
3. Identify significant gaps in knowledge, with special reference to California requirements, and make recommendations on steps that could be taken to address the deficiencies.

1.3 Structure of Report

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

Chapter 3 presents a detailed analysis of the crude oils that are produced in POCSR waters and oils that are moved by tanker into California ports. The purpose of this is (1) to determine whether there is a reasonable number of oils handled in California waters 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 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 tanker 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.

Chapter 6 assesses the potential net environmental benefit of using dispersants to treat the selected spills. 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.

1.4 Scope and Limitations of Study

This research project attempts to address all key aspects of dispersant use in southern and central California, including dispersant effectiveness, operational feasibility, logistics and environmental effects. The approach 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, 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 assess the limits 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 ratio 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 or Time Windows (TW) 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 California. 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.

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. The chapter is an abbreviated version of the same chapter in the above-noted Gulf of Mexico study that is available for download at http://www.mms.gov/tarprojects/349.htm.

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.

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.

Diesel fuel, which is used as fuel on the OCS platforms and on the vessels that serve the offshore industry, 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, as 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.

2.1.2.1 Drifting

Drifting or advection is the process of surface slicks moving away from the site of a spill by water currents and winds. The vector combination of water currents and winds determines the final slick drift. 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 as well as water current forces, and thus can be driven ashore by onshore winds. On the other hand, if the oil is dispersed, movement of the oil droplets in the water will only be influenced by 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.

2.1.2.2 Slick Spreading

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. Some models take into account the influence of pour point in the spreading process. The "pour point" of an oil is the temperature below which it will not flow. Pour point increases as the spilled oil evaporates. Pour point is a major problem for many oils, but generally not for POCSR crude oils or crude oils brought into the state by tanker. Most of these will become highly viscous through emulsification well before the pour point of the spilled oil reaches the 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 today.

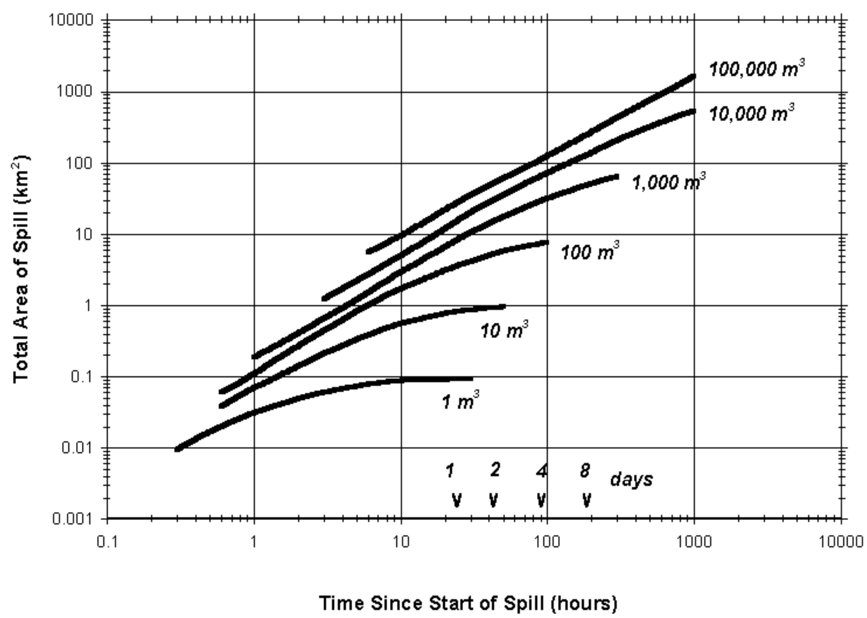


Figure 2-1 Total Area of Slick (thick + thin) versus Time

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 importance in regard to dispersant effectiveness. It is now generally accepted in the U.S. (SEA 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).

2.1.2.3 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 “emulsifies” or “gels”. This greatly increases the viscosity of the residual oil and its resistance to chemical or natural dispersion.

Most evaporation models today follow a similar approach of determining an overall “mass transfer coefficient” as a function of environmental conditions (see for example, Nadeau and

Mackay 1978 and Stiver and Mackay 1983). In these models 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. 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)

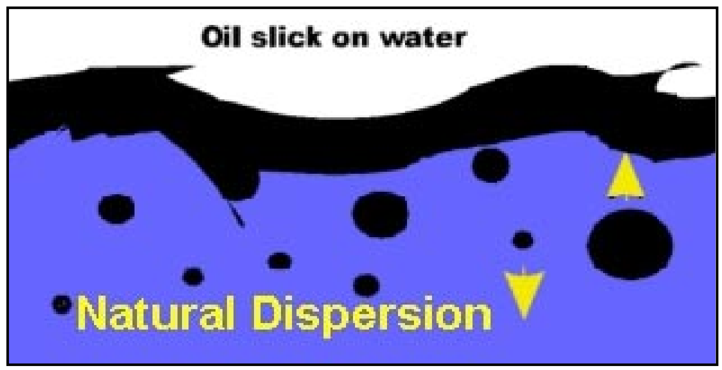
	Oil Loss (Percent)					
	Exposure Time = 6 h			**Exposure Time = 24 h**		
Sea State	**5°C**	**15°C**	**25°C**	**5°C**	**15°C**	**25°C**
Low (0 to 1)	16	21	28	23	32	38
Medium (2 to 3)	23	32	39	28	37	44
High (4 to 6)	26	35	42	29	38	45

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

Spills associated with above-surface or platform-based blowouts tend to evaporate much faster than shown above 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 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 POCSR oils.

2.1.2.4 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.



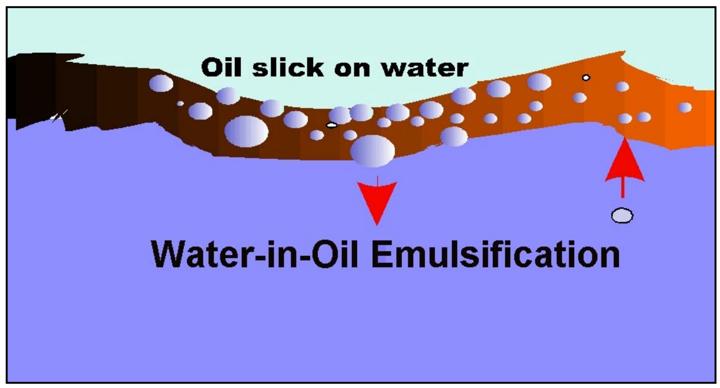
In slick dispersion, oil droplets are dispersed from the slick into the water by oceanic mixing. The larger of these droplets, which are buoyant, resurface quickly and rejoin the slick. The smaller droplets remain in suspension in the water column. The lighter, more water-soluble hydrocarbons partition 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 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).

2.1.2.5 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.



Several theories have been advanced about the main chemical mechanisms involved in the emulsification 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 coalesce into larger droplets, which would sink through and leave the oil phase. 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 "break" such emulsions; that is, their presence tends to promote the separation or the "creaming" 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 processes 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 "stable", 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 1982a,b) 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 the tendency of an oil to form emulsion, but does not predict rates of 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 short time frame as a single "batch" of oil. A pipeline failure can lead to the release of oil at the seabed and its rise 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 blowout can occur at the surface and cause oil can "rain down" on the water's surface. Each of these spill types results in a unique initial slick configuration that can 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 briefly. More detailed discussions are available elsewhere (SL Ross 1997a, 2000).

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 seabed and rises through the water column to the water surface. The other possibility is an above-surface blowout in which the platform maintains its position during the accident 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.

2.1.3.1 Shallow Water Subsea Blowouts

Oil-well blowouts generally involve two fluids, namely crude oil and natural gas. The natural gas provides the driving force for an uncontrolled blowout. 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. At the surface the oil droplets spread and coalesce and the resulting slick takes on a hyperbolic shape when subjected to water current, with its apex pointed up-current. Figure 2-2 schematically depicts the characteristics of a shallow well blowout.

2.1.3.2 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. Atmospheric dispersion and the settling velocity of the oil particles determine the fate of the oil at this point. The oil will "rain" down, with the larger droplets falling closer to the release point. 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 evaporation, the oil's physical properties will change significantly by the time the oil reaches the water's surface.

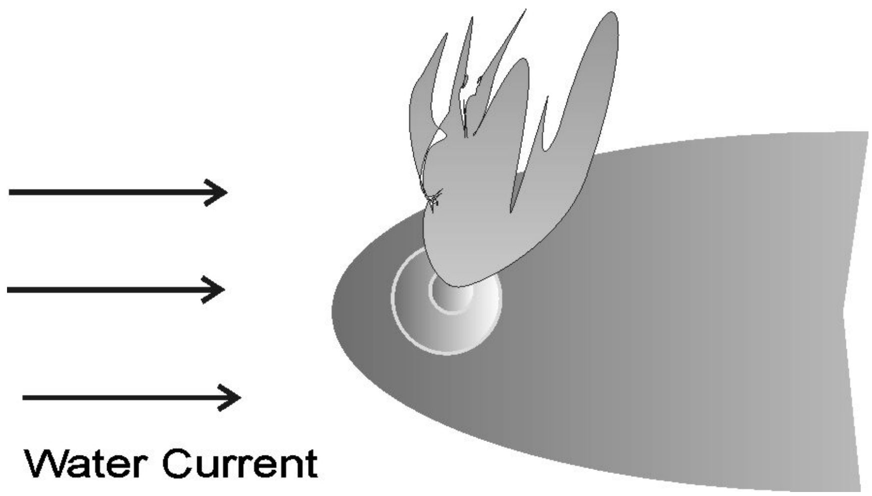
As seawater passes under the area of falling oil it will be "painted" by the falling oil and an accumulation of oil over the width of the fallout zone will occur. Changing wind and water current directions will affect the ultimate distribution of the oil on the water surface in the fallout.

2.1.3.3 Pipeline Discharges

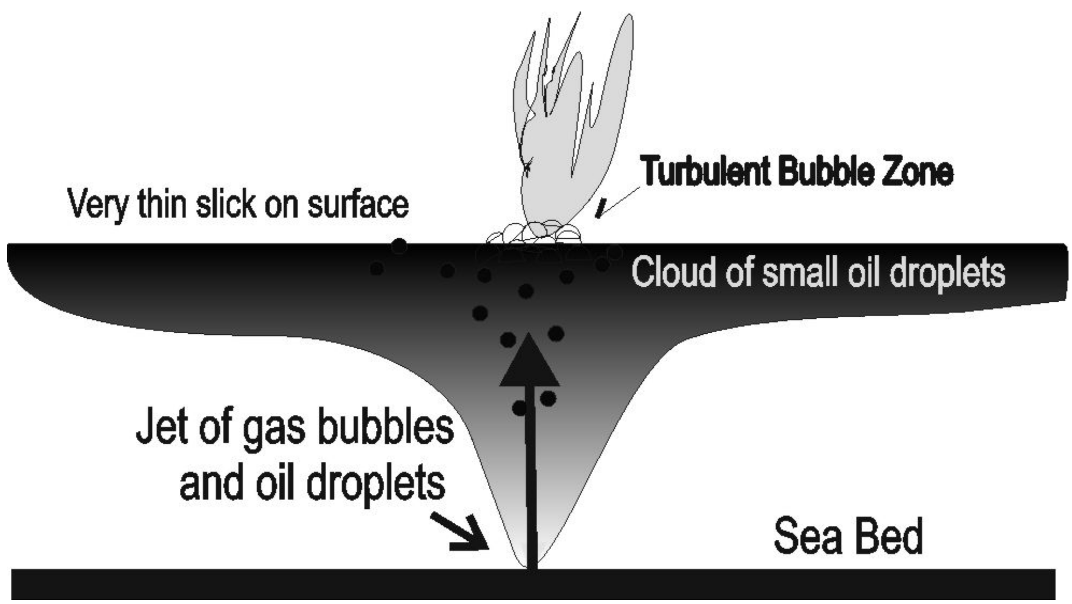
Pipelines can carry either a mixture of gas and oil (”live" pipelines) or simply crude oil. Ruptures from "live" pipelines will behave like short-term blowouts. "Crude only" pipeline spills will result in surface slicks similar to surface tanker releases because the oil will quickly rise to the surface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

2.1.4 Modeling Oil Spill Fate and Behavior

The spill processes discussed above (evaporation, spreading, etc.) 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.



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

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 used. Emulsification is modeled using the relationship developed by Mackay and Zagorski (1982a,b), 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 POCSR 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. These have been used 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 exposure of a specific resource to oil 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.

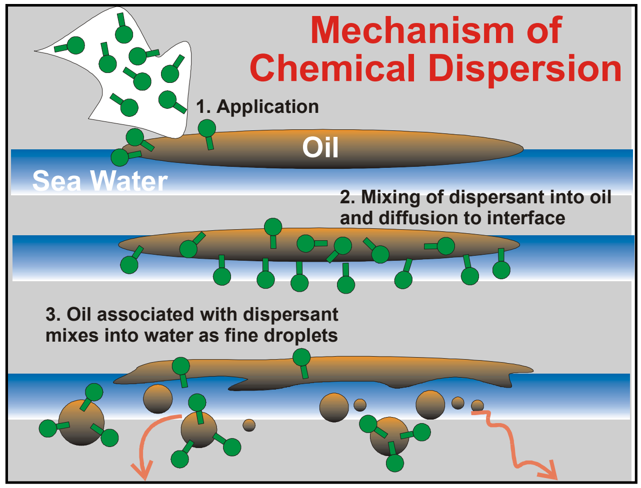
2. The second deals with the potential trajectories of spills. This portion of the analysis consists of running a large number of hypothetical trajectories. Analyses are conducted on spills launched from specific locations. In each run, the trajectory is a consequence of the integrated action of temporally and spatially varying winds and ocean currents. Details of the derivation of the winds and current fields are given in Johnson et al. 2000. 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 Johnson et al. 2000.

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.

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 would 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 about 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 workboats. 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 can be applied by 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 de-aromatized 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). Preliminary 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 "coated" with surfactant molecules, oriented in such a way that coalescence between droplets is prevented when droplets approach each other or collide, and droplets tend not to stick to things like bird feathers, sand particles, and the like. However, because 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. In the end, the main benefit of dispersing oil spills is the breakup of the mass of oil into droplets and the dilution of these droplets 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 California marine 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?

"Dispersant 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 "operational 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, "dispersant 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 – 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.

Table 2-2 Dispersibility of Oil versus 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 chemically 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.

Ignoring the problem of high-pour-point oils for the moment, the table indicates that oils with 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, 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

[1] API gravity of 18° = Specific Gravity of 0.95

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 "mixing" 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.

2.3.3.1 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 under-dosed 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 1986) 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.

2.3.3.2 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. Also, as mentioned earlier, it is important to remark that certain, newer dispersant products, such as Corexit 9500, may be effective at higher viscosities than noted here.

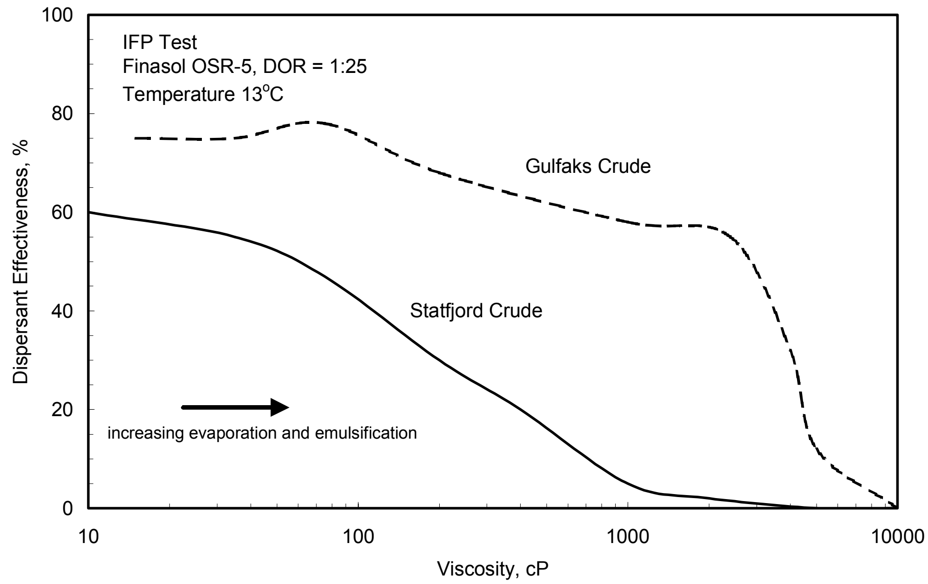


Figure 2-3a Effect of Viscosity on Dispersant Effectiveness (after Daling 1986)

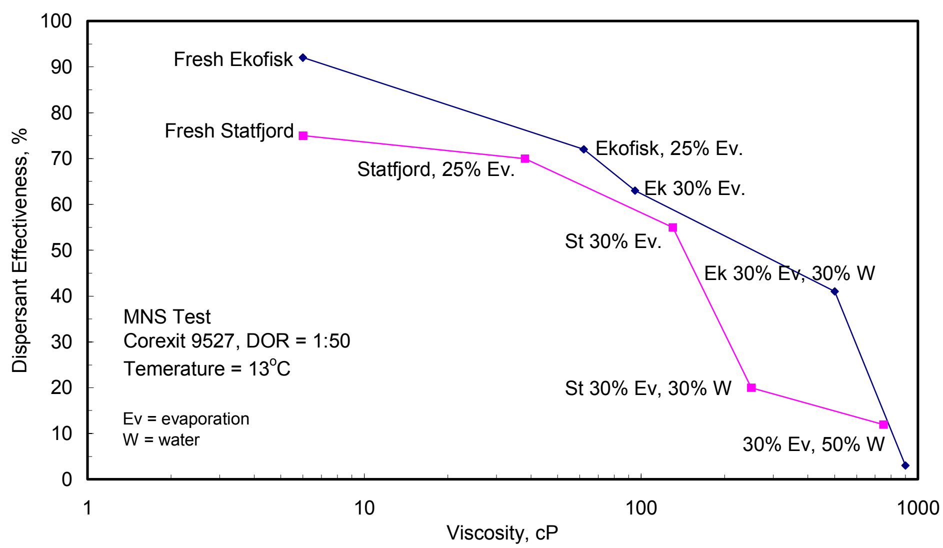


Figure 2-3b Effect of Viscosity on Dispersant Effectiveness (after Daling and Brandvik1991)

Finally, it should also 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.

2.3.3.3 Herding and Dispersant Drop Size

The phenomenon of slick "herding" 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 1986). 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 workboats is in the vicinity of 500 µm (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).

2.3.3.4 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.

2.3.3.5 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. A few years ago, Corexit 9500 was developed to replace Corexit 9527. Corexit 9500 contains the same surfactant chemicals in the same amounts as Corexit 9527. However, a low-toxicity, hydrocarbon-based carrier in Corexit 9500 replaces the glycol-based carrier of Corexit 9527. 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 et al. in California using a modified version of the Swirling Flask Test (Blondina et al. 1997). 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.

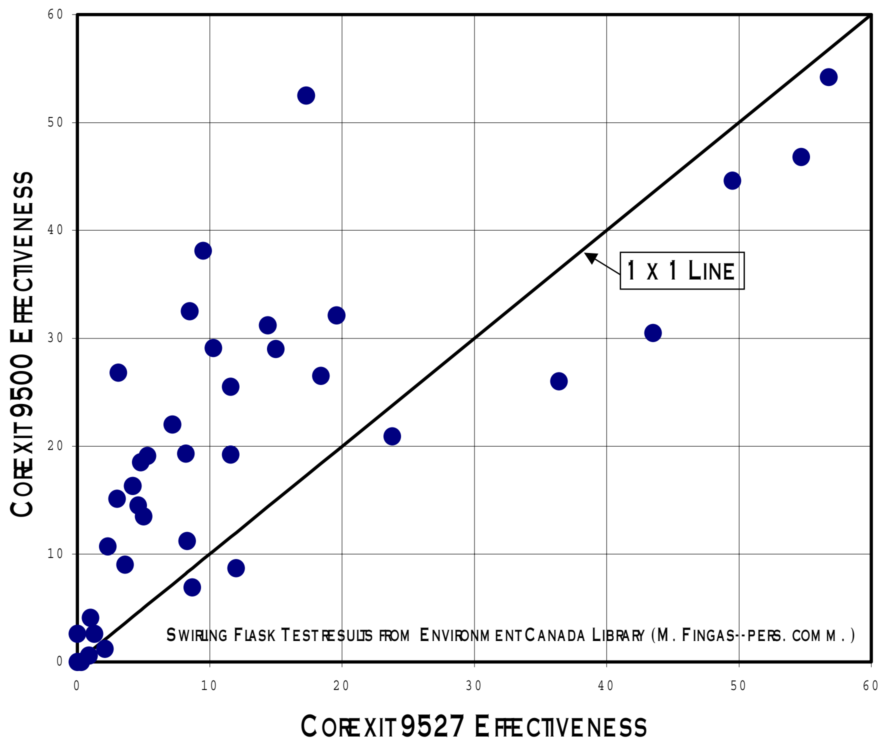


Figure 2-4 Comparison of Corexit 9500 to Corexit 9527

2.3.3.6 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 (Belore and Ross 2000a,b,c) with Corexit 9527 and Corexit 9500 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.

2.3.3.7 Temperature

There is a general misconception that temperature, *per se*, is a problem in dispersant effectiveness, and that dispersants should not or cannot 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 California situation.

2.3.3.8 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).

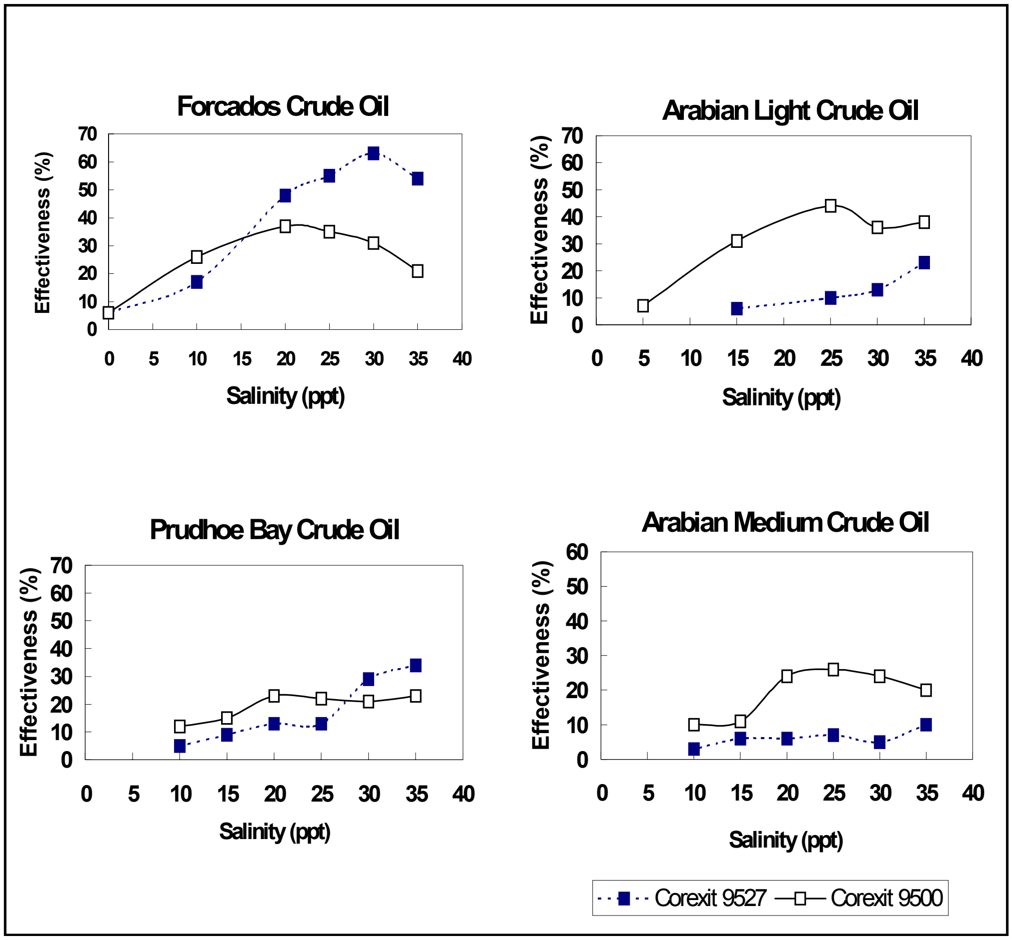


Figure 2-5 Mean Effectiveness of Corexit 9527 and 9500 on Four Crude Oils

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 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. Detailed reviews of these experimental spills and the *Sea Empress* spill are readily available elsewhere (see SL Ross 1997b or SL Ross 2000) and are not repeated here. SL Ross 2000 is available for download at the MMS web site, http://www.mms.gov/tarprojects/349.htm . Suffice to note here that the results of the experimental spills and the experience at the *Sea Empress* response provided convincing evidence that dispersants have the potential to greatly enhance the dispersion of spills at sea. The success of using dispersants during the response to the *Sea Empress* spill was particularly impressive, and may have influenced thinking in the U.S. regarding the utility of this countermeasures approach.

The results of the field experiments also confirmed that dispersant use is no magic solution to oil spill control, but rather that the effectiveness of the approach is highly dependent on the oil involved and its weathered state, the dispersant used, the prevailing sea state, and the application methods used. The idea is to factor these issues into the contingency planning process to ensure that the dispersant response is as effective as possible under the circumstances of the spill.

3. "California" Oils and their Likely Dispersibility

3.1 Introduction

There are three basic kinds of oils that are of interest in the study. The first are crude oils produced in California OCS waters, which would be involved in spills from blowouts, and accidents to pipelines and offshore storage facilities. The second are crude oils shipped by tanker from Alaska and oils imported from other countries, and the third is fuel oil that could be spilled in any of a number of marine industrial activities. Understanding the properties of specific oils in these three categories is important from a dispersant-use perspective because dispersants can only work if the spilled oil at the time of treatment has a 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.

The following analysis of all oils of interest in this study (called "California oils" for convenience) is divided into sections on POCSR produced oils and oils shipped to the state by tanker. Unfortunately, no comprehensive database was available concerning the third category of California oils, the fuel oils and refined products transported as fuel or cargo. For this reason, this group is represented in this study by No.2 fuel oil only. First, an overview of produced oils (Section 3.2) and imported oils (Section 3.3) is presented; this is followed by a tabular representation and grouping of all oils and their important properties (Section 3.4).

3.2 Oils Produced in the POCSR

Recognized discoveries of federally controlled oil and gas fields in the POSCR are shown in Figure 3-1. Within the area shown are twenty-four oil and gas production facilities—twenty-two of which produce oil and gas, and two are processing facilities. With one exception, all of these facilities are in operation. As of April 2001, these facilities have produced a total of over one billion barrels of oil and 1.2 trillion cubic feet of gas. Currently, six companies are operating offshore oil and gas facilities in the Pacific Region. Information about these facilities is available at http://www.mms.gov/omm/pacific/toc.htm.

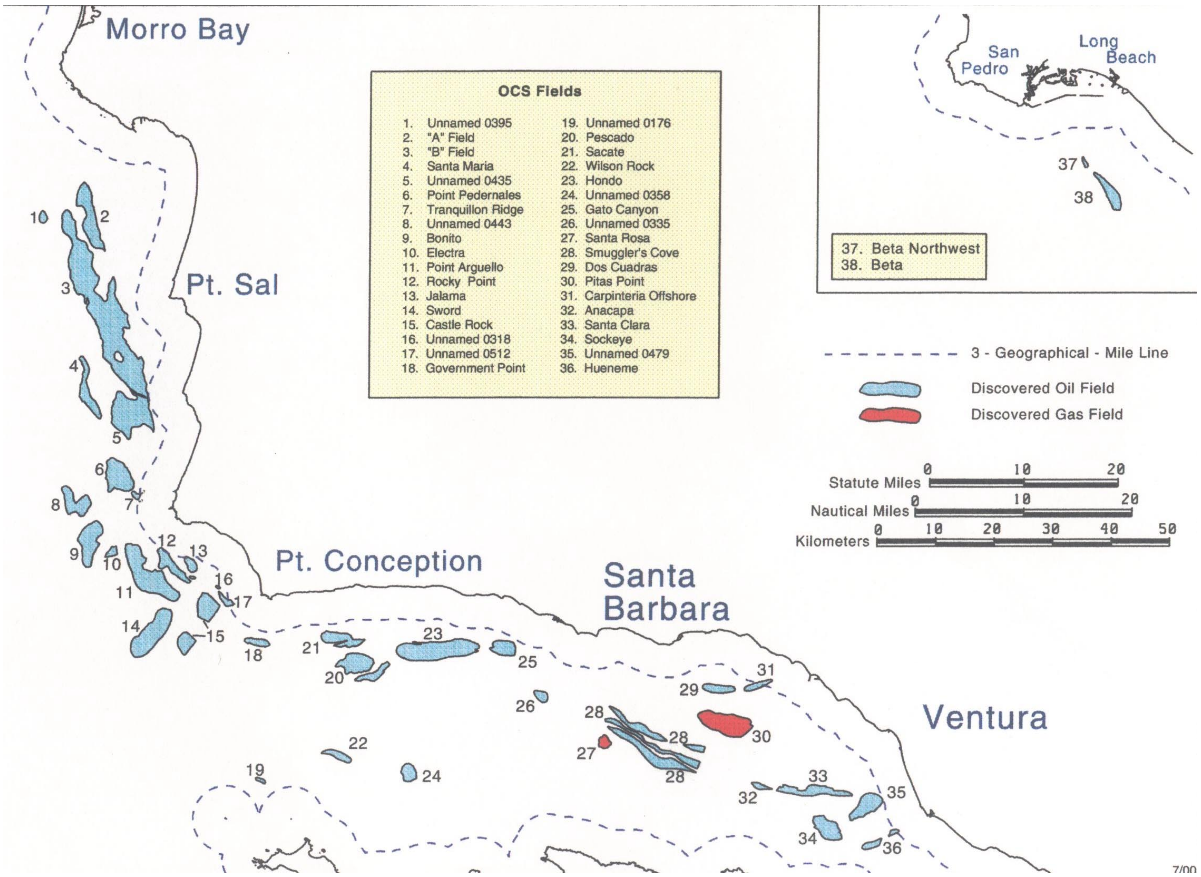


figure from http://www.mms.gov/omm/pacific/images/fig-04new.gif

Figure 3-1 Oil and Gas Fields in the Pacific OCS Region

Until recently, the properties of oils produced off California were not well understood from an oil spill dispersant perspective. API gravity information was readily available, as always, but such information alone is of limited value in assessing the issue of spill dispersibility. As discussed in the previous chapter, oil density by itself correlates only roughly to spill dispersibility. Except for very heavy or very light oils, it is impossible to predict the dispersibility of spilled oils 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 evaporates and possibly emulsifies over time. These data can only be obtained by conducting weathering and spill-related tests in the laboratory on the oils of interest.

Fortunately, in 1999, MMS sponsored an oil spill-related project (Jokuty et al. 1999) that involved a thorough testing of oils that are being produced at a number of the 22 platforms, and it is information from this testing that is particularly useful in assessing the dispersibility of POCSR oils. To start the assessment, Table 3-1 was prepared.

Note that most oils are relatively heavy - the weighted average API gravity of all produced oils is only 20.2^{o}. According to Table 2-2 in the previous chapter, this is barely outside the range of oils that are generally considered to be either very difficult or impossible to disperse (dispersibility category 4—oils with API gravity less than 17^{o}). The first impression, then, is that POCSR oils are not good candidates for chemical dispersion. It remains to analyze the oils more thoroughly, by use of a spill model, to confirm whether this is true or not. This is done in Section 3.4.

3.3 Crude Oils Shipped to California

It is surprisingly difficult, using publicly available information, to determine exactly what oils are brought into California by tanker. The best database of crude oils imported into California (or any U.S. region) is that provided by the U.S. Department of Energy at:

http://www.eia.doe.gov/oil_gas/petroleum/data_publications/company_level_imports/cli.html.

Table 3-1 POCSR Fields, Platforms and Oils

Oil Field Name	Platform Name	POCSR API Gravity (1)	MMS/EC Oil Catalog (2) Name	API Gravity	Average Annual Production 1996-2000 (BBLS) (3)
Beta	Ellen Elly Eureka Edith	17.3 - 18.3	Beta	13.7	2,364,019
Carpinteria	Hogan Houchin Henry	24.2	Carpinteria	22.9	808,641
Dos Cuadras	Hillhouse A B C	24.3	Dos Cuadras	25.6	2,473,702
Hondo	Hondo Harmony	21.5	Hondo	19.6	13,938,138
Hueneme	Gina	20.9	Port Hueneme		222,569
Pescado	Heritage	21.5			11,968,537
Pitas Point	Habitat		Pitas Point	38	3,099
Point Arguello	Hidalgo Harvest Hermosa	22.2	Point Arguello Commingled Point Arguello Heavy Point Arguello Light	21.4 18.2 30.3	9,627,539
Point Pedernales	Irene	21.1	Platform Irene	11.2	3,294,989
Sacate					2,187,755 (4)
Santa Clara	Gilda Grace	20.9	Santa Clara	22.1	1,145,562
Sockeye	Gail	21.6	Sockeye Sockeye Commingled Sockeye Sour Sockeye Sweet	26.2 19.8 18.8 29.4	1,735,719
			Platform Holly	11	

(1) From a table presented at a POCSR workshop, June 7, 2001. From samples taken between Jan, 99 & Oct, 99
(2) Jokuty,P.,s. Whiticar, Z. Wang, B. Fieldhouse, and M. Fingas,
A Catalogue of Crude Oil and Oil Product Properties for the Pacific Region, 264p 1999.
(3) Pacific Production Information and Data Available in ASCII Files for Downloading:
http://www.gomr.mms.gov/homepg/pubinfo/pacificfreeasci/product/pacificfreeprod.html
(4) Sacate shows up in the production files in 1999 with 0.25 MBbl and then in 2000 with 2.0 MBbls

For every tanker shipment of crude oil imported to California from 1992 to 2000, the database contains information on: (1) the company importing the oil, (2) month and year of shipment, (2) the port of entry or city, (3) the quantity of oil, (4) the sulfur content of the oil by weight percent, (5) the API gravity of the oil, and (6) the country of origin for the oil.

One deficiency of the database is that it does not contain information on oils brought into the state from Alaska. A greater problem is that the database does not provide the exact names of the oils that are imported. This is important because there are different types of oils imported from each country and these can vary greatly in terms of viscosity, dispersibility and other properties.

For example, four main oils are available for export from Saudi Arabia (Arab Extra Light., Arab Light, Arab Medium, and Arab Heavy) and these have very different properties.

In order to solve the problem, the sulfur and API data in the database were matched with the data of known oils. This was done by referring to a range of available oil property databases and by accepting help from contacts in the oil industry who are involved in petroleum shipping or refining in California. The end result of the exercise is shown in Table 3-2. Because the type of oils imported and the countries of origin change over time for a number of reasons, it was decided to restrict the data in Table 3-2 to the last three years in order to present a representative picture of oils being imported recently.

Note that there are two or three dozen oils imported annually. The most important, Alaska North Slope crude oil, represents about 50% of all oil imported by tanker; hence, the dispersibility of this oil is crucial to this study.

Few of the remaining oils make up more than 10% of the market. To arrive at a manageable number of oils, we limited the oils to those that make up 90% of the annual imported volume, or, put another way, represent 90% of the spill risk. These are highlighted in gray in Table 3-2. Notice that there is some variation in the yearly rankings, but the same oils are in the top ten, or are close, for each of the last three years.

The next step in the analytical process was to determine whether enough information about the top ten oils existed to model their spill behavior and ultimately to determine their likely dispersibility if spilled. Table 3-3 summarizes some key fresh-oil properties of the top ten oils.

The fresh-oil properties shown in Table 3-3 are not sufficient for determining the dispersibility of an oil if spilled and allowed to weather. The main piece of information missing is the oil's tendency to form emulsion. Fortunately, such information is available for the top five oils in the table from the results of testing done at Environment Canada's Emergencies Science Division (ESD) Laboratory[2]. As discussed in the next section, these data provide the necessary input for

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

current oil spill behavior models, including the SL Ross Oil Spill Model (discussed in Chapter 2, Section 2.1.4), ADIOS (Automated Data Inquiry for Oil Spills), the oil spill model maintained by NOAA[3], and the popular ASA model[4].

At this time, equivalent information is not available for the other five oils in Table 3-3, so the following analysis is restricted to the top five oils. These in total represent about 65% by volume of all oil imported. It is impossible to say how representative these oils are of the five for which data are missing (bottom five in the table). The bottom five oils are on average somewhat lighter than the top five (API gravity of 31.5^{o} versus 28.4^{o}).

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[3] See NOAA's latest model at the web site http://response.restoration.noaa.gov/software/adios/adios.html
[4] See a description of the ASA oil spill model at http://www.appsci.com/

Table 3-2 Summary of California Crude Oil Imports for 1999, 2000 and 2001

SUMMARY: OILS RANKED BY VOLUME (1999)

Name of Oil	Volume (1000 bbls)	Fraction of Total	Cumulative Total
Alaska North Slope	188743	56.3%	56.3%
Oriente	28274	8.4%	64.7%
FAO Blend	26546	7.9%	72.6%
Basrah Light	21410	6.4%	79.0%
Arab Extra Light	9617	2.9%	81.9%
Arab Light	5657	1.7%	83.6%
Maya	9987	3.0%	86.6%
Escalante	8063	2.4%	89.0%
Arab Medium	5751	1.7%	90.7%
Minas	4774	1.4%	92.1%
Loreto	4637	1.4%	93.5%
Kuwait	3074	0.9%	94.4%
Oriente Lt.	3069	0.9%	95.3%
Sumatran Heavy	2664	0.8%	96.1%
Eocene	2482	0.7%	96.8%
Bintulu	1469	0.4%	97.3%
Dai Hung	1199	0.4%	97.6%
Isthmus	1196	0.4%	98.0%
Tapis Blend	1087	0.3%	98.3%
Lucula	869	0.3%	98.6%
Magellanes	749	0.2%	98.8%
Djeno Blend	723	0.2%	99.0%
Burgan	627	0.2%	99.2%
Seria Lt	584	0.2%	99.4%
Basrah Heavy	455	0.1%	99.5%
Lagomedio	384	0.1%	99.6%
Cano Limon	381	0.1%	99.7%
???? (Mexico)	347	0.1%	99.8%
BCF 24	262	0.1%	99.9%
???? (Malaysia)	244	0.1%	100.0%

SUMMARY: OILS RANKED BY VOLUME (2000)

Name of Oil	Volume (1000 bbls)	Fraction of Total	Cumulative Total
Alaska North Slope	163233	47.7%	47.7%
FAO Blend	39955	11.7%	59.4%
Oriente	34941	10.2%	69.6%
Arab Medium	17083	5.0%	74.6%
Arab Light	9396	2.7%	77.4%
Maya	12863	3.8%	81.1%
Yemen	9802	2.9%	84.0%
Basrah Light	9507	2.8%	86.8%
Escalante	6993	2.0%	88.8%
Minas	4110	1.2%	90.0%
Arab Extra Light	4065	1.2%	91.2%
Eocene	2825	0.8%	92.0%
Barrow Island	2801	0.8%	92.9%
Tapis Blend	2526	0.7%	93.6%
Dai Hung	2367	0.7%	94.3%
Cossack	2345	0.7%	95.0%
BCF 24	2320	0.7%	95.7%
Kuwait	2161	0.6%	96.3%
???? (Mexico)	1995	0.6%	96.9%
Oriente Light	1921	0.6%	97.4%
Basrah Heavy	1787	0.5%	98.0%
Loreto	1494	0.4%	98.4%
Cano Limon	1237	0.4%	98.8%
Taching (Daqing)	835	0.2%	99.0%
Burgan	780	0.2%	99.2%
Bachaquero	694	0.2%	99.4%
Murban	423	0.1%	99.6%
Seria Light	414	0.1%	99.7%
Griffin	411	0.1%	99.8%
Bintulu	384	0.1%	99.9%
Champion Export	237	0.1%	100.0%
Dubai	54	0.0%	100.0%

SUMMARY: OILS RANKED BY VOLUME (2001*)

Name of Oil	Volume (1000 bbls)	Fraction of Total	Cumulative Total
Alaska North Slope**	48091	49.7%	49.7%
Arab Medium	9092	9.4%	59.1%
FAO Blend	6531	6.7%	65.8%
Maya	6130	6.3%	72.1%
Arab Light	5325	5.5%	77.6%
Yemen	4149	4.3%	81.9%
Oriente	3527	3.6%	85.6%
Cossack	2566	2.7%	88.2%
Murban	2282	2.4%	90.6%
Escalante	2176	2.2%	92.8%
Arab Extra Light	1690	1.7%	94.6%
Seria Light	811	0.8%	95.4%
BCF 24	804	0.8%	96.2%
Vasconia	745	0.8%	97.0%
Minas	623	0.6%	97.6%
Lucula	560	0.6%	98.2%
???? (Australia)	433	0.4%	98.7%
???? (Congo)	399	0.4%	99.1%
Arab Heavy	332	0.3%	99.4%
Loreto	290	0.3%	99.7%
Jackson Blend	196	0.2%	99.9%
Cano Limon	75	0.1%	100.0%

*data for January to April 2001

**note: volume for Alaska estimated assuming 12% decline from 2000, which reflects trend of last five years

In above three charts, a total of ten oils (highlighted) represent 90% of the volume in a given period.

Table 3-3 Some Fresh Oil Properties of Top Ten Oils Shipped to California, 1999-2001

Oil Type	Identifying Properties				Sufficient spill-test data for modeling purposes?
	API gravity	Sulfur content, %	Viscosity at 15°C, cP	Pour point, °C	
Alaska North Slope	26.8	1.15	17	-15	yes[a]
Arab Medium	30.8	2.4	29	-10	yes[a]
Maya	21.8	3.3	299	-20	yes[a]
Arabian Light	33.4	1.77	14	-53	yes[a]
Oriente	29.2	1.01	85	-4	yes[a]
Basrah Light	33.7	1.95	≈20	-15	no
Escalante/Canadon Seco	24.1	0.19	?	?	no
Arabian Extra Light	37.9	1.2	?	?	no
FAO Blend	31.0	3.0	?	?	no
Yemen	31.0	0.6	?	?	no

a. See Table 3-4

3.4 Modeling and Categorizing Representative California Oils

Using the simple technique discussed in Section 2.3.2 and summarized in Table 2-2, where spill dispersibility is assessed only on the basis the API gravity and pour point of the fresh oil (no evaporation or emulsification), all of the imported oils shown in Table 3-3 and several of the produced oils in Table 3-1 might be considered to be reasonably dispersible. The question is: Will this remain to be the case when oil weathering and emulsification are taken into account?

To answer this question the SL Ross Oil Spill Model was used to describe the time-dependent spill characteristics of the 18 California oils—produced oils, imported oils, and diesel oil—for which spill-related test results are available. The modeling for each oil considered 1000-bbl and 10,000-bbl batch spills under average environmental conditions. The 18 oils (from Tables 3-1 and 3-3) were then divided into three categories of "emulsion formation tendency" ranging from highly emulsifiable oils to oils that do not emulsify. The end result is shown in Table 3-4 (see end of section).

It is seen that 12 of the 18 oils are considered to be highly emulsifiable and will have a very narrow "window of opportunity" for successful treatment 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 examples of Arab Medium crude or Pt. Arguello Light crude. In each case, a 1000-barrel spill of either oil will begin to emulsify immediately once exposed to the marine environment and will reach a viscosity of 2000 cP in only about 4 hours. In 6 to 7 hours it will have a viscosity of 5000 cP, and in 22 to 23 hours it will reach a viscosity of 20,000 cP. Assuming the viscosity cut-off point for effective use of dispersants is in the range of 5000 to 20,000 cP (it depends on the type of dispersant and oil—there is uncertainty on this), there is limited time available for a dispersant response to the spill, especially if the viscosity cut-off points are in the lower range.

The next category is for so-called Av-E oils. These are oils that will start to emulsify after 11 to 29% evaporation. Consider ANS crude, by far the most important oil in this study and the crude oil that will be taken 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, 38 to 67 hours depending on the selected spill size and viscosity cut-off value.

Finally, the situation is ideal for the final category of No-E oils, of which there are two in this study—Diesel oil and Pitas Point crude, which can be considered a heavy gas condensate. These 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.

In summary, the opportunity for using dispersants effectively on the example oils shown in the table is limited. The major exception is Alaska North Slope crude, which represents about 50% of the oil spill risk from tankers in the state. Another key exception is diesel oil which tends to be spilled relatively frequently everywhere because of its ubiquitous nature. For the produced oils the situation is less promising, but if the spill circumstances are right and response is very rapid, some success might be possible.

This conclusion speaks of tanker spills and produced oil spills in general. No two spills are alike, of course, and there will be exceptions to the general statements. 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. The following chapter now looks at several specific oil spill scenarios in California marine waters and analyses the dispersant-use possibilities in great detail.

Table 3-4 POCSR and Imported California Oils That Have Undergone Spill-Related Testing

Crude oil name	API Gravity	Fresh oil Pour Point °C	Oil Viscosity @ 15°C at various weathered states			Emulsion formation tendency	Size of "Window of Opportunity" for successful dispersant use	Hours for oil to reach specified viscosity in 5 m/s (10 kt) winds and at 15°C water temperature					
								1000 Barrel Batch Spill			10,000 Barrel Batch Spill		
			0%	~ 15%	~ 25%			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 % oil evaporation)													
Arab Medium	29.5	-10	29	91	275	Yes @ 0%	very narrow	4.2	6.4	22.0	4.9	7.7	39.0
Arab Light[a]	31.8	-53	14	33	94	Yes @ 0%	narrow[a]	10.0	36.0	Disp @41 hr	13.3	68.8	Disp @ 68
Hondo	19.6	-15	735	9583	449700	Yes @ 0%	very narrow	2.0	3.0	5.5	2.4	3.7	6.2
Hueneme	14.8	-9	4131	20990		Yes @ 0%	very narrow	0.0	0.5	1.9	0.0	0.5	1.9
Maya	21.8	-20	299	99390		Yes @ 0%	very narrow	1.6	2.3	4.8	1.8	2.6	5.1
Oriente	25.9	-4	85		6124	Yes @ 0%	very narrow	2.2	3.2	5.2	2.8	3.8	6.4
Pt Arguello Comingled	21.4	-12	533	41860	2266000	Yes @ 0%	very narrow	1.6	2.6	4.3	1.7	2.9	4.9
Pt Arguello Heavy	18.2	-4	3250		4953000	Yes @ 0%	very narrow	0.0	0.5	1.7	0.0	0.5	1.9
Pt Arguello Light	30.3	-22	22	183	671	Yes @ 0%	very narrow	4.4	6.9	23.0	5.1	8.1	42.0
Santa Clara	22.1	-3	304	1859	22760	Yes @ 0%	very narrow	2.6	3.8	6.6	2.9	4.4	7.9
Sockeye	26.2	-12	45	163	628	Yes @ 0%	very narrow	3.9	5.6	13.2	4.3	6.4	20.4
Sockeye Sour	18.8	-22	821	8708	475200	Yes @ 0%	very narrow	1.1	1.9	3.1	1.3	2.0	3.5
MEDIUM EMULSIFIABLE OILS (Av-E Oils) (Emulsion forms at 11 to 29 % oil evaporation)													
Alaska North Slope	26.8	-15	17	110	650	Yes @ 26%	narrow	37.9	39.7	43.3	60.7	62.2	66.7
Carpinteria	22.9	-21	164	3426		Yes @ 11%	narrow	5.6	6.6	8.9	8.3	9.5	12.0
Dos Cuadras	25.6	-30	51	187	741	Yes @ 11%	narrow	5.4	7.0	11.0	7.4	8.9	14.3
Sockeye Sweet	29.4	-20	20	39	321	Yes @ 17%	narrow	8.6	10.6	28.8	11.6	14.1	47.8
OILS THAT DO NOT EMULSIFY (No-E Oils) (Emulsion does not form)													
Diesel	39.5	-30	8	25	100	No	very wide	60.0	Disp @ 69 hr		101.0	Disp @ 111 hr	
Pitas Point	38.0	<-60	2		2	No	very wide	Disp @ 2.3 hr			Disp @ 3.5 hr		

a. Although Arab Light is a highly emulsifiable crude oil, the viscosity of its emulsion is estimated to be relatively low, explaining the "narrow" time window designation rather than "very narrow".

4. Oil Spill Scenarios

4.1 Basic Considerations

The objective of the study is to conduct an assessment of the operational and environmental factors associated with the use of chemical dispersants to treat California marine oils spills, including spills from POCSR facilities and spills from tankers. 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 to reflect the range of possibilities. Specifically, the spills of interest are:

a. Batch (or instantaneous) spills of various size from platforms or vessels;
b. Subsea oil well blowouts;
c. 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, a review of existing contingency plans was undertaken for the region and the spill scenarios in these plans were documented. Table 4-1 provides a summary of the scenarios identified in these plans. The scenarios are broken down into two categories. The first category includes spills from production facilities (blowouts, platform and pipeline releases) and the second are spills from vessels.

The locations where blowouts were identified in the plans were in the Arguello and Santa Clara units. Many of the production sites have low formation pressures and therefore oil well blowouts are not an issue at these sites. Detailed oil property information is also available for the oils at these facilities; therefore, the spill scenarios from the contingency plans for these facilities (blowouts and small batch spills) have been selected to represent spills of locally produced oils. The oils produced in these locations are also typical of those produced in the region, as is shown in Table 3-4 (previous chapter).

The vessel spill scenarios from the plans have been selected to encompass the range of oil types and spill sizes that are of interest in the region.

4.2 Environmental and Other Conditions

Average wind speeds, air and water temperatures were selected for four distinct sets of scenarios. The values used in the fate/behavior modeling for these four locations are shown in Table 4-2.

The production Gas-to-Oil Ratios (GOR) reported for the various platforms were used in the blowout scenarios. For the above-sea releases, the discharges are assumed to occur through 6-inch (inner diameter) pipe and from a location 15 meters above the water. For the sub-sea blowouts the discharges are assumed to flow through six-inch (inner diameter) pipe and from water depths specific to the platform locations. Pipeline releases are assumed to behave like surface batch spills.

Table 4-1 Discharge Rates and Volumes for Spill Scenarios

Identifier	Location	Oil	Batch Spill, bbl	Well Blowout, bbl/day
PLATFORM SPILLS				
Point Arguello Unit[a]				
Hermosa	34.455N, 120.646W			
- blowout				1070 bbl/d x30 days
- pipeline discharge		Arguello Comm'd	2217	
Hidalgo Platform	34.495°N,120.702° W			
-blowout		Arguello Light		973 bbl/d x30 days
-pipeline discharge			500	
Harvest	34.469N, 120.681W	Arguello Heavy		
-blowout				5000 bbl/d x30 days
-pipeline discharge			292	
Santa Clara Unit[b]				
Gail				
-blowout		Sockeye		882 bbl/d x30 days
-platform vessels and piping			2068	
- pipelines			131	
Grace				
- pipelines			313	
VESSEL SPILLS[b]				
San Francisco Bay Area[c]				
1. N shore of SE Farallon Jan- winds historic		ANS	300,000 bbl	
2. N shore of SE Farallon Aug winds historic		ANS	300,000 bbl	
3. Anchorage 9, Winter winds – 20 kts SW		ANS	12,000 bbl	
4. Harding Rock – Feb winds historic		ANS	300,000 bbl	
5 Harding Rock – Aug-winds historic		ANS	300,000 bbl	
6. Benecia- April- April 10 kts NW		ANS	2,500 bbl	
7. Benecia- April- winds 20 kts S		ANS	2,500 bbl	
8. Benecia- April- winds 10 kts NW		ANS	2,500 bbl	
9. Benecia- April- winds 20 kts S		ANS	2,500 bbl	
Los Angeles Area[d]				
Northern Sector				
Tanker spill	SB Channel	Monterey crude	210,000 bbl	
Cargo vessel	SB Channel	#6 fuel oil	8000 bbl	
Platform spill	SB Channel	Monterey crude	2200 bbl	
Southern Sector				
Tanker spill	identified	ANS crude	1.5 MM bbl	
Cargo vessel	El Segundo Term	ANS crude	3000 bbl	

1. Based on Arguello Inc. 2001. Oil Spill Response Plan for Platforms Hidalgo, Harvest, Hermosa and Associated Pipelines.
2. Based on Venoco Inc. 2001
3. MSO San Francisco Area Contingency Plan Section 4000, Page 4600-27
4. Los Angeles/Long Beach Area Contingency Plan, Section 4700 Scenario and Scenario Development, Page 4700-1

Table 4-2 Environmental Conditions Used in Spill Scenario Modeling

Scenario Location	Wind Speed (knots)	Air and Water Temperature (°C)
Pt. Arguello	14	14
Santa Clara	7	17
Los Angeles (summer)	5	18
San Francisco (spring)	12	11

4.3 Oil Selection

Four oils produced off California and three transported oils have been selected for use in the scenarios. The blowout and pipeline spill scenarios use the oil that is specific to the production formation at the release location. The Gail platform spill uses oil properties the Sockeye field. The Pt. Arguello scenarios use properties of the heavy, light or commingled Pt. Arguello oils. The vessel spill scenarios use Alaska North Slope, Arab Medium and diesel fuel properties. These oils range from No-E oils, with very wide TWs for effective dispersant use (diesel), to Hi-E oils, with a very small TW (e.g., Arab Medium). The physical properties of the crude oils and their general spill behavior are shown in Table 4-3. The highlighted oils are those transported by vessels; the remaining ones are production oils.

4.4 List of Selected Scenarios and Analysis Approach

Eighteen basic scenarios are chosen for analysis (see Table 4-4). The first twelve are spills that have been identified in existing contingency plans for production facilities. The remaining eight scenarios are generic spills selected to cover the range of vessel spill volumes also identified in existing contingency plans. The objective is to describe the behavior of the scenarios in concise, quantitative terms. All spill behavior modeling work was done with the SL Ross Oil Spill Model, which is briefly described in Chapter 2. Because there are many scenario variations, attempts are made to describe the spills succinctly, focusing on issues of importance to dispersant use; for a more general and basic description of batch and blowout spills, please see Chapter 2.

Table 4-3 Selected Oils for California Spill Scenarios

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					
							1000 Barrel Batch Spill			10,000 Barrel Batch Spill		
		0%	~ 15%	~ 25%			2000 cP	5000 cP	20,000 cP	2000 cP	5000 cP	20,000 cP
Hi-E Oil Arabian Medium	29.5	29	91	275	Yes @ 0%	Very narrow	4.2	6.4	22.0	4.9	7.7	39.0
Av-E Oil Alaska North Slope	26.8	17	110	650	Yes @ 26%	Wide	37.9	39.7	43.3	60.7	62.2	66.7
No-E Oil Diesel	39.5	8	25	100	No	Very Wide	60	Disp @69		101.0	Disp @111	
Hi-E Oil Pt. Arguello Hvy	18.2	3250		>500000	Yes @ 0%	Very narrow	0.0	0.5	1.7	0.0	0.5	1.9
Hi-E Oil Pt. Arguello Lt.	30.3	22	183	671	Yes @ 0%	Very narrow	4.4	6.9	23.0	5.1	8.1	42.0
Hi E Oil Sockeye	26.2	45	163	628	Yes @ 0%	Very narrow	3.9	5.6	13.2	4.3	6.4	20.4

% refers to volume evaporated

Table 4-4 California Marine Oil Spill Scenarios

#	Spill Description	Spill Volume	Oil	Comments
Local Production Spill Scenarios				
1	Hermosa Platform -subsea blowout	1070 bopd for 30 days	Pt. Arguello Heavy	water depth of 184 m 480 scf gas / bbl oil, 14 knot winds, 14 °C
2	Hermosa -surface blowout	1070 bopd for 30 days	Pt. Arguello Heavy	480 scf gas / bbl oil, 14 knot winds, 14 °C
3	Hermosa Platform - batch	2217 bbl	Pt. Arguello Commingled	pipeline discharge, 14 knot winds, 14 °C
4	Hidalgo Platform -subsea blowout	973 bopd for 30 days	Pt. Arguello 4 a) Heavy 4 b) Light	water depth of 130 m, 14 knot winds, 14 °C, 763 scf gas / bbl oil
5	Hidalgo -surface blowout	973 bopd for 30 days	Pt. Arguello 5 a) Heavy 5 b) Light	763 scf gas / bbl oil, 14 knot winds, 14 °C
6	Hidalgo Platform - batch	500 bbl	Pt. Arguello 6 a) Heavy 6 b) Light	Pipeline discharge, 14 knot winds, 14 °C
7	Harvest Platform -subsea blowout	5000 bopd for 30 days	Pt. Arguello Heavy	water depth of 206 m, 14 knot winds, 14 °C, 1435 scf gas / bbl oil
8	Harvest Platform -surface blowout	5000 bopd for 30 days	Pt. Arguello Heavy	1435 scf gas / bbl oil, 14 knot winds, 14 °C
9	Harvest Platform -batch	292 bbl	Pt. Arguello Heavy	Pipeline discharge, 14 knot winds, 14 °C
10	Gail Platform -subsea blowout	882 bopd for 30 days	Sockeye crude	water depth of 225 m, 7 knot winds, 17 °C, 4071 scf gas / bbl oil
11	Gail Platform -surface blowout	882 bopd for 30 days	Sockeye crude	4071 scf gas / bbl oil, 7 knot winds, 17 °C
12	Gail Platform -batch	a) 2068 bbl b) 131 bbl	Sockeye crude	Platform vessels and piping, 7 knot winds, 17 °C
Vessel Spills				
13	Very Large Batch	250,000 bbl	13 a) ANS 13 b) Arab Med	Los Angeles area in Summer 5 knot winds 18 °C
14	Very Large Batch	250,000 bbl	14 a) ANS 14 b) Arab Med	San Francisco area in Spring 12 knot winds 11 °C
15	Large Batch	10,000 bbl	15 a) ANS 15 b) Arab Med 15 c) Diesel	Los Angeles area in Summer 5 knot winds 18 °C
16	Large Batch	10,000 bbl	16 a) ANS 16 b) Arab Med 16 c) Diesel	San Francisco area in Spring 12 knot winds 11 °C
17	Small Batch	3000 bbl	17 a) ANS 17 b) Arab Med 17 c) Diesel	Los Angeles area in Summer 5 knot winds 18 °C
18	Small Batch	3000 bbl	18 a) ANS 18 b) Arab Med 18 c) Diesel	San Francisco area in Spring 12 knot winds 11 °C

4.5 Scenario Modeling Results

The oil fate modeling results for spills from production facilities (scenarios 1 through 12) are summarized in Table 4-5a. The results of the vessel based spill modeling are summarized in Table 4-5b. The data in these tables can be read as follows.

1. The first three rows of data for in each table summarize the basic characteristics of each spill, including its tendency to form emulsion.

2. 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 4b, 10,15c, 16c, 17c and 18c). 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.

3. The time taken for the surface slick to dissipate completely (due to natural dispersion, evaporation, etc.) is the next row of data presented in Table 4-5. 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.

4. 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.

5. The final data presented in Table 4-5 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 top 10 meters of water is likely to drop below 5, 1 and 0.01 ppm are reported. 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 4-5.

4.5.1 California Production Facility Spills: Scenarios 1 through 12

The common thread in the behavior of the spills for all of the production facility scenarios is the rapid emulsification and high persistence of the oils used in the scenarios. The oils modeled are not atypical for the region, so the modeling results should be representative of these types of spills. The windows of opportunity for the use of dispersants for all of these production facility spills are determined by the amount of time available prior to an increase in the oil's viscosity due to emulsification. Refer to Table 4-5a for detailed spill behavior information for these scenarios.

Table 4-5a Spill Scenario Modeling Result Summary: Local Production Facilities

	Spill Scenario Identifier (refer to Table 4-4 for full description of scenario)															
	1	2	3	4a	4b	5a	5b	6a	6b	7	8	9	10	11	12a	12b
Spill Information																
Emulsification Tendency	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi
Volume Spilled (bbl)	32100	32100	2217	29190	29190	29190	29190	500	500	150000	150000	292	26460	26460	2068	131
Discharge Rate (BOPD)	1070	1070	batch	973	973	973	973	Batch	Batch	5000	5000	batch	882	882	Batch	batch
Viscosity (cP)																
Time to Visc.>5000 cP (hr)	0.0	0.0	1.8	0.0	-	0.0	2.0	0.17	4.7	0	0	0.17	-	4.6	7.0	5.6
Time to Visc.>20000 cP(hr)	0.01	0.0	3.1	0.01	-	0.0	3.5	1.0	22	0.01	0	1.0	-	8.9	12.4	9.6
Time to Loss of Slick (hr)	>720	>720	>720	216	0.16	>720	>720	>720	141	>720	>720	>720	0	>720	>720	>720
Time to < .05 mm (hr)	0	0	>720	0	0	1.0	>720	-	140	0	>720	>720	0	>720	>720	>720
Initial Slick Thickness	0.015	0.238	20	0.014	0.014	0.213	0.184	20	20	0.027	0.77	20	0.006	0.33	20	20
Thickness at 6 Hours	0.012	0.212	10.5	0.012	0	0.189	0.147	10.2	4.1	0.0222	0.71	8.9	0	0.26	6.4	2.8
Thickness at 12 Hours	0.012	0.208	9.6	0.011	0	0.185	.0142	9.3	3.6	0.0219	0.70	8.1	0	0.24	5.7	2.5
Thickness at 48 Hours	0.011	0.2	7.6	0.011	0	0.179	0.134	7.6	2.3	0.0206	0.67	6.6	0	0.23	4.6	2.1
Thickness when viscosity at 5000 cP	0.015	-	12.3	0.014	-	-	0.156	17.6	4.3	0.027	-	16.7	-	0.27	2.9	
Thickness when viscosity at 20000 cP	0.014	0.238	11.4	0.014	-	-	0.151	13.1	3.1	0.020	-	11.9	-	0.25	5.7	2.6
Initial slick width	527	28	150	504	504	28.5	30.0	71	71	1357	40	54	1682	22	145	36
Width at 6 Hours	527	28	200	504	0	28.5	30.0	97	143	1357	40	79	1682	23	245	91
Width at 12 Hours	527	28	207	504	0	28.5	30.0	100	149	1357	40	81	1682	24	256	95
Width at 48 Hours	527	28	226	504	0	28.5	30.0	107	164	1357	40	86	1682	25	274	98
Width at Loss of Slick or 720 hrs	527	28	259	504	0	28.5	30.0	107	171	1357	40	86	1682	25	279	98
Naturally Dispersed Oil (top 10 meters)																
Time when < 5ppm (hr)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Time when < 1 ppm (hr)	-	-	-	-	0.16	-	-	-	-	-	-	-	-	-	-	-
Time when < 0.1 ppm (hr)	-	-	-	-	12	-	-	-	12	-	-	-	24	-	-	-
Peak Concentration (ppm)	.00085	0.00084	0.0318	0.00083	1.05	0.00094	0.00865	0.0033	0.3	0.0008	0.0007	0.003	0.56	0.0058	0.07	0.04
Time Peak Reached (hr)	0.8	0.4	1.82	0.8	0.16	0.24	3.5	1.0	1.0	0.06	1.0	1.0	0.0	2.7	1.0	1.0

Table 4-5b Spill Scenario Modeling Result Summary: Vessel Spills

	Spill Scenario Identifier (refer to Table 4-4 for full description of scenario)															
	13a	13b	14a	14b	15a	15b	15c	16a	16b	16c	17a	17b	17c	18a	18b	18c
Spill Info																
Emulsification Tendency	Av	Hi	Av	Hi	Av	Hi	No	Av	Hi	No	Av	Hi	No	Av	Hi	No
Volume Spilled (bbl)	250 k	250 k	250 k	250 k	10 k	10 k	10 k	10 k	10 k	10 k	3000	3000	3000	3000	3000	3000
Discharge Rate (BOPD)	batch	batch	batch	batch	batch	batch	batch	batch	batch	batch	batch	batch	batch	batch	batch	batch
Time to Visc.>5000 cP (hr)	166	22	104	8	90	19	-	56	7	-	74	17	208	45	6	-
Time to Visc.>20000 cP (hr)	188	120	107	87	112	63	-	59	51	-	91	48	-	48	36	-
Time to Loss of Slick (hr)	>720	>720	>720	425	665	375	560	360	155	97	535	273	208	272	106	74
Time to < .05 mm (hr)	>720	>720	>720	420	650	375	255	350	150	90	520	271	204	270	105	73
Initial Thickness	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Thickness at 6 Hours	12.2	13.1	13.1	14.5	6.0	6.8	4.1	6.9	8.9	4.2	4.2	4.8	2.8	7.9	6.5	2.8
Thickness at 12 Hours	10.3	11.8	11.2	13.7	4.7	5.9	3.1	5.3	7.9	3.0	3.2	4.1	2.1	3.7	5.8	2.0
Thickness at 48 Hours	6.5	10.0	7.3	11.4	2.7	4.6	1.7	3.0	5.6	1.3	1.8	3.2	1.2	2.1	3.5	0.7
Thickness when viscosity at 5000 cP	4.1	10.9	5.4	14.1	2.0	5.4	-	2.8	8.7	-	1.53	3.9	0.025	2.1	6.4	-
Thickness when viscosity at 20000 cP	4.0	8.6	5.4	10.1	1.9	4.4	-	2.7	5.5	-	1.49	3.2	-	2.0	3.9	-
Initial Width	1457	1457	1457	1457	318	318	318	318	318	318	174	174	174	174	174	174
Width at 6 Hours	1716	1663	1654	1566	527	496	646	492	433	624	342	320	421	318	275	405
Width at 12 Hours	1846	1714	1760	1586	590	523	716	549	447	686	385	338	464	357	285	442
Width at 48 Hours	2272	1794	2081	1655	743	561	841	686	487	781	485	362	539	441	310	495
Width at loss of slick or 720 hrs	2769	2079	2411	1829	847	615	927	722	515	797	531	386	582	452	318	499
Time when < 5ppm (hr)	-				-						-		-	-	-	
Time when < 1 ppm (hr)	-		120	108	-					108	-		-	-	-	
Time when < 0.1 ppm (hr)	540	>720	>720	>720	665	48	260	216	300	288	48	17	108	96	170	168
Peak Concentration (ppm)	0.7	0.3	1.7	1.0	0.35	1.2	0.94	0.85	0.5	4.3	0.27	0.16	0.75	0.68	0.42	3.5
Time Peak Reached (hr)	24	12	24	84	12	6	12	6	36	6	6	6	6	6	6.4	6

4.5.2 Batch Spills of California Production Oils: Scenarios 3, 6, 9 and 12

The windows of opportunity for the use of dispersants for the batch spill scenarios 3, 6, 9 and 12 are between 2 to 20 hours. Because of this small TW, it will be difficult to mount a dispersant operation for these spills. The thickness of all batch spills, after 6 to 12 hours, ranges from 2.5 to 10 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 100 to 300 meters during dispersant operations.

Peak in–water oil concentrations in the 0.03 to 0.3 ppm range are predicted for these scenarios due to the rapid emulsification of these oils retarding the natural dispersion processes.

4.5.3 Above Sea Blowouts: Scenarios 2, 5, 8 and 11

The primary differences between the batch spills and above-sea blowout results are the initial thickness and widths of the oil slicks and the long-term release characteristics of the blowouts. The thick oil portions of the surface blowouts will only be about 20 to 40 meters wide and will be 0.3 to 0.8 mm thick. The window of opportunity for dispersant application for these spills varies from only 0 to 2 hours. The oil in scenarios 2, 5a and 8 (Pt. Arguello Heavy crude) will be too viscous for dispersant to be effective when it first reaches the water surface. The Pt Arguello Light and Sockeye crude oils of scenarios 5a and 11 will be amenable to dispersant use only if dispersant is applied within 2 hours of release. Some of the oil that is released overnight during this blowout will not be amenable to effective dispersant treatment the next day. Dispersed oil concentrations from the natural dispersion of these spills will be very low due to the rapid emulsification of the oil (< 0.01 ppm in all cases).

4.5.4 Subsea Blowouts: Scenarios 1, 4, 7 and 10

The primary difference between the surface and subsea blowout predictions is the wider initial oil slick and thinner starting thickness. In scenarios 1, 4a and 7 the oil is thick enough to persist and rapidly form emulsion that would not be amenable to dispersant application. Even though these spills are all continuous releases, the oil emulsifies so rapidly that it is unlikely that dispersant would be effective if applied even a few minutes after the oil surfaces. The peak dispersed oil concentrations from these subsea blowouts will be very low due to the high persistence of the emulsion (< 0.01 ppm).

In scenarios 4b and 10 the somewhat lighter oils (Pt. Arguello Light and Sockeye crude oils) and very thin initial oil thicknesses (5 to 14 microns) result in a prediction of rapid dispersion of the surface slick. If this rapid natural dispersion did indeed take place there would obviously be no need for dispersant application. The peak dispersed oil concentrations from these spills would be in the 0.5 to 1.0 ppm range.

4.5.5 Tanker Spills of Crude and Diesel: Scenarios 13 through 18

Table 4-5b summarizes the tanker spill scenarios modeled. The a, b and c designations in the scenario identifier of this table refer to Alaska North Slope crude, Arab Medium crude and Diesel fuel, respectively. Three spill volumes have been considered: 250,000, 10,000 and 3000 barrels. Diesel spills have not been considered for the largest spill volume because vessels in the region do not generally transport these quantities of diesel fuel.

The largest variations in behavior of the largest spills (13 and 14) are related to oil types (ANS vs. Arab Medium) and wind speeds (5 knots for scenarios13a and b and 12 knots for scenarios 14a and b). The ANS crude scenarios have a longer TW for dispersant use (time to 5000 cP) than the Arab Medium crude because of their delay in onset of emulsification. The available time for effective dispersant application for the large-spill ANS scenarios (13a and 14a) are 166 and 104 hours. The shorter time for scenarios 14a illustrates the effect of the higher wind speed, and to some extent lower temperature, for this scenario. The large Arab Medium spills have much shorter time lines for dispersant use of 22 and 8 hours (13b and 14b). The shorter time for scenario 14b is again primarily due to the higher winds, thus more rapid evaporation and emulsification.

The time available for effective dispersant use decreases for all of the batch spills as the spill volume decreases. For example, the windows of opportunity for the ANS scenarios drop from 166 to 90 to 74 hours for the 250,000, 10,000 and 3,000 barrel spills with 5-knot winds. The same trends of longer application times for ANS compared to Arab Medium and shorter times for the high wind scenarios also apply for all of the smaller spill scenarios. The time available for dispersant use for the ANS crude and 12-knot wind scenarios range from 104 to 56 to 45 hours. The Arab Medium scenarios resulted in windows of opportunities of 22, 19 and 17 hours, under light winds and decreasing spill volumes. Under heavy winds these times dropped to 8, 7 and 6 hours for the 250,000, 10,000 and 3,000 barrel spills, respectively.

The diesel fuel spills (scenarios 15c, 16c, 17c and 18c) are all amenable to dispersant use up to the time that they would naturally disperse since these spills will not form emulsions and their viscosities will remain well below 5000 cP. For the 10,000 barrel spills the window of opportunity for dispersant use ranges from 208 to 560 hours. The shorter time is again due to higher winds, but in this case the higher winds tend simply to naturally disperse the slick faster rather than speed up the increase in viscosity. The time available for application for the 3,000-barrel scenarios ranges from 74 to 97 hours.

The slicks for all of the batch spills will generally be relatively thick throughout the time periods when dispersant application would be effective. For the 250,000-barrel spills the thick oil portions are estimated to be between 4 to 14 mm thick (effective parent oil thickness, not emulsion thickness) at the time when the oil has reached a viscosity of 5000 cP. The oil will be thicker prior to this time. The oil in the 10,000-barrel spills of crude oil will be a bit thinner than for the 250,000-barrel scenario and will range from 2 to 9 mm thick at the point when dispersants are no longer effective. These thicknesses drop to 1.5 to 6.5 mm for the 3,000-barrel crude oil spills. For the diesel spills the slicks will be between 1 and 2 mm thick 48 hours after release.

Maximum dispersed oil concentrations from the batch spills of crude oil will generally be low and will range from 0.2 to 1.7 ppm. The lighter diesel fuel will disperse more rapidly, especially in the higher wind scenarios. The peak dispersed oil concentrations predicted for the diesel spills range from 0.75 ppm (light wind and 3,000 barrel spill) to 4.3 ppm (high winds and 10,000 barrel spill).

5. Logistics and Feasibility of Operations

5.1 Introduction

This chapter considers aspects of the California industrial setting, response capability and weather that influence the effectiveness of a dispersant-use response. Even if the dispersant products are highly effective and the spilled oils are initially dispersible, success of the response effort will depend on a variety of other factors, including the following:

(1) **Spill conditions.** The spill conditions (e.g., spill volume, type of spill, Time Window (TW) for effective dispersant use) define the quantity of dispersants needed and the rate at which they must be delivered in order to treat the spill effectively.
(2) **Availability and characteristics of spraying platforms.** There are a variety of different dispersant application systems and these differ in their logistic and dispersant delivery characteristics, as well as the numbers of units available and their start-up times.
(3) **Distance from base to spill.** The various types of platforms operate from different bases that are usually at different distances from spill sites. This matter is further complicated by the fact that different platforms have greatly different transit speeds.
(4) **Weather and daylight hours.** Dispersant operations can be conducted only during the hours of daylight.
(5) **Availability of dispersant product.** Obviously, dispersant delivery rates will be limited by the amount of dispersant available at the time of the spill.
(6) **Ability to spray only the thicker patches of oil slicks.** Dispersants will be most efficient if applied to thick patches of oil where it will do the most good, rather than being wasted spraying sheen. In order to achieve this, operators must be capable of identifying the thick patches of oil and directing the spraying platforms to them.
(7) **Effectiveness monitoring.** Dispersant operations will be most efficient if only those patches of oil that are amenable to dispersant are sprayed. Only on-site monitoring can ensure that spraying is being effective.

One of the main components of this section is the analysis of the logistic capabilities of platforms to response to California spills. The spill scenarios used in the analysis were based on those in local area contingency plans (ACPs) and company oil spill plans. This was done so that the results of the work could be readily related to existing planning activities. The sources of the scenarios include the ACPs for the Los Angeles/Long Beach and San Francisco areas, and the worst-case spill scenarios described in oil spill contingency plans for the offshore production operations in the Point Arguello and Santa Clara fields.

The chapter contains four sections:

- **Setting** — summarizes briefly the spill conditions in the California scenarios.
- **Delivery Capacity** —summarizes a) the available dispersant spraying systems, their characteristics and distribution in and near the study area; and b) uses the output of logistic models to describe the capacity of dispersant response resources in available to treat hypothetical spills under a range of conditions.
- **Daylight Conditions** — describes the degree to which day length conditions in the different study areas may influence dispersant response.
- **Targeting and Monitoring** — describes quality assurance activities that are applied at the point of dispersant spraying that can maximize the efficiency of dispersant application.

5.2 Setting

The following summarizes the aspects of California oil spill scenarios that will influence the time factors in the responses. These include: a) the spill conditions (e.g., Time Windows (TWs); and b) the distances over which dispersant platforms must operate.

5.2.1 Spill Conditions and Behavior

In the following sections blowouts (continuous spills) and batch (instantaneous) spills have been dealt with separately. Batch spills are simpler and are discussed first.

5.2.1.1 Batch Spills

The behavior of the batch spill scenarios has been summarized in Table 5-1. Scenarios have been grouped according to emulsification tendency of oils (and hence the TWs for dispersant operations). All of these spills, regardless of size and oil type, produce spills that persist for at least several days, pose a significant environmental threat, and therefore merit cleanup. As was explained above, it has been assumed that the critical viscosity threshold for dispersant effectiveness is 5000 cP. Oils are assumed to be amenable to dispersion at viscosities less than this, but completely resistant to dispersion at viscosities greater than this.

The TW for mounting dispersant operations varies greatly among the spills. Spills of oils that emulsify quickly (Hi-E oils) reach a viscosity of 5000 cP in less than 24 hours, under all conditions. In some cases, emulsification time is only a few hours. In scenarios with average emulsifying oils (Av-E oils), spills emulsify and become persistent, but the TWs for chemical dispersion are relatively long, ranging from approximately 2 to 6 days. The oils that do not emulsify (No-E oils) remain dispersible as long as the slicks persist.

5.2.1.2 Blowout Spills

The production-related scenarios are summarized in Table 5-2. Scenarios have been divided into blowout spills and pipeline (batch) spills. The blowout spills have been ranked from left to right, with the spills that are most amenable to dispersant treatment on the right.

1) The five spills on the extreme left (4b, 10, 1, 4a, 7), are all subsea blowout spills and appear not to be amenable to dispersion. This is because the slicks are so thin initially that they either disperse naturally quickly on their own or they emulsify quickly, within minutes. In any case, these spills are very thin to start with and are difficult to treat because relatively large dispersant droplets from conventional spray systems will penetrate the slicks without mixing with the oil (see Section 2.3.3.3). In addition, the slicks are so thin that they might be expected to break up and disperse naturally on their own.

Table 5-1 Summary of Fate of Vessel Spills

	High Emulsifying Oils (ARM)[a]						Average Emulsifying Oils (ANS)						No Emulsifying Oils (DIE)			
Scenario	13b	14b	15b	16b	17b	18b	13a	14a	15a	16a	17a	18a	17c	15c	16c	18c
Volume	250k	250k	10k	10k	3k	3k	250k	250k	10k	10k	3k	3k	3k	10k	10k	3k
Time to 100% dispersion, hr	720	425	375	155	273	106	720	720	665	360	535	272	208	560	97	74
Initial thickness (mm)	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Time to 5000 cP[b], hr	22	8	19	7	17	6	166	104	90	56	74	45	-	-	-	-
Time to 20,000 cP[b], hr	120	87	63	51	48	36	188	107	112	59	91	48	-	-	-	-

a. ARM = Arabian Medium Crude Oil, ANS = Alaska North Slope Crude Oil, DIE = diesel fuel

Table 5-2 Summary of Fate of Production Spills

	Blowout Spills										Batch (pipeline spills)					
Scenario	4b	10	1	4a	7	5a	2	8	11	5b	6a	9	3	6b	12b	12a
Oil type[a]	PA-L	SE	PA-H	PA-H	PA-H	PA-H	PA-H	PA-H	SE	PA-L	PA-H	PA-H	PA-Co	PA-L	SE	SE
Spill Volume, barrels	29190	26460	32100	29190	29190	29190	32100	29190	26460	29190	500	292	227	500	131	2068
Discharge rate, BOPD	973	882	1070	973	5000	973	1010	882	882	5000						
Surf/Subs[b]	ss	ss	ss	ss	Ss	sf	sf	sf	sf	sf						
Time to 100% dispersion, hr	0.2	0	720	216	720	720	720	720	720	720	720	720	720	141	720	720
Initial thickness (mm)	0.01	0.01	0.02	0.01	0.03	0.2	0.2	0.77	0.3	0.2	20	20	20	20	20	20
Time to 5000 cP, hr	-	-	0	0	0	0	0	0	4.7	2	0.2	0.2	1.8	4.7	5.6	7
Time to 20,000 cP, hr	-	-	0.01	0.01	0.01	0	0	0	8.9	3.5	1	1	3.1	22	9.6	12.4

a. PA-L = Point Arguello Light, PA-H = Point Arguello Heavy, PA-Co = Point Arguello-Commingled, SE=Sockeye

b. ss = subsea blowout, sf = surface blowout

2) The next three scenarios (5a, 2 and 8) involve a Hi-E oil, Point Arguello Heavy crude oil. Although these slicks are somewhat thicker than in the previous group of spills, they emulsify to untreatable viscosities almost instantaneously and effectively have no TW for dispersants.

3) The last two scenarios (11 and 5b) appear to offer somewhat longer TWs — 2 to 8.9 hours. Although these times appear to be short, it must be remembered that these are blowouts and involve continuous discharges at fairly low discharge rates (36 and 208 barrels of oil per hour) over long periods. Given the appropriate dispersant delivery system and operating conditions, it may be feasible to treat this oil continuously as it is discharged.

The pipeline spills are actually batch spills (Table 5-2) and these have been ranked from left to right with the more amenable scenarios to the right. The three spills on the left (6a, 9, 3) would be very challenging as they appear to emulsify to undispersible viscosities within approximately one hour. Under most conditions, it is unlikely that an operation could be initiated within this time for a pipeline spill. On the other hand, the last three offer a somewhat longer TW, ranging from 5 to 7 hours. Given the relatively small size of these spills, an effective operation might be completed within this time.

5.2.2 Spill Locations and Operating Distances

The distances between the spill launch sites and bases of dispersant operations or staging areas are important because these distances, coupled with the transit speeds of the platforms dictate the amount of time that platforms spend traveling back and forth to the spill for purposes of re-supply (dispersant and fuel). Some representative distances between spill sites and different bases are given in Table 5-3a and b. The distances are as follows:

Table 5-3a Distances Between Spill Sites and Bases of Operation for Spill Scenarios in the Los Angeles/Long Beach Area

Spill Launch Point	Coordinates of Launch Point	Distance to base or staging area						
		Vessels			Helo	AT-802	Large, Fixed-Wing Aircraft (C-130)	
		Carpinteria	Oxnard	Long Beach	Nearest Land.	Nearest Airport[a]	LA Airport (LAX)	SF Airport (KSFO)
Production spills								
PF Hidalgo	34.495N,120.702W	52	77	125	6	33 (KIZA)	125	NA
Pt Arguello Pipeline	34.468N,120.549W	41	67	105	3	24 (KIZA)	110	NA
PF Gail	34.125N,119.400W	25	12	67	10	15 (KOXR)	53	NA
Santa Clara Pipeline	34.284N, 119.506W	15	15	71	7	17 (KOXR)	58	NA
Tanker spills, LA/LB ACP								
Tanker SBCh	34.22N, 119.80W	15	30	85	13	28 (KIZA)	75	NA
Tanker NW SBCh	34.32N, 120.47W	40	65	115	12	30 (KIZA)	105	NA
Tank Vessel (1.5 m bbl)	Not available							NA
El Segundo Term	Not available							NA
Longest Distance							180	180
Range of Distances,(n.mi.)		**15 to 125**			**1 to 13**	**15 to 34**	**53 to 180**	**180**

a. KIZA = distance to Santa Ynez Airport, KOXR = distance to Oxnard Airport, Oxnard, CA, LAX=Los Angeles International, KSFO=San Francisco International

Table 5-3b Distances from Spill Sites to Bases of Operation for Scenarios in the San Francisco Area

Spill Launch Point	Coordinates of Launch Point	Distance to base or staging area			
		Vessel	Helo	AT-802	Large, Fixed-Wing Aircraft (C-130)
		San Francisco	Nearest Land	Nearest Airport	San Francisco Airport (KSFO)
Farallon Is		40	30	30 (KSFO)	30
Anchorage 9		10	5	10 (KSFO)	10
Harding Rk		15	5	20 (KSFO)	20
Benecia		45	5	35 (KSFO)	35
Longest Distance					180
Range of Distances (n. mi.)		**10 to 45**	**5 to 30**	**10 to 35**	**10 to 180**

(1) Ship-based dispersant system - distances from spill sites to vessels' home ports are 10 to 100 nautical miles;

(2) Helicopter-based system – distances to nearest point on mainland where staging area might be located are 5 to 30 nautical miles;

(3) Small, single-engine fixed-wing aircraft – distances to nearest airport of kind are 10 to 30 nautical miles; and

(4) Large, fixed-wing aircraft – distances to nearest airport with runways of sufficient length to accommodate C-130 and DC-4 are 10 to 100 nautical miles.

For purposes of this analysis it is recognized that while tanker spills are more likely to occur in high traffic areas near San Francisco, Los Angeles or in the Santa Barbara Channel, they may also occur at any point along the coast of California. In the event of a large spill outside of either of the two study areas, the dispersant response may involve large, fixed wing aircraft. Regardless of the location of the spill, these aircraft might operate out of the nearer of the two large international airports with runways long enough to accommodate both the C-130s flying the ADDS Packs and the large transport aircraft transporting large volumes of dispersant to the area. No point in the shipping lanes between San Francisco and Los Angeles is more than 200 nautical miles from either the San Francisco International or Los Angeles International Airport.

5.3 Dispersant Delivery Capacity

5.3.1 Dispersant Response Resources

5.3.1.1 Spraying Equipment and Platforms

The platform used to spray dispersants is the central component of the dispersant response system. The operational characteristics and numbers of these systems dictate the cleanup capability of responders. This section describes the types and characteristics of spray systems available to respond to spills in California and provides an estimate of the capability of each to deliver dispersant to large spills over different distances. The latter is based on output of a logistics model developed for the assessment of dispersant technology in the Gulf of Mexico (SL Ross 2000).

The type of platforms available to California responders at the time of writing are listed in Table 5-4. The list includes all of the systems in California, plus all of the high capacity, rapidly deployable equipment (e.g., aircraft systems) available elsewhere in North America. For purposes of completeness, the locations of all of the existing ADDS Packs available for use globally have also been identified. The inventory of California resources is based on existing area contingency plans (ACPs) for San Francisco (USCG 2000), Los Angeles/Long Beach (USCG 2001), as well as interviews with the California response agencies. Resources outside California are based on the most recent annual SL Ross survey of dispersant response capabilities in North America.

The inventory in Table 5- 4 shows that only a limited amount of dispersant response equipment is in place in California at present. In southern California there are two ship-based systems, and two Simplex helicopter bucket systems, all located in Carpinteria. There are no dispersant delivery systems in place in the San Francisco area, although Clean Bay Cooperative is in the process of acquiring a ship-based system. There is a considerable quantity of high capacity response equipment located throughout North America that can be cascaded to California in the event of a large spill. Realistically, however, these outside resources would be available for a California spill only on the second day of response or later.

The logistics characteristics of the spraying systems likely to be used in spills in California are listed in Table 5-5. These have been used to estimate the maximum theoretical (MT) dispersant delivery capacity of these platforms in responding to large, batch spills (Table 5-6).

Table 5-4 Dispersant Spraying Equipment Available to Respond to Spills in California

Organization	**Location**	**Type and Quantity of Equipment**
Within California (all dispersant response resources)		
Clean Bay Coop Concord CA	Concord, CA	1 x vessel-spray system [a]
Clean Seas Coop Carpinteria, CA	Carpinteria, CA Carpinteria, CA	2 x Simplex helicopter-bucket systems 2 x vessel-spray systems
Clean Coastal Waters Long Beach, CA	Coolidge, AZ	2 x AT-802 Agtruck systems
North America - Outside California (rapid response, high capacity response resources only)		
Biegert Aviation, Chandler, AZ	Chandler, AZ	1 x ADDS Pack
Alyeska Pipeline Service Co Anchorage, AK	Anchorage AK	2 x ADDS Packs
Clean Islands Council/ State of Hawaii, Honolulu, HI	Honolulu, HI	1 x ADDS Pack
Clean Caribbean Coop Ft. Lauderdale FL	Ft. Lauderdale, FL	1 x ADDS Pack
USAF 910 Airlift Wing (ASAFR 757 Air Wing) Vienna, OH	Vienna, OH	1 x Custom aircraft spray system
Airborne Support Inc. Houma, LA	Huoma, LA	1 x DC-4 Custom aircraft spray system 2 x DC-3 Custom aircraft spray system
Emergency Airborne Dispersant Consortium, Tynan, TX	Rigby, IO Rigby, IO Coolidge, AZ Coolidge, AZ Rosenberg, TX Rosenberg, TX Tynan, TX Mer Rouge, LA Ft. Pierce, FL Ft. Pierce, FL	2 x AT-802 Agtruck 2 x AT-502 Agtruck 1 x AT-802 Agtruck 1 x AT-802 Agtruck 3 x AT-502 Agtruck 1 x AT-802 Agtruck 1 x AT-802 Agtruck 2 x AT-802 Agtruck 1 x AT-802 Agtruck 5 x AT-802 Agtruck
ADDS Pack Systems (world-wide)		
Oil Spill Response Limited London, U.K.	Southampton, U.K.	1 x ADDS Pack
East Asia	Singapore	1 x ADDS Pack
[a] Commercial contract with operator in Coolidge AZ		

Table 5-5 Characteristics of Dispersant Spraying Platforms Available to Operators in California

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	
Agtruck AT-802	800	120	80	200	4	140	0.5	1	200 miles
Agtruck AT-502	500	120	80	200	4	140	0.5	1	200 miles
Helicopter	150	79	80	90	1	50	0.5	0.25	1.75 hours
Vessel A[b]	1000	10	120	7	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 Clean Seas boom type vessel spray system.
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 the vessel, swath width is 140';
- Vessel speed – maximum speed is 25 knots

Table 5-6 Dispersant Spraying Capacity of Platforms as a Function Of Distance [a]

Platform	Operating distance n. mi.	Number of sorties per day	Payload, barrels	Volume of dispersant sprayed per day, barrels	Volume of oil dispersed per day [b], barrels
C-130/ADDS Pack [c]	10	4	130.8	523.2	10464
	30	4	130.8	523.2	10464
	100	3	130.8	392.4	7848
	200	3	130.8	392.4	7848
DC-4 [d]	10	6	47.6	285.6	5712
	30	5	47.6	238.1	4761
	100	4	47.6	190.4	3808
AT-802	10	8	18.9	151.2	3024
	30	7	18.9	132.1	2642
	100	5	18.9	94.4	1887
	200	3	18.9	56.6	1132
Helicopter	1	30	5.7	169.8	3396
	10	21	5.7	119.7	2394
	30	11	5.7	62.3	1245
Vessel A	1	3	23.8	71.4	1428
	10	2	23.8	47.6	952
	30	1	23.8	23.8	476
	100	1	23.8	23.8	476

a. Based on response a batch spill of 3180 m^3 (20,000 bbl).
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 US gal (20.8 m^3. = 130.8bbl), Recommended Capacity = 5000 US gal (18.9 m^3.).
d. Values reported in literature for payload of DC-4 range from 2000 to 2500 US gal (7.5 to 9.5 m^3). Value used here is 2000 US gal (= 47.6 bbl) as per ASI, Huoma, LA.

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 (Table 5-5). In theory a single C-130 ADDS Pack system might be capable of fully treating all of the oil spilled in the blowout spills and all of the oil in the 30,000 bbl batch spills, provided the TWs are of the order of several days. Its main drawback in California is that at present the nearest ADDS Pack units are outside the state, in Anchorage AK, Honolulu, HI and Ft. Lauderdale FL. In order to deploy an ADDS Pack in California, a suitable C-130 aircraft and crew must be located to "fly" the ADDS Pack, while one or more ADDS Pack units must be transported from their storage sites to the California operating site. As a consequence of these delays, start-up times may be lengthy and spraying is not likely to begin until the second day of the spill. Five ADDS Packs are available in the U.S. so that more than one of these can be put into service during a large spill, provided suitable aircraft and trained crews can be located.

2) **DC-4.** This platform is modeled after the dedicated dispersant spraying aircraft owned by Airborne Support Incorporated (ASI) of Houma, LA (Table 5-4). Its delivery capacity is approximately one-half of that of the C-130 ADDS Pack. The ASI DC-4 is dedicated to the task of oil spill response and therefore is available for immediate take-off. However, given that the only available unit is located in Huoma LA, a lengthy transit period required for spills in California. Realistically, as with the ADDS Pack, the earliest this aircraft can be operational spraying dispersant in California is probably the second day. Because only one of these systems exists, only one would be available.

3) **Cessna AT-802 (Agtruck).** These are small, single engine aircraft that are purpose-built for aerial spraying. These operators guarantee that they are prepared to leave their home base to travel to a spill within four hours or less of being called up. These

have a lesser payload capacity than certain of the larger aircraft and they have a somewhat more limited range over water than the large, multi-engine aircraft. In the U.S. a group of operators have organized to offer a dispersant spraying service using this aircraft. None of these are available in California, although one operator in Arizona may currently be under contract to a California oil spill cooperative. Under many conditions, this platform too may not be available until the beginning of the second day. The advantage of this platform is that a number of these are available for use in a large spill (Table 5-4).

4) **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. Two are available in southern California.

5) **Vessels.** Globally speaking, ship-based systems vary widely in their operational capabilities (e.g., payloads, pump rates and swath widths). In general, the relatively low payloads and slow transit speeds 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. There are only two ship-based systems currently available in California and at least one more system is planned. Due to the slow transit speed of this type of platform, it is unlikely that systems from outside California would be available to respond to a spill, except in the event of a prolonged blowout spill.

5.3.1.2 Dispersant Products

A major limiting factor in dispersant operations is 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[5] can be legally sprayed. The most recently published NCP Product Schedule (December 2001) included the following products:

- Corexit 9527
- Corexit 9500
- Dispersit SPC 1000
- JD-109
- JD-2000
- Neos AB 3000
- Mare Clean 200

Of these, only Corexit 9527 and Corexit 9500 are stockpiled in large quantity within the U.S. The products, U.S. Polychemical Dispersit SPC 1000, JD-109, and JD 2000 have been recently added to the list and are 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 5-7. The values are approximate because quantities change constantly. The amount of dispersant available in California is 41,560 gallons (=989 barrels). Based on the 1:20 rule of thumb, this quantity would be sufficient for a spill of approximately 20,000 barrels of oil. A quantity of 273,615 gallons (=6514 barrels) is held in North American stockpiles outside California, for a total amount of 315,175 gallons (=7504 barrels). At least a portion of the 6514 barrels could be made available for use on spills in California. Using the 1:20 rule of thumb again, the total North American stockpile of dispersant is sufficient for a spill of approximately 150,000 barrels.

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[5] See http://www.epa.gov/oilspill/docs/schedule.pdf

Table 5-7 Stockpiles of Dispersants in California and Elsewhere in North America

Organization	Location	Type of Dispersant	Quantity of Dispersant (gallons)
Within California			
Clean Bay Coop Concord CA	Concord, CA	Corexit 9527	15,015
Clean Seas Coop Carpinteria, CA	Carpinteria, CA	Corexit 9527	20,000
Clean Coastal Waters Long Beach CA	Long Beach, CA (CCW Yard)	Corexit 9527	6545
Total Within California			41,560
North America outside California			
Alyeska Pipeline Service Co.	Anchorage, AK Valdez, AK	Corexit 9527 Corexit 9527	56,000 4000
Clean Islands Council/State of Hawaii,	Honolulu, HI	Corexit 9527 Corexit 9500	3080 34,180
Clean Caribbean Coop Ft. Lauderdale, FL	Pt. Everglades, FL Pt. Everglades, FL	Corexit 9527 Corexit 9500	4070 25,300
LOOP, Inc New Orleans, LA	Huoma, LA	Corexit 9527	33,600
Clean Gulf Associates New Orleans, LA	Sugarland, TX Huoma, La (ASI)	Corexit 9500 Corexit 9527	28,985 5665
Marine Spill Response Corp Edison, NJ	Lyndon, NJ	Corexit 9527	24,640
CISPRI (CIRO) Cool Inlet, AK	Niski, AK Anchorage, AK	Corexit 9527 Corexit 9527	9295 11,275
Marine Industry Resources-Gulf, MIR-G	Huoma, LA (ASI)	Corexit 9527	16,000
Airborne Support, Inc. Huoma, LA	Huoma, LA	Corexit 9527 Corexit 9500	2000 4470
National Response Corp Houston, TX	Cameron, LA Morgan City, LA	Corexit 9527 Corexit 9500	1540 220
Clean Sound, Everett WA	Blaine WA	Corexit 9527	6270
Delaware Bay Coop Lewes, DE	Slaughter Beach, DE	Corexit 9527	1650
Clean Harbors Lyndon, NJ	Lyndon, NJ	Corexit 9527	1375
Nalco/Exxon Energy Chemicals, Sugarland TX	Sugarland, TX	Corexit 9527 Corexit 9500	
U.S. Polychemical Corp Chestnut Ridge NY	Chestnut Ridge, NY	Dispersit SPC 1000	
Total North America Outside California			**273,615**
Total Dispersant Product Available			**315,175**

5.3.2 Analysis of Logistics

This section considers potential operational effectiveness of different dispersant application platforms in dealing with spill scenarios in California ACPs and operators' contingency plans. Operational effectiveness is limited not only by the platforms' capabilities to deliver dispersant, but also oil weathering and the distances over which the platforms must operate. A key factor in this regard is the speed with which the oil emulsifies to the point that it is no longer amenable to dispersion, that is, the TW (time window) for dispersant use. This section considers the interaction among four factors in determining the potential operational effectiveness of different platforms in dealing with California spill scenarios. These factors are: a) volume of the spill; b) TW; c) distance; and d) logistical characteristics of the platforms.

The objective of this exercise is to identify how well each type of platforms might deal with the hypothetical spill scenarios identified in the ACPs and operators' contingency plans. The approach here has been to estimate whether a single unit of each platform might be capable of fully treating the various California spill scenarios, given different distances from the spill to platform's base of re-supply.

The response capabilities of the different platforms have been estimated using simple logistic models developed for the recent assessment of dispersant technology for spills in the U.S. Gulf of Mexico (SL Ross 2000). These models estimate the rate at which platforms can deliver dispersant by determining the volume of dispersant delivered during a single sortie and then estimating the length of time needed to complete the sortie. The latter is the sum of time on scene, transit time and re-supply time). The models are described in SL Ross (2000) and are not discussed here. It is important to recognize that start-up time is also critical. Start-up times vary from platform to platform and may range from a few hours to several days. However, start-up times will change with improvements in preparedness. In order to place the different platforms on an even footing for purposes of comparison, the start-up times of all platforms have been held constant at one hour. The errors arising from this assumption are addressed in the text.

5.3.2.1 Batch Spills

The batch spills are based on the hypothetical tanker or vessel-based spills occurring near Los Angeles and San Francisco, as described in the ACPs. The results of the logistical analysis are summarized in Table 5-8. The analyses of spills of Av-E oils clearly illustrate the differences in logistic capabilities among the different types of platforms. Begin by considering the smallest spill (3000 barrels), of Av-E oil (scenario 17a, TW =74 hours). Single units of all of the fixed-wing aircraft systems (C-130, DC-4, AT-802) are capable of delivering enough dispersant to fully treat this small spill at all distances from 1 to 200 nautical miles. A single unit of the helicopter system is capable of treating the spill, up to 30-nautical miles (nmi). Spills at 100 and 200 nmi are beyond the helicopter's operating range. The capacity of the ship-based system is adequate at the shorter distances, but is exceeded at the 30-nmi distance, so at 30 nmi and beyond, two units are needed to deliver the requisite amount of dispersant. The performance of both the ship-based and helicopter-based platforms can be greatly enhanced if they are re-supplied at the spill site. If this is done the performances of these two platforms are similar to that at the one-n mi distance.

Note that both its slow transit speed and its small payload limit the performance of this ship-based system. In this treatment we have used the characteristics of ship-based systems that are currently available in California (payload =1000 gallons, transit speed 7 knots). Vessels with faster transit speeds and larger payloads (several thousand gallons) are currently in use in other jurisdictions. A crew-cargo vessel with a 20,000-gallon payload and 25-knot transit speed is either in service or is planned for the Gulf of Mexico. Increasing the payload and speed of response vessels in California will improve the response capacity proportionately. Also, as mentioned above, the performance of the existing ship-based and helicopter-based platforms in California can be greatly enhanced if they are re-supplied at the spill site.

Table 5-8 Estimated capabilities of platforms vs batch spill scenarios in California

Spill scenario	Volume remaining after evaporation, barrels	Time window, days	Platform	Distance = 1 mi			Distance = 10 mi			Distance = 30 mi			Distance = 100 mi			Distance = 200 mi		
				Volume of oil dispersed per unit	Proportion of oil dispersed per unit	Number of units req'd to disperse all oil	Volume of oil dispersed per unit	Proportion of oil dispersed per unit	Number of units req'd to disperse all oil	Volume of oil dispersed per unit	Proportion of oil dispersed per unit	Number of units req'd to disperse all oil	Volume of oil dispersed per unit	Proportion of oil dispersed per unit	Number of units req'd to disperse all oil	Volume of oil dispersed per unit	Proportion of oil dispersed per unit	Number of units req'd to disperse all oil
Average -E Oil (Alaska North Slope Crude Oil)																		
Scenario 17a 3000 bbl	2500	3	vessel	4284	1.00	1	2775	1.00	1	1428	0.57	2	1428	0.57	2	0	0.00	0
	2500	3	helo	10188	1.00	1	7182	1.00	1	3735	1.00	1	0	0.00	0	0	0.00	0
	2500	3	AT-802	9072	1.00	1	9072	1.00	1	7926	1.00	1	5646	1.00	1	3396	1.00	1
	2500	3	DC4	17136	1.00	1	17136	1.00	1	14283	1.00	1	11424	1.00	1	6600	1.00	1
	2500	3	C130	31392	1.00	1	31392	1.00	1	31392	1.00	1	23544	1.00	1	23544	1.00	1
Scenario 15a 10000 bbl	8000	4	vessel	5712	0.71	2	3700	0.46	3	1904	0.24	5	1904	0.24	5	0	0.00	0
	8000	4	helo	13584	1.00	1	9576	1.00	1	4980	0.62	2	0	0.00	0	0	0.00	0
	8000	4	AT-802	12096	1.00	1	12096	1.00	1	10568	1.00	1	7528	0.94	2	4528	0.57	2
	8000	4	DC4	22848	1.00	1	22848	1.00	1	19044	1.00	1	15232	1.00	1	8800	1.00	1
	8000	4	C130	41856	1.00	1	41856	1.00	1	41856	1.00	1	31392	1.00	1	31392	1.00	1
Scenario 13a 250000 bbl	170000	7	vessel	9996	0.06	18	6475	0.04	27	3332	0.02	52	3332	0.02	52	0	0.00	0
	170000	7	helo	23772	0.14	8	16758	0.10	11	8715	0.05	20	0	0.00	0	0	0.00	0
	170000	7	AT-802	21168	0.12	9	21168	0.12	9	18494	0.11	10	13174	0.08	13	7924	0.05	22
	170000	7	DC4	39984	0.24	5	39984	0.24	5	33327	0.20	6	26656	0.16	7	15400	0.09	12
	170000	7	C130	73248	0.43	3	73248	0.43	3	73248	0.43	3	54936	0.32	4	54936	0.32	4
High-E Oil (Arabian Medium Crude Oil)																		
Scenario 17b 3000 bbl	2500	1	vessel	1428	0.57	2	925	0.37	3	476	0.19	6	476	0.19	6	0	0.00	0
	2500	1	helo	3396	1.00	1	2394	0.96	2	1245	0.50	3	0	0.00	0	0	0.00	0
	2500	1	AT-802	3024	1.00	1	3024	1.00	1	2642	1.00	1	1882	0.75	2	1132	0.45	3
	2500	1	DC4	5712	1.00	1	5712	1.00	1	4761	1.00	1	3808	1.00	1	2200	0.88	2
	2500	1	C130	10464	1.00	1	10464	1.00	1	10464	1.00	1	7848	1.00	1	7848	1.00	1
Scenario 15b 10000 bbl	8000	1	vessel	1428	0.18	6	925	0.12	9	476	0.06	17	476	0.06	17	0	0.00	0
	8000	1	helo	3396	0.42	3	2394	0.30	4	1245	0.16	7	0	0.00	0	0	0.00	0
	8000	1	AT-802	3024	0.38	3	3024	0.38	3	2642	0.33	4	1882	0.24	5	1132	0.14	8
	8000	1	DC4	5712	0.71	2	5712	0.71	2	4761	0.60	2	3808	0.48	3	2200	0.28	4
	8000	1	C130	10464	1.00	1	10464	1.00	1	10464	1.00	1	7848	0.98	2	7848	0.98	2
Scenario 13b 250000 bbl	170000	1	vessel	1428	0.01	120	925	0.01	184	476	0.00	358	476	0.00	358	0	0.00	0
	170000	1	helo	3396	0.02	51	2394	0.01	72	1245	0.01	137	0	0.00	0	0	0.00	0
	170000	1	AT-802	3024	0.02	57	3024	0.02	57	2642	0.02	65	4482	0.03	38	1132	0.01	151
	170000	1	DC4	5712	0.03	30	5712	0.03	30	4761	0.03	36	3808	0.02	45	2200	0.01	78
	170000	1	C130	10464	0.06	17	10464	0.06	17	10464	0.06	17	7848	0.05	22	7848	0.05	22
High-E Oil (Arabian Medium Crude Oil)																		
Scenario 18c 3000 bbl	2500	3	vessel	4284	1.00	1	2775	1.00	1	1428	0.57	2	1428	0.57	2	0	0.00	0
	2500	3	helo	10188	1.00	1	7182	1.00	1	3735	1.00	1	0	0.00	0	0	0.00	0
	2500	3	AT-802	9072	1.00	1	9072	1.00	1	7926	1.00	1	5646	1.00	1	3396	1.00	1
	2500	3	DC4	17136	1.00	1	17136	1.00	1	14283	1.00	1	11424	1.00	1	6600	1.00	1
	2500	3	C130	31392	1.00	1	31392	1.00	1	31392	1.00	1	23544	1.00	1	23544	1.00	1
Scenario 16c 10000 bbl	8000	4	vessel	5712	0.71	2	3700	0.46	3	1904	0.24	5	1904	0.24	5	0	0.00	0
	8000	4	helo	13584	1.00	1	9576	1.00	1	4980	0.62	2	0	0.00	0	0	0.00	0
	8000	4	AT-802	12096	1.00	1	12096	1.00	1	10568	1.00	1	7528	0.94	2	4528	0.57	2
	8000	4	DC4	22848	1.00	1	22848	1.00	1	19044	1.00	1	15232	1.00	1	8800	1.00	1
	8000	4	C130	41856	1.00	1	41856	1.00	1	41856	1.00	1	31392	1.00	1	31392	1.00	1

When the spill volume is increased to 10,000 barrels of Av-E oil (scenario 15a, TW=90 hours), the two large fixed-wing platforms (C-130, DC-4) are still capable of treating the spill fully at all distances from 1 to 200 nmi. However, a spill of this size exceeds the capacity of a single AT-802 at 100 nmi and beyond. The helicopter system is adequate at distances of 1 and 10 nmi, but its capacity is exceeded at 30 nmi. Two units of the ship-based system are needed at even 1 nmi. At 10 nmi and beyond, three or more units would be needed, which is more than the number currently available in the study area. The latter reflects the payload limitation of the existing vessels.

When the spill volume is increased to 250,000 barrels (scenario 13a, TW=166 hours or 6.9 days), this amount of oil exceeds the capacities of single units of all platforms. Moreover, it greatly exceeds the capacities of all available units of any platform, with the possible exception of the C-130/ADDS Pack. The spill volume is within the capacity of three (at 10 and 30 nmi) or four (at 100 and 200 nmi.) C-130/ADDS Pack units. This is true even if these units do not arrive on scene until the morning of the second day of the spill. (Realistically, however, only one or two of these units may be available on the second day, but additional units would probably not arrive until later on in the spill.).

Before considering the response to the Hi-E spill scenarios, it is important to recognize that, at present, all fixed-wing spraying systems (C-130, DC-4, AT-802) are based outside the study and are unlikely to arrive on scene until the second day of the spill. This is too late to treat spills with TWs of 24 hours or less. In the future these systems may be available in California, so for purposes of this analysis a 1-hour start-up is assumed for all platforms.

The shorter time-windows (<24 hours) of the Hi-E oil have a great impact on operational effectiveness (Table 5-8, rows 4-6). Beginning with the smallest of the Hi-E spills, the 3000-barrel spill (scenario 17b, TW=17 hours), the spill volume is within the capacity of the C-130/ADDS Pack at all distances. The same is true for the DC-4, except for the 200-nmi distance where 2 x DC-4s would be needed in order to deliver the requisite amount of dispersant within the very short TW. A single AT-803 would be sufficient for the spill at distances up to 30 nmi, but full treatment at distances of 100 and 200 nmi would require 2 and 3 units respectively. At a distance of one nmi, one helicopter unit could fully treat this spill, but two would be needed at 10 nmi. More than two would be needed beyond that distance (Only two helicopter bucket systems are currently available in California). Two ship-based systems would be needed to treat the spill at a 1 nmi-distance, but more than two would be needed at longer distances.

When the spill is enlarged to 10,000 barrels of Hi-E oil (scenario 15b, TW=19hours), one C-130/ADDS Pack is sufficient from 1 to 30 nmi, but two are needed beyond that distance. The spill is beyond the capacity of one DC-4 at even 1 nmi distance, so two DC-4s are needed at the 1 through 30 nmi distances. Three or four are needed at the 100- and 200-nmi distances. Three AT-802s are needed at the 1- and 10-nmi distances; 4, 5 and 8 units are needed at distances of 30, 100 and 200 nmi, respectively. The spill is well beyond the capacities of the either the available helicopter and ship-based systems.

When the size of the Hi-E spill is increased to 250,000 barrels, this volume of oil is so large that the combined one-day delivery capacities of all platforms would treat only a small fraction of it.

In summary, for spills involving Av-E oils, the smallest of the model batch spills (3000 barrels) are easily within the maximum theoretical capability of all platforms to respond, provided that they are within 30 mi of a re-supply base for vessel-based or helicopter-based systems. For spills beyond these distances, responses must be with small or large fixed-wing aircraft. The 10,000-barrel spills are beyond the capacity of the existing vessels unless they are within a few miles of the vessels' home berth. They are also at the limit of the capacity of helicopter systems. These spills are easily within the capability of small and large fixed wing aircraft systems. Realistically, the 250,000-barrel spills are well beyond the capacities of realistic numbers of any existing platform, even with a 4 to 7 day TW.

5.3.2.2 Blowout Spills

The blowout spill scenarios are based on those described in oil spill response plans for the point Arguello and Santa Clara fields. These scenarios are summarized in Table 5-2. Note that pipeline scenarios are also mentioned in this table, but all of the following deals with the blowout spills.

The first two spills on the extreme left in Table 5-2 (4b, 10) are subsea blowout spills involving Av-E oils. These spills form slicks that are very, very thin initially and disperse naturally almost instantaneously. Natural dispersion is so quick that chemical dispersion would not be required. The next six scenarios (1, 4a, 7, 5a, 2, 8) involve Hi-E oils. These spills also form relatively thin slicks, but unlike the Av-E spills above, computer simulations suggest that these emulsify to undispersible viscosities almost instantaneously and would resist chemical dispersion immediately.

The last two scenarios (11, 5b) are above-sea blowouts of Av-E that yield relatively thick slicks. These will weather, emulsify and form persistent slicks, but they have TW of 2 to 4 hours, during which dispersants might be applied. This 2- to 4-hour period might not be sufficient to treat a batch spill of any size, but these are blowouts and involve continuous discharges of oil at relatively low discharge rates, 37 and 208 bbl per hour. Since some platforms are capable of delivering dispersant at these rates or greater, it may be possible to treat these spills. The logistics of treating these two blowout spills are summarized in Table 5-9.

In the scenario with the lower discharge rate (scenario 11), the logistics analysis suggests that all platforms can apply dispersant at this rate at all distances, except for the ship-based system, whose capacity is exceeded at 30 nmi and beyond.

In the larger scenario (scenario 5b), the large, fixed-wing aircraft systems can fully treat a discharge of this rate at all distances. The smaller, fixed wing aircraft (At-802) can fully treat the discharge at short distances, 1, 10 and 30 nmi, but multiple platforms are needed at distances of 100 and 200 nmi. A single helicopter can fully treat the discharge at distances of 1 and 10 nmi, but two are needed at 30 nmi. Two ship-based systems are needed even at 1 nmi, and more than two are needed at greater distances.

Table 5-9 Estimated Capabilities of Platforms vs Blowout Spill Scenarios

					Distance = 1 mi			Distance = 10			Distance = 30 mi			Distance = 100 mi			Distance = 200 mi		
Spill scenario	Volume spilled per hour, barrels/hr	Volume remaining after evaporation, barrels/hour	Time window, hours	Platform	Volume of oil dispersed per unit	Proportion of oil dispersed per unit	Number of units req'd to disperse all oil	Volume of oil dispersed per unit	Proportion of oil dispersed per unit	Number of units req'd to disperse all oil	Volume of oil dispersed per unit	Proportion of oil dispersed per unit	Number of units req'd to disperse all oil	Volume of oil dispersed per unit	Proportion of oil dispersed per unit	Number of units req'd to disperse all oil	Volume of oil dispersed per unit	Proportion of oil dispersed per unit	Number of units req'd to disperse all oil
Sockeye Crude Oil																			
Scenario 11	37	30	4	vessel	476	1.00	1	316	1.00	1	160	1.00	1	160	1.00	1	n/a	n/a	n/a
Blowout of		30	4	helo	1132	1.00	1	800	1.00	1	416	1.00	1	n/a	n/a	n/a	n/a	n/a	n/a
886 bbl oil		30	4	AT-802	1008	1.00	1	1008	1.00	1	880	1.00	1	628	1.00	1	380	1.00	1
per day for		30	4	DC4	1904	1.00	1	1904	1.00	1	1588	1.00	1	1268	1.00	1	732	1.00	1
30 days		30	4	C130	3488	1.00	1	3488	1.00	1	3488	1.00	1	2616	1.00	1	2616	1.00	1
Point Arguello-Light Crude Oil																			
Scenario 5b	208	160	4	vessel	476	0.74	2	316	0.49	3	160	0.25	4	160	0.25	4	0	n/a	n/a
Blowout of		160	4	helo	1132	1.00	1	800	1.00	1	416	0.65	2	n/a	n/a	n/a	n/a	n/a	n/a
5000 bbl oil		160	4	AT-802	1008	1.00	1	1008	1.00	1	880	1.00	1	628	0.98	2	380	0.59	2
per day for		160	4	DC4	1904	1.00	1	1904	1.00	1	1588	1.00	1	1268	1.00	1	732	1.00	1
30 days		160	4	C130	3488	1.00	1	3488	1.00	1	3488	1.00	1	2616	1.00	1	2616	1.00	1

Although all platforms appear to be capable of dealing with these blowout scenarios, in practice the platforms that can remain permanently on station are best suited to these particular conditions of short TWs and low flow rates. These blowout scenarios require almost constant dispersant application because the spilled oil must be treated as soon as it is discharged. It is not feasible to allow oil to accumulate on the surface for many hours and then treat it all at once, as might be possible if the TWs were very long (24 to 36 hours). Both ship-based and helicopter-based systems are well suited to this task because they can be re-supplied on site. Fortunately, the oil flow rates involved are low and are therefore are within the capacities of either ship-based or helicopter-based systems. Fixed-wing aircraft might be used effectively for this purpose, but the slow oil discharge rate would be require only a tiny fraction of their delivery capacity to treat.

It is important to recognize that, in blowout spills where TW are short (much less than the period of darkness), the operational effectiveness of the dispersant operation is limited by an apparent “overnight effect.” As discussed in SL Ross (2000), during blowouts oil may be discharged continuously, night and day, for many days. However, dispersant operations must be suspended during the period of darkness. Even though responders can disperse all of the oil produced through the daylight hours, oil accumulates on the surface at night when spraying is suspended. If the TW is long, as it was with many oils in the Gulf of Mexico study (SL Ross 2000), the oil discharged overnight remains dispersible on the following day and may be effectively dispersed by dispersant application. However, in cases where the TW is short, some of the oil discharged overnight weathers to an undispersible state before morning. Regardless of how efficient the dispersant operation is during the day, overall effectiveness is compromised by oil that is discharged and becomes undispersible overnight.

5.3.2.3 Summary of Logistics Analysis

Tanker spills may occur at any point in California’s offshore waters; they may be of any size and may involve No-E to Hi-E oils, that is, oils with no emulsification tendency or high emulsification tendency. The present analysis suggests that ship- and helicopter-based dispersant systems may be adequate to deal with small tanker spills close to their bases of re-supply. In addition, they may be adequate to deal with mid-sized spills, provided the TW is long enough.

However, these platforms are limited in their capability to respond to spills at a distance either because of slow transit speed or limited operating range. These limitations can be overcome in some circumstances by re-supplying them at or near the spill site. The small- to mid-sized spills that occur at considerable distance from the response centers appear to be well suited to the small, fixed wing aircraft, provided the TW is long enough to accommodate their slower startup time. Very large spills appear to require the delivery capacities of the large, fixed-wing platforms, such as the C-130/ADDS Pack system. However, at present, this system is useful only for spills with longer (several days) TW, given that the startup time is at least 24-hour. Spills of Hi-E oils, of the kind analyzed here (TW<24 hours), are amenable only to locally based resources that can respond within hours. The startup times of resources based outside California may be too long to be useful. The present analysis showed that even the smaller spills of H-E oils described in the ACPs may require multiple platforms in order to deliver adequate dispersant within the TW.

Production-related spills in California appear to pose challenges for dispersant planners. Many of the spills analyzed here, including all spills of Hi-E oils and subsea blowouts of Av-E oils appeared to be poor candidates for chemical dispersion, either because of very rapid emulsification (very short TW) or rapid natural dissipation. The blowouts of Av-E oils appear to be good candidates for treatment using ship-based or helicopter-based systems because these systems can remain on-scene and deliver dispersants constantly when needed. Happily, discharge rates of worst-case blowouts described in contingency plans for California fields are low enough to be within the capacities of these systems.

It is important to reiterate that the performance of the ship-based system is limited by both their slow transit speed and small payload. In this analysis we have used the characteristics of systems that are currently available in California (payload =1000 gallons, transit speed 7 knots). Larger and faster vessels are currently in use elsewhere and can be developed in California. The performance of these larger vessels should be better than those used here.

5.4 Influence of Day Length, Weather, and Oceanographic Conditions

Dispersant operations are limited or influenced by day length and oceanographic conditions. This section summarizes these conditions for key locations within the study area and assesses possible impact on dispersant operations. The areas for which physical environmental conditions were analyzed were:

i. Southern California off Los Angeles
ii. West end of the Santa Barbara Channel
iii. Off San Francisco

5.4.1 Day Length and Visibility

Day length exerts a strong influence over dispersant operations because all dispersant operations involve aircraft, either as a spraying platform or spotter. When spraying operations involve aircraft, low-altitude flying is required. Even when dispersants are sprayed by boat, an airborne controller is required to direct the operation. As such, to date all spraying operations involve aircraft, therefore are possible only when conditions permit VFR flying, that is during the hours of daylight.

The annual average period of daylight in the study area is approximately 12 hours. At this latitude the period of daylight varies somewhat with season, ranging from 14.7 hours in early July to 9.6 hours in early January, as seen in Table 5-10.

Table 5-10 Hours Of Daylight at Northern and Southern Limits of Study Area[a]

Location	Jan 1	Apr 1	Jul 1	Oct 1
San Francisco	9.60	12.63	14.73	11.48
Los Angeles	9.93	12.57	14.38	11.50

a. Online-Photoperiod Calculator V 1.93 (http://www.saunalahti.fi/~jjlammi/zsun.php3)

At this latitude operators will have as much as 20% more operating time on July 1 and 20% less on January 1. By contrast, the period of daylight in the Prince William Sound area of Alaska varies seasonally by as much as ± 62%, from 19.5 hours in mid-summer to 5.7 hours in mid-winter. For purposes of this analyzing dispersant logistics, day lengths have been assumed to be constant at 12 hours. Some platforms may perform somewhat better during the longer summer days and somewhat more poorly in winter.

5.4.2 Wave Height and Wind Speed

Both mechanical recovery and dispersant countermeasures are sensitive to sea state or significant wave height. Mechanical recovery systems are far more sensitive to wind and waves, but dispersants too have their limitations. 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, dispersants will be limited by excessive wind and waves. The data in table below show that spraying systems deployed from workboats 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. Similarly workboats can spray dispersants under wave height conditions of up to 3. A rule of thumb is that mechanical containment systems can operate effectively at wave heights of 1.5m, but not beyond 2 m.

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 5-12, shows that there is adequate mixing energy for dispersant use virtually all of the time.

The data suggest that sea states are lowest in the Channel Islands location. In the December to May period in this area sea states seldom exceed one meter only approximately 50% of the time and in June to November only 10 to 20% of the time. Waves seldom exceed two meters. This suggests that wave conditions are suitable for mechanical recovery operations most of the time. Wind speeds in this area seldom if ever exceed 21 knots so they are suitable for dispersant operations for all types of dispersant platforms all of the time.

Wave heights and heights are greatest at the location at the western end of the Santa Barbara Channel. Here wave heights exceed 1 m approximately 90% of the time in all seasons. Unlike the situation described above, wave heights exceed 2 m frequently throughout the year, approximately 20% of the time in summer and as much as 60% of the time in winter. This suggests that wave conditions in this area will commonly make mechanical recovery operations difficult. In this area wind speeds are favorable for dispersant spraying by all types of platforms in all seasons with wind speeds being less than 21 kts from 76 to 90% of the time.

5.4.3 Temperatures

Air and water temperatures influence the rates of oil fate processes, as well as the physical properties of the spilled oil. By global standards, air and sea temperatures within the study area are moderate, with seasonal averages for all parts of the study area ranging from 11.1 to 19.6 ^{o}C. Within each location the seasonal variation is very small, as seen in Table 5-13.

Table 5-12 Wave Height ad Wind Speed Conditions in the Study Area[a]

Parameter		Jan	Apr	Jul	Oct
West End of Santa Barbara Channel (46023)[b]					
Wave Height					
Percent Frequency	>1m	93.7	90.7	89.1	90.0
	>2m	58.9	49.5	18.5	34.1
Mean Wind Speed (kts)					
Percent Frequency	calm	4.2	1.0	0.6	1.2
	<21	90.0	76.2	82.7	82.4
	<27	98.7	92.4	98.9	97.4
	<34	100.0	99.1	100.0	100.0
Among Channel Islands (46025)					
Wave Height					
Percent Frequency	>1m	49.9	38.0	11.2	17.6
	>2m	9.1	7.2	0.0	1.0
Mean Wind Speed (kts)					
Percent Frequency	calm	5.7	3.8	4.6	5.3
	<21	97.3	96.6	100.0	99.5
	<27	99.5	99.8	100.0	100.0
	<34	100.0	100.0	100.0	100.0
Off San Francisco (46026)					
Wave Height					
Percent Frequency	>1m	89.5	75.9	49.8	56.9
	>2m	45.4	24.4	3.3	7.9
Mean Wind Speed (kts)					
Percent Frequency	calm	0.9	1.2	0.7	3.7
	<21	95.0	92.6	98.6	97.5
	<27	98.8	99.2	99.9	99.9
	<34	99.9	100.0	100.0	100.0

[a] NOAA (1990)
[b] Values in parentheses are station numbers for NDBC buoys

Table 5-13 Sea and Air Temperature Conditions within the Study Area[a]

Parameter	Jan	Apr	Jul	Oct
West End of Santa Barbara Channel (46023)				
Mean Temperature, Air (°C)	13.6	12.5	14.7	16.1
Mean Temperature, Water (°C)	14.3	12.8	15.2	16.5
Among Channel Islands (46025)				
Mean Temperature, Air (°C)	14.5	14.6	18.0	18.4
Mean Temperature, Water (°C)	15.1	15.4	19.6	19.4
Off San Francisco (46026)				
Mean Temperature, Air (°C)	11.1	11.1	12.9	13.8
Mean Temperature, Water (°C)	11.9	11.6	13.5	14.4
a. NOAA (1990). Numbers in parentheses are NOAA station code numbers.				

5.5 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.

5.5.1 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 the entire 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 infrared 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.

5.5.2 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. Observing the treated slick from the air, either visually or by remote sensing, does this. 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 meter 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. Assessing Net Environmental Benefit

6.1 Introduction

This chapter assesses the environmental benefits and drawbacks of treating typical spills in California waters with dispersants. Balancing of benefits and losses associated with using dispersants 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 slick to species at the sea surface and at shorelines, it increases risks to in-water and seabed-dwellers. Before using dispersants on a spill, it is critical to consider whether their environmental benefits outweigh their drawbacks, that is, whether they offer a net environmental benefit (NEB).

Section 6.2, that follows, summarizes the methods used to quantify environmental impact and assess the NEB of dispersant use. Section 6.3 considers three spill scenarios in California waters, considering the environmental impacts and the NEB associated with dispersant use in each case. The scenarios used are based on spills already used for planning in California and have already been discussed in earlier sections.

6.2 Methods for Assessing Net Environmental Benefit for Dispersants

This section describes the methods by which oil spill impact is estimated and net environmental benefit (NEB) is assessed in this study.

Historically, two approaches have been used to assess the NEB associated with dispersant use:

1) Intuitive approach for has been used for spills in deep, offshore waters; and
2) More rigorous, analytical approach is used for spills in nearshore waters.

The intuitive approach is based on a long-standing consensus among regulators and responders that dispersants pose little environmental risk when used in deeper, offshore waters (farther than one to three miles offshore in waters greater than 30 to 60 feet deep). This intuitive approach is the basis for dispersant pre-approval agreements for waters in many jurisdictions (e.g., IMO 1995; many Regional Response Team Regions in the U.S.).

The more rigorous, analytical approach is needed for assessing dispersant NEB issues in nearshore waters, where dispersant use poses greater environmental risks. This analytical approach involves estimating and comparing the potential impacts of the untreated and chemically dispersed spills to determine which option yields the lesser overall environmental impact. Techniques have been developed for conducting these analyses including: Trudel (1984), Trudel et al. (1986, 1987, 1988, 1989, 2001), S.L. Ross (2000), Aurand et al. (1998), Pond et al (2000). These methods all involve analyzing specific spill scenarios. Impacts of both untreated and dispersed spills are first estimated in each scenario by: a) identifying the resources at risk; b) estimating the oil exposures experienced by each target resource; and c) identifying the nature and amount of damage to each resource, as well as the length of time needed for each to recover. NEB is then determined by listing the impacts of the untreated and chemically dispersed spills, side by side and comparing them to determine which approach yields the lesser overall environmental impact. In all cases the targets are defined as clearly identifiable entities such as reproductively isolated stocks of biological resources. The resources included are all of the environmental groups that figure in spill-related decision-making, such as living marine habitat resources, invertebrates, finfish and wildlife, as well as human use resources and installations.

This more rigorous method is described in the following sections, as is information on the types of valued ecosystem components that drive dispersant decisions in the California environment.

In the present case the resources considered are those included in the Environmental Sensitivity Index Map series for Southern California (NOAA, 1999). In the absence of additional information on the subject, the “target” for estimating impact was the stock of the species in Southern California.

6.2.1 General Method for Analyzing Spill Scenarios

Net environmental benefit was assessed by analyzing selected oil spill scenarios in a rigorous way, using methods of Trudel (1984), Trudel et al. (2001), S.L. Ross (2000), and Pond et al (2000). Initially all scenarios in Table 4-4 were considered for analysis, but only three were selected (see Table 6-1). The reasons for selecting these scenarios are given in Section 6.4.1. For each scenario, estimates of environmental impact were formulated for the untreated and chemically dispersed cases. The results of the scenario analysis are reported in Section 6.3. The general approach is illustrated in Figure 6-1.

Table 6-1 Scenarios Considered for Analysis

No.	Source	Type	Spill Condition	Oil	Location	Season	Ref
14a	Tanker	Batch	10,000 barrels	ANS	N. End Santa Barbara Channel	Winter	1
14a	Tanker	Batch	10,000 barrels	ANS	Santa Barbara Channel	Winter	2
11	Gail Platform	Blowout, above sea	883 BOPD x 30d 26460 barrels	Sockeye	34.125N, 119.400W	Autumn	3

1. USCG 2000 Area Contingency Plan: Los Angeles/Long Beach - Northern Sector/Max. Most Probable Discharge, p 4700-9
2. USCG 2000 Area Contingency Plan: Los Angeles/Long Beach - Northern Sector/Worst-Case Discharge, p 4700-1
3. Venoco Inc. 2001. Platforms Grace and Gail; Oil Spill Response Plan – Worst Case Discharge Scenario

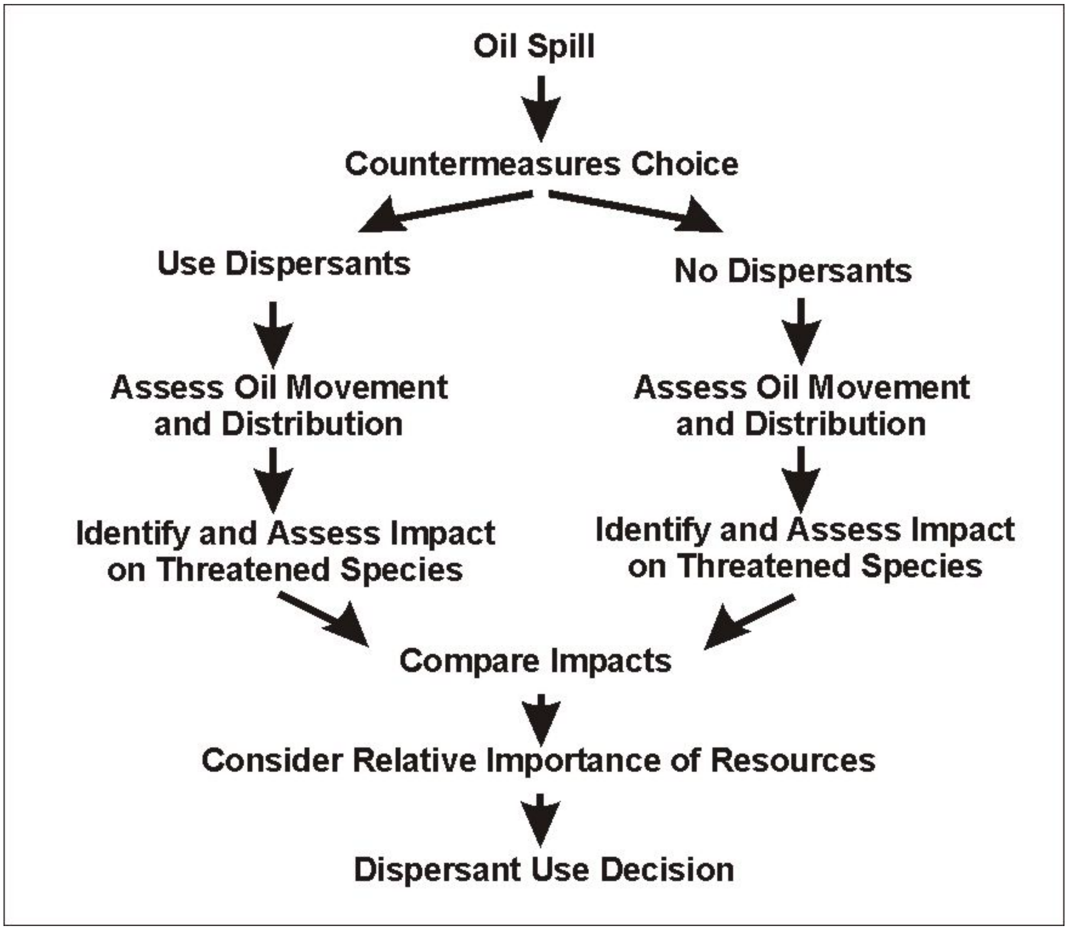

Figure 6-1 Flowchart of Method for Assessing Net Environmental Benefit

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

Step 1. Estimate the potential fate and movements of the oil spill for both the untreated and chemically dispersed cases.

Step 2. Identify the resources threatened by either the untreated and dispersed spill cases. This is based on both: a) the movement and fate of oil; and b) the geographic distribution of oil-sensitive resources.

Step 3. Estimate the kind and amount of damage to each target resource 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 resource to oil; c) the spatial distribution of the target resource; d) the vulnerability of the various resources life stages to oiling, and e) the potential or each target resource to recover.

Step 4. Quantify the impacts of the untreated and dispersed spills and compare these to determine which approach yields the lesser overall environmental impact, that is, which offers a net environmental benefit. This is assessment is based on: a) the resources at risk from the treated and untreated spills; b) the level of acute damage suffered by each target resource; c) the length of time required for each damaged target resource to recover to its pre-spill condition; and d) the value placed on each target resource by the local human population.

The method for expressing the level of damage is critical to this work. A number of methods 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 (Trudel et al. 1987, 1989, S.L. Ross 2000, Pond et al. 2000). Any method used must be simple and must apply equally well to a wide variety of resources using a common set of criteria. At present there is no universal standard method. For purposes of this study, we have used the risk analysis method used by Pond et al. (2000). This approach has been used so that the present project will be consistent with the earlier and on-going dispersant work in California. As illustrated below (Figure 6-2), this approach quantifies impacts in a three-point scale as "HIGH" ecological concern, "MODERATE" ecological concern and "LIMITED" ecological concern, based on the combination: a) type of injury; b) magnitude of acute impact; and c) recovery time.

Figure 6-2 Definitions of Levels of Concern [1,2]

		Recovery Time			
		> 7 years (1)	3 to 7 years (2)	1 to 3 years (3)	<1 year (4)
% of Target Resource Damaged	>60% (Large) (A)	1A	2A	3A	4A
	40 to 60% (B)	1B	2B	3B	4B
	20 to 40 % (C)	1C	2C	3C	4C
	5 to 20% (D)	1D	2D	3D	4D
	0 to 5% (Small) (E)	1E	2E	3E	4E

1. From Pond et al. (2000)
2. Definitions:
   - dark gray = "high" level of concern
   - middle gray = "moderate level of concern
   - light gray = "limited" level of concern

6.2.2 Fate and Movements of Oil

The movement, fate and behavior of the untreated and chemically dispersed oil are key determinants of the impacts of spills. In the case of the untreated oil slick, this involves the movement, spreading and persistence of slicks. In the case of the dispersed oil, this involves the movement, spreading and dilution of the cloud. These processes determine where the oil moves (and where effects will take place), 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 determine whether on not effects occur, as well as the location and size of the areas affected.

The present study involved simulating the fate and movements of spill scenarios, including both batch spills and blowouts. In all cases the fate of the oil and the trajectories were handled separately as follows.

6.2.2.1 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 4-5a and 4-5b.

For the blowouts or continuous spill scenarios, the spill was modeled as a series of many discrete parcels of oil or spillets. The persistence and spreading of the spillets and the changes in oil properties with time were calculated for a single spillet and applied to all spillets (Tables 4-5a and 4-5b). 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 assumed to disperse as a single parcel, dispersing instantaneously at the midpoint of the operating day. That is, if dispersant operations took place from 0600 to 1800 on a given day, dispersing 5000 barrels of oil, then all 5000 barrels 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 as a single parcel, according to the SLROSM model. In general, this approach had the effect of yielding a worst-case estimate of impact.

6.2.2.2 Movement of Oil

The environmental damage caused by a spill is strongly influenced by where it is carried by winds and currents. In this study, the movements of oil slicks (batch spills) and spillets (blowout spills) were determined in several ways. For the two batch spills, the trajectories, point(s) of contact with the shoreline, and transit times were as specified in the scenarios developed in the Area Contingency Plan (USCG et al. 2000). The level of shoreline oiling was estimated using the volume of oil in the slick at the time of contact and either the Okubo width of the slick at the time of shoreline contact or the dimensions of the slick as it contacts land. For the blowout spill, the levels of shoreline oiling and trajectories were inferred based on conditional probabilities of shoreline contact as estimated in Johnson et al. (2000).

Movements of clouds of chemically dispersed oil were estimated based on mean seasonal surface current information in Johnson et al. (2000).

6.2.3 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, and these resources interact with oil in a variety of ways and suffer a range of effects or injuries. 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 (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 6-2. 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, referred to here as an “area-of-effect”. 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 6-2 Effect Thresholds Used in Estimating Impact		
Resource	**Untreated Oil**	**Chemically Dispersed Oil**
SENSITIVE ENVIRONMENTS		
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.
Kelp Forests	Complete or partial mortality of the part of the frond exposed to slicks at the sea surface. Fronds are insensitive to physically dispersed oil.	Complete or partial mortality of the kelp fronds is expected at exposure concentrations of 10 ppm of total petroleum hydrocarbons as chemically dispersed oil.
WILDLIFE		
Marine Mammals	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. For hairy mammals such as sea otters, seals, fur seals and sea lions, it is assumed that slick thicknesses of 0.1 mm are lethal.	No effect.

Table 6-2 Effect Thresholds Used in Estimating Impact (Cont.)		
Resource	**Untreated Oil**	**Chemically Dispersed Oil**
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 6-2 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.
Fisheries	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 6-2 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.

6.2.4 Vulnerability and Spatial Distribution of Resources

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: a) whether or not oil-sensitive resources occupy the parts of the environment that are contaminated by oil and b) 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, and sea turtles.

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 straightforward. 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.

6.2.5 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 6-2, above.

6.2.6 Relative Importance of Valued Environmental Components

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 and panel discussions 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).

6.2.7 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 and the level of potential impact on each from the spill. From the tabulated information in Table 6-3 it can be determined: a) the target resources at risk from the spill; b) potential damage to each from the untreated spill; c) the degree to which this damage might be ameliorated through dispersant use; and d) the potential increase in damage to any resources resulting from dispersant use. From this information conclusions can be drawn about the net environmental benefits or drawbacks of dispersant use in this scenario and any uncertainties associated with the assessment.

6.3 Valued Environmental Components

As explained above, in order avoid biasing the NEB analysis either in favor of or against dispersants; it is critical to include every important resource that is threatened by either the untreated or the dispersed spills 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 that are used by government agencies in their own environmental impact assessment process (as described in MMS Pacific OCS Region 2001, NOAA 1999a, 1999b). The groups of environmental resources used in the present analysis are listed in Table 6-4.

Table 6-3 Example Summary of Impacts Table

Valued Environmental Components	Untreated	Dispersed
SHORELINES (km)	20.54	0
5 - Mixed Sand and Gravel	0.33	0
4 - Med t Coarse Sand	2.95	0
3 - Fine Sand	0.79	0
2 - Exp. Rocky Shorelines	9.35	0
2 - Exp. Rocky Ledges	7.12	0
HUMAN USE FEATURES		
Channel Is. Nat. Mar. Sanctuary	Limited (1)	Limited (1)
Channel Is. Nat. Park	Limited (1)	Limited (1)
OIL-SENSITIVE LIVING HABITAT		
Giant Kelp Forest (San Miguel)	Limited	0
BIRDS - seabirds		
Storm Petrel, Ashy	High	0
Storm Petrel, Leach's	High (2)	0
Oystercatcher, Black	Limited	0
Cormorant, Brandts	Limited	0
Auklet, Cassins	High (3)	0
Xantu's Murrelet	High (4)	0
Guillemot, Pigeon	Limited	0
Cormorant, Pelagic	Limited	0
Gull, Western	Medum	0
Western Snowy Plover F T	Medium	0
MARINE MAMMALS		
Harbor Seals	Limited-Medium	0
Northern Elephant Seal	Medium	0
Northern Fur Seal	High	0
California Sea Lion	Limited-Medium	0
Guadelupe Fur Seal F T	High (?) (5)	0
California Sea Otter F T	Medium	0
MARINE REPTILES	0	0
None Shown in ESI maps		
FINFISH	0	0
None shown on ESI maps		
SHELLFISH	0	0
None shown in ESI maps		

1. The risk to thesehuman-use resources is difficult to assess.
2. The actual numbers of induvuduals ar risk is very small
3. Very large proportion of Southern California population is at risk
4. Virtually all of the SC population is at risk in this scenario
5. Numbers of individuals is low.

Table 6-4 Types of Oil-Sensitive Resources Considered in this Analysis

• Shorelines • Oil Sensitive Environments a) Wetlands b) Kelp Forests c) Surfgrass • Wildlife a) Coastal and Marine Birds b) Marine Mammals	• Finfish, Shellfish a) Finfish b) Invertebrates • Recreational Resources and Human-Use Features a) Commercial and Recreational Fisheries b) Recreational waterfronts c) National / State Parks, Wildlife Refuges, National Seashores

Information concerning the species present and the characteristics of their distribution that determines their susceptibility to impact by oil has been derived from several sources including:

1. Environmental Sensitivity Index maps for Southern California (NOAA 1999);
2. MMS Environmental Impact Statements (e.g., MMS Pacific OCS Region 2001); and
3. MMS Marine Mammal and Seabird Computer Database Analysis System (MMS 2001).

6.4 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 southern California. As described above, for each spill scenario, the environmental impact is estimated for both the untreated and chemically dispersed cases, and these impacts are compared to determine whether dispersant use might reduce the overall environmental impact of the spill and yield a net environmental benefit.

6.4.1 Selection of Scenarios

The list of spill scenarios that might have been analyzed in this study was large and diverse, but it was possible to analyze only three of these. Decisions regarding the selection of scenarios were made in consultation with MMS-Pacific Region. The rationale for selecting scenarios was as follows.

The first step in the selection process was to select among the range of spill types, spill sizes and oil types and spill locations. In general the spills included the following: a) spills that dissipate naturally offshore, causing no shoreline oiling or impact in the nearshore; b) spills that could reach shore, but can be fully dispersed offshore**,** including 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; and c) spills in which dispersant operations do little to reduce the amount of oil reaching the shoreline, such as very large spills of persistent oils or spills that emulsify quickly, resulting in considerable oil arriving at the shoreline. The scenarios that were analyzed were selected from among those in b, above, because in these cases dispersants could do most to reduce the overall impact of the untreated spill. In these scenarios the potential net environmental benefit is most clear and visible. The scenarios selected included both blowout spills and batch spills from vessels, as follows.

1. San Miguel Island – Batch Spill of 10,000 Barrels of Crude Oil. A batch spill, this scenario is based on a spill scenario used in the 2000 Area Contingency Plan (ACP) Los Angeles/Long Beach (USCG et al. 2000). This scenario was chosen to be analyzed first because it is a simple case in many respects: a) it is a batch spill and therefore simpler to analyze than a blowout spill; b) the spill trajectories of both untreated and dispersed spills are relatively simple; and c) the spill takes place far enough offshore that it can be fully treated with dispersants before it reaches the nearshore environment. Certain of the conditions of the spill were altered for purposes of convenience or to make the spill conditions more useful for our purposes (e.g., the oil type was changed from relatively undispersible No. 6 fuel oil to more dispersible Alaska North Slope crude oil.)

2. Santa Barbara Channel - Batch Spill of 10,000 Barrels of Crude Oil. A more complex batch spill, this scenario was based on the Worst-Case Discharge (Northern Sector) from USCG (2000). The scenario is more complex than the above in several respects: a) it is within the Santa Barbara Channel; b) it is near enough to shore that the cloud of dispersed oil enters the nearshore area, placing resources in shallow, nearshore areas at risk; and c) the trajectories are complex, involving impacts of untreated oil on both mainland and island environments. The spill size was reduced from a relatively unmanageable 210,000 barrels to a size of 10,000 barrels that can be fully treated within its time window. The oil type was altered to be Alaska North Slope crude oil for which oil property information is available.

3. Production Spill from Platform Gail – Blowout of 882 BOPD for 30 Days; a blowout spill of long duration involving a relatively large amount of oil. This scenario was selected because, as a blowout, it was the most challenging from the perspective of estimating impact and assessing NEB. There were several reasons for selecting this platform from among all the platforms in Federal waters off California: a) oil from the Sockeye and Pt Arguello Fields may be dispersible, whereas those from fields may be far less dispersible, even when freshly spilled; b) the Santa Clara field was chosen over Point Arguello because, according to spill trajectory analyses conducted in Johnson et al. (2000), much of the oil discharged from Gail threatens nearshore areas on the mainland and offshore islands, whereas Point Arguello spills are transported in an offshore direction. Therefore spills from Pt. Arguello fields pose limited environmental risk, making the NEB question moot; c) the autumn case was chosen over those in other seasons because according to Johnson et al. autumn spills are likely to be carried to the west up the Santa Barbara Channel oiling both the mainland shore and the Channel Islands, while spills in other seasons are carried to the S or SE threatening the offshore islands to the S; and d) the above-sea blowout was considered rather than the subsea blowout because in the latter case, the initial slick is so thin that it disperses almost instantaneously, whereas the above-sea blowout, slick fragments persist on the surface for more than 30 days.

6.4.2 San Miguel Island Spill Scenario

This scenario is based on the "Maximum Most Probable Discharge" scenario in the 2000 Area Contingency Plan (ACP) Los Angeles/Long Beach (USCG 2000, p. 4700-9). It was chosen for analysis here because it appears to be a simple case from the perspective of decision-making. The spill poses a large impact risk because a large proportion of the oil would reach shore on San Miguel Island if it were left untreated. However, the spill could potentially be fully dispersed well offshore because the TW for chemical dispersion is long. The spill takes place approximately 35 km to the NW of San Miguel Island at 1200 noon on February 20. As mentioned above, a spill of 10,000 barrels ANS crude oil, an Av-E oil has been substituted for the spill of 8000 barrels of No.6 fuel oil.

Movement and Fate of the Spill. The movements and behavior of the oil slick in the untreated case are summarized in Table 6-5 and Figures 6-3 and 6-4a. The surface slick moves in a southeasterly direction under the influence of both the winds and currents. Approximately 7300 barrels of oil strand on the shoreline of the western end of San Miguel Island, contaminating a section of shoreline 5.5 km in length with an average of 8.2 l of oil per linear meter of shoreline.

Table 6-5 Persistence and Movement of Slick in San Miguel Spill of 10,000 barrels of ANS

Time Since Spill, Hours	Spill Location		Slick Conditions	
	Distance from Spill Site, Km	Distance from San Miguel Is., km	Volume Remaining, Barrels	Diameter Oil-Covered Water, km
0	0	35	10,000	0.95
8	10	25	8000	1.7
24	20	17	7725	3.1
36	30	5	7500	4.3
42-54	35	0	7300	5.5

In the chemically dispersed case, realistically speaking little dispersant could be applied on the first day, so dispersant operations are assumed to begin at dawn on Day 2. According to the theoretical dispersant delivery rates given earlier, sufficient dispersant to fully treat this spill could be delivered in a single day by a single C-130 operating from Los Angeles International Airport (at a range of 110 nautical miles) or three to four AT-802s operating out of any of the smaller airports in the Santa Barbara area (at a range of 40 nautical miles from the spill site). The worst-case situation from the perspective of peak oil concentration in the water would result if all of the oil were to be dispersed at once. Assuming that this takes place at midday on the second day, a cloud of dispersed oil with a diameter of 3.1 km and average oil concentration of 15.9 ppm of dispersed oil would be generated at approximately 20 km SE of the spill site (or 17 km NW of the western end of San Miguel Island). The cloud would move in a southerly direction (see Table 6-6 and Figure 6-4b).

Table 6-6 Persistence and Movement of Dispersed Oil in San Miguel Spill

Time Since Spill, Hours	Location	Distance from San Miguel Is., km	Mean Concentration Of Dispersed Oil in Cloud, ppm	Mean Cloud Diameter,
24	34.125N;120.565W	16.5	16.0	3.1
48	34.075N;120.520W	8	5.0	5.6
72	34.025N;120.535W	9	2.3	8.2
96	33.975N;120.560W	11.6	1.0	12.6

Environmental Impact and Net Environmental Benefit. The results of the impact analyses for the chemically dispersed and untreated spills are summarized in Table 6-7.

As noted in Table 6-8, the untreated spill threatens to contaminate a 20-km section of shoreline at the western end of San Miguel Island at an average level of 8 liters of oil per linear meter of shoreline. This level of contamination would be highly visible and would pose a threat of redistributing to adjacent areas, so it would require cleanup. The shoreline itself is made up largely of rock substrate with smaller amounts sand and gravel shores. In general the sensitivity of these shores to oiling is low. If dispersants are used as described above all oil would be dispersed offshore and shoreline oiling would not occur.

There is living habitat, in the form of giant kelp forest, in the area at risk from the untreated oil. Approximately 20% of the 16 km^2 of kelp forest surrounding San Miguel Island lies within the area swept by the untreated spill. However, it is unlikely that the slick will damage the kelp and so it has been assigned a level of concern of LIMITED to ZERO. The risk to the kelp forest may be of some concern in the chemically dispersed case, because the trajectory of the cloud of chemically dispersed oil passes nearby. However, in this case the trajectory does not contact the kelp zone at all, so dispersant use eliminates any risk to the kelp, reducing the level of concern to ZERO.

The untreated case poses a very great risk to local wildlife and this risk is virtually eliminated by chemical dispersion, as follows. The untreated spill poses a threat to nine species of marine birds and the level of concern for five of these species is MODERATE or HIGH. The most serious threat is to the Cassin's Auklet stock. According to data contained in the EPA/NOAA/USCG ESI database (NOAA 1999), most (≈90%) of the breeding and foraging activity of this species in southern California lies around San Miguel Island. Approximately ≈90% of the San Miguel foraging area lies in the path of this slick (based on weighting the foraging areas). Thus, according to the ESI data, approximately 50% of the Southern California stock of Cassin's auklets lie in the path of this slick and may be killed by this spill. Since auk populations are notoriously slow to recover from spill damage, the threat to Cassin's auklets is rated as HIGH. Similarly, threats to Ashy and Leach's storm petrels and Xantu's Murrelets are also HIGH, and to the western gull is MODERATE. The threat to the shorebird, the western snowy plover, would be LOW, based on the proportion of the southern California stock that is at risk from this spill. However, the level of concern is raised to MEDIUM because this species is classed as threatened. The use of dispersants in this scenario reduces the level of concern to ZERO, as it prevents the majority of the oil from reaching the foraging areas around San Miguel Island.

The untreated spill also poses a threat to six species of marine mammals. The greatest level of concern is for the northern fur seals because, according to the ESI database, approximately 2/3 of the foraging area for this species in southern California is around San Miguel Island and virtually all of this area is in the path of the untreated slick. This, combined with the relatively high level of susceptibility of fur seals to oiling and the slow rate of recovery of their populations if damaged, results in the level of concern for this species/stock as HIGH. Risks to the four other species at risk range from LOW-MEDIUM to HIGH. The use of dispersants in the offshore area reduces the level of concern for all species to ZERO.

Based on the ESI database the risks to marine reptiles, finfish and invertebrates in this area from either untreated or dispersed spills are ZERO.

Net Change in Environmental Impact with Dispersant Use. On balance, the net effect of using dispersants in this scenario appears to be positive. Dispersing offshore keeps the oil away from the nearshore areas around San Miguel Island and thereby eliminates: 1) the very serious threats to marine bird and mammal species; 2) the risks, if any, to the kelp forest; and 3) the problem of shoreline oiling. There appear to be few, if any risks associated with dispersing the spill in the deep, offshore waters as envisioned here. Therefore there appears to be a large net environmental benefit associated with using dispersants in this scenario.

Uncertainties. There are a number of sources of uncertainty in this scenario, but only one will significantly impact the NEB assessment. Most of the uncertainties relate to the fate and persistence of the untreated oil, however, assuming that the slick will contact San Miguel Island as predicted, these uncertainties would not alter the predicted impacts of the untreated spill greatly. There is some uncertainty concerning the trajectory of the dispersed oil. There should be some concern that surface currents may carry some of the dispersed oil into the area of the giant kelp forest off western San Miguel Island. However, this concern will not alter the result of the NEB assessment because, by the time any dispersed oil reaches the kelp forest, oil concentrations will have declined to levels that are well below those needed to cause toxicity to the kelp plants.

In short, regardless of these uncertainties, there appears to be a very clear net environmental benefits from dispersant use in this scenario.

Figure 6-3 Behaviour of San Miguel Oil Spill

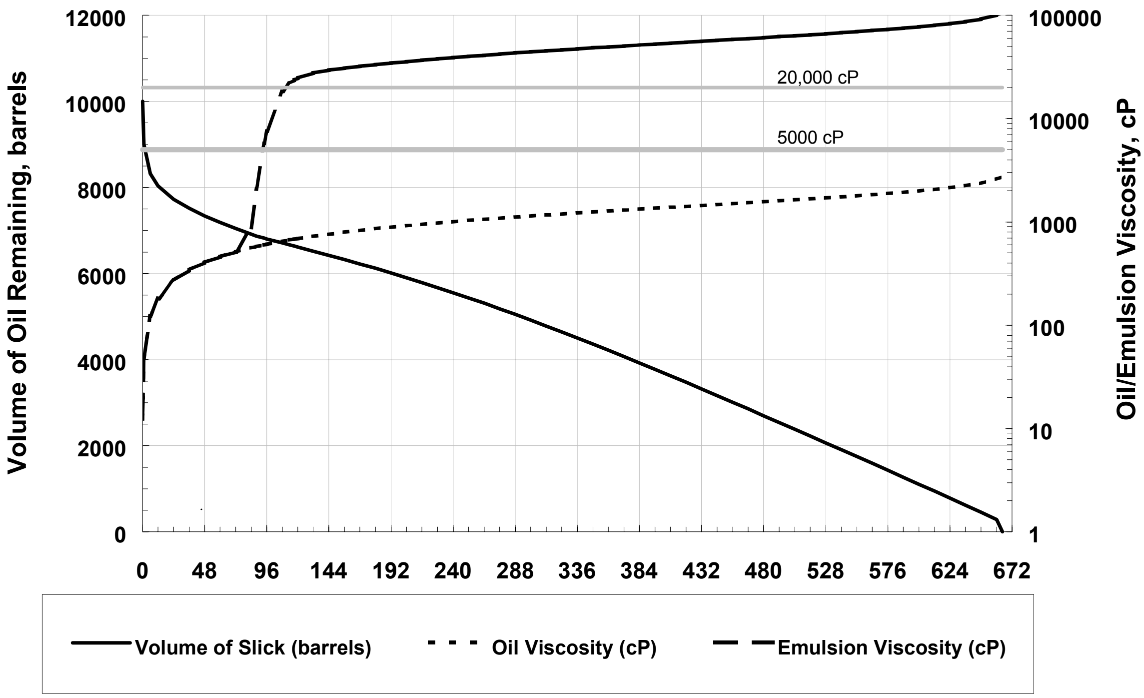

Figure 6-4a Movement of Untreated Spill: San Miguel Winter Scenario

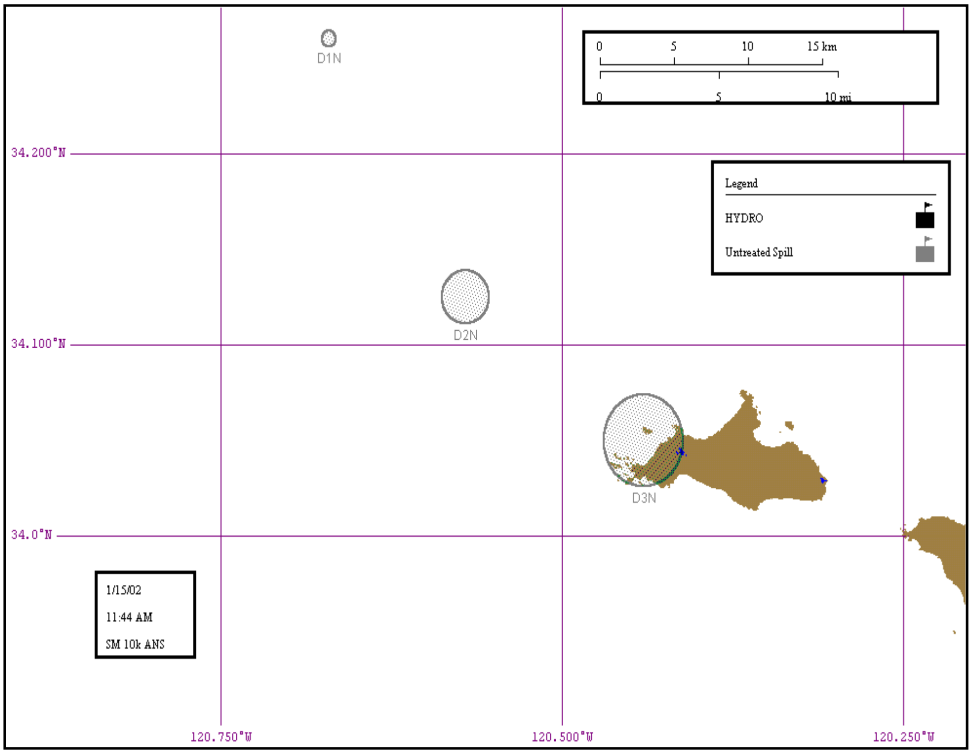

Figure 6-4b Movement of Chemically-Dispersed Spill: San Miguel

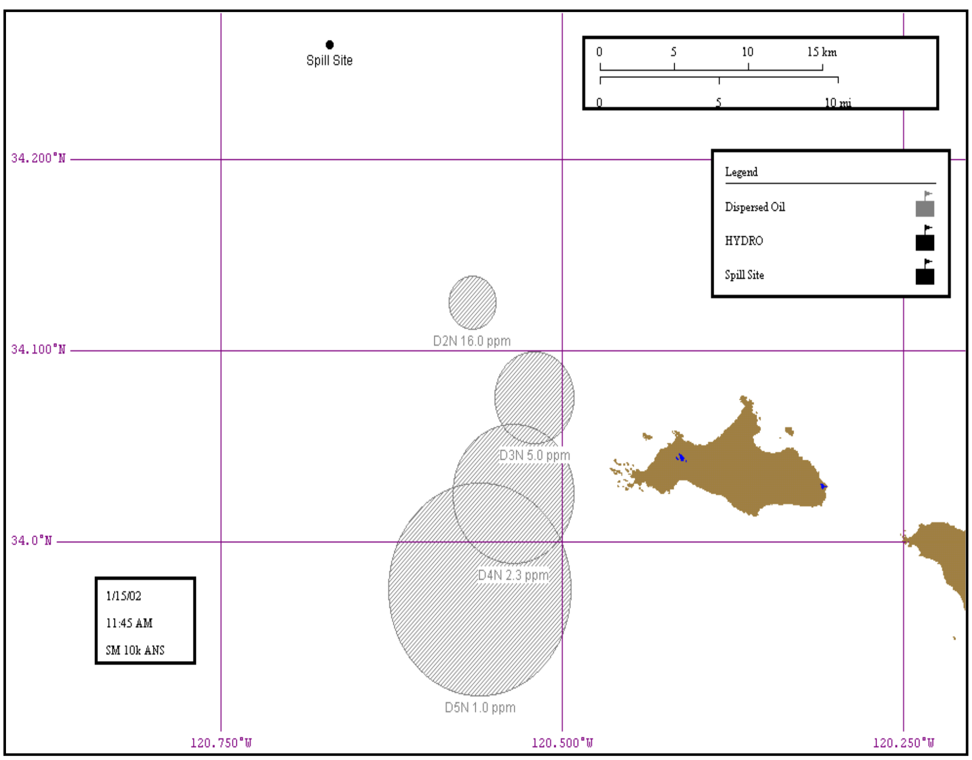

Table 6-7 Summary of Impacts: San Miguel Spill		
Valued Environmental Components	**Untreated**	**Dispersed**
SHORELINES (km)	20.54	0
5 - Mixed Sand and Gravel	0.33	0
4 - Med t Coarse Sand	2.95	0
3 - Fine Sand	0.79	0
2 - Exp. Rocky Shorelines	9.35	0
2 - Exp. Rocky Ledges	7.12	0
HUMAN USE FEATURES		
Channel Is. Nat. Mar. Sanctuary	Limited (1)	Limited (1)
Channel Is. Nat. Park	Limited (1)	Limited (1)
OIL-SENSITIVE LIVING HABITAT		
Giant Kelp Forest (San Miguel)	Limited	0
BIRDS - seabirds		
Storm Petrel, Ashy	High	0
Storm Petrel, Leach's	High (2)	0
Oystercatcher, Black	Limited	0
Cormorant, Brandts	Limited	0
Auklet, Cassins	High (3)	0
Xantu's Murrelet	High (4)	0
Guillemot, Pigeon	Limited	0
Cormorant, Pelagic	Limited	0
Gull, Western	Medum	0
Western Snowy Plover F T	Medium	0
MARINE MAMMALS		
Harbor Seals	Limited-Medium	0
Northern Elephant Seal	Medium	0
Northern Fur Seal	High	0
California Sea Lion	Limited-Medium	0
Guadelupe Fur Seal F T	High (?) (5)	0
California Sea Otter F T	Medium	0
MARINE REPTILES	0	0
None Shown in ESI maps		
FINFISH	0	0
None shown on ESI maps		
SHELLFISH	0	0
None shown in ESI maps		

1. The risk to thesehuman-use resources is difficult to assess.
2. The actual numbers of induvuduals ar risk is very small
3. Very large proportion of Southern California population is at risk
4. Virtually all of the SC population is at risk in this scenario
5. Numbers of individuals is low.

6.4.3 Santa Barbara Channel Spill Scenario

The spill circumstances of this scenario are based on the “Worst Case Discharge” in the 2000 Area Contingency Plan (ACP) Los Angeles/Long Beach (USCG 2000, p. 4700-1). This scenario was chosen for analysis because the decision-making problem is more complex than in the previous scenario, with the dispersed oil cloud penetrating into the nearshore area. In this a case, a large proportion of the untreated oil would impact the shore on the mainland and possibly on Anacapa and Santa Cruz Islands. Chemical dispersion is feasible, but would occur near enough to land that some dispersed oil might be expected to spread into shallow, nearshore waters. The spill takes place approximately 20 km to the WNW of Port Hueneme at 1600 on February 20. For purposes of this study, a spill of 10,000 barrels ANS crude oil, an Av-E oil, has been substituted for the spill of 210,000 barrels of Monterey crude oil.

Movement and Fate of the Spill. In the untreated spill, the surface slick persists for approximately 72 hours (Figure 6-5), during which time it moves in a circular trajectory under the influence of strong, but shifting winds (Figure 6-6a). The slick contacts shorelines and nearshore areas on the mainland, as well as on Anacapa and Santa Cruz Islands. Approximately 16 km of shoreline on the mainland are contaminated with approximately 3000 barrels of oil (30 liters of oil per m of shoreline) and approximately 1000 barrels of oil are deposited on 32 km of shoreline on the islands (4 liters per linear m).

In the chemically dispersed case, realistically, little dispersant could be applied on the first day, so dispersant operations are assumed to begin at dawn on Day 2. According to the theoretical dispersant delivery rates given above, sufficient dispersant to fully treat this spill could be delivered in a single day by a single C-130 operating from Los Angeles International Airport (at a range of 60 nautical miles) or three to four AT-802s operating out of any of the smaller airports in the Santa Barbara or Oxnard areas (at ranges of 10 to 20 nautical miles from the spill site). The worst-case situation from the perspective of peak oil concentration in the water would result if all of the oil were to be dispersed at once. Assuming that this takes place at midday on the Second Day, a cloud of dispersed oil with a diameter of 3.1 km and average oil concentration of approximately 15 ppm of dispersed oil would be generated at approximately 7 km NE of the spill site (or 15 km NW of the port Hueneme). Estimates of the location, size and average oil concentration in the cloud of dispersed oil are reported in Table 6-8 below and are illustrated in Figure 6-6b.

Table 6-8 Persistence and Movement of Dispersed Oil Santa Barbara Channel Spill

Time Since Spill, Hours	Location	Distance from Pt. Hueneme, km	Mean Concentration Of Dispersed Oil in Cloud, Ppm	Mean Cloud Diameter,
20	34.265N;120.325W	17	16.0	3.1
32	34.245N;120.312W	14	8.5	4.3
56	34.225N;120.300W	12	3.5	6.8
80	33.210N;120.290W	10	1.7	9.6
104	33.190N;120.280W	8	1.0	12.4

Environmental Impact and Net Environmental Benefit. The results of the impact analyses for the chemically dispersed and untreated spills are summarized in Table 6-9. In the untreated case, the spill threatens to contaminate a total of almost 50 km of shoreline on both the mainland and the offshore islands, Anacapa and Santa Cruz. The level of contamination would be an average 30 l of oil per m of shoreline on the mainland and 4 l/m on the islands. In both locations, these concentrations would be highly visible, sufficient to cause impact to intertidal biota and would require cleanup. On the mainland, the shoreline in question is composed of porous substrate types with intermediate biological sensitivity, so some biological damage might be expected here, as described below. The shorelines on the islands are composed partly of intermediate sensitivity gravel substrate and partly low sensitivity rock. The latter, coupled with the lesser level of oiling, makes shoreline contamination on the islands of lesser concern than on the mainland. In short, the greatest concern here is for the mainland shores that are of intermediate sensitivity and are heavily oiled. If dispersants were to be used as described above, all shoreline oiling would be avoided.

A number of human use features are at risk from this spill. These include recreational shorelines, recreational fishing areas and a water intake. Oiling may render these resources unusable for periods of from days to months, until the oil is cleaned up. Because these are out of use for a period of less than a year, the level of risk is LIMITED.

The areas of mainland shore that are at risk of oiling apparently have no living habitat resources that would be vulnerable to this spill. However, the spill threatens several oil-sensitive habitat types on the islands. Historically, the threat from slicks to the submerged habitat types, such as the giant kelp is limited. The risk would be particularly low in the present scenario in view of the small amount of oil that persists on the surface by the time the slick arrives at the Islands. Based on this the level of risk to the kelp is ZERO. The oil, even the small amounts remaining on Day 3 may pose a risk to the intertidal surfgrass on Anacapa Island. Much of the standing stock of surfgrass on the north side of Anacapa Island must be considered to be at risk. This stock appears to be one of the few examples of this type of habitat in Southern California and for this reason; the level of concern assigned to this resource is MODERATE. The spill also poses a risk to the intermittent coastal wetland on Santa Cruz Island. The level of oiling involved is modest (4 l/m of shoreline), so, at worst, the spill poses a risk of sublethal effects to the aboveground portions of the wetland plants on the seaward edge of the wetland. Moreover, this patch of wetland is one of many such wetlands in southern California, so the level of concern here is LIMITED. The use of dispersants as described above would reduce these risks to ZERO.

The untreated spill poses very significant risks to a number of species of marine birds and shorebirds. In all, combining the mainland and island areas, the spill poses a risk of at least LIMITED-level risks to more than ten species of marine and shore birds. The level of risk to six of these species is MODERATE or HIGH, and four of these species, namely Brown Pelican, California Least Tern, Western Snowy Plover and Peregrine Falcon, are threatened or endangered species. With most species, the true biological risks would be considered LIMITED because track of the oil slick overlays approximately 5% of distribution of the species in southern California. For threatened or endangered species, the level of concern is raised by one category in recognition of its endangered status. The Xantu's Murrelet appears to be at far greater risk than other species because this is one of the few locations where the species is found in Southern California. Approximately 50% of the area used by this species in Southern California is at risk from the untreated slick, so its level of concern is rated as HIGH. In all cases, the use of dispersants as described above would eliminate the risk to marine birds.

At least five species of marine mammals occupy the Island areas threatened by the untreated spill. Three of these are bare-skinned mammals and are at little risk from the spill. It is questionable whether adults of the hairy mammal species the California Sea Lion and Harbor Seal in the threatened area are at any risk of lethal effects from oiling. However, young-of-the-year of the latter species may be at risk. The California Sea Lion and Harbor Seal are both widely distributed in southern California, so the risk to this stock from this spill is rated as LIMITED. This risk is reduced to ZERO if the spill is chemically dispersed offshore.

Several species of finfish and shellfish are at risk from this spill. The California spiny lobster occurs in the exposed area at the time of the spill, but is relatively invulnerable to the spill because of its subtidal habit. The intertidal species, surfperch, littleneck clam and Pismo clam are at risk of some lethal effects from the untreated spill because of the high level of exposure in the surf and intertidal zone. Risk to the surfperch and littleneck clam are judged to be LIMITED because they are broadly distributed in Southern California and the stock in the threatened area represents only a small proportion of the total Southern California population. The Pismo Clam is less widely distributed so the level of concern for that species is MODERATE. The stocks of all four of these species may be exposed to the cloud of chemically dispersed oil, when it spreads into the shallow, nearshore area of the mainland by midnight on Day 3 (Figure 6-6b). However, by the time that these species are exposed to the cloud the average hydrocarbon concentration in the cloud had fallen below the assumed toxic threshold for these resource types. So the expected risk to these would be ZERO or at most, ZERO to LIMITED.

Net Change in Environmental Impact with Dispersant Use. Despite the apparent exposure of nearshore fish and invertebrate species on the mainland to dispersed oil, there appears to be a clear environmental advantage to using dispersants in this case. Dispersing offshore keeps the oil away from the mainland shores and the Island areas and thereby eliminates: 1) the risks to the living habitat types; 2) the very serious threats to marine bird species and lesser risk to the sea lion and seal stocks; 3) the limited risks to human use features on the mainland; and 4) the problem of heavy shoreline oiling. Although there is some exposure of fish and invertebrates to chemically dispersed oil, the level of exposure is low, is not lethally toxic, and therefore poses little or no ecologically significant risk. Therefore, despite the existence of downside risks from dispersant use, the environmental trade-offs strongly favor the use of dispersants in this case.

Figure 6-5 Behaviour of Santa Barbara Channel Oil Spill

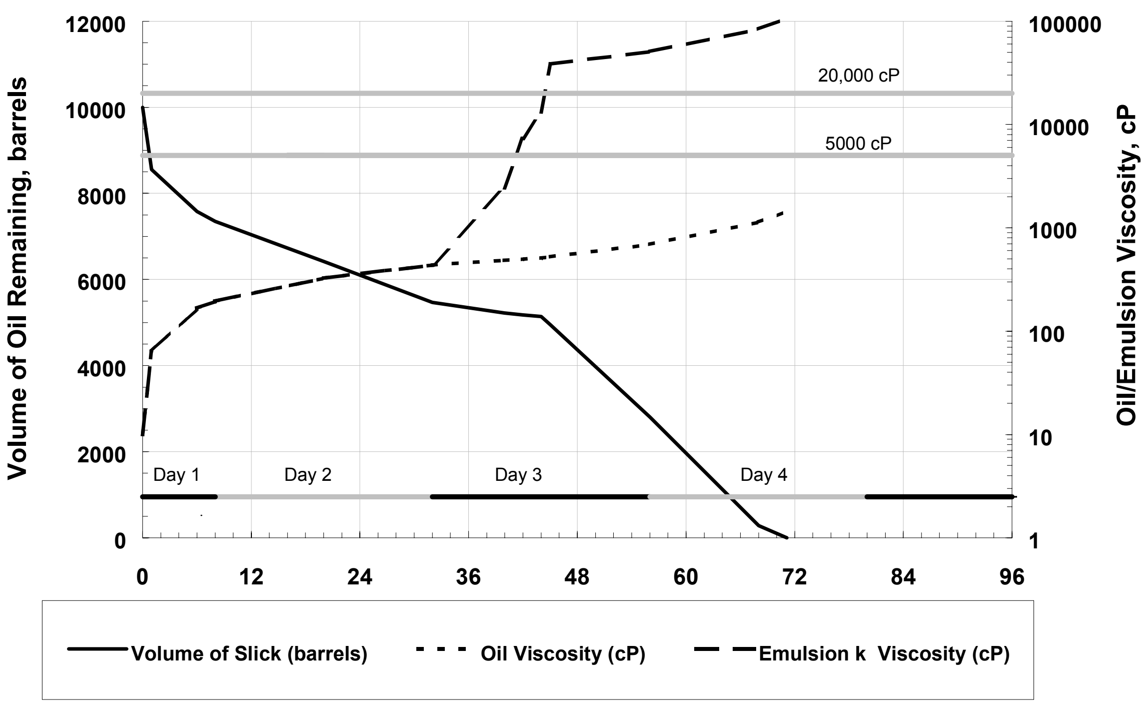

Figure 6-6a Movement of Untreated Spills: Santa Barbara Channel

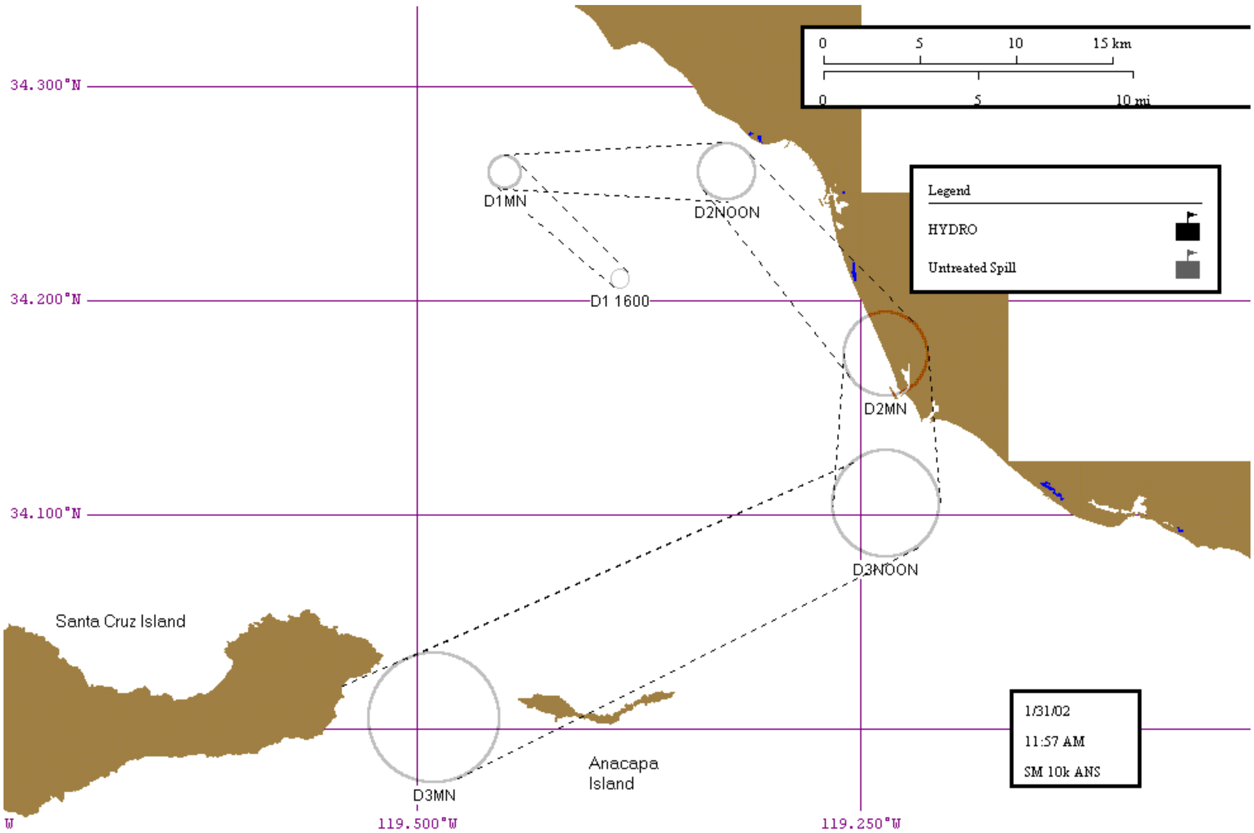

Figure 6-6b Movement of Chemically Dispersed: Santa Barbara Channel

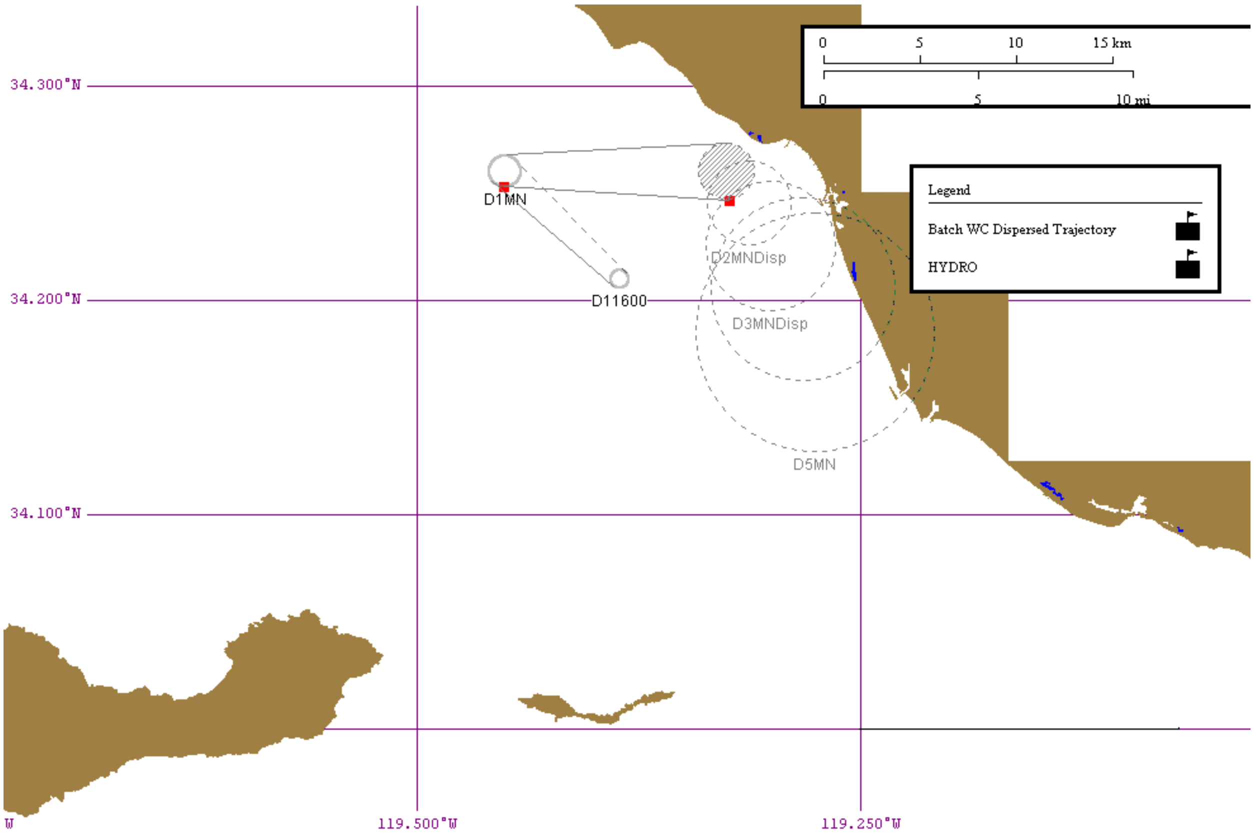

Table 6-9 Summary of Impacts: Santa Barbara Channel Spill

Valued Environmental Components	Untreated	Dispersed
SHORELINES (km)	48.5	0
Mainland		
6- Gravel / Rip-rap	5.5	0
5 - Mixed Sand and Gravel	1.4	0
4 - Med t Coarse Sand	1.7	0
3 - Fine Sand	7.2	0
2- Rocky Ledges	0	0
1- Exp. Rocky Shorelines	0	0
Islands		
6- Gravel / Rip-rap	10.2	0
5 - Mixed Sand and Gravel	3.2	0
4 - Med t Coarse Sand	0	0
3 - Fine Sand	0	0
2- Rocky Ledges	0.9	0
1- Exp. Rocky Shorelines	18.4	0
HUMAN USE FEATURES		
Recreational Beach (Solimar Beach?)	Limited	0
San Buenaventura State (Recreational)	Limited	0
State Beaches:McGrath, Mandlay, Oxnard,Hoolywood,	Limited	0
Ventura Marina	Limited	0
Recreational Fishing (off Ventura	Limited	0
Recreational Fishing (off Pt.	Limited	0
Commercial Fishing (off Pt.	Limited	0
Water Intake in Pt	Limited	Limited
Channel Is. Nat. Pk/Nat Mar.	Limited	0
OIL-SENSITIVE LIVING HABITAT		
Mainland	0	0
none		
Islands		
Giant Kelp	0	0
Surf Grass	Moderate	0
Intermittent Coastal	Limited	0
MARINE BIRDS		
Mainland		
California Least Tern (F/E)	Moderate	0
Brown Pelican (F/E) (includes impacts on Island	Moderate	0
Western Snowy Plover	Limited - Moderate	0
cormorant	Moderate	0
terns	Limited	0
gulls	Limited	0
Islands		
Peregrine Falcon (F/E)(b)	Moderate	0
Brown Pelican (F/E)	Moderate	0
Xantu's Murrelet	High	0
Cassin's Auklet	Limited	0
Brandts Cormorant	Limited	0
Pelagic Cormorant	Limited	0
Western Gull (b)	Limited	0
Black oystercatcher (b)	Limited	0
Ashy Storm Petrel (b)	Limited	0
Pigeon Guillemot (b)	Limited	0
MARINE MAMMALS		
California Sea Lion	Limited	0
Harbour Seal	Limited	0
Bottlenose Dolphin	0	0
Common Dolphin	0	0
Risso's Dolphin	0	0
FINFISH AND SHELLFISH		
Surfperch	Zero-Limited	0
Common Pacific Littleneck Clam	Limited	0
California Spiny Lobster	0	0
Pismo Clam	Moderate	0
MARINE REPTILES	0	0
None		

6.4.4 Platform Gail Blowout Spill Scenario

This scenario is included to illustrate the impacts and NEB considerations during a blowout spill. Fortunately, because of the spill conditions in this scenario, this case is useful in assessing environmental issues where dispersants are only partly effective in eliminating the oil slick. The spill circumstances in this scenario are based on an uncontrolled above-sea blowout from the highest capacity well at Gail lasting 30 days, as described in Venoco Inc. (2001). The spill is a continuous blowout of 882 BOPD of Sockeye crude oil, lasting 30 days. Platform Gail is located 18 km W of Port Hueneme and 13 km N of Anacapa Island.

Movement and Fate of the Spill. In this scenario, the fate and movements of oil have been estimated using a combination of fate (SLROSM Model) and trajectory models (Johnson et al. 2000). In the untreated case, the slick generated at the spill site can be conceptualized as a series of overlapping slicklets or a ribbon, originating at the spill site and stretching away for many kilometers. Slicklets are formed at the spill site by oil droplets from the blowout falling on the sea. The ribbon of slicklets is narrowest and thickest at the spill site and broadens and thins with increasing distance due to weathering and spreading. In this scenario the spillet volume is 0.82 barrels. Approximately 15% of each slicklet is lost by evaporation or dispersion within the first 24 hours. Thereafter the remaining oil is lost very slowly with approximately 70% remaining on the surface after 30 days, probably in the form of slick fragments (Figure 6-7 and 6-8a). At the spill site the slick is modeled to be 22 m wide and 0.33 mm thick and is probably continuous (not patchy). After 3 hours the slicklet has traveled 1 km from the spill site, spread to a width of 175 M and is 35 uM thick (average) and after 15 hours it has traveled 5 km, is 1 km wide and 5 uM thick (average).

The movement of the surface oil has been inferred from the MMS-sponsored oil spill risk analyses (Johnson et al. 2000). Unlike the batch spill case where the oil moves cohesively under the influence of a single set of winds and currents, in a blowout spill oil is discharged slowly over a long period under changing wind and current conditions. As a result, during a blowout, parcels of oil discharged at different times move in different directions. Trajectory modeling reported in Johnson et al. (2000) has predicted the movements of parcels of oil discharged from

Platform Gail, on a seasonal basis, under historical wind and current conditions. Based on these analyses, the likely directional movement of the spillets at sea is demonstrated by the conditional probability of the oil contacting certain at-sea grids adjacent to the spill site. These analyses by suggest that the vast majority of oil slicklets discharged at Platform Gail in the autumn will move the west, along the Santa Barbara Channel. Only a very small proportion will move to the east. When the output of Johnson et al. is expressed as conditional probability of shoreline contact, the data suggest that 85% of the spillets will contact shorelines within 30 days of the time of discharge. The spatial distribution of the points of contact is summarized in Figure 6-8a. This figure shows that all oiled shorelines are in a generally westerly direction from Gail, in the sector from the S to the NW, as illustrated by the arc in the figure.

The location and size of the area-of-effect on surface dwellers of the surface slick from this blowout is not precisely known. Obviously the areas at greatest risk from the blowout are in the sector from the S to NW from the platform, but it is uncertain whether resources at distance from the blowout site (e.g., San Miguel Island) will be at risk or whether only resources near the spill are threatened. The continuous "thick" slick near the spill site is obviously hazardous to seabirds and other surface dwellers and it probably continues to pose a threat even after it has spread and thinned for several hours and has moved several km from the spill site. Within these few hours the "ribbon" probably ceases to be a continuous slick, but breaks up into a discrete patches. These in turn break up repeatedly until the "ribbon" is actually many small slick fragments widely separated by broad expanses of open water and the slick appears to have dissipated. It is not clear at what point the slicklets become so weathered, fragmented and spread out that they are no longer visible as a slick and, more importantly, no longer pose a real toxic threat to surface dwellers. For purposes of this scenario, the highly conservative assumption has been made that the ribbon becomes innocuous to biota when the thickness declines to 0.001 mm. This occurs by 60 hours when the slick is 6 km wide and has reached 17 km from the spill site. Based on this reasoning the area-or-effect for seabirds and other surface dwellers from this slick is assumed to be the arc of 17-km radius illustrated in Figure 6-8a.

The slicklets appear to be dispersible when fresh, but emulsify quickly becoming undispersible within 6 to 12 hours (Figure 6-7). The existing dispersant spraying platforms appear to be capable of fully dispersing all of the 882 barrels of oil discharged daily (or the 36 barrels of oil that are discharged hourly), given the distances involved. However, these spraying systems can operate only during the hours of daylight. Operations must be suspended at dusk and recommenced at dawn. Since emulsification is rapid, it may be that some of the oil discharged overnight may not be dispersible at dawn. This problem, termed the "overnight effect", is discussed at length in S.L. Ross (2000). In this case, the oil discharged in the hours just before dawn may be fresh enough to be dispersible at daybreak, but some of the oil spilled during the previous evening may have already become undispersible. For the purposes of this study, it has been assumed that all of the oil spilled from midnight to daybreak can be fully chemically dispersed on the following day, but the oil spilled during the six hours from nightfall to midnight becomes undispersible overnight. It is also assumed that all of the oil dispersed during each day is dispersed at once at midday.

Environmental Impact and Net Environmental Benefit. The results of the impact analyses for the chemically dispersed and untreated spills are summarized in Table 6-9.

In the untreated case, the spill threatens to contaminate approximately 300 km shoreline on both the mainland and Channel Islands (see Figure 6-8a). The level of oiling on each shoreline segment (see Johnson et al. 2000 for definitions of segments) has been estimated based on: a) the conditional probability of spillets stranding on a given shoreline segment within 30 days; b) the volume of the spillet; and c) the proportion of oil in the spillet remaining at the time of grounding. In all cases, the level of oiling was based on the worst-case assumption that oil stranding on a segment would accumulate until all oil had stranded. In this way the volume on each segment was the total amount that accumulated over the 30-day duration of the spill, plus a 30-day period following the release of the last spillet. On some segments, the level of oiling is heavy enough (> 1l/m) to pose a toxic risk to intertidal flora and fauna, to be visible and to require cleanup. Other segments, however, are only lightly oiled (< 1 l/m); oil poses no toxic risk, is not visible and therefore requires no cleaning. The total length of shoreline that is heavily oiled was 171.1 km, which includes approximately 60 km on the mainland and 110 km on the islands. Most of the approximately 60 km of oiled mainland shore is fine sand beach, while most of the 110 km of oiled shore on the islands is rocky shore.

As described above, if dispersants are used to treat the spilled oil the operations could be expected to treat all of the oil discharged during the hours of daylight, plus approximately half of the oil discharged at night. However approximately half of the oil discharged overnight cannot be disperse due to the “overnight effect”. As a result, chemical dispersion does not completely eliminate shoreline oiling, but only reduces the amount that is heavily oiled (> 1 l/m) to 28.1 km in total. Oiling of mainland shore is virtually eliminated and oiling on the islands is reduced to the sections of Anacapa and Santa Cruz Islands closest to the blowout. The latter involves mostly rocky shores, which are the least sensitive of the shoreline types to oiling. In these areas dispersion reduces the level of oiling in this scenario to marginal levels just slightly above 1 l/m.

The untreated spill will pose a risk of short-term disruption to human use features and resources such as aquiculture operations, coastal recreation areas and a recreational beach on the mainland. These risks are assessed to be at the LIMITED level because although they may render the resource unusable for a time, the disruption will be of short duration (< 1 year). Using dispersants to treat the spill will largely eliminate these risks. The untreated spill will pose a similar level of risk to the Channel Islands National Marine Park. Chemical dispersion will reduce level of oiling somewhat, but will not eliminate the risk.

Living habitats are at little risk from oiling anywhere outside the parts of Anacapa and Santa Cruz Islands that are contaminated directly with fresh oil from the blowout (Figure 6-8a). The remaining areas of the Channel Islands and mainland are likely to be exposed only to small fragments of heavily weathered oil, which will pose little risk of toxicity. Even within the area exposed to direct oiling from the blowout, the risk of mortality to the giant kelp forests is small because: a) the kelp fronds are submerged and are unlikely to contact the surface slicks; and b) only small amounts of oil persist on the sea surface long enough to reach the areas where kelp occurs. The level of risk to the kelp is assessed as ZERO and is not registered in Table 6-9. The risk to surfgrass is somewhat higher (due to its more intertidal habit). However, the risk to surfgrass is also questionable, in this case due to the small amounts of oil to which organisms are exposed. If toxic effects were expected, then the level of concern would be MODERATE because the Anacapa Island stock of surfgrass is unique as it is one of the few such stocks reported in the ESI maps for Southern California. The risk to stands of surfgrass is greatly reduced, though not eliminated by using dispersants as described above.

The untreated spill poses significant risks to a number of species of marine birds. The spill poses a MODERATE- or HIGH-LEVEL risk to at least eight species of marine birds, two of which are either threatened or endangered species. The use of dispersants would greatly reduce the level of exposure of these stocks to oil, but would not eliminate it. The reduction in impact resulting from dispersant use will depend on a variety of factors, including the direction of movement of any undispersed oil. For purposes of this work we have assumed that the reduction in impact is directly proportional to the reduction in the volume of oil persisting to undispersible viscosities, in this case 75%. This represents an important reduction in impact on all species in question, as shown in Table 6-9.

The untreated spill probably poses little risk to marine mammals in this scenario. The spill clearly poses no risk to the bare skinned mammals in the area (e.g., Bottle-nose Dolphins, Common Dolphins), and probably poses very little risk to adults of the hairy marine mammal species (e.g., California Sea Lions, Harbor seals). At worst they might pose some risk of mortality to young-of-the-year of the latter species and for this reason a level of risk of LIMITED has been assigned. If dispersants were used as described even these risks would be reduced.

The risk to finfish from both untreated and chemically dispersed spills is probably ZERO. In the untreated case, the ESI database suggests that there are no notable finfish concentrations in the nearshore areas exposed most directly to fresh oil from the blowout. There are finfish in the areas where weathered oil accumulates on the mainland shoreline, but oil concentrations in these areas would be too low and the oil too weathered to be of concern to these finfish species, so risks here are also ZERO. Figure 6-8b shows that nearshore concentrations of finfish are not exposed to dispersed oil because the dispersed oil plumes are kept in the middle of the Channel by prevailing currents. The risks from dispersed oil are ZERO.

Two species of invertebrates are at risk here. The California mussels of Anacapa Island may be at risk of toxicity from exposure to relatively fresh slicks. This is one of only a limited number of areas where this species is found in high concentrations in the Southern California and so the level of concern must be MODERATE. The California little-neck clams in the oiled areas of the mainland shore may be exposed to oil, but exposures are low, oil is weathered and the proportion of the stock in southern California stock is low, so the risk is ZERO to LIMITED at worst.

Net Change in Environmental Impact with Dispersant Use. In this scenario, the decision-making problem is complicated by the "overnight effect" on dispersant operational effectiveness, which means that the dispersant operation can be only 75% effective. If dispersant operations were 100% effective, the net environmental benefit of dispersion would be clear. Dispersants would eliminate the risks of shoreline oiling, as well as the risks to human use features, invertebrates, important risks to wildlife from the untreated oil, while there would be no apparent risks from the chemically dispersed oil to any in-water resources of note. In this case, however, even though dispersion is not complete, it does reduce the volume of oil escaping from the spill site by 75%. This is sufficient to almost eliminate shoreline oiling and greatly reduce or eliminate risks to living habitats, wildlife and invertebrates. As a result, dispersion appears to offer a clear net environmental benefit in this case. It must be borne in mind that this may not be the case in all scenarios.

In actual practice, mechanical cleanup would probably be the primary response tool in this scenario, with dispersants being used in a supplementary role. The daily recovery rate planning standard for booms and skimmers greatly exceeds the daily spill rate both in terms of fresh oil (880 barrels) and water-in-oil emulsion (2640 barrels) (see Arguello Inc., 2000). Based on historical weather conditions for the area, wind/wave conditions can be expected to exceed the operating limits of mechanical recovery for 0 to 29% of the time, depending on the season, or for up to nine of the 30 days of the blowout (See Table 5-12, Among Channel Islands site). This would allow up to 7920 barrels of oil to escape fro the spill site. During these times dispersants could be used, dispersing 5940 barrels of oil, but allowing approximately 1980 barrels to escape due to the "overnight effect". The above assessment of net environmental benefit applies equally well when dispersants are used in a supplementary role dealing with a smaller amount of oil.

Figure 6-7 Spill Behavior and Persistence of a Slicklet:
Gail Platform Blowout Spill, 882 bbl/day of Sockeye Crude Oil
(Spillet Volume = 0.86 bbl)

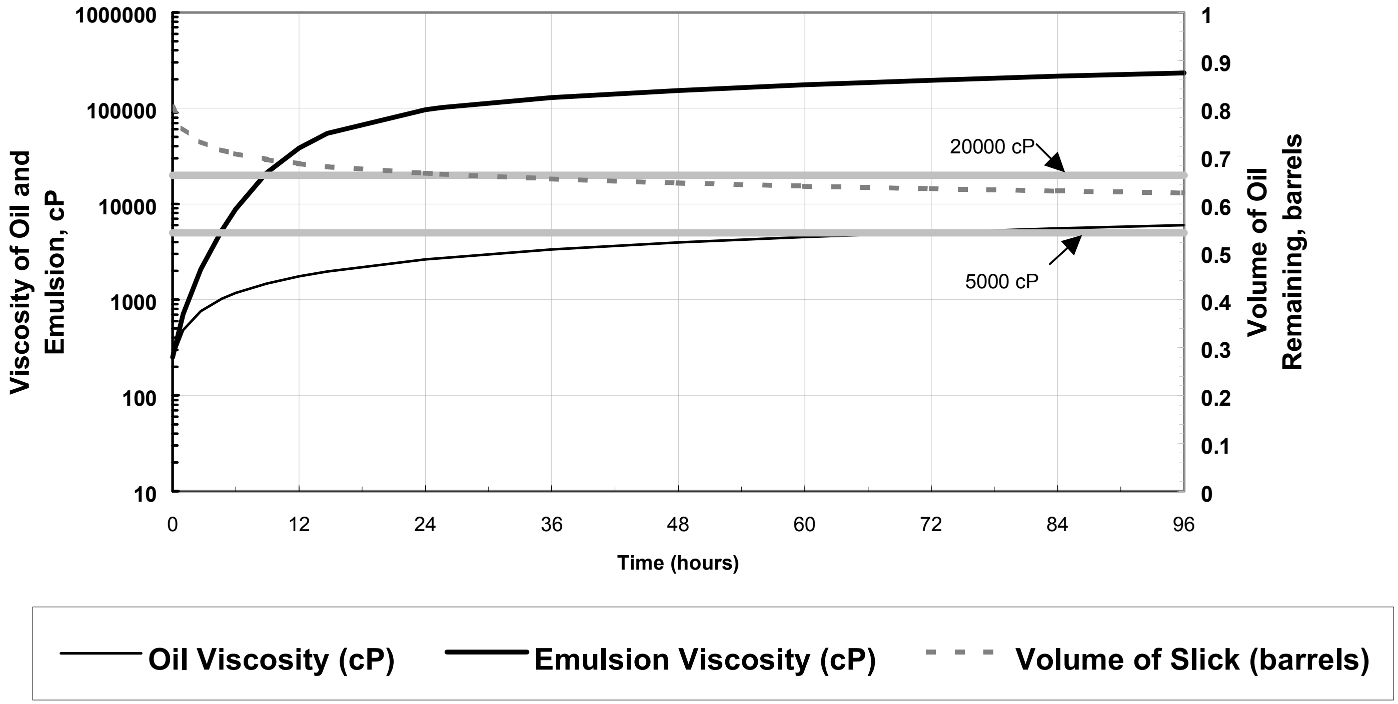

Figure 6-8a Directions of slicklet movement and predicted distribution of shoreline oiling

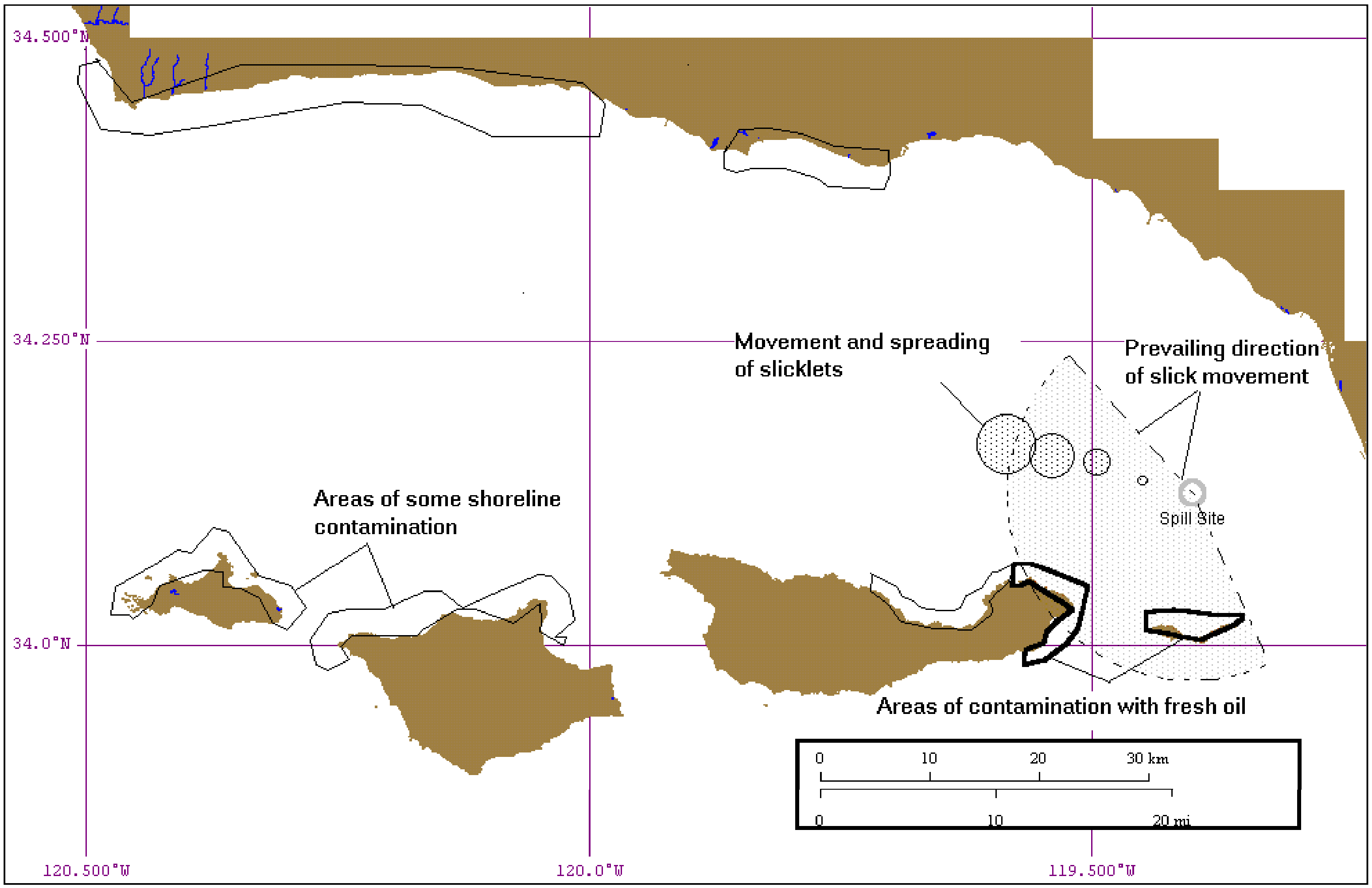

Figure 6-8b Movement of Chemically Dispersed Oil

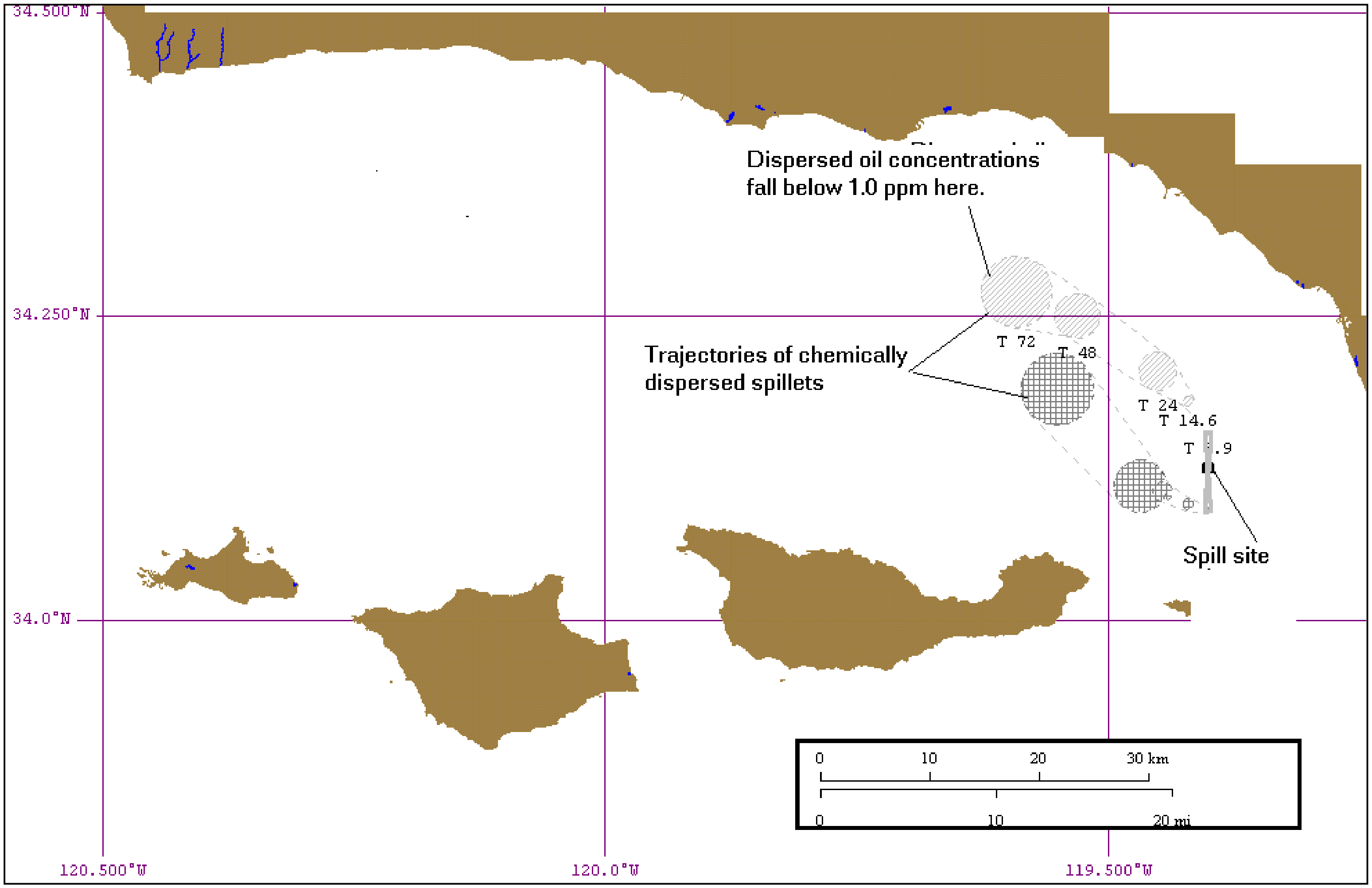

Table 6-9 Summary of Impacts: Santa Barbara Channel Spill

Valued Environmental Components	Untreated	Dispersed
SHORELINES (km)	171.1	28.1
Mainland		
7- Rip-rap	0.5	0
6- Gravel / Rip-rap	0.5	0
5 - Mixed Sand and Gravel	3.6	0
4 - Med t Coarse Sand	0	0
3 - Fine Sand	50.5	0
2- Rocky Ledges	4.9	0
1- Exp. Rocky Shorelines	1	0
Islands		
6- Gravel / Rip-rap	0.8	0.8
5 - Mixed Sand and Gravel	5.3	2.7
4 - Med t Coarse Sand	15.3	3.8
3 - Fine Sand	8	0
2- Rocky Ledges	20.1	0
1- Exp. Rocky Shorelines	61.1	20.8
HUMAN USE FEATURES		
Aquiculture (four installations on mainland)	Limited	0
Access areas (nine locations, plus Refugio and El Capitan State Parks, plus Channel Islands Nat Mar Sanct and Park	Limited	0
Recreational Beach (unidentified)	Limited	0
OIL-SENSITIVE LIVING HABITAT		
Mainland		
none		
Islands		
Surf Grass	Moderate (?a)	Moderate (?a)
MARINE BIRDS		
Peregrine Falcon (F/E)(b)	High	Moderate-High
Brown Pelican (F/E)	Moderate	Limited
Xantu's Murrelet	High	Moderate
Brandts Cormorant	Moderate	Limited
Pelagic Cormorant	Moderate	Limited
Western Gull (b)	Moderate	Limited
Black oystercatcher (b)	Moderate	Limited
Pigeon Guillemot (b)	High	Moderate
MARINE MAMMALS		
California Sea Lion	Limited	0
Harbour Seal	Limited	0
FINFISH AND SHELLFISH		
California Mussel	Moderate	Limited
Common Littleneck Clam	0 to Limited	0

a. It is uncertain as to whether the level of exposure will be great enough or the oil fresh enough (unweathered)to do damage.

6.5 Discussion of Net Environmental Benefit Analysis

In this study, dispersants offer a clear net environmental benefit in all scenarios. The reason is that the launch sites for all spills are somewhat offshore. If left untreated, slicks from these spills all move onshore where they threaten a variety of resources. However, in these deeper offshore waters, where dispersants would be used, the ESI maps show very few sensitive resources. As a result, dispersant use in these offshore areas poses few serious environmental threats and impacts of the untreated spills always exceed those of dispersed spills.

The scenario off San Miguel Island is very simple and is typical of spills in areas outside the Santa Barbara Channel. In this case, the net environmental benefit of dispersants is clear because the untreated spill threatens very significant damage to important wildlife. On the other hand, chemical dispersion poses few, if any environmental risks. The low risk of dispersed oil was due to two factors: a) dispersion could be completed well offshore; and b) surface currents kept the dispersed oil well offshore, away from sensitive nearshore targets such as the giant kelp forests. Even uncertainties about factors such as trajectories do little to alter the conclusion. On one hand, the untreated slick threatens significant damage to a variety of resources regardless of its trajectory, as long as it contacts the shore of San Miguel Island. On the other hand, the dispersed oil poses little threat regardless of where the oil is carried by currents. Even if currents were to drive dispersed oil onto the San Miguel Island kelp beds, there would be little likelihood of damage because the dispersed oil would be well diluted by the time it reached the kelp and no toxic effects to the kelp would be expected. In short, regardless of uncertainties, NEB favors dispersant use.

The batch spill scenario in the Santa Barbara Channel is more complex because the spill is close to shore and dispersed oil enters nearshore waters. However, the net environmental benefit still favors dispersants because risks from the dispersed oil are still limited, while there are numerous important resources threatened by the untreated spill. Dispersed oil poses limited risk in this scenario because: a) the small number of in-water resources in the shallows, (as per the ESI maps); b) the in-water resources at risk were widely distributed in Southern California and so only small proportions of the regional populations were threatened by the spill; and c) hydrocarbon concentrations were relatively low when contamination reached the shallows.

The blowout scenario from platform Gail addressed two complicating factors: a) the complexities arising from a continuous spill that lasts many days as compared to an instantaneous batch spill; and b) the problem of a dispersant operation that is less than 100% efficient. Blowout spills pose somewhat different environmental risks from batch spills of similar size. The impacts of treated or untreated blowouts may be larger or smaller than those of batch spills depending on spill location and the nature of the receiving environment. In the present case, the impact of the untreated blowout is significant, though smaller than that of the corresponding batch spill. However, based on ESI map data, the impact of the dispersed blowout is negligible as dispersion takes place offshore. As a result, dispersants still offer a clear net environmental benefit in this case. Dispersants will commonly offer a NEB for offshore blowouts, provided the untreated blowout poses some significant environmental risk. This is because dispersing blowouts involves dispersing thin slicks (in this case 0.3 mm thick), containing relatively small amounts of oil (in this case 36 bbl per hour), producing small plumes of dispersed oil with relatively low concentrations of hydrocarbons. These plumes dissipate to innocuous levels quickly, near the spill site. Since they are well offshore, these small plumes pose little environmental threat compared to the untreated slicks and environmental trade-offs generally favor dispersion. This situation was observed in the NEB analysis for a blowout spill in the Gulf of Mexico in S.L. Ross (2000).

In this scenario the dispersant operation is only 75% effective and this could have complicated the NEB calculation. Historically, when faced with incomplete dispersion, some decision-makers have perceived that situations involving combined impacts from both dispersed oil and untreated oil, regardless of the magnitude of the impacts, must be worse than that of the untreated spill alone. However, in the present case, NEB clearly favors dispersant use because a 75%-reduction in the volume of oil leaving the spill site virtually eliminates most risks posed by the untreated spill. At the same time the risk from the chemically dispersed oil is nearly negligible whether dispersion is 75% or 100% effective. So regardless of whether the dispersant operation is 100% effective or 75% effective, it still results in a dramatic reduction in the overall impact of the spill.

This will commonly be true of offshore blowouts, but will definitely not be true of all blowouts occurring in shallow nearshore waters.

Based on this analysis it is reasonable to conclude that for most marine spills of this size in this area, chemical dispersion will generally offer a net environmental benefit. This is certainly true for offshore spills and appears to be true for spills in shallower, nearshore waters as well.

7. Major Findings

The most important findings from this work are as follows.

Basic Dispersibility of California Oils. For oils produced in the POCSR, the dispersant situation is not promising. Most oils are either highly viscous and/or emulsified and are poor candidates for dispersion. Only a small number appear to be amenable to dispersion.

The most important crude oil imported into California, Alaska North Slope crude oil, is dispersible, when fresh. Based on the API gravity values of other important imports, some appear to be dispersible when fresh, some are not and for some their spill-related properties are not known.

Modeling Standard Scenario. The 18 oils modeled in this study can be divided into three categories based on their “emulsion formation tendency”. Twelve oils are highly emulsifiable (called Hi-E oils) and have very narrow Time Windows (TWs) for chemical dispersion (TWs range from 0 to 24 hours). Four oils, including Alaska North Slope crude oil, emulsify only after weathering (TW of 38 to 67 hours). The final category of oils do not emulsify regardless of weathering, allowing an unlimited TW for dispersants. This category includes diesel oil Pitas Point crude, a heavy gas condensate.

Spill Scenario Modeling. The dispersibility of blowout spills depends on the spill conditions. Subsea blowout spills are probably poor candidates for dispersion. When lighter oils are involved the spills disperse very quickly by natural means and do not require dispersion. With heavier oils, spills emulsify almost immediately, allowing no TW for dispersion. The picture is different for the above sea blowouts, in that spills of lighter oils have somewhat longer TW, up to eight hours. However, blowouts of Hi-E oils emulsify almost immediately and are poor candidates for dispersion.

For batch spills from ships, amenability to dispersion varies with oil type and spill volume. TWs for Alaska North Slope crude oil scenarios decline from 166 to 90 to 74 hours for spills of 250,000, 10,000 and 3,000 barrels, respectively, for spills in 5-knot winds. The same trend holds for different oil types. Diesel fuel spills are all amenable to dispersant use up to the time that they would naturally disperse since these spills will not form emulsions.

Logistics and Feasibility of Operations. Only a limited amount of dispersant response equipment is in place in California at present, although equipment located throughout North America could be cascaded to California in the event of a large spill. Approximately 41,560 gallons (=989 barrels) of dispersants are available in California at present and an additional 273,615 gallons (=6514 barrels) are held in North American stockpiles elsewhere in North America.

Production-related spills in California pose challenges for dispersant planners. Many production oils are poor candidates for dispersants because of short TWs, but blowouts of Av-E oils are amenable to treatment if the response is rapid and the appropriate equipment, ship-based or helicopter-based systems, are used.

Ship- and helicopter-based dispersant systems may be adequate to deal with small and mid-sized tanker spills provided that: a) they are close to their bases of re-supply; and b) their TW are long. Small- to mid-sized spills that occur at a distance from response centers are well suited to the small, fixed wing aircraft. Very large spills require the delivery capacities of the large, fixed-wing platforms, such as the C-130/ADDS Pack system.

Net Environmental Benefit of Dispersant Use. Dispersants offer a net environmental benefit in every scenario analyzed in this study. The reason for this is that launch sites for all spills were on the open coast where they could be dispersed with limited environmental risk. If left untreated, the slicks from these spills will move shoreward, where they pose significant environmental threats to a variety of resources. The NEB favors dispersant use because in all scenarios there were few identifiable environmental drawbacks from using dispersants in all cases.

8. Conclusions and Recommendations

Conclusion. #1. A few of the oils produced in the POCSR appear to be good candidates for dispersants, but many oils are not. Time Windows (TWs) for dispersion are short, even with the more promising oils.

Recommendation #1.1. Since TWs for production-related spills will be short, it will be essential to shorten start-up times and minimize re-supply times, in order to make responses as efficient as possible. Obviously, responses to these spills must involve operating strategies suited to blowouts, like using vessel- and helicopter-spray systems.

Recommendation #1.2. Because of concerns that the oil will become undispersible quickly, it will be critical to have effectiveness monitoring in place as quickly as possible.

Conclusion #2. Dispersant use for tanker spills is promising because a sizable proportion of the volume of imported oil is dispersible when fresh.

Recommendation #2.1. Tanker spills may be large, may occur some distance offshore, and may have TW of only one or two days. Therefore, a rapid response with a high capacity platform is needed. Arrangements should be put in place to use high-capacity spraying systems such as large, fixed-wing aircraft or a high capacity, high speed dispersant spraying vessels of the kind not currently not available in the state. Plans and arrangements must enable spraying no later than dawn on the day following the spill.

Conclusion #3. The TWs for some imported oils are long, while those for others are short. The spill-related properties of many others are not known; their amenabilities to dispersion are thus not known also.

Recommendation #3.1. It will be essential to have conventional response capabilities in place for situations where dispersants may not work.

Recommendation #3.2. Our practical understanding of dispersant effectiveness is still very limited. One way of gaining a better understanding of dispersants will be to use trial applications of dispersants in some spill situations regardless of the uncertainties about their potential value. To be a useful and effective learning exercise, it will be critical to have effectiveness monitoring in place.

Recommendation #3.3. It is important to conduct analyses on all of the important imported oils in order to learn their spill-related properties and amenability to chemical dispersion.

Conclusion #4. For marine spills such as those examined here, effective chemical dispersion offers a clear, substantial net environmental benefit. This is certainly true for spills in the Santa Barbara Channel area, where the scenarios in this study were located. It may also be true for offshore spills and for spills in shallower, nearshore waters.

Recommendation #4.1. For reasons of environmental protection, dispersants should be used as a first response tool for cleaning up spills of dispersible oils on the open coast in this area.

Recommendation #4.2. It is clear that the ESI maps used here were developed for the purpose of responding to oil spills with conventional methods, not for conducting net environmental benefit analysis involving a range of cleanup methods. As a consequence, resources that might be vulnerable to the effects of chemically dispersed oil and other non-conventional response methods are under-represented in the ESI maps. This deficiency did not influence the outcome of this study. However, better documentation of dispersed-oil-sensitive resources may have strengthened the study's conclusions and might reassure stakeholders that the resources in which they are interested are always given full and proper consideration during spill planning.

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