Volume II

Alaska Oil Spill Commission

Appendix J-L

SPILL

The Wreck of the *Exxon Valdez*

Appendix J-L

State of Alaska

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FINAL REPORT

AN ASSESSMENT OF TANKER TRANSPORTATION SYSTEMS IN COOK INLET AND PRINCE WILLIAM SOUND

PREPARED FOR:

ALASKA OIL SPILL COMMISSION
707 "A" STREET, SUITE 202
ANCHORAGE, ALASKA 99501

PREPARED BY:

ENGINEERING COMPUTER OPTECNOMICS, INC. (ECO)
1036 CAPE ST. CLAIRE CENTER
ANNAPOLIS, MARYLAND 21401

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APPENDIX J

AN ASSESSMENT OF TANKER TRANSPORTATION SYSTEMS IN COOK INLET AND PRINCE WILLIAM SOUND

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EXECUTIVE SUMMARY

As a direct result of the EXXON VALDEZ oil spill in March, 1989, the Alaska Oil Spill Commission (AOSC) was established by the State of Alaska legislature. Among other tasks, the AOSC was charged with the specific task of analyzing the oil tanker transportation system throughout Alaska and in particular, within Cook Inlet and Prince William Sound. As a result of this assessment, the AOSC is required to provide recommendations to minimize future oil spills from tanker operations, to improve the timeliness of oil spill response and to increase the effectiveness of oil spill cleanup techniques.

Engineering Computer Optecnomics, Inc. (ECO) was tasked to conduct an analysis of oil tanker operations in both Cook Inlet and Prince William Sound. ECO's report was to address hazard locations, risk sources, impact locations, various mitigating measures; including improved oil tanker design and improved oil spill response systems, as well as, the costs associated with the proposed mitigating measures. ECO's report includes a chapter on each of the following topics:

- Hazard Assessment;
- Risk Analysis;
- Contingency Planning;
- Improved Tanker Design; and,
- System Effectiveness and Economic Analysis.

The Hazard Assessment chapter describes the operating environments within which the tankers operate; identifies the navigational hazards to which the tankers are exposed and the geographic locations where tanker accidents are apt to occur; and determines the probabilities of oil spill occurrence. These probabilities are determined within specified ranges of oil spill volumes at current levels of tanker activities and under existing conditions in both Cook Inlet and Prince William Sound. This chapter identifies three high risk areas in Cook Inlet; specifically, the marine terminals at Nikiski, Kachemak Bay, and the Kennedy Entrance at the southern end of Cook Inlet.

Within Prince William Sound, three high risk areas were also identified; namely, the marine terminal in Port Valdez, Valdez Arm, and Hinchinbrook Entrance, which is the southern entrance to Prince William Sound.

From the previously identified six high risk areas, three in Cook Inlet and three in Prince William Sound, the Risk Analysis chapter develops computer simulations of three oil spills at each of the six locations. These simulated oil spills range in size from 1 million to 21 million gallons at each of three locations in Cook Inlet and from 3 million to 75 million gallons at each of the three locations in Prince William Sound. The spills are simulated over various periods of time under typical summer and winter climatic and oceanographic conditions. The measure of consequences is the identification of areas, including shorelines, which will be affected by each of the various spills. A total of 96 spills are computer simulated, the results of which are presented in Appendix A for Cook Inlet, Appendix B for Prince William Sound and Appendix C for the offshore locations. This chapter illustrates that for oil spills of one million gallons or larger, recovery and/or cleanup is extremely difficult since the spill covers such a vast area in such a small amount of time and results quickly in major beach contamination. While oil spill recovery and cleanup techniques must be improved, prevention should be the first line of defense for large spills. In simple terms, the preferable way to clean up a large oil spill in either Cook Inlet or Prince William Sound is to prevent that spill from occurring.

The Contingency Planning chapter addresses the capabilities presently in place in Alaska for responding to spill incidents and the implications of those capabilities on potential damage resulting from an oil spill. The following areas are discussed:

- Cleanup response in Cook Inlet and Prince William Sound;
- Review of selected contingency plans for Cook Inlet and Prince William Sound; and,
- Recommendations for contingency plan modifications.

This chapter emphasizes that while contingency plans and oil spill recovery equipment have failed for large oil spills, the vast majority of oil spills are small spills. For these more frequent small spills, contingency plans and oil spill cleanup equipment have the capacity to perform satisfactorily. A well organized response effort can be successful in responding to smaller spills. Further, effective response to these spills can prevent substantial environmental damage to sensitive areas. Continuing to strive for a high level of effectiveness in mechanical recovery will both prevent significant environmental damage and improve response techniques and equipment so that they will be more effective for larger spills. Potential decision-makers must develop programs based on a series of credible spill events and develop a structure of response that allows the response to occur in independent operations. A single, encompassing contingency plan based on a series of credible spill events, for a specific body of water, and including state, federal, industry, and other stakeholders in its planning and execution, is mandatory if future spill mitigation efforts are to succeed.

The chapter on Improved Tanker Design provides technical information and the overall cost increase for the following systems:

- Double hulls;
- Centralized bunker tanks;
- Automated cargo control system;
- Auxiliary thrusters;
- Precise navigation display system; and,
- Improved lifeboats.

Two improved double hull tanker designs are presented. The improved 70,000 deadweight ton double hull crude carrier, for Cook Inlet operations, was shown to increase in cost from 85 million dollars to 93 million dollars. This 8 million dollar increase in construction cost equates to a cost increase of 9.4 percent for the 70,000 deadweight ton crude carrier. The improved 250,000 deadweight ton double hull crude carrier, for Prince William Sound operations, increased in cost from 175 million dollars to 192.2 million dollars. This 17.2 million dollar construction cost increase equates to a 9.8 percent increase for the 250,000 deadweight ton crude carrier.

The System Effectiveness and Economic Analysis chapter provides information on the technical aspects, effectiveness and costs on various system modifications which can mitigate oil spills. The system modifications are grouped according to the time required for their implementation.

Group I modifications are institutional in nature, can be implemented within a short period of time, and consist of the following items:

- Mandatory drug and alcohol testing;
- Emergency and high-risk navigation area training;
- Port restrictions/port closure system;
- Two person watchstanding requirement;
- Improved loading/unloading procedures;
- Local spill cleanup/prevention involvement; and,
- Spill response equipment coordination.

Group II modifications involve the acquisition of shipboard and shoreside equipment, could be implemented within a three to five year time frame, and involve the following:

- Vessel monitoring system;
- Traffic separation lanes with one-way traffic;
- Designated anchorage areas;
- Emergency response/pollution control vessels; and,
- Improved loading/unloading designs.

The Group III modification is improved tanker design. Its implementation would occur over a longer period of time as new double hull tankers are constructed to replace the aging single hull tankers. This chapter examines the reduction in tanker oil spills for each group of system modifications. Specifically, Group I reduces tanker oil spills by

14 percent, the combination of Group I and II by 49 percent and the combination of Group I, II and III by 77 percent.

This chapter also addresses the costs of these system modifications. For Cook Inlet, the total cost for the Group I modifications is 2 cents per barrel of crude oil transported, for Group I and II the cost is 16.7 cents per barrel, and for Group I, II and III the cost is 21 cents per barrel. For Prince William Sound the cost per barrel of crude oil is much lower because the volume of oil transported is much larger in Prince William Sound as compared with Cook Inlet. For Prince William Sound the total cost for the Group I modifications is 0.1 cent per barrel of crude oil transported, for Group I and II the cost is 0.8 cent per barrel, and for Group I, II and III the cost is 6.4 cents per barrel. In summary, this chapter indicates that a substantial reduction in tanker oil spills can be achieved with a relatively small increase in cost in Cook Inlet, and to an even greater extent, in Prince William Sound.

CHAPTER II - HAZARD ASSESSMENT

Section II.1 - Introduction

This chapter discusses the operating environment and hazards in present Alaskan North Slope (ANS) crude oil tanker operations and oil spill response in Cook Inlet (Section II.2) and in Prince William Sound (Section II.3). It does not include any tank barges or the liquefied natural gas (LNG) and bulk urea ships in Cook Inlet.

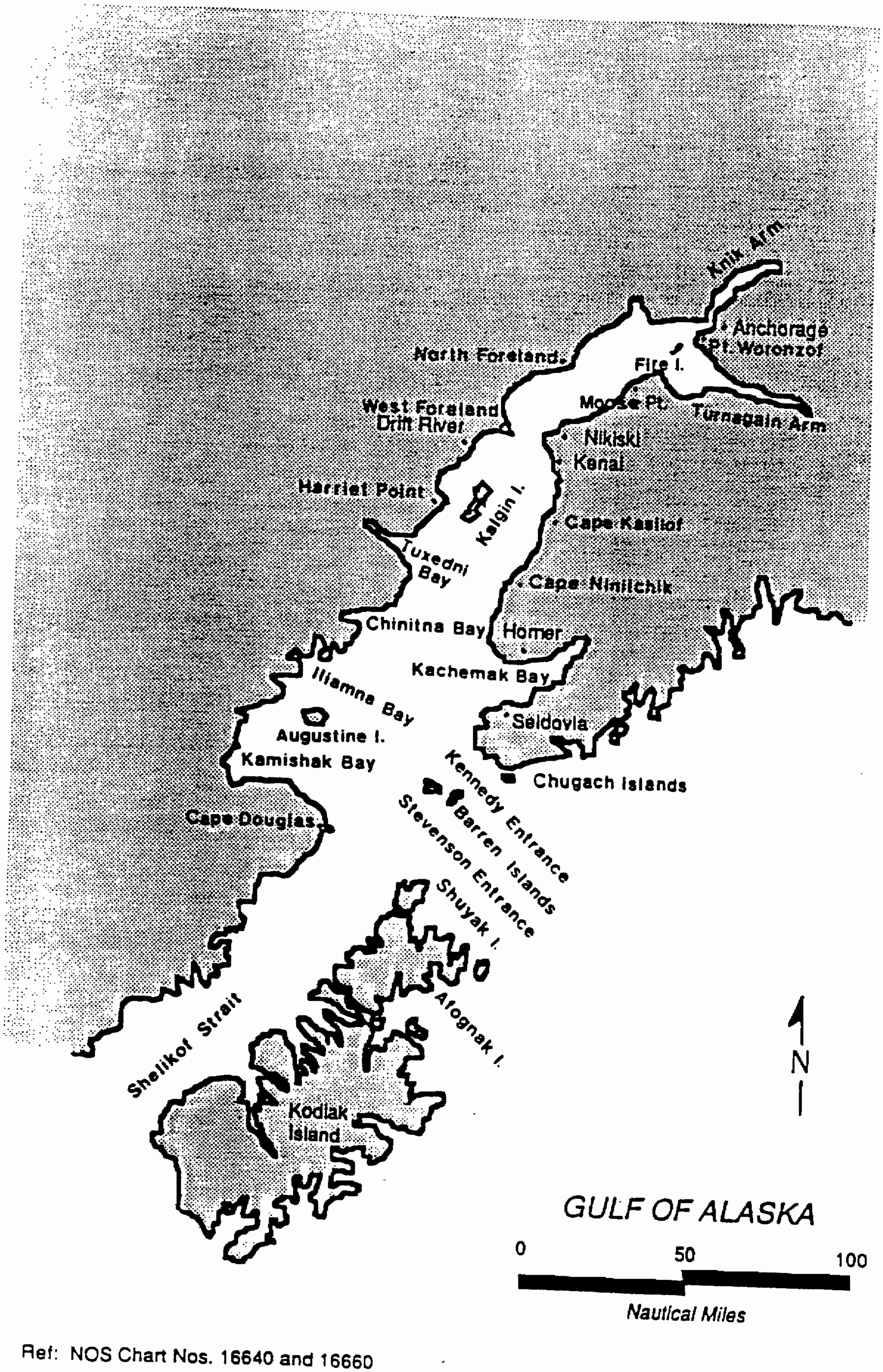
Based upon those operating environments, the hazards to tanker operations, and historical tanker accident data, high risk areas are identified and oil spill probabilities and their associated spill volumes are developed and presented in Section II.6.

Section II.2 - Cook Inlet Environment and Hazards

<u>II.2.1 Overview</u> Cook Inlet is a large tidal estuary which flows into the Gulf Of Alaska between the Kenai and Alaska Peninsulas. (See Figure II - 1.) It extends nearly 200 miles north of Cape Douglas and the Barren Islands and has an average width of about 50 miles. Cook Inlet has average water depths in mid-channel of about 200 feet.

Shuyak Island, Afognak Island, and Kodiak Island are separated from the Alaska Peninsula southwest of Cook Inlet by the Shelikof Strait. Cook Inlet merges with the Shelikof Strait on the western side of the Kenai Peninsula through a wide unobstructed passage west of the Barren Islands. Leading directly from the Gulf of Alaska to Cook Inlet are the Kennedy Entrance and the Stevenson Entrance, to the north and to the south respectively of the Barren Islands, and Chugach Passage inside the Chugach Islands. From the entrance it is 48 miles to Seldovia, 59 miles to Homer, 110 miles to Nikishka, and 175 miles to Anchorage.

The diurnal range of tide in Cook Inlet varies from 14.3 feet at Port Chatham to 29.0 feet at Anchorage. The tidal currents in Cook Inlet are very strong. At the entrance to Cook Inlet the tidal currents have an estimated velocity of two to three knots. In



Ref: NOS Chart Nos. 16640 and 16660

FIGURE I I

general, the tidal currents increase up the inlet, with very large velocities in the vicinities of Harriet Point, East and West Forelands, and the entrances to Knik and Turnagain Arms. A current velocity of five knots has been measured near East and West Forelands, Tyonek, and Point MacKenzie. These measurements were taken out of the full strength of the current and it has been estimated that the velocity of the current during a large tide may be as much as eight knots between East and West Forelands and probably more between Harriet Point and the south end of Kalgin Island. The available current information throughout Cook Inlet is derived largely from observations near the shores. In the middle of Cook Inlet, it is therefore probable that the current velocities are larger than those published. In general, the direction of the current is approximately parallel to the trend of the nearest shore. Off the various bays, the current sets toward the bay on a flood current and from the bay on an ebb current.

Current data for several locations are given in "Tidal Current Tables, Pacific Coast of North America and Asia". (See Table II - 1 and Figure II - 2.) Tidal currents of considerable velocity are found in Kennedy Entrance and Stevenson Entrance, the flood current setting approximately northwest and the ebb southeast. Ebb currents set strongly to the east along the edge of the bank bordering the north side of the Barren Islands to the south between Ushagat and Amatuli Islands, and to the east, north of Sugarloaf Island. The ebb currents are variable for a few miles south from the Barren Islands. Farther south, they set steadily to the southeast. On the flood, there is a strong current north of the Barren Islands which sets to the west. The current in general does not exceed four knots.

In Chugach Passage, east of Elizabeth Island, the flood current sets to the north and the ebb current sets to the south with velocities of 3.1 knots and 1.8 knots, respectively. Currents of about twice these velocities have been reported in heavy weather.

The diurnal range of tide is 14.3 feet at Port Chatham. The tidal currents have little velocity in the entrance to and the harbor of Port Chatham, but in the approach on either side of Elizabeth Island there are strong tidal currents. The diurnal range of tide is about 16.5 feet at Port Graham. Strong tidal currents, both ebb and flood, set across

TABLE II - 1 TIDAL CURRENTS IN COOK INLET

	AVERAGE MAXIMUM CURRENTS			
	FLOOD		EBB	
	DIRECTION (° TRUE)	AVERAGE VELOCITY (KNOTS)	DIRECTION (° TRUE)	AVERAGE VELOCITY (KNOTS)
CHUGACH PASSAGE	355	3.1	170	1.8
INISKIN BAY	000	0.9	180	1.2
ANCHOR POINT, 3 MILES SW OF	000	2.4	195	1.9
CHINITNA BAY	260	1.0	080	1.1
CAPE NINILCHIK, 1 MILE W OF	020	2.2	205	1.4
TUXEDNI CHANNEL	330	1.1	160	1.9
CAPE KASILOF, 3 MILES W OF	020	2.4	195	2.6
KENAI, 6 MILES SW OF	020	2.4	195	2.6
NIKISHKA	000	3.8	180	2.6
WEST FORELAND, MIDCHANNEL	025	3.8	175	3.6
MOOSE POINT, 3 MILES NW OF	065	2.9	245	2.6
ANCHORAGE, 1 MILE OFF OF	050	2.9	220	2.9
KNIK ARM, S OF GOOSE CREEK	015	3.6	180	3.9

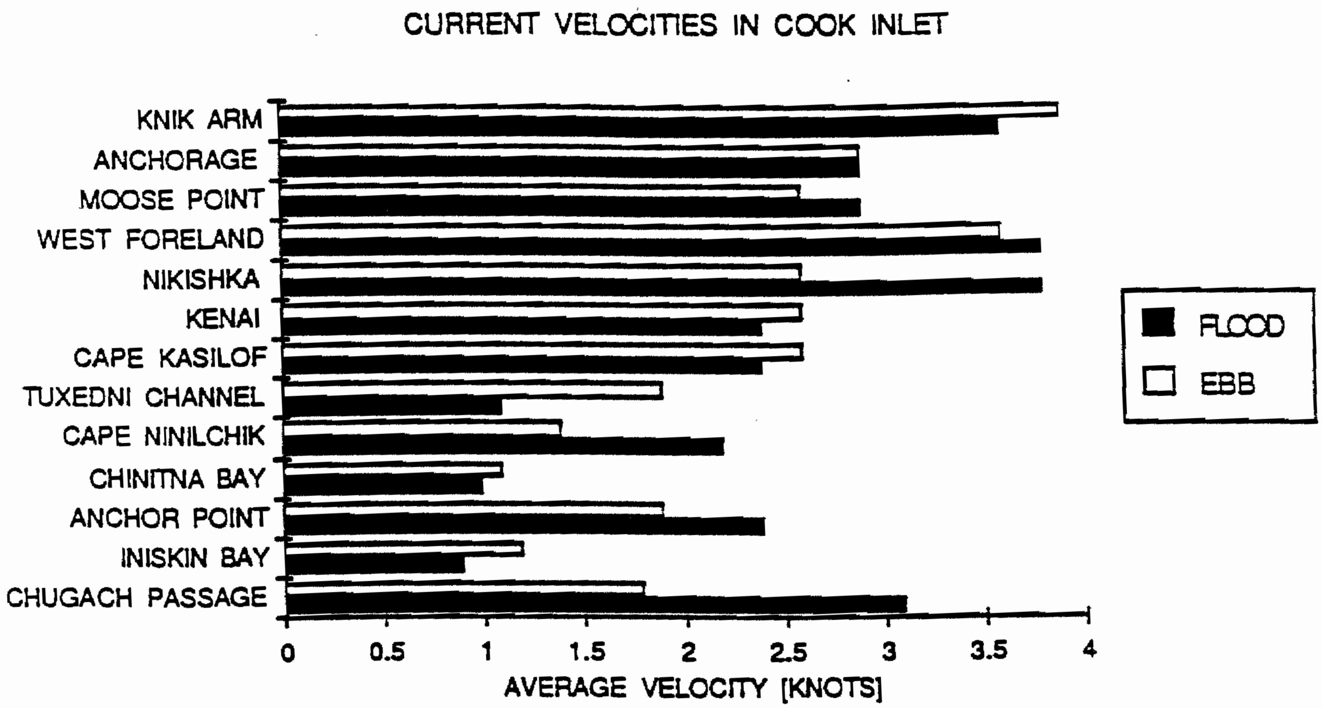

CURRENT VELOCITIES IN COOK INLET
KNIK ARM
ANCHORAGE
MOOSE POINT
WEST FORELAND
NIKISHKA
KENAI
CAPE KASILOF
TUXEDNI CHANNEL
CAPE NINILCHIK
CHINITNA BAY
ANCHOR POINT
INISKIN BAY
CHUGACH PASSAGE
0
0.5
1
1.5
2
2.5
3
3.5
4
AVERAGE VELOCITY [KNOTS]
FLOOD
EBB

FIGURE II-2

the mouth of the harbor, but there is little current at or inside of Passage Island. The diurnal range of tide is 17.8 feet at Seldovia. The tidal currents at Seldovia have an estimated velocity of one to two knots.

At Dangerous Cape, a current of nearly three knots sets across the broken ground around the cape, causing heavy rips and overfalls. From Dangerous Cape, a flood current sets up Kachemak Bay with a velocity of one to two knots in a northwest direction, and the ebb flows in a southwest to west direction. Maximum current velocities in Kachemak Bay have been estimated to be about three knots. The currents at Seldovia also have an estimated velocity of one to two knots.

The currents are very swift at Harriet Point, exceeding five knots on large tides, and with winds from the south, severe tide rips occur between Harriet Point and Kalgin Island, and extend some distance to the south. In the northern part of Kamishak Bay, the currents follow the coast, flooding to the northeast and ebbing to the southwest at a rate of about one knot at strength. With a strong westerly wind, tide rips occur about two to four miles north of Chinitna Point.

The upper part of Cook Inlet is more or less obstructed during the winter by ice which forms on the flats and in the shallower waters. If there were no tidal action in Cook Inlet, a solid sheet of ice would form at freeze-up in the fall and would remain until break-up in the spring. Tidal action and tidal currents keep the ice in a shattered condition.

The ice problem is most severe in upper Cook Inlet north of the Forelands. The Port of Nikiski is somewhat protected from ice drifting down from the upper inlet by the constriction formed by East Foreland and by the winds which tend to blow the ice to the Drift River side of Cook Inlet. Nevertheless, Nikiski occasionally has ice problems which can be considered serious with regard to ship approaches, berthing, and loading operations.

It can happen that by the latter part of January, very close pack ice will exist from Anchorage to Moose Point with close to very close pack ice south of Moose Point to Kalgin Island. From Kalgin Island south to Anchor Point and along the west side of Cook Inlet to Kamishak Bay, open to pack ice may exist with the heaviest concentrations along the edges of the inlet.

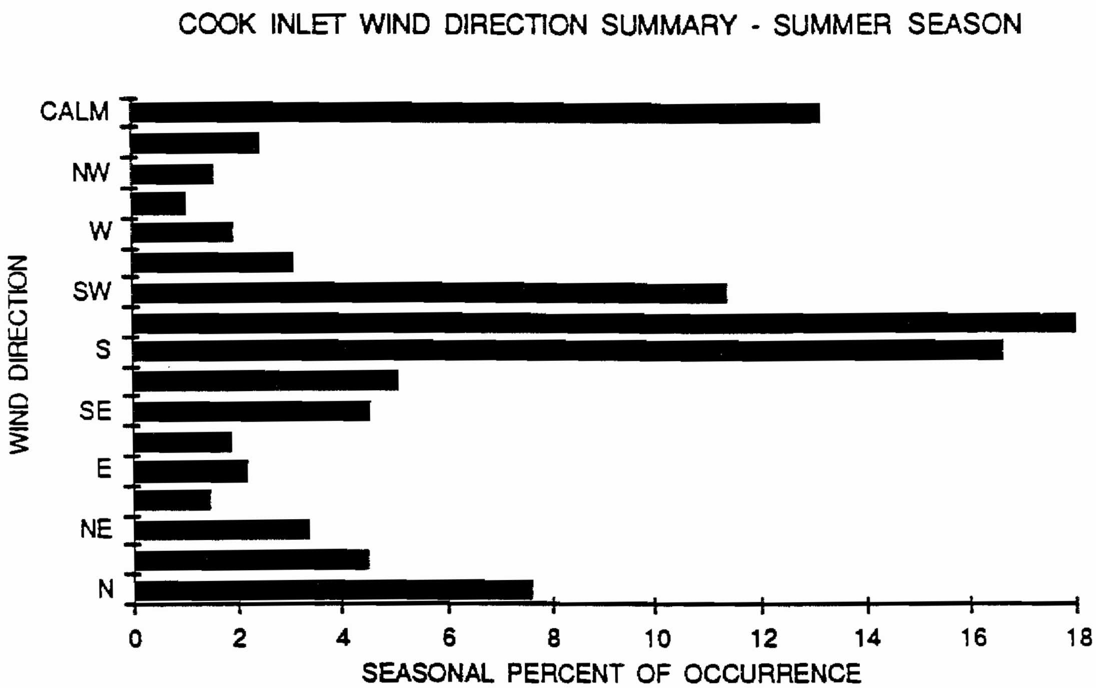
The ice problem decreases considerably in the southern part of the inlet. Generally speaking, there is no ice or very little ice south of Anchor Point.

The prevailing wind pattern throughout the Cook Inlet Basin is predominately from the southwest up the inlet during the summer and from the northeast down the inlet during the winter. (See Figures II - 3 through II - 6.)

The surface water temperature at the northern end of Cook Inlet typically varies from 30° F to 58° F over the year. Outside of the entrance to Cook Inlet, the surface water temperature typically varies from 38° F to 54° F.

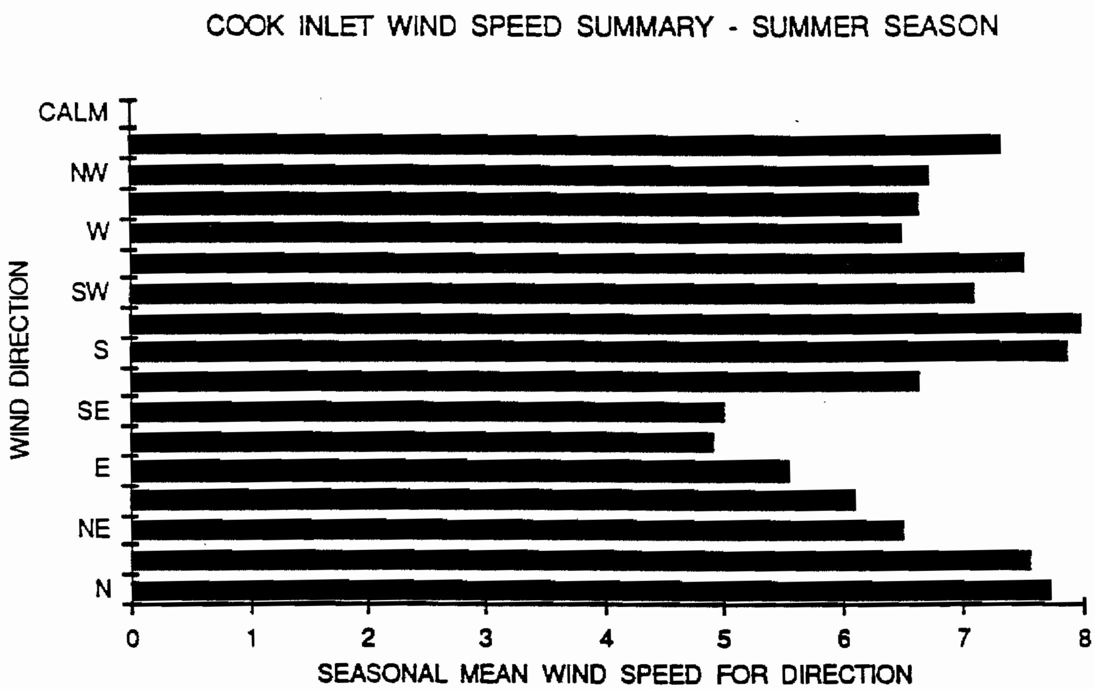
<u>II.2.2 The Barren Islands and Kennedy and Stevenson Entrances</u> The Barren Islands are a group of mountainous islands in the middle of the entrance to Cook Inlet between the Chugach Islands and Shuyak Island. A pinnacle rock covered by 27 feet of water and marked by a buoy, is in the approach to Cook Inlet just over 16 miles east of East Amatuli Island Light and about 11 miles south of East Chugach Light. Another shoal area, Cowanesque Rock, unmarked and with a least depth of 15 feet, is approximately seven and one quarter miles southeast by east from East Amatuli Light. A rock awash at half tide is one and one quarter miles north from the northernmost point of West Amatuli Island. A bare rock, eight feet high, is about three quarters of a mile west of the northwest point of Ushagat Island. Two rocks awash at half tide are about a tenth of a mile to the northwest and one half of a mile east-southeast of the bare rock.

Kennedy and Stevenson Entrances are the main deep-draft entrances to Cook Inlet from the east. Kennedy Entrance is between East Amatuli and Perl Islands. It has a



COOK INLET WIND DIRECTION SUMMARY - SUMMER SEASON
CALM
NW
W
SW
S
SE
E
NE
N
WIND DIRECTION
0
2
4
6
8
10
12
14
16
18
SEASONAL PERCENT OF OCCURRENCE

FIGURE II - 3



COOK INLET WIND SPEED SUMMARY - SUMMER SEASON
CALM
NW
W
SW
S
SE
E
NE
N
WIND DIRECTION
0
1
2
3
4
5
6
7
8
SEASONAL MEAN WIND SPEED FOR DIRECTION

FIGURE II-4

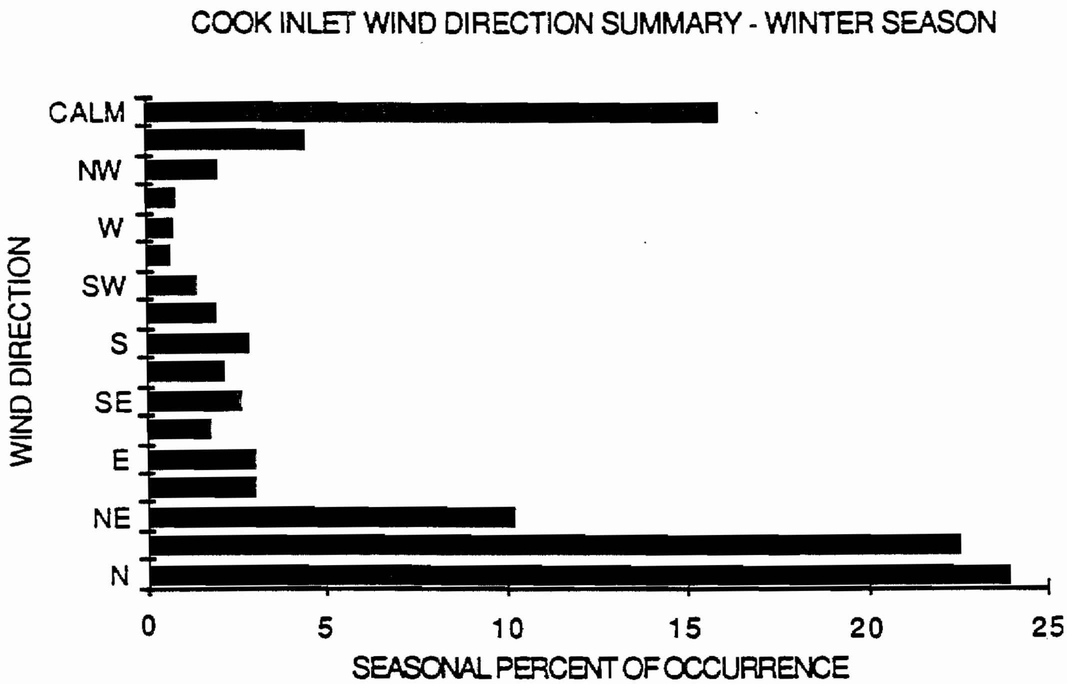

COOK INLET WIND DIRECTION SUMMARY - WINTER SEASON
CALM
NW
W
SW
S
SE
E
NE
N
WIND DIRECTION
0
5
10
15
20
25
SEASONAL PERCENT OF OCCURRENCE

FIGURE II - 5

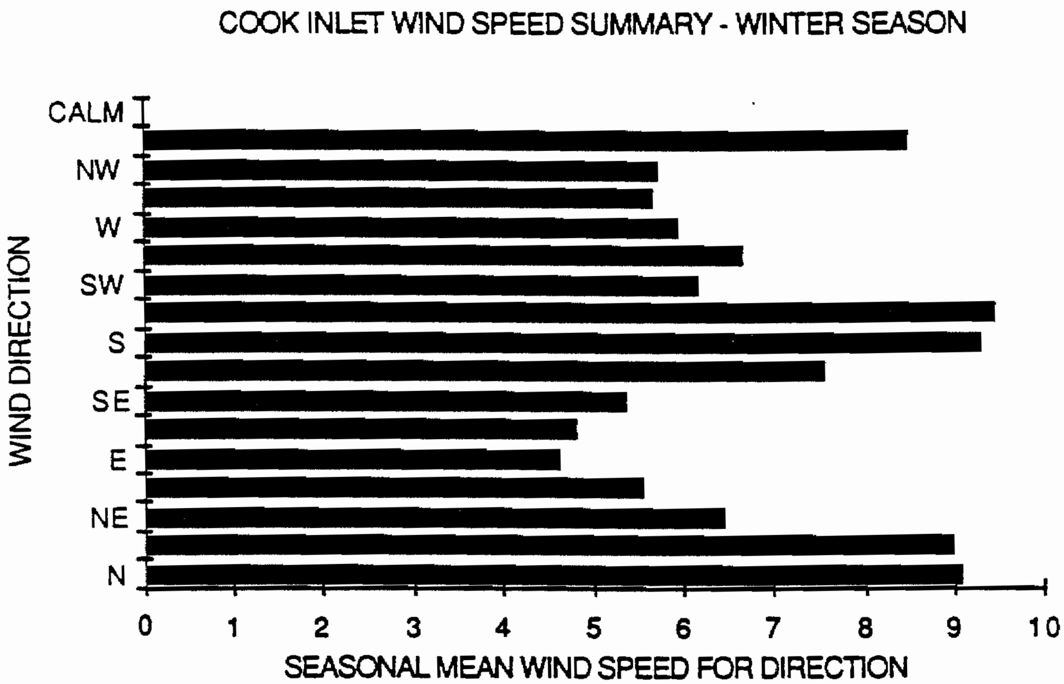

COOK INLET WIND SPEED SUMMARY - WINTER SEASON
CALM
NW
W
SW
S
SE
E
NE
N
WIND DIRECTION
0
1
2
3
4
5
6
7
8
9
10
SEASONAL MEAN WIND SPEED FOR DIRECTION

FIGURE II - 6

clear width of about seven miles, with general depths of 30 to 110 fathoms, though detached rocks and reefs extend three miles off Perl Island and one and one half miles off East Amatuli Island. Stevenson Entrance, south of the Barren Islands, has a clear width of about eight miles between the dangers that extend off the Barren Islands on the north and off Shuyak Island on the south, with general depths of 26 to 100 fathoms

II.2.3 The Western Shore of Cook Inlet On the western shore of Cook Inlet, about 20 miles northwest of Cape Douglas, is Kamishak Bay. The bay has numerous reefs rising to within a few feet of the surface throughout the area. The shore throughout the bay is bordered by reefs, most of which uncover at low water. The south shore of Kamishak Bay is foul with extensive reefs and ledges and adjoining mudflats. The diurnal range of tide at Nordyke Island located to the northeast of McNeil Head within the bay, is 15.2 feet.

Augustine Island is a 4,304-foot high volcanic peak. It is located just to the northeast of Kamishak Bay and due west of Port Graham across Cook Inlet. Augustine Rocks are approximately seven and one quarter miles south of the peak of Augustine Island. They are two flat rocks, with a smaller one between, all covered at high water.

Iliamna Bay is on the north side of Kamishak Bay 13 miles north from Augustine Island. The diurnal range of tide is 14.5 feet in lower Iliamna Bay. The currents just inside the entrance to the bay have an estimated strength of one to two knots.

Chinitna Bay is a shoal and filled with ice during the winter. Tidal currents average about one knot in Chinitna Bay. An extensive shoal, with a rocky, very irregular bottom extends from the western shore between Chinitna Bay and Tuxedni Channel. The shoal extends about six miles offshore. Numerous boulders, some awash, are just north of the entrance to Chinitna Bay and extend as far as one to two miles offshore.

Floating debris, including large logs, often forms long windrows parallel to the shore about four miles off the western shore of Cook Inlet in the vicinity of Chinitna Bay.

Although logs are common throughout Cook Inlet, they seem to gather at Chinitna Bay more frequently than at other places.

Chisik Island is located on the south side of the entrance to Tuxedni Bay. Tuxedni Channel is on the southwest side of Chisik Island. The channel is reported to be blocked with ice from December to March. The diurnal range of tide is 16.6 feet in Tuxedni Channel. The current floods to the northwest at a velocity of 1.1 knots and ebbs to the south-southwest at a velocity of 1.9 knots. Tuxedni Bay consists largely of shoals and reefs. A narrow channel extends from Tuxedni Channel nearly to the head of the bay. The channel shoals rapidly after leaving Chisik Island.

From Tuxedni Bay to Harriet Point, the western shore of Cook Inlet is a gravel bluff. Harriet Point is a clay bluff with boulders at the water. A boulder reef extends about three quarters of a mile east from Harriet Point.

From Harriet Point to West Foreland, two shallow bights form Redoubt Bay. About ten miles north of Harriet Point and south of Drift River is the Drift River Marine Terminal, an offshore, crude oil loading facility in 60 feet of water.

Kalgin Island runs approximately ten miles from north to south. The southern end of the island lies four and one half miles off Harriet Point and its northern end lies about six miles off the Drift River Marine Terminal. A shoal marked at its southern end by a seasonal lighted bell buoy, extends 16 miles south from Kalgin Island. There are spots bare at low water for nearly eight miles from the island. To the south the least depth found is 6 feet. The bottom is very broken. The currents on either side of the island can be as high as three to four knots at times. A sand ridge which nearly uncovers, is about two and one half to three and one half miles west of Kalgin Island. A lighted seasonal bell buoy is set off the west side of the shoal. During the summer months, floating debris and logs may be encountered in the channel west of the buoy. A boulder-strewn shoal with depths of 42 feet or less extends eight miles north from the northeast point of Kalgin Island. The outer boulders which uncover are two and one half miles from the island in depths of 22 feet of water.

West Foreland is a flat headland with a bluff at the water. The shore at West Foreland and for a distance of four to five miles to the north is fringed with boulders which extend below low water.

II.2.4 The Eastern Shore of Cook Inlet The Chugach Islands consist of East Chugach, Perl, and Elizabeth Islands near the coast of the Kenai Peninsula at the entrance to Cook Inlet. Chugach Passage is between Perl and Elizabeth Islands and the rounded end of the mainland. Port Chatham is at the end of the Kenai Peninsula north of Elizabeth Island. Chrome Bay is on the northern side of the entrance to Port Chatham.

Port Graham lies about 12 miles further up the coast of the Kenai Peninsula from Chrome Bay. Its entrance is between Russian Point on the south and Dangerous Cape on the north. The entrance has extensive outlying reefs covered at various stages of the tide.

Seldovia Bay is located seven miles to the northeast of Port Graham on the Kenai Peninsula. There are several shoals covered less than eighteen feet in the entrance, and the inner part of the bay has shoals.

Kachemak Bay is a large bay on the eastern side of Cook Inlet. The entrance to Kachemak Bay lies between Seldovia Point on the south and Anchor Point on the north. If offers excellent anchorage for vessels of all classes and sizes. Winds in the Kachemak Bay area are predominantly from the northeast from late fall to early spring. During the remainder of the year, southwest winds are the most frequent. Winds are strongest during the late summer and early fall.

Homer Spit, on the north side of Kachemak Bay, is a low gravel and shingle spit. The spit is four and one half miles long and varies from 100 to 500 yards in width. The City of Homer is located at the base of Homer Spit. The diurnal range of tide at Homer is

18.1 feet. The pilot boarding station for Cook Inlet is one mile south of Homer Spit Light. Archimandritof Shoals extend west from Homer Spit and are marked on the southeast side by a lighted buoy.

From Homer Spit to Anchor Point the coast is a line of bluffs. Numerous hazardous rocks are offshore between Homer and Anchor Point. The main bluff line recedes about one half of a mile from the shore at Anchor Point and approaches the coast again about one mile to the north, then continues close to the shore up to Cape Starichkof. From north of Anchor Point to Cape Ninilchik, the coast is free from dangers so far as is known. Cape Kasilof is on the east side of Cook Inlet opposite Kalgin Island. Five miles southwest from Cape Kasilof and about two and one quarter miles offshore are The Sisters, three prominent rocks, the highest of which is five feet. The foul ground back of The Sisters extends about ten miles from Cape Kasilof and is strewn with boulders 15 to 50 feet high.

Karluk Reef is four miles north of Cape Kasilof and three and one half miles from the eastern shore. The reef is partially bare at low water. Salmo Rock is nine and one half miles north of Cape Kasilof and two miles from the shore. The City of Kenai is located 11 miles north of Cape Kasilof and on the north side of the mouth of the Kenai River. The diurnal range of tide is 20.7 feet at the Kenai River entrance and the current in the river attains velocities in excess of five knots.

Nikiski, eight and one half miles north-northwest of Kenai, is the site of three, deep-draft piers: (1) the Union Chemical Wharf with 40-foot of water alongside; (2) the Kenai LNG Dock also with 40-foot of water alongside; and, (3) the Kenai Pipeline Co. wharf with 42-foot of water alongside. A shoal area, about five miles long with depths of 13.5 feet to 33 feet, marked by a seasonal buoy, is about two miles off the piers. Average tidal currents at Nikiski attain a velocity of about 3.8 knots on the flood and about 2.6 knots on the ebb. Extreme maximum currents are six to seven knots. Estimated extreme wave heights at Nikiski vary from 4 to 12 feet. Wave heights of 10 to 12 feet are said to occur about three times a year. Ice floes are a severe problem at Nikiski during January and February; more so on the flood than the ebb.

East Foreland is 60 miles north of Anchor Point and about 56 miles from Anchorage. A 21-foot shoal, marked near its western edge by a seasonal buoy, extends two to three and one half miles to the west and southwest of East Foreland Light.

Middle Ground Shoal, which uncovers six feet for three and one half miles of its length, is a long ridge of hard sand with a rocky bottom in places. It is located in the middle of Cook Inlet nine miles north of East Foreland.

II.2.5 Offshore Oil Drilling Operations in Cook Inlet Extensive oil drilling operations occur in Cook Inlet extending as far north as Anchorage. The heaviest concentration of these operations is in the vicinity of Middle Ground Shoal. Obstructions in these waters consist of submerged wells, oil well platforms, mooring piles, anchor and mooring buoys, pipeline, and stakes.

In general, oil well platforms on or adjacent to the edges of navigable channels and fairways are required to display lights and sound fog signals for the safety of navigation. Associated structures within 100 yards of the main structure are not normally lighted. In addition, uncharted submerged pipelines and cables may exist in the vicinity of the structures or between such structures and the shore.

II.2.6 Upper Cook Inlet and Anchorage From Boulder Point, a prominent boulder reef with few breaks in it, extends for 20 miles along the shore to Moose Point. For the greater part of this distance the boulders, some very large, show at low water to a distance of two miles from the shore, and there are occasional ones which show above high water. Moose Point Shoal is five miles long and partly bare at low water. It begins opposite Moose Point and extends about two miles from the eastern shoreline of Cook Inlet. A 13.5-foot spot, six and one half miles west-northwest from Moose Point Light is marked by a seasonal lighted buoy. Beluga Shoal covered by one and one half feet, is in the middle of Cook Inlet about midway between North Foreland and Fire Island and about eight to nine miles north of Moose Point.

Point Possession is 36 miles northeast of East Foreland and almost due east of North Foreland on the western shore of Cook Inlet. It is on the southwestern side of the entrance to Turnagain Arm. A reef extends about one mile off the northwestern side of Point Possession.

Turnagain Arm is only partially surveyed. Most of it is a large mudflat, bare at low water and intersected by winding sloughs. Navigation is safe only for small craft drawing less than six feet of water.

Fire Island is about six miles north-northeast of Point Possession. The channel in Cook Inlet west of Fire Island is marked by a lighted range set on an axis of 058 degrees true. A rock awash is reported to be about three quarters of a mile off the range line and lying 2.7 miles southwest of Fire Island. West Point, the southwest extremity of Fire Island, is marked by Fire Island Light. Fire Island Shoal with a least depth of one foot, is about 2.8 miles west-northwest of West Point. The shoal is about three and one half miles long and one half of a mile wide and is marked on its southeastern edge by a seasonal lighted bell buoy.

Point Campbell is on the northeastern side of the entrance to Turnagain Arm and is two and one half miles east of Fire Island. Point Woronzof is three and one half miles northeast of Point Campbell and on the southern side of the entrance to Knik Arm.

Northeast of Race Point there is a lighted range set on an axis of 242 degrees true. There is second lighted range on Point Woronzof set on an axis of 081.5 degrees true and a third lighted range on Point MacKenzie set on an axis of 061 degrees true. These three lighted ranges mark the channel in Cook Inlet from Fire Island to Point Woronzof. Point MacKenzie is on the northern side of the entrance to Knik Arm and about two and one half miles north-northeast of Point Woronzof.

The City of Anchorage is on the southeastern side of Knik Arm. The diurnal range of tide at Anchorage is 29 feet and the observed extreme mean low water was six and one half feet below mean lower low water. Close off Anchorage, the current floods to the northeast at a velocity of one and one half knots and ebbs to the southwest at a velocity of two and one half knots. One mile off the city, the current averages nearly three knots. Strong currents and swirls in the area make navigation difficult.

The main shipping channel to Anchorage runs between Fire Island and the shoals to the north and west of the island. The channel is marked by the previously described lighted ranges and seasonal buoys set at critical locations.

In addition to the dangers previously described, there is a shoal area on the northern side of the channel north of Fire Island which changes radically from year to year. At last report, the shoal was shifting south-southeast onto the Point MacKenzie Range. The crest of the shoal bares several feet at low water. Knik Arm Shoal, with a least depth of 14 feet and marked by two seasonal buoys, is in about the center of the channel, approximately two miles west of Point Woronzof. Woronzof Shoal is located about one and one quarter miles to the northwest of Knik Arm Shoal and has a least depth of 13 feet. There also is a long shoal that bares about one and one quarter miles west of Point Woronzof; a series of rocks close to the northwest edge of Point Woronzof; the flats off Anchorage; two submerged dolphins off the Anchorage waterfront; and, a partially submerged barge reported to be one half of a mile west-northwest of the Anchorage cargo terminals which constitute hazards to shipping.

As previously stated, Upper Cook Inlet rarely, if ever, freezes solid because of the enormous tidal range. Throughout the winter, from about November to mid-April, the ice floes move with the tide and patches of open water are occasionally visible. Vessels can and do navigate the upper portion of Cook Inlet during the winter, but not without a serious threat of damage to their hulls and propellers.

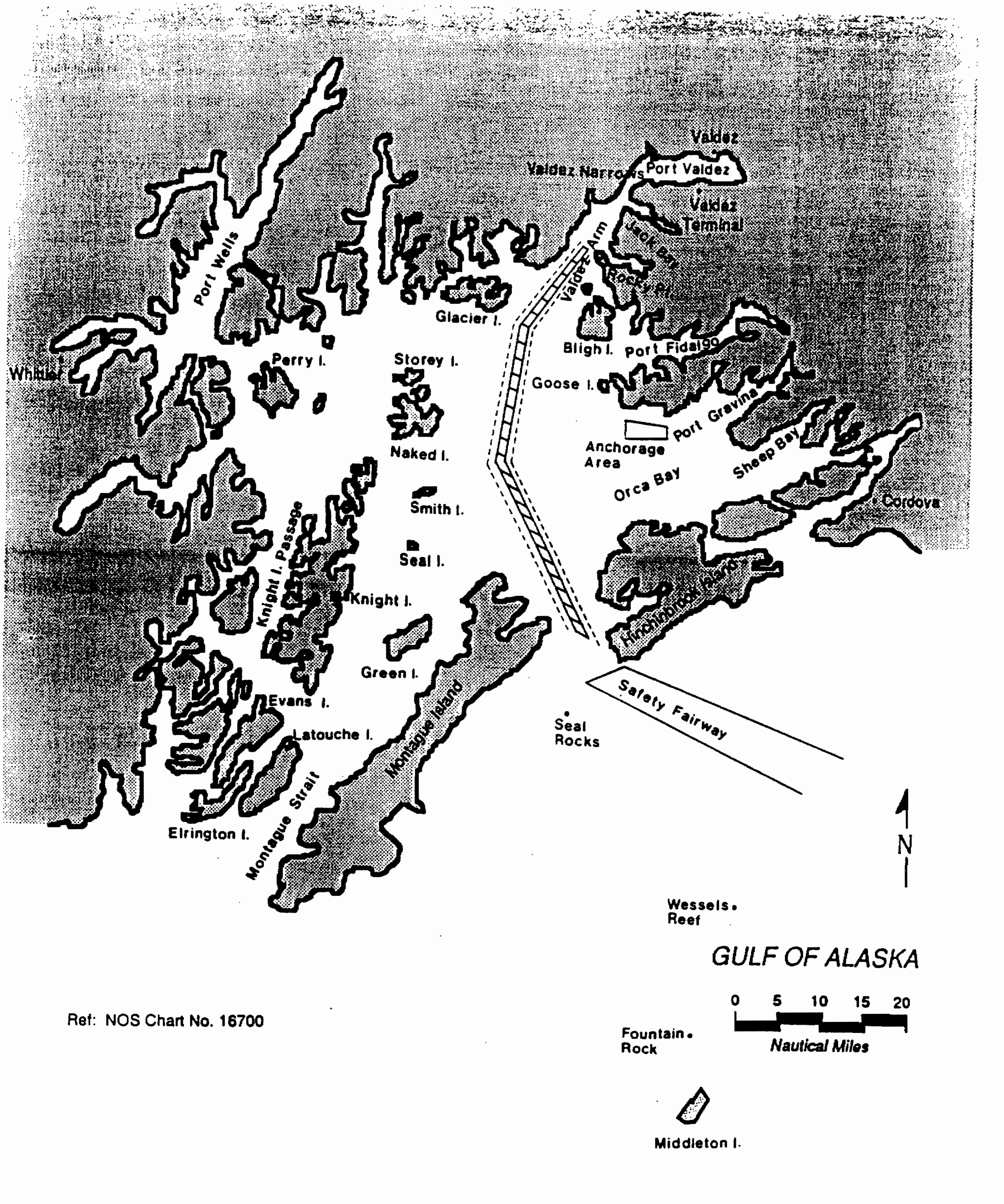
Section II.3 - Prince William Sound Environment and Hazards

II.3.1 Overview Prince William Sound is an extensive body of water covering about 2,500 square miles. The perimeter is very irregular with many fjords, inlets and bays radiating in all directions. (See Figure II - 7.) The entrance, from Cape Hinchinbrook on the east to Cape Puget on the west, is 58 miles across, but is mostly obstructed by islands. The largest of these islands is Montague Island which extends well out into the Gulf of Alaska.

The off-lying dangers in the approaches to Prince William Sound are Middleton Island, Fountain Rock, Wessels Reef, and Seal Rocks. Middleton Island is about 50 miles off the entrance to Prince William Sound. The island is fringed by vast areas of reefs, rocks, and kelp. Fountain Rock is four miles north of Middleton Island. The rock, which uncovers two feet, and the danger area centered around the rock, is about one half of a mile square. Wessels Reef is about 19 miles north of Middleton Island. It is approximately two miles in length running along a north-northeast to south-southwest axis and bares at low water. Depths of 30 fathoms or more are close to the reef and with smooth seas, it can hardly be detected. Seal Rocks are six to seven miles southwest from Cape Hinchinbrook and over six miles from Montague Island. They are two bare rocks surrounded by other low rock. Rocks, submerged and awash, extend to the northeast and to the southwest from Seal Rocks. The entire reef within the ten fathom curve forms an obstruction nearly three miles long.

An offshore safety fairway is designated under Title 33, Code of Federal Regulations, §166.400(b) as the Prince William Sound Safety Fairway in the approach from the southeast to the Hinchinbrook Entrance. (A "shipping safety fairway" or "fairway" means a designated lane or corridor in which no artificial island or fixed structure, whether temporary or permanent, is permitted. It does not mean that a vessel is obligated in any way to remain within such fairways.)

Offshore of the entrance to Prince William Sound the currents are strong. Currents along the approach to Prince William Sound set to the southwest and occasionally reach a velocity of two and a half knots. Outside the Hinchinbrook Entrance along the southeast coast of Hinchinbrook Island, the current sets to the southwest almost constantly. The tidal currents in the entrance set directly in and out of Prince William Sound, except east of Seal Rocks where the currents usually run from east to west.



Ref: NOS Chart No. 16700

FIGURE II-7 PRINCE WILLIAM SOUND

There is a strong set in the direction of Seal Rocks when the wind is blowing out of the east and the tide is ebbing. In the Hinchinbrook Entrance the velocity of the current is about one knot.

Within Prince William Sound, with the exception of the western passages, the tidal currents tend to be weak (less than one knot) and variable. In the various western passages, the current generally follows the axis of the passage with velocities ranging from approximately one knot to three knots. (See Table II - 2.) The diurnal range of the tide within Prince William Sound is between 10 and 13 feet.

Glacial ice is not ordinarily found in the open waters of Prince William Sound. Ice discharged by the Columbia Glacier, located on the northern shore of the sound, is driven into the sound by northerly winds. That ice, depending upon the winds, can be expected from Bligh Island to as far west as Bald Head Chris Island and as far south as Storey Island. Large bergs may be found at any time along the northern shore of Prince William Sound from Point Freemantle to Fairmount Island.

There are numerous discharging glaciers in Port Wells, the northwestern arm of Prince William Sound. However, that glacial ice rarely reaches the entrance to that arm. There is a discharging glacier at the head of Blackstone Bay, but that glacial ice is confined to the bay. Ice also is discharged by the Chenega Glacier on the south-western side of Prince William Sound which occasionally drifts as far as Point Helen on the southern end of Knight Island and the northern entrance to Latouche Passage.

The waters of Prince William Sound are very deep and are chilled by the meltwater from the surrounding glaciers. The average water depth exceeds 900 feet.

The meeting of the cold water and the colder air from the mountains with the warmer waters and vapor-laden airs of the Gulf of Alaska causes changeable weather. Sudden wind squalls and fog are common.

TABLE II - 2 TIDAL CURRENTS IN PRINCE WILLIAM SOUND

	AVERAGE MAXIMUM CURRENTS			
	FLOOD		EBB	
	DIRECTION (° TRUE)	AVERAGE VELOCITY (KNOTS)	DIRECTION (° TRUE)	AVERAGE VELOCITY (KNOTS)
BOX POINT, 2.3 MI E OF MONTAGUE I	-	-	190	0.7
ELRINGTON PASSAGE	035	1.6	230	1.3
PRINCE OF WALES PASSAGE	000	0.8	210	2.5
BAINBRIDGE PASSAGE	050	3.1	235	2.4
ELEANOR I - NAKED ISLAND, BETWEEN	[1]	[1]	[1]	[1]
PERRY PASSAGE	[2]	[2]	[2]	[2]
CULROSS PASSAGE	[2]	[2]	[2]	[2]
WELLS PASSAGE, I MI N PT CULROSS	[2]	[2]	[2]	[2]
VALDEZ ARM	[2]	[2]	[2]	[2]
VALDEZ NARROWS	[2]	[2]	[2]	[2]

[1] CURRENT USUALLY FLOWS EASTWARD WITH AVERAGE VELOCITY OF 0.8 KNOT.
[2] CURRENTS WEAK AND VARIABLE.

Wind data for Prince William Sound show that the eastern quadrant is the predominant direction of origin for the prevailing winds. The range of wind speeds is typically between 0 and 30 knots with average velocities less than ten knots. (See Figures II - 8 to II - 11.) However, as previously stated, unexpected and sudden changes in wind to extreme velocity conditions are not uncommon.

II.3.2 The Hinchinbrook Entrance The Hinchinbrook Entrance is the main entrance to Prince William Sound. It is about six miles wide and is a clear passage with the exception of Seal Rocks.

Cape Hinchinbrook is on Hinchinbrook Island on the east side of Hinchinbrook Entrance. A few rocky islets are close to the southeastern and southwestern sides of the cape. Submerged reefs on which the sea breaks in a moderate swell are southeast and south of Cape Hinchinbrook. Zaikof Point is on Montague Island on the west side of Hinchinbrook Entrance. Schooner Rock, marked by a light, is a pinnacle 75 feet high just off Zaikof Point.

II.3.3 The Prince William Sound Vessel Traffic Services System The Prince William Sound Vessel Traffic Services area begins on a line drawn between Cape Hinchinbrook Light on Hinchinbrook Island and Schooner Rock Light off Montague Island. This vessel traffic service is regulated under Title 33, Code of Federal Regulations, §161.301 to §161.387. In the Hinchinbrook Entrance, inbound vessels enter the northbound traffic lane within a traffic separation scheme which is a network of one-way traffic lanes with an intervening separation zone. In addition to the traffic separation scheme, the existing Prince William Sound Vessel Traffic Services consists of two other major components: (1) a vessel movement reporting system; and, (2) radar surveillance in Valdez Arm, Valdez Narrows, and Port Valdez.

As previously stated, the traffic separation scheme comprises a network of one-way traffic lanes with a separation zone in between. The traffic lanes which begin in the Hinchinbrook Entrance, are each 1,500 yards wide from that point to the vicinity of Bligh Reef at the southeast end of Valdez Arm. These lanes then gradually decrease

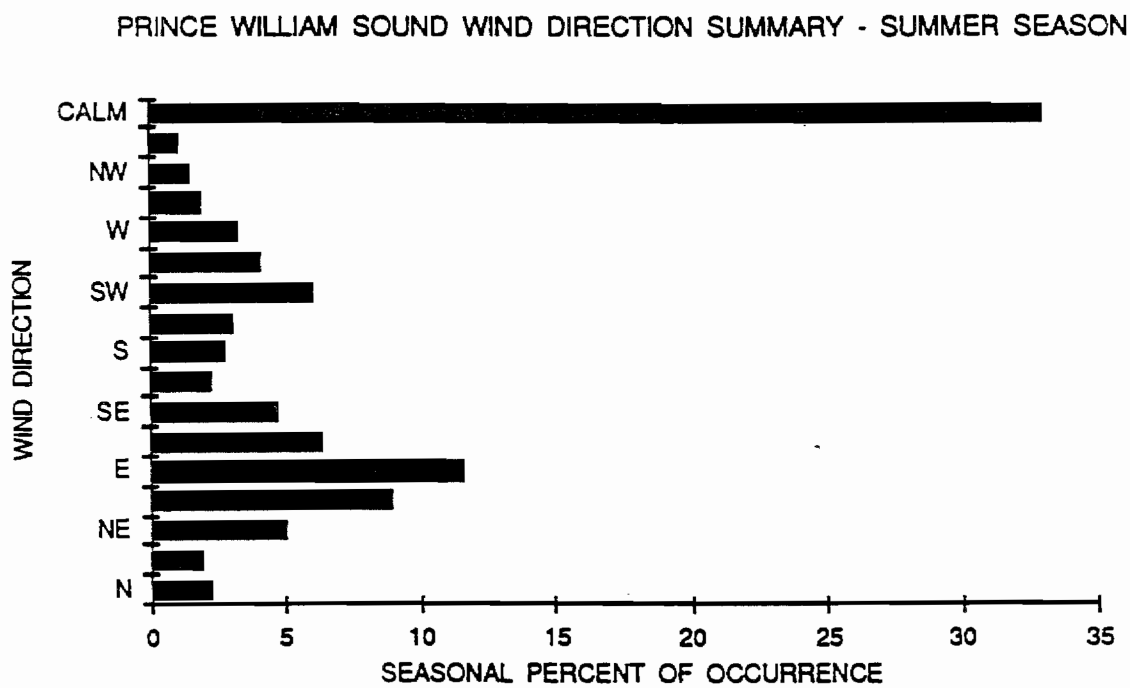

PRINCE WILLIAM SOUND WIND DIRECTION SUMMARY - SUMMER SEASON
CALM
NW
W
SW
S
SE
E
NE
N
WIND DIRECTION
0
5
10
15
20
25
30
35
SEASONAL PERCENT OF OCCURRENCE

FIGURE II - 8

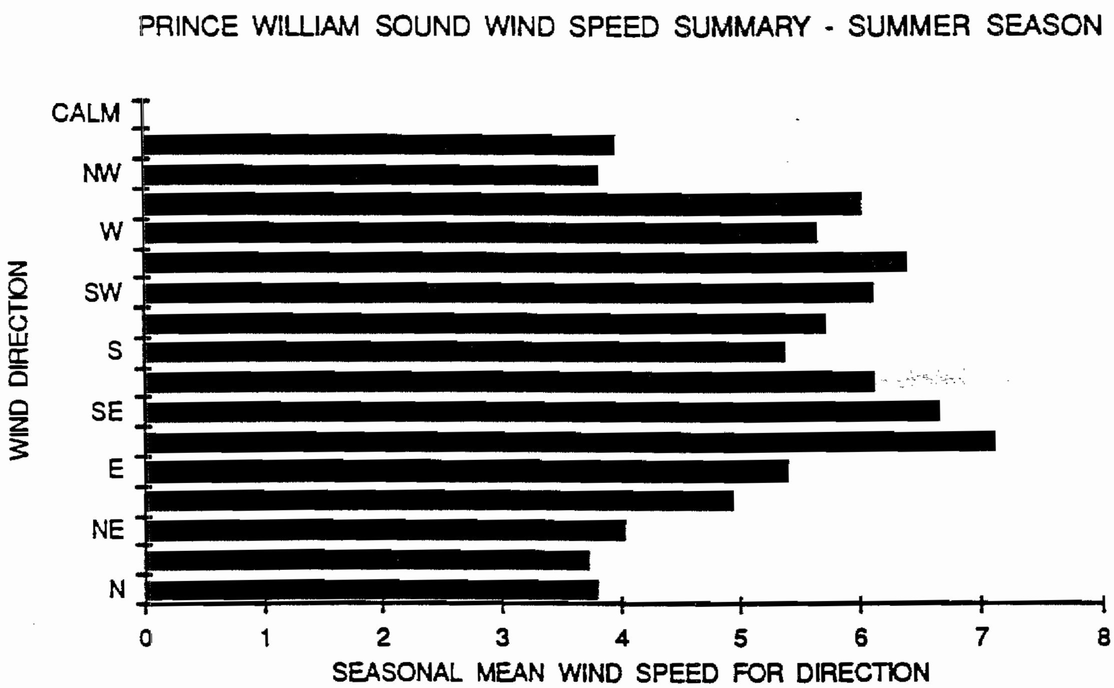

PRINCE WILLIAM SOUND WIND SPEED SUMMARY - SUMMER SEASON
CALM
NW
W
SW
S
SE
E
NE
N
WIND DIRECTION
0
1
2
3
4
5
6
7
8
SEASONAL MEAN WIND SPEED FOR DIRECTION

FIGURE II - 9

PRINCE WILLIAM SOUND WIND DIRECTION SUMMARY - WINTER SEASON

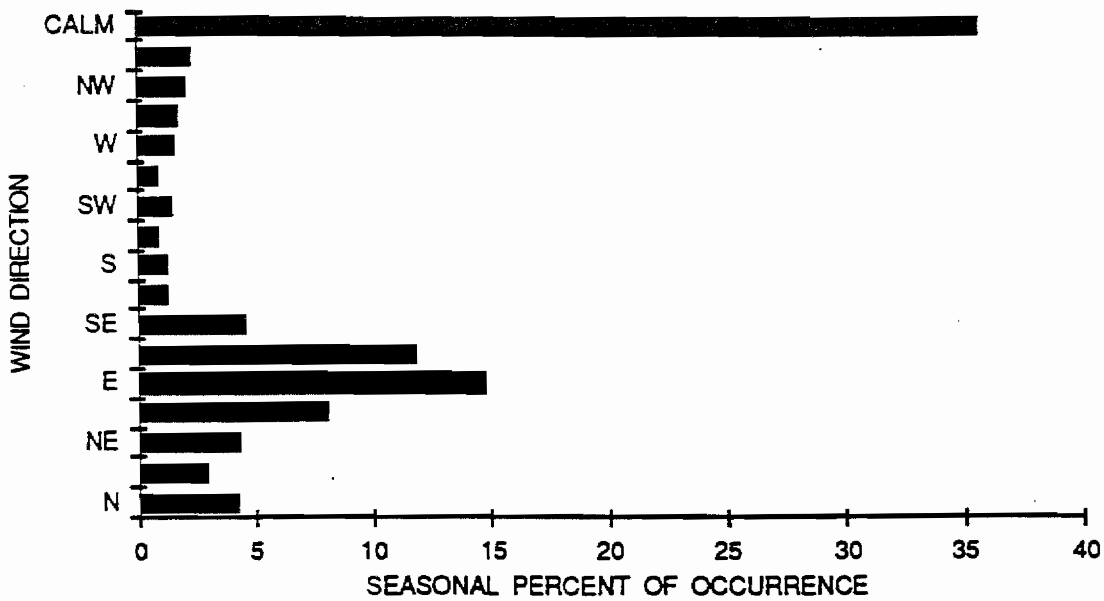


FIGURE II - 10

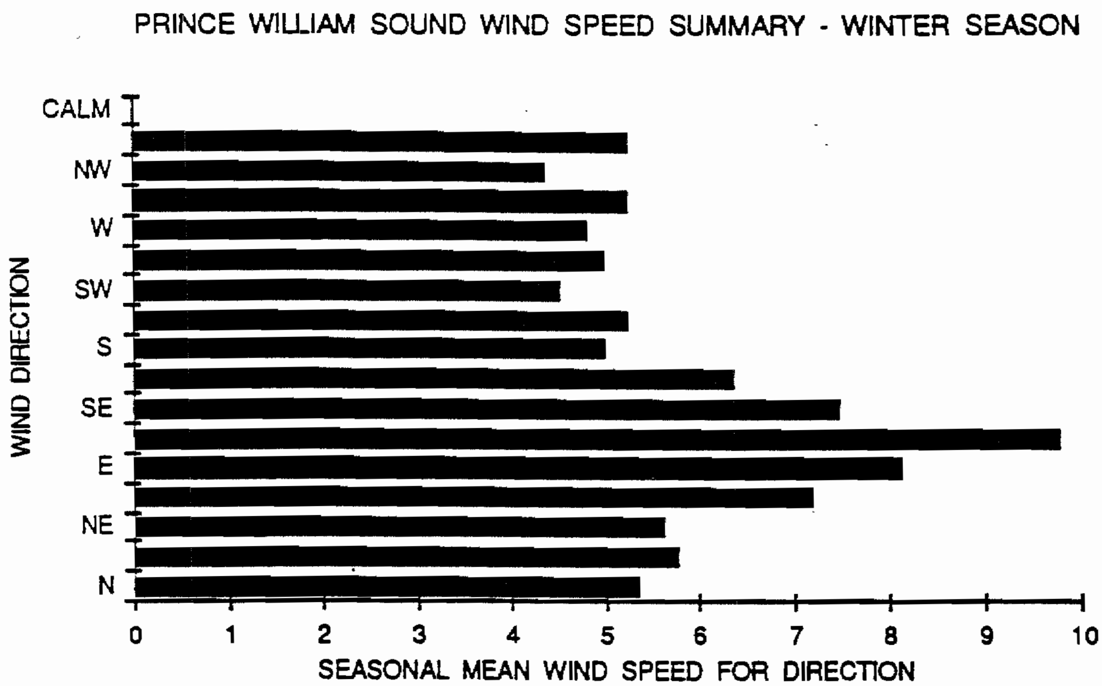

PRINCE WILLIAM SOUND WIND SPEED SUMMARY - WINTER SEASON
CALM
NW
W
SW
S
SE
E
NE
N
WIND DIRECTION
0
1
2
3
4
5
6
7
8
9
10
SEASONAL MEAN WIND SPEED FOR DIRECTION

FIGURE II - 11

in width to 1,000 yards and terminate at Rocky Point. The separation zone is 2,000 yards wide between the Hinchinbrook Entrance and the vicinity of Bligh Reef. It then gradually decreases in width to 1,000 yards and also terminates at Rocky Point.

The vessel movement reporting system throughout the Prince William Sound Vessel Traffic Services area is controlled by the Vessel Traffic Center (VTC) which is operated by the U.S. Coast Guard. The VTC maintains radio telephone communications with vessels in the Prince William Sound Vessel Traffic Services area. The VTC receives, assembles, and processes information from vessels through mandatory and voluntary reports, and in turn disseminates information to vessels. In general, mandatory reports are required: (1) before a vessel enters or begins to navigate in the vessel traffic services area; (2) when a vessel enters or departs the vessel traffic services area at the Hinchinbrook Entrance; (3) when a vessel is abeam of Naked Island; (4) whenever a vessel within the vessel traffic services area increases or decreases speed by more than 1 knot; (5) before a vessel joins, leaves, or crosses a traffic lane; and, (6) whenever a vessel anchors, moors in, or departs from the vessel traffic services area. Tank vessels of 20,000 deadweight tons or greater operating in the Prince William Sound Vessel Traffic Services Area are further required to have: (1) two separate, operating marine radar systems for surface navigation; (2) an operating LORAN-C receiver; (3) an operating rate of turn indicator; and, (4) two operating radio telephones with compatible frequencies with the VTC.

The existing radar surveillance system covers Valdez Arm, Valdez Narrows, and Port Valdez from U.S. Coast Guard operated radar sites. (At the time of the EXXON VALDEZ grounding, vessels were only being tracked as a matter of routine to the vicinity of Rocky Point.) One site is at Potato Point, on the west side of Valdez Narrows, and the other is on Valdez Spit, which borders the south and east sides of the small boat basin at Valdez. A continuous watch of the Valdez Arm, Valdez Narrows, and Port Valdez areas is maintained by the VTC.

<u>II.3.4 Lower and Eastern Prince William Sound</u> Just inside the Hinchinbrook Entrance on the northwest side of the entrance to Port Etches on Hinchinbrook Island are

Porpoise Rocks. These are three high rocks with numerous small rocks among and east of them. Johnstone Point is at the northwest end of Hinchinbrook Island and is the southern end of the mouth to Orca Bay from which waterborne access is provided to Port Gravina, Sheep Bay, Orca, and Cordova. Knowles Head is due north of Johnstone Point and is the northern end of the mouth to Orca Bay. Off Knowles Head, in Orca Bay, is a designated anchorage area.

This anchorage area is regulated under Title 33, Code of Federal Regulations, §110.233. This anchorage area is for the temporary use of vessels during: (1) adverse weather conditions; (2) vessel equipment failure; or, (3) delays at Port Valdez. Vessels are not permitted to anchor in this area without notifying the VTC in Valdez and anchored vessels are required to notify the VTC in Valdez when they weigh anchor.

The entrance to Port Fidalgo, an eastern arm of Prince William Sound, is between Goose and Bligh Islands. Goose Island is on the south side of the entrance. Bligh Island is on the north side of the entrance to Port Fidalgo. At the entrance to Port Fidalgo, north of Goose Island, the velocity of the current is about one half of a knot. On the northwest side of Bligh Island are smaller islands with foul ground between. A rock awash is located approximately one quarter of a mile off the southwestern end of Reef Island which is located to the west of Bligh Island.

Bligh Reef is to the west of Reef Island and is approximately two miles in length and has depths ranging from 1.5 to 56 feet and has bare shoals near its center. A lighted bell buoy is set about one quarter of a mile from the west side of Bligh Reef. The steamship OLYMPIA was lost on Bligh Reef in 1910 and the tanker EXXON VALDEZ ran aground on this same reef in March of 1989. Busby Island is located off the northwest end of Bligh Island. It is surrounded by a reef to a distance of nearly one half of a mile.

<u>II.3.5 Valdez Arm and Valdez Narrows</u> Valdez Arm, the main northern arm of Prince William Sound, extends about 13 miles northeast from Busby Island and Point Freemantle to the northern end of Valdez Narrows, then turns east for 11 miles to the

head of Port Valdez. The water is very deep and there are no known outlying dangers except for Middle Rock near the northern end of the narrows and two shoals at 13.5 and 42 feet, about a quarter of a mile apart, near the western edge of the arm about three to four miles to the northeast of Point Freemantle. The south side of the 42-foot shoal is marked nine miles from Point Freemantle. Tatitlek Narrows separates the northeast shorelines of Busby and Bligh Islands from the mainland. Rocky Point is located on the eastern shore of Valdez Narrows and is just below the entrance to Galena Bay. A group of rocky, grass-covered islets extends one half of a mile off the north point at the entrance of Galena Bay. Tongue Point, on the south side of Jack Bay and on the eastern shore of Valdez Arm, lies approximately six miles from Rocky Point. The diurnal range of tide at Rocky Point is 12.1 feet. The currents throughout Valdez Arm are reported to be weak and variable.

Entrance Point, one mile to the north of Jack Bay on the east side on Valdez Narrows, and Potato Point on the west side of the narrows, are marked by lights. Entrance Island, east of Middle Rock, also is marked with a light. Port Valdez is the designation given the body of water extending from Valdez Narrows to the head of the bay.

Valdez Narrows is about eight tenths of a mile wide, with deep water and bold shores. Middle Rock, near the middle of the northern end of the narrows is a pinnacle barely covered at extreme high tides; it is marked with a light. A shoal west of the pinnacle, extends east from the mainland about one half of a mile. The shoal consists of a rock covered two feet at the inner end, a 21-foot depth at the outer end, and a wooded islet in between. The tidal currents in Valdez Narrows also are weak and variable. However, deep-draft tankers maneuvering at the regulated speed of six knots will be affected appreciably by the currents.

The Valdez Narrows One-way Traffic Area consists of those waters in Valdez Arm, Valdez Narrows, and Port Valdez northeast of a line bearing 307 degrees true from Tongue Point and southwest of a line bearing 307 degrees true from Entrance Island Light. This area is restricted to one-way traffic whenever a tank vessel of 20,000 deadweight tons or greater is navigating therein. Such vessels may not enter the

Valdez Narrows One-way Traffic Area unless: (1) it has obtained permission from the VTC; (2) it is in compliance with any directions received from the VTC to remain separated from another vessel; (3) the radio telephone equipment required by the Prince William Sound Vessel Traffic Services are in operation; (4) the radar required by the Prince William Sound Vessel Traffic Services is manned and in operation; and, (5) the vessel is free of any condition that may impair its navigation. In addition, no such laden tank vessel may transit that portion of Valdez Narrows between Middle Rock and Potato Point at a speed in excess of six knots and no such tank vessel, laden or otherwise, may transit the Valdez Narrows One-way Traffic Area at a speed in excess of 12 knots. Lastly, all such laden tank vessels are required to be provided with tug assistance between Port Valdez and the Hinchinbrook Entrance where the term, tug assistance, means the use of a sufficient number of tugs or emergency response vessels, properly manned and positioned and with enough power and maneuverability to enable the laden tank vessel to accomplish its intended maneuvers safely. Pilotage is required throughout the area between the marine terminal at Port Valdez and the southern extremity of Bligh Island.

II.3.6 Port Valdez Port Valdez is the designation given the body of water extending from the Valdez Narrows to the head of the bay. Jackson Point is a jutting piece of land extending from the mainland on the south side of Port Valdez. The Valdez Marine Terminal is on the south side of Port Valdez between Jackson Point and Saw Island. It is the terminus of the Trans-Alaska Pipeline.

The diurnal range of tide at Valdez is 12 feet. Tidal currents in Port Valdez are weak and variable. In 1966, however, it was observed that noticeable currents from the Robe River discharging into the southeast end of Port Valdez are created at times of low and high stand of the tide. This current affects the area of the Old Valdez waterfront. It sets due north flowing perpendicular to the ruins of the piers at Old Valdez. In 1979, it was reported that the surface currents in Port Valdez had a maximum velocity of one half of a knot to one knot. Shoup Bay is located at the face of Shoup Glacier on the northern shore of Port Valdez. Shoup Bay occasionally has floating ice, some of which escapes into Port Valdez under certain wind and tide conditions.

II.3.7 Northern Prince William Sound Glacier Island is on the north side of Prince William Sound west of the entrance to Valdez Arm. Iceberg Point forms the western extremity of Glacier Island. A dangerous rock is reported one half of a mile to one mile southeast of this point but its exact position is unknown.

Between Point Freemantle and Columbia Bay, the coast is encumbered by dangerous rocks extending at least one quarter of a mile offshore. A shoal with a least known depth of 27 feet is reported one half of a mile south of Elf Point.

Columbia Glacier closes the head of Columbia Bay. At any time of the year, but especially in summer and fall months, iceberg, and brash ice discharged from the glacier may completely fill Columbia Bay and block the passages and coves north of Glacier Island. Particularly dangerous to vessels in the open waters of Prince William Sound are the low-lying icebergs known as growlers which emanate from the Columbia Glacier and which scarcely show above the water.

II.3.8 Northwestern Prince William Sound The northwest part of Prince William Sound has long inlets and fjords, most of which are very deep. The bottom of the entire area is glacial silt of very fine texture, and often sticky. However, the silt is only a few inches thick over the underlying rocky bottom.

Naked, Peak, and Storey Islands, near the center of and toward the western side of Prince William Sound, form a group of islands about eight miles long in the north-south direction and six miles wide. The bottom in the vicinity of the Islands is rocky and very broken.

A broken rocky bottom extends three miles to the northeast of Smith Island which also is located near the center of Prince William Sound. A lighted bell buoy is just over one quarter of a mile south of a 35-foot patch, one mile east of Smith Island.

Seal Island is five to six miles south of Smith Island. Close to the east end of the Island are two bare rocky islets, and just off the west end is a small rock which uncovers eight feet. Rocky, broken areas extend one mile northeast and north from Seal Island. Pennsylvania Rock, one mile north of Seal Island and marked by a buoy, is covered by 13.5 feet of water. About three quarters of a mile southwest of the island is a 34.5-foot rocky area.

II.3.9 Southwestern Prince William Sound The west entrance of Prince William Sound between Cape Cleare and Cape Puget is divided into a number of passages between the various islands. They are Montague Strait, Latouche Passage, Elrington Passage, Prince of Wales Passage, Bainbridge Passage, and Knight Island Passage.

Montague Strait, between Montague Island on the east and Latouche and Knight Islands on the west, is the broadest of the passages west of Montague Island leading from the sea to Prince William Sound. The strait offers an unrestricted channel four and one half miles wide. The current velocity within Montague Strait is about one knot.

Manning Rocks, about two miles off the entrance to the Bay of Isles on the east side of Knight Island, are three pinnacles which, because of the 1964 earthquake uplift, are now bare at low water. Surrounded by deep water, they are the worst dangers on the east side of Knight Island.

Applegate Rock and the surrounding reef area were substantially uplifted during the March 1964 earthquake. Applegate Rock, marked by a light, now bares about ten feet at high water and the reef bares at high water for a distance of about one half of a mile, with many off-lying rocks baring at low water. At the northeast corner of this area is a 27-foot spot three and one half miles to the south-southeast of Seal Island. Detached from this area's western limit is a 20-foot spot just over five miles to the south-southwest of Seal Island. The passage between Seal Island and the reef area has ample depth for a width of approximately two miles. Very foul ground surrounds Green Island which is located between Knight Island and the northern part of Montague Island.

Numerous rock and shoal spots are along the northwest coast of Green Island. These include a prominent outlying rock, 25 feet high, approximately one and one quarter miles northwest of Putnam Point. A small rocky islet, 15 feet high, is about one mile southwest from the sharp point forming the west end of Green Island.

The Needle is a flat-topped, steep-sided rock, about 45 feet high, in Montague Strait just under four miles from the nearest point of Montague Island and five and one half miles southeast from Point Helen, the southern extremity of Knight Island. Close to the north-northeast and south-southwest of The Needle are rocks that uncover. A shoal with a least depth of 19.5 feet and 36 feet at both ends extends northeast about two miles from a point about one half of a mile south of The Needle. Two shoal spots, 42 feet and 45 feet are close southwest and west of the southern extremity of the shoal, and a shoal area, 33 to 51 feet is about three quarters of a mile north-northeast of The Needle.

Knight Island Passage is on the western and southern sides of Knight Island. From its northern entrance between Herring Point and Crafton Island, where it is five miles wide, the passage extends south for about 16 miles to Pleiades Islands with a least width of two miles at the southeastern end of Chenega Island. The channel leads east of the Pleiades where it is about one and one quarter miles wide between the Pleiades Islands and Point of Rocks. From these islands the passage has a southeasterly trend for ten miles with widths of three to four miles to Montague Strait between Point Helen and the northern end of Latouche Island. The eastern shore of Latouche Island on the west side of Montague Strait is precipitous and the 100-fathom curve is less than one quarter of a mile off in places.

The depths in Knight Island Passage range from 40 to 400 fathoms. From Lower Herring Bay to Pleiades Islands, the eastern shore is foul for about three quarters of a mile off, with islands, rocks, and reefs. Channel Rock, a prominent rock about six feet high, is located approximately one mile off the entrance to Lower Herring Bay.

Pleiades Islands, in the middle of the bend in Knight Island Passage, are a chain of seven islands one mile long. The tidal currents in Knight Island Passage have a velocity of one to two knots. Considerable glacial ice has been seen in the passage south of Pleiades Islands. That ice comes east between Point Countess and Chenega Island and drifts as far as Latouche Passage with the ebb.

Latouche Passage, east of Elrington Island, is seven miles long and from three quarters of a mile to one mile wide with depths under 30 fathoms in most places. It has its seaward entrance between Danger island and Elrington Island. The current in Latouche Passage has a velocity of approximately one knot. The entrance bar has depths from 33 to 66 feet. Occasionally large pieces of glacial ice drift into Latouche Passage from Knight Island Passage.

Elrington Passage, west of Elrington Island, is eight miles long, one half of a mile to one mile wide, deep and clear. The flood current sets to the northeast and the ebb current sets to the southwest with velocities of about one and a half knots. Sawmill Bay indents the east side of Evans Island near the northern entrance to Elrington Passage. The diurnal range of the tide in Sawmill Bay is 11.3 feet and little or no current exists in the bay.

Prince of Wales Passage, between Evans Island and Bainbridge Island, is between ten and eleven miles long and from one half of a mile to two miles wide. Prince of Wales Passage has several dangers. The principal channel at the northern entrance is east of Flemming Island. A foul area with a depth of 51 feet is about one quarter of a mile offshore and about one half of a mile south of the point on the east side of

Bainbridge Island, approximately three miles south of Flemming Island. The channel west of Flemming Island has considerable foul ground off Amerk Point. Iktua Rocks are about one half of a mile off Evans Island and one and one half miles south of Elrington Island.

Off Amerk Point at the narrowest part of Prince of Wales Passage, the flood current sets to the north at a velocity just in excess of three quarters of a knot and ebbs to the southwest at a velocity of two and a half knots. Between Flemming and Evans Islands at the north end of Prince of Wales Passage, the current velocity varies from one and a half to two knots.

Section II.4 - Commercial Maritime Traffic in Cook Inlet and Prince William Sound

II.4.1 Cook Inlet Commercial maritime traffic in Cook Inlet primarily consists of vessels which load and/or discharge cargo at Anchorage, Nikiski, and Drift River although such activities also occur, but at lower levels, in Homer, Seldovia, and Port Graham.

Anchorage, for example, receives approximately one quarter of a million tons per year of refined petroleum products mainly in the form of jet fuel, gasoline, and diesel oil. Anchorage also ships and receives about one and one half million tons per year of dry cargo which in terms of tonnage, is the fourth highest level of dry cargo activity in any port throughout the United States.

Crude oil is loaded aboard tankers at the Drift River Marine Terminal and at the Nikiski KPL dock. This crude oil is transported from Cook Inlet for distribution to the "Lower Forty-Eight". Alaskan North Slope (ANS) crude oil is transported into Cook Inlet from the Valdez Marine Terminal. This ANS crude oil is delivered for processing at the Tesoro Petroleum and Chevron refineries in Kenai. Between the offshore, crude oil loading facility at Drift River and the refineries in Kenai, approximately four and one half million tons of crude oil are transported and handled in Cook Inlet on an average annual basis.

In all, there are, on an average basis, 171 oil tanker port calls in Cook Inlet excluding oil barge traffic. This number also neither includes the LNG ships and bulk urea ships which are loaded at Nikiski nor the dry cargo ships (including container ships) and dry cargo barges which call at Anchorage.

II.4.2 Prince William Sound The marine terminal at Valdez, by itself, ships more tonnage in crude oil than the total tonnage of all cargoes shipped from and received by any other port throughout the United States and its possessions. Over the most recent years, in excess of 100 million tons per year have been shipped each year from Valdez in an average of 896 crude carriers.

In addition to the marine terminal at Valdez, other cargoes (including petroleum products) are shipped into Port Valdez as well as to other areas in Prince William Sound such as Cordova and Whittier.

Section II.5 - Tanker Oil Spills

II.5.1 Tanker Oil Spill Data in General There are three striking characteristics of tanker oil spill data. First, the historical range of the magnitude of such spills is extremely large. These spills range in magnitude from a few gallons to tens of millions of gallons. (The two largest tanker oil spills to date were 80 million gallons from CASTILLO DE BELLVER, a 263,000 deadweight ton tanker, which broke up and partially burned off the coast of South Africa in 1983, and 76 million gallons from AMOCO CADIZ, a 228,500 deadweight ton tanker, which ran aground and subsequently broke up off the Normandy Coast of France in 1978). With the largest oil tankers in existence today (over 500,000 deadweight tons), there is the potential for oil spills twice as great as those from CASTILLO DE BELLVER and AMOCO CADIZ. This means that with respect to spill size, one is dealing with a variable which historically has ranged over eight orders of magnitude and which can range over nine orders of magnitude.

The second characteristic of tanker oil spill data is the phenomenon that the great majority of all spills are at the lower end of the magnitude scale. Relatively speaking, most oil spills are small.

The third characteristic is the fact that most of the total oil spilled emanates from a few, very large spills. In other words, a small minority of all oil spill events account for the vast majority of the total oil spill volume.

These three characteristics of oil spills imply that with respect to the expectation or prediction of oil spill volume, a single number estimate of the amount of oil which will be spilled is essentially meaningless. At best, such a single number estimate will be the average of the amount that will be spilled. However, in situations where the amount spilled can vary by a factor of one to ten million, an average value is of little use for it is unlikely that the amount spilled will be anywhere near that average value. Most will be much smaller than such an average and a few will be considerably larger than that average. Furthermore, the fact that most of the oil spilled will emanate from the very large, very rare spills implies that any estimate of an average is unlikely to be very accurate.

It also must be understood that the ecological impact of any given amount of spillage will depend upon both the frequency and the size of the spills making up the total volume expected to be spilled. The ecological impact of ten, so-called, average spills will be quite different from the impact of a single spill which is ten times the average spill volume.

Large spill volume statistics are too small to expect that such data exhibit statistical regularity. On the other hand, the sample size of the number or incidence of oil spills is large and exhibits statistical regularity. Moreover, as opposed to spill volume or amount, each such individual spill event counts equally.

<u>11.5.2 Worldwide Tanker Oil Spill Data</u> Another problem with tanker oil spill data is that because of their relatively limited population in any particular locale they have

limited statistical reliability. It therefore becomes difficult to manipulate that data such as by tanker size or accident type without cutting the sample size down even further and correspondingly decreasing the data's statistical reliability. Thus, it oftentimes becomes necessary to look beyond site-specific but limited oil spill data to the broader based and more extensive worldwide oil tanker data base in order to make probabilistic statements about future occurrences. Figure II - 12 shows the distribution of worldwide tanker accident events by type of accident; i.e., collisions (COL), groundings (GRD), rammings[1] (RAM), fires/explosions (FRE/EXP), mechanical breakdowns (BKD), and structural failures (STF). As can be seen from that figure, collisions and groundings account for 50 percent of the accidents and are very nearly equal to one another. Rammings and breakdowns account for 15 percent each while fires/explosions and structural failures account for approximately 10 percent each. (The remaining and unshown one percent is attributable to other accident types such as capsizings.)

In general, one out of every seven to eight tanker accidents results in an oil spill. Figure II - 13 gives the distribution of worldwide tanker spill events by the same types of accident categories. From this and the previous figure it can be said that given an accident, collisions, groundings, fires/explosions, and structural failures are more likely to have an oil spill while rammings and breakdowns are less likely to have an oil spill.

The foregoing worldwide tanker accident and oil spill data have been extracted from ECOTANK©, a proprietary data base which goes back to 1969 and on an average annual basis contains about 500 tank ship (greater than 10,000 deadweight tons) accidents of which approximately 65 will have had oil spills associated with them on the average. ECOTANK was developed and is maintained by ECO, Inc., of Annapolis, Maryland. The data base contains such information as tanker characteristics including, but not limited to principal dimensions, gross tonnage (an indicator of volumetric cargo capacity), deadweight tonnage (a measure of cargo and consumable liquid (fuel and fresh water) weight capacity), age, and flag of registry. The data base

[1] A ramming is defined to be a ship impact with a non-ship object such as a bridge or pier whereas collisions are ship-to-ship impacts.

WORLDWIDE TANKER ACCIDENTS

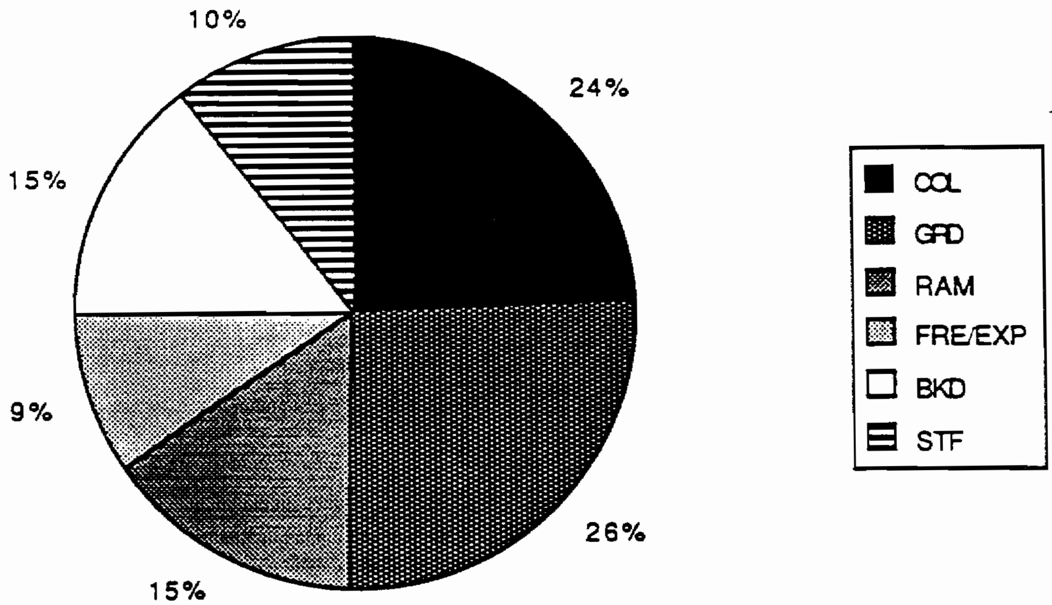


FIGURE II - 12

WORLDWIDE TANKER SPILL INCIDENTS

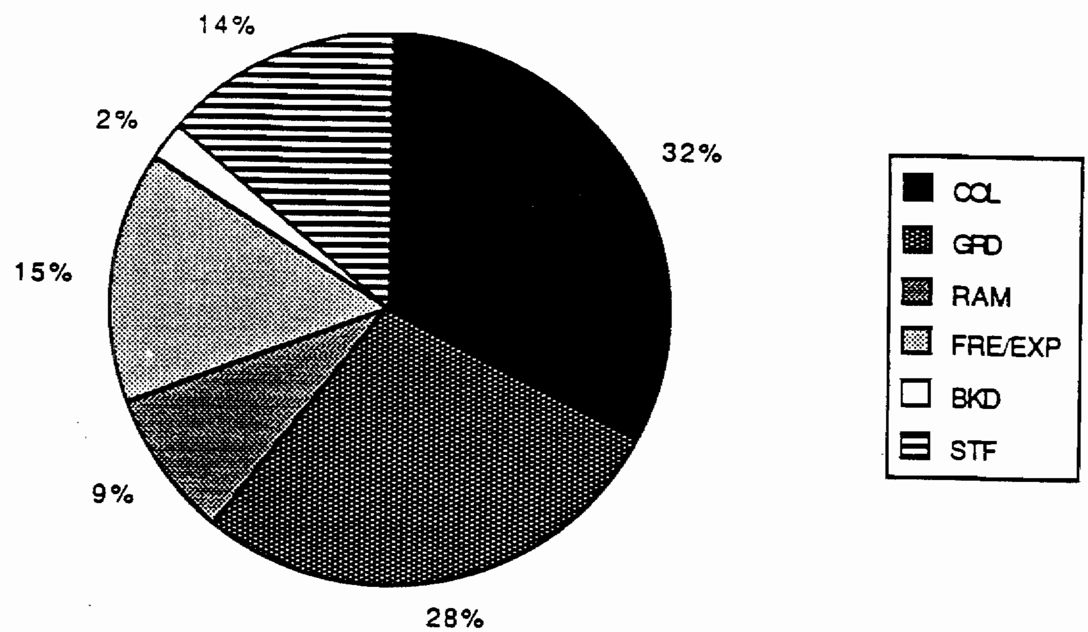


FIGURE II - 13

also contains accident event information including, but not limited to, the date of occurrence; the geographical location and other details of where the accident occurred; the type of accident; the extent of damage to the tanker; whether the tanker was loaded or not; whether any oil was spilled as a result of the accident and if so, the amount and type of oil spilled.

II.5.3 Tanker Oil Spills in Cook Inlet Oil tankers operating in Cook Inlet are exposed to multiple navigation hazards in the forms of large ranges of tides, excessive tidal currents, periodic waves, seasonal ice, numerous detached rocks, shoals, and reefs, an overall, changing bottom, other traffic, and generally speaking, less than optimum and quickly changing weather conditions in terms of winds, precipitation, visibility, and storms. Except for the seasonal ice which ordinarily does not extend sound beyond Anchor Point on the eastern shore and Kamishak Bay on the western shore, all of these hazards are present throughout the year and throughout Cook Inlet and with some variation in both tidal range and current velocity.

In Cook Inlet, there are three areas which pose a high level of hazards to shipping and oil tankers in particular. The first one is the vicinity of the marine terminals at Nikiski which has a high level of traffic activity in a relatively restricted and foul area. Moreover, the area is subjected to excessive currents and seasonal ice and periodically, to severe wave regimes.

The second area is in the vicinity of the anchorage located at the entrance to Kachemak Bay. Once again, the level of traffic activity is high due to both the presence of the anchorage and the fact that all ships arriving and departing from Cook Inlet must enter the mouth of Kachemak Bay to provide a lee to embarking and disembarking pilots. Although not as excessive as those at Nikiski, the currents in the mouth of Kachemak Bay are nevertheless strong in terms of ship controllability. The entrance to Kachemak Bay has ample water depths; typically, 120 fathoms. However, both the northern and southern shoreline have numerous detached rocks and a number of shoals.

The third area is in the Kennedy Entrance which is the main entrance to Cook Inlet for shipping to and from the east and south including the "Lower Forty Eight". Thus, it is an area of traffic confluence. Kennedy Entrance provides a clear passage of 7 miles and deep water; i.e., on the order of 100 fathoms. There are, however, detached rocks and reefs off both Perl Island to the northeast and East Amatuli Island to the southwest.

Over the past ten years, there were a total of 19 known tanker or "tanker induced"[2] oil spills within Cook Inlet. The spill volumes ranged from one gallon to 220,000 gallons and involved both crude oil and petroleum products such as kerosene, gasoline, diesel oil, and a variety of other fuels oils. Spills less than 300 gallons (approximately one long ton) accounted for the majority of these events. Spills greater than 300 gallons ranged from approximately 1,000 gallons to the previously cited 220,000 gallon figure. The two largest spills - one of 207,000 gallons and the other of 220,000 gallons - both emanated from ship groundings.

II.5.4 Tanker Oil Spills in Prince William Sound Oil tankers operating in Prince William Sound also are exposed to multiple navigation hazards not unlike those in Cook Inlet. These hazards occur in the forms of large ranges of tides, periodic waves, occasional glacial ice, numerous detached rocks, shoals, and reefs, an overall, unforgiving bottom, other traffic, and generally, less than optimum and quickly changing weather conditions in terms of winds, precipitation, visibility and storms. Except for the seasonal glacial ice in certain areas previously described in this chapter, all of these hazards are present throughout the year and throughout Prince William Sound.

Within Prince William Sound, there are three areas which pose a high level of hazards to shipping and oil tankers in particular. The first one is the vicinity of the marine terminal at Valdez which has a high level of traffic activity and loading operations as well as being in a area subject to sudden and drastic changes in weather; particularly the winds.

[2] A tanker induced oil spill is an oil spill at a loading or discharge terminal which occurred due to fault on part of the tanker and not the terminal.

The second area is within Valdez Arm. Valdez Arm is the point of confluence of all tanker traffic departing from and entering Port Valdez. Within Valdez Arm, tankers are obliged to pick up and discharge pilots and at times, the waters of the arm contain floating glacial ice discharged from the Columbia Glacier. Although Valdez Arm is relatively unrestricted in terms of water depth (on the order of 200 fathoms), both shorelines from Point Freemantle and Bligh Island have numerous detached rocks, shoals, and reefs.

The third area is in the vicinity of Seal Rocks, offshore of the Hinchinbrook Entrance. The Hinchinbrook Entrance is the main entrance to Prince William Sound and therefore, is an area of traffic confluence. As stated in subsection II.3.1 the off-lying dangers in the approaches to the Hinchinbrook Entrance are Middleton Island, Fountain Rock, Wessels Reef, and Seal Rocks. Seal Rocks are six to seven miles from Cape Hinchinbrook and are two bare rocks surrounded by other low rocks. Rocks, submerged and awash, extend to the northeast and to the southwest from Seal Rocks. The entire reef within the ten fathom curve forms an obstruction nearly three miles long. Lastly, this area is where the cold waters of Prince William Sound and the colder air from the mountains meets with the warmer waters and vapor-laden airs of the Gulf of Alaska which causes highly changeable weather including sudden wind squalls and fog.

Between January, 1980, and March, 1989, there were a total of 270 known tanker or tanker-induced oil spills within Prince William Sound. The spill volumes ranged from one gallon to the ten to eleven million gallons spilled by EXXON VALDEZ and were for the most part crude oil although some were petroleum products. As in the case of Cook Inlet, the majority of the spills were less than 300 gallons. The majority of these spills occurred at or in the vicinity of the marine terminal in Valdez.

Section II.6 - Oil Spill Probabilities and Oil Spill Volumes

<u>II.6.1 Methodology for the Determination of Probabilities</u>. Two statements may be made concerning the incidence of tanker oil spills. The first is that such spills occur

independently from one another; i.e., the fact that an oil spill occurs does not change the probability of the next spill occurring. The second statement is that the probability of the occurrence of an oil spill in a particular exposure interval is proportional to the amount of exposure in the interval. These two statements, when taken together, suggest that oil spill occurrence is governed by a Poisson process. This process is mathematically expressed as follows:

$$p(n|\lambda) = \frac{e^{-\lambda t} (\lambda t)^n}{n!}$$

where $p(n|\lambda)$ is the probability of having n number of spills over some future interval given λ, the mean spill incidence rate (number of spill events per port call), and t is the exposure variable or the expected number of tanker port calls in that future interval. The mean spill incidence rate is the historical number of tanker oil spills over some past interval divided by the corresponding number of tanker port calls which took place over that same past interval.

From the foregoing equation, the probability of having no spills ($n = 0$ and therefore, $n! = 0! = 1$) is as follows:

$$p(0|\lambda) = e^{-\lambda t}, \text{ and}$$

the probability of having one or more spills in that same interval is:

$$p((1,2,\ldots n)|\lambda) = 1 - e^{-\lambda t}.$$

11.6.2 Spill Volume Domains For the purposes of this analysis the lower bound of the spill volume domain has been taken at 300 gallons or approximately, one long ton.

The 300 gallon lower bound has been used to eliminate those numerous, but low volume spills which principally emanate from cargo handling operations at the terminals.

In any analysis of oil spills from tankers, the upper bound of the spill volume domain is determined by the size of the tanker. In other words, the largest oil spill cannot be greater than the total contents of the largest tanker.

In the case of Cook Inlet, it has been assumed that the largest crude carrier is a nominal, 70,000 deadweight ton tanker with a cargo capacity of 21 million gallons at a draft of 40 feet. This tanker has 18 equally sized cargo tanks with a capacity of approximately 1.2 million gallons each.

For the Cook Inlet, 70,000 deadweight tons crude carrier, the first range of oil spills extends from the lower bound (i.e., 300 gallons) of the entire spill domain to one million gallons which is the approximate total contents of a single cargo tank. The second range of oil spills extends from the upper bound of the first range to nine million gallons or the approximate total contents of eight of the 18 cargo tanks. The third and last range of oil spills extends from the upper bound of the second range to the limiting 21 million gallon spill.

In Prince William Sound, it has been assumed that the largest crude carrier is a nominal, 250,000 deadweight ton tanker with a cargo capacity of 75 million gallons at a draft of 65 feet. The tanker has seven centerline cargo tanks and seven pairs of wing cargo tanks. Each of the seven centerline cargo tanks has a capacity of approximately six million gallons and the largest of the 14 wing tanks (seven to port and seven to starboard) has a capacity of approximately three million gallons.

For the Prince William Sound, 250,000 deadweight tons crude carrier, the first range of oil spills extends from the 300-gallon lower bound to three million gallons which is the approximate total contents of one of the largest single, wing cargo tanks. The second range of oil spills in Prince William Sound extends from the upper bound of the first range to 11 million gallons or the approximate total contents of two centerline cargo tanks or two adjacent wing cargo tanks and a centerline cargo tank. (This volume also coincides with the total estimated spill from EXXON VALDEZ.) The third and last range of oil spills in Prince William Sound extends from the upper bound of the second range to the limiting 75 million gallon spill.

II.6.3 Methodology for Determination of Mean Spill Incidence Rates As a general rule, local oil spill data are insufficient for statistical purposes when such data are required to be analyzed, for example, by type of accident, by ship size or characteristic, or by spill size. Such is the case in both Cook Inlet and Prince William Sound where the problem is further exacerbated by the fact that their historical, tanker oil spill data are heavily predominated by relatively small spills at the various terminals.

In such instances, it has become common practice to use, for example, the type of accident, the ship size, and the spill size distributions from national data or worldwide data for operating areas similar to the area under consideration.[3] It is necessary to use such a methodology of statistical inference in order to make probabilistic estimates about future tanker oil spill occurrences not only as a function of spill size, but to include the very largest of potential spill sizes. Using only the local Cook Inlet and Prince William Sound spill data by themselves would permit neither of the foregoing.

It also is necessary to use such a methodology in order to assess the impact on future events by any proposed changes or modifications to the system. For example, if it were proposed to provide a collision avoidance device within the confines of a harbor, bay, inlet, or sound and it was known or estimated that such a device would reduce ship collisions in such locations by some percent, it would be necessary to know the

[3] Table II - 3 gives an exemplary listing of projects conducted by ECO, Inc., in which broader base spill data such as its proprietary, worldwide tanker accident and oil spill data base was used in a similar manner. It should be noted that the listing shown on Table II-3 is not an all encompassing listing but rather gives a single example for each year since ECO's inception in 1973. Other organizations such as, the Oceanographic Institute of Washington have used a similar methodology of using national or worldwide spill data distributions for estimating tanker transportation system risks in a particular locale whose spill data are limited. (See: "Existing and Northern Tier Increment of Oil Spill Risk in Greater Puget Sound, Federal Northern Tier Pipeline Environmental Impact Statement"; 1978, and "Offshore Petroleum Transfer Systems for Washington State," A report to the 44th Legislative, State of Washington, 1975.)

TABLE II - 3 HAZARD ASSESSMENT / RISK ANALYSIS PROJECTS

1973 - ATLANTIC OCEAN AND GULF OF ALASKA OCS PETROLEUM STUDY,
COUNCIL ON ENVIRONMENTAL QUALITY, WASHINGTON, D.C.

1974 - ENVIRONMENTAL IMPACT OF TANKER TRANSPORTATION SYSTEMS IN CASCO BAY,
DEPARTMENT OF ENVIRONMENTAL PROTECTION, STATE OF MAINE.

1975 - TRANS-ALASKA GAS PROJECT - MARINE TRANSPORTATION AND PORT SAFETY ANALYSIS,
EL PASO NATURAL GAS COMPANY, HOUSTON TX.

1976 - RISK ANALYSIS OF LOOP AND SEADOCK TANKER OPERATIONS IN STRAITS OF FLORIDA,
STATE OF FLORIDA, TALLAHASSEE, FL.

1977 - ALGERIA II GAS PROJECT - MARINE TRANSPORTATION AND PORT SAFETY ANALYSIS,
MATAGORDA BAY, TEXAS,
EL PASO NATURAL GAS COMPANY, HOUSTON, TX.

1978 - RISK ASSESSMENT OF PROPOSED BRIDGE AT DAME POINT TURN ON ST. JOHNS RIVER,
PORT OF JACKSONVILLE MARITIME COMMITTEE, JACKSONVILLE, FL.

1979 - ANALYSIS OF ACCIDENT EVENTS FOR SHIPS ENGAGED IN CARRIAGE OF RADIOACTIVE MATERIAL PACKAGES,
SANDIA NATIONAL LABORATORIES, ALBURQUERQUE, NM.

TABLE II - 3 HAZARD ASSESSMENT / RISK ANALYSIS PROJECTS (CONT'D.)

1980 - PORT OF ARZEW ALGERIA - SAFETY AND RISK ANALYSIS AND DEVELOPMENT OF PORT MANAGEMENT AND SAFETY PROGRAM,
SONATRACH, INDUSTRIAL ZONE OF ARZEW, ALGERIA.

1981 - MARINE OIL SPILL DATA FOR THE GULF OF MEXICO MASS TRANSPORT MODEL,
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, WASHINGTON, D.C.

1982 - LAKE CHARLES LNG PROJECT - MARINE TRANSPORTATION AND SAFETY ANALYSIS,
TRUNKLINE LNG COMPANY, HOUSTON, TX.

1983 - OPERATIONAL DISCHARGES AND SPILL EVENTS FROM TANKERS OPERATING ALONG EAST COAST OF UNITED STATES,
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, WASHINGTON, D.C.

1984 - SIMULATED TANKER OPERATIONS FOR WEST COAST OF UNITED STATES AND ALASKA,
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, WASHINGTON D.C.

TABLE II - 3 HAZARD ASSESSMENT / RISK ANALYSIS PROJECTS (CONT'D.)

1985 - SPILL RATES FOR INCINERATION SHIP, MOBILE, ALABAMA,
U.S. ENVIRONMENTAL PROTECTION AGENCY, WASHINGTON, D.C.

1986 - WORST CASE OIL SPILL ANALYSIS FOR MULTIPURPOSE DEEPWATER PORT AND
CRUDE OIL DISTRIBUTION SYSTEM AT GALVESTON, TEXAS,
U.S. ARMY ENGINEER DISTRICT, GALVESTON, TX.

1987 - RISK ANALYSIS FOR BARGE TRANSPORTATION OF CW TON CONTAINERS FROM
ABERDEEN PROVING GROUND,
H&R TECHNICAL ASSOCIATES, OAK RIDGE, TN.

1988 - ACCIDENT FREQUENCIES AND SPILL VOLUMES FOR TANKER AND CHEMICAL CARRIER
OPERATIONS IN LAS MAREAS, PUERTO RICO,
PHILLIPS PUERTO RICO CORE, INC., GUAYAMA, P.R.

distribution of tanker spill events resulting from collisions by location. As previously indicated, most local spill data will not be sufficient to make this determination.

Accordingly, this analysis uses the worldwide distribution by accident type for ships between 25,000 deadweight tons and 75,000 deadweight tons and the worldwide probability distribution function[4] for spills between 300 gallons and 21 million gallons along with the local spill data for spills greater than 300 gallons in order to determine the mean spill incidence rates for Cook Inlet. Similarly, it uses the worldwide distribution by accident type for ships between 100,000 deadweight tons and 250,000 deadweight tons and the worldwide probability distribution function for spills between 300 gallons and 75 million gallons along with the local spill data for spills greater than 300 gallons in order to determine the mean spill incidence rates for Prince William Sound.

<u>II.6.4 Mean Spill Incidence Rates, Spill Probabilities and Spill Recurrence Intervals in Cook Inlet</u> Based on the historical oil spill data previously discussed, a mean spill incidence rate has been determined for each of the three spill ranges in Cook Inlet. As shown on Table II - 4, those rates are 0.00260, 0.000244, and 0.0000892 spill incidents per port call respectively for the three spill ranges or a 0.00293 spill incident per port call rate for all spills 300 gallons or greater.

Given the existing level of oil tanker traffic activity in Cook Inlet or 171 tanker port calls per year and by use of the Poisson distribution function, Table II - 4 gives the probabilities per year for each of the three spill ranges as well as the total probability per year for all spills of 300 gallons or greater. That table also gives the recurrence interval (in years) for each of the three spill ranges and the recurrence interval for the total for all spills of 300 gallons or greater. As can be seen from Table II - 4, a spill in the first range may be expected, on the average, once every 2.2 years; a spill in the second range may be expected, on the average, once every 24 years; and, a spill in the third range may be expected, on the average, once every 66 years. Any spill of

[4] The probability distribution function is determined by the exponential distribution function which is a special case of the gamma distribution function.

TABLE II - 4 EXISTING SPILL PROBABILITIES AND RECURRENCE INTERVALS - COOK INLET

LOWER SPILL LIMIT (GALLONS)	300	1,000,001	9,000,001	300
UPPER SPILL LIMIT (GALLONS)	1,000,000	9,000,000	21,000,000	21,000,000
MEAN INCIDENCE RATE (SPILL/PORT CALL)	0.00260	0.000244	0.0000892	0.00293
NUMBER OF PORT CALLS PER YEAR	171	171	171	171
PROBABILITY OF 1 OR MORE OCCURRENCES/YEAR	0.36	0.041	0.015	0.39
RECURRENCE INTERVAL (YEARS)	2.2	24	66	2.0

300 gallons or greater in Cook Inlet, may be expected, on the average, once every two years.

<u>II.6.5 Mean Spill Incidence Rates, Spill Probabilities and Spill Recurrence Intervals in Prince William Sound.</u> Similar to that discussed in the previous subsection for Cook Inlet, a mean spill incidence rate has been determined for each of the three spill ranges in Prince William Sound. As shown on Table II -5, these rates are 0.000868, 0.0000859, and 0.0000275 spill incidents per port call respectively for the three spill ranges or a 0.000981 spill incident per port call rate for all spills of 300 gallons or greater. It should be noted that these incidence rates in Prince William Sound (on a per port call basis) are about one third of those for Cook Inlet. This suggests that Cook Inlet is significantly more hazardous than Prince William Sound.

Given the existing level of oil tanker traffic activity in Prince William Sound or 896 tanker port calls per year and by use of the Poisson distribution function, Table II - 5 gives the probabilities per year for each of the three spill ranges as well as the total probability per year for all spills of 300 gallons or greater. Table II - 5 also gives the recurrence interval for each of the three spill ranges and the recurrence interval for the total of all spills of 300 gallons or greater. As can be seen from Table II - 5, a spill in the first range may be expected, on the average, once every 1.3 years; a spill in the second range may be expected, on the average, once every 13 years; and, a spill in the third range may be expected, on the average, once every 41 years. Any spill of 300 gallons or greater in Prince William Sound, may be expected, on the average, once every 1.1 years.

Although the mean spill incidence rates in Prince William Sound are less than those for Cook Inlet, the probabilities per year and thus, the recurrence intervals, for Prince William Sound are worse. This occurs because of the fact that there is in excess of five times more exposure (port calls) by tankers in Prince William Sound than in Cook Inlet.

TABLE II - 5 EXISTING SPILL PROBABILITIES AND RECURRENCE INTERVALS - PRINCE WILLIAM SOUND

LOWER SPILL LIMIT (GALLONS)	300	3,000,001	11,000,001	300
UPPER SPILL LIMIT (GALLONS)	3,000,000	11,000,000	75,000,000	75,000,000
MEAN INCIDENCE RATE (SPILL/PORT CALL)	0.000868	0.0000859	0.0000275	0.000981
NUMBER OF PORT CALLS PER YEAR	896	896	896	896
PROBABILITY OF 1 OR MORE OCCURRENCES/YEAR	0.54	0.074	0.024	0.58
RECURRENCE INTERVAL (YEARS)	1.3	13	41	1.1

CHAPTER III - RISK ANALYSIS

Section III.1 - Introduction

The primary focus of the risk analysis is to expand on the results of the hazard assessment and to determine what geographic areas will be at risk from those hazards identified. Specifically, the risk analysis will develop oil spill projections in Cook Inlet and Prince William Sound based on the tanker accident and spill scenarios discussed in the hazard assessment.

The oil spill projections are created using a computer program to determine where an oil slick will go based on a number of variables. The computer program is a proprietary spreading and transport model developed by ECO, Inc. over the course of several years. The program employs a combination of theory and empirical knowledge derived from actual oil spill data to ensure close agreement with reality. The results of the computer model are presented in the form of charts of Cook Inlet and Prince William Sound showing what areas the oil slicks would impact over a period of time if a spill occurred. In all of the cases discussed here, the resulting slicks are predicted to grow quickly to an unmanageable size, highlighting the importance of spill prevention, since beach contamination occurs rapidly and cleanup efforts could only cover a small portion of the affected areas.

Section III.2 - Methodology

The proprietary computer program used here has been developed by ECO, Inc. for many applications to predict the location and extent of oil slicks versus time. This computer model is a two-dimensional spread and transport model which is concerned only with the area an oil slick might affect, not the thickness of the slick. This feature makes the model especially appropriate in this instance since the concern here is what areas might be affected and not to what extent they might be affected.

Oil slicks grow principally in size under the influence of two broad types of forces, spreading and transport. These two types of forces act on a slick simultaneously to produce a net effect. Spreading forces are those forces such as gravity, and surface tension differentials which would cause a volume of oil to spread and disperse over a body of calm water, increasing the area of the oil slick and decreasing its thickness. Transport forces are those forces such as wind and current which tend to move the slick as a whole while also increasing its area and decreasing its thickness. Spreading forces generally influence the size of the slick more than the transport forces do for a short time after the spill starts. Then the transport forces become more important, and they can quickly overshadow the effects of the spreading forces.

The mathematical model used to predict spreading forces and their effects are based in part on Fay's well-established three-phase spreading model (35)[1]. The first spreading phase, known as the gravity-inertia phase, starts when the oil hits the water and forms a "pool" on top of and in the water. This pool of oil collapses on top of and in the water, with gravity acting to collapse and spread the pool, and inertia forces acting to retard the spread. The next phase, the gravity-viscous phase, begins when the viscosity of the oil takes over in its action to retard spreading while the gravity force is still dominant in its action to increase the area of the slick. The third phase is the surface tension phase where differences in the surface tension forces between the two fluids, oil and water, dominate and continue spreading. Eventually the slick reaches a final area when the slick will no longer grow and the magnitude of the spreading forces become zero. The effects of these three phases of spreading are summarized in Figure III-1 (31: 2-5) which shows the radius of a slick versus time. It should be noted that this figure is not directly applicable here since this graph was developed for a crude oil with markedly different properties than Alaskan North Slope crude oil.

Transport forces are somewhat simpler to model, but after a short period of time they generally have a considerably greater effect on the area of a slick than the spreading forces do. Again, the transport model in this program is based on well-established principles that have been used, confirmed and agreed upon in most oil spill models. The two major transport forces to consider are wind and current, while wave motion and dispersion have smaller and less predictable effects.

[1] Numbers in parentheses refer to the entry number in the bibliography. When a second number appears after a colon, it refers to a page number in the work referenced.

SLICK RADIUS VERSUS TIME FOR 30° API GRAVITY OIL SPILLS OF VARIOUS VOLUMES (10 - 10^5 BBL), ACCORDING TO FAY (1971) THREE PHASE SPREADING.

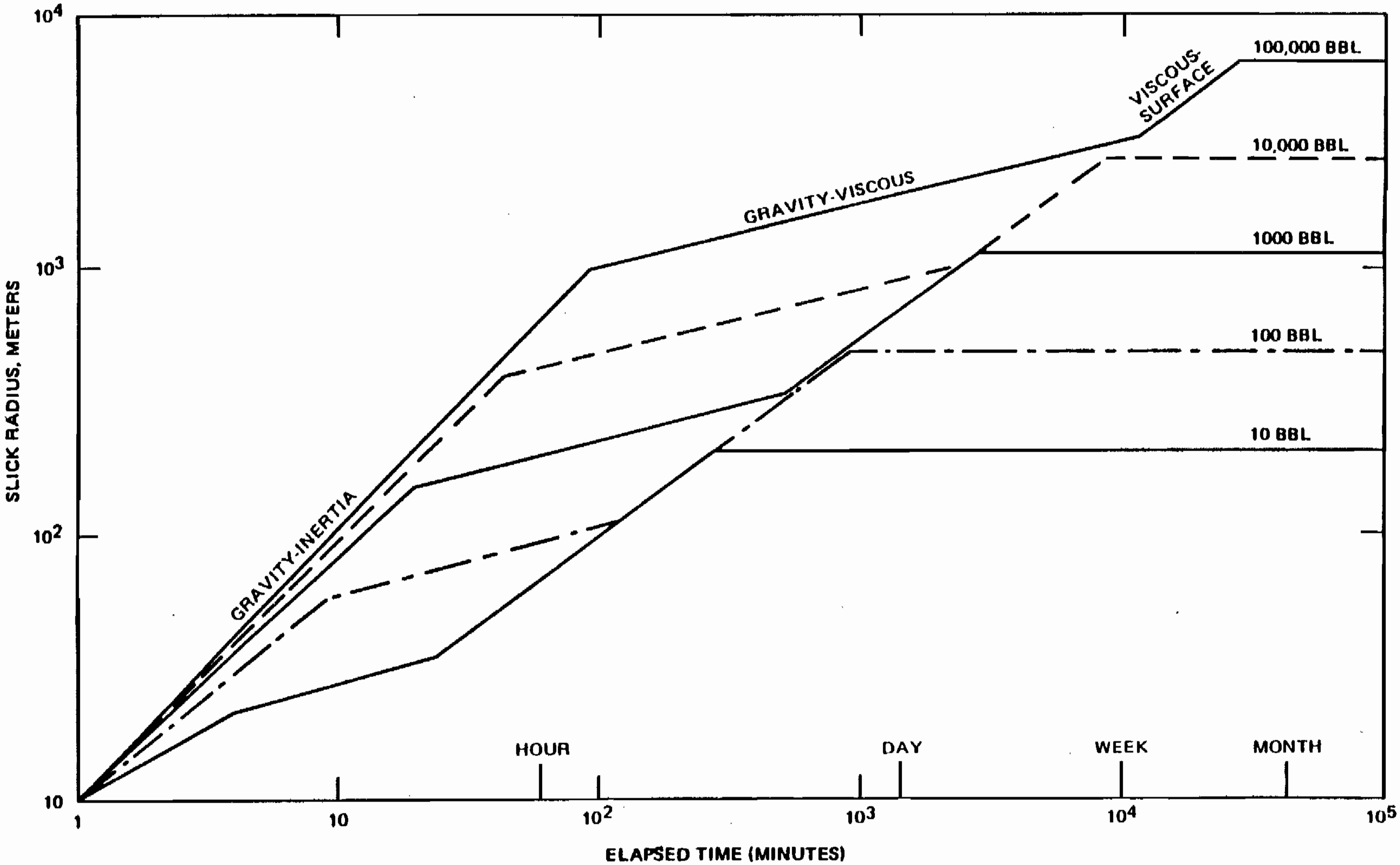


FIGURE III-1

Tidal and non-tidal currents transport oil slicks in the direction the current is flowing at one hundred percent of the current velocity that the slick is exposed to. The Japanese Current is an example of a non-tidal current which has direct bearing on these oil spill projections. Non-tidal currents typically flow with a relatively constant magnitude and direction. In the case of the Japanese Current in the vicinity of Prince William Sound and Cook Inlet, this velocity is about one knot toward the southwest. Tidal currents such as those in Cook Inlet and in parts of Prince William Sound change in both magnitude and direction over time, and they are cyclic. The magnitude of non-tidal current varies sinusoidally with time, flowing in one direction for slightly over six hours, and then reversing direction. The magnitudes and directions of these currents are discussed in more detail in Chapter II.

Winds drive an oil slick in the same direction the wind is blowing, at a fraction of the wind velocity. This fraction of the wind velocity is generally considered to be between three percent and five percent. Since this is an empirically derived number and is based on observations made under many different conditions, it is difficult to find a universally accepted number. Some models claim that the effect of waves can be accounted for by this coefficient of wind velocity, since wind and waves usually act in the same direction. This model, like many others, uses a value of three percent of the wind velocity to calculate the wind-induced transport of the slick.

Current and wind vectors can be considered independently, with their vector sum giving the net effect. The actual wind and current data used in this model is discussed in Chapter II. Some models include a theoretical Coriolis deflection off the direction of the sum of the wind and current vectors. This Coriolis deflection varies with latitude. However, Coriolis deflection has not been observed to have any significant effect in the majority of actual spill observations, so it has not been included in this model.

It has been observed many times that once oil hits a beach, it stays on that beach for an extended period in the absence of vigorous and repeated cleanup efforts. However, when the flood tide comes in, a portion of that residual oil is lifted off the beach and further advanced with the wind and current. When the ebb tide goes back out, this oil is left on the beach at its new advanced location. When the tide comes back in, it picks up the oil here, moves it forward again, and repeats this entire transportation process. Thus an oil slick can move along a beach very quickly since oil is persistent, never retreats significantly on the ebb, and always advances on the flood. This process has been included in the model.

There are several other processes such as evaporation, emulsification, and dispersion, which also affect oil spilled in water. These processes do affect the thickness of the slick and the composition and viscosity of the oil, but none of these processes has a significant or predictable influence on a slick's area. This model does calculate the evaporation rate of the spilled oil according to MacKay's well-established evaporation model (31:II-19 - II-34), but to be consistent with accepted practice, the evaporation rate does not affect the area covered by the slick. Validation runs of the model are included in Appendix D and are discussed at the end of this chapter.

Finally, it should be noted that it was impractical to project spills occurring in Cook Inlet past one week in time since the slicks got out into undocumented currents after that time. The spills in Prince William Sound however, could be projected out as far as four weeks since they stayed in the sound so long, and then were affected principally by the well-known Japanese Current.

Section III.3 - Results

III.3.1 General As noted before, the results of this computer model are represented by charts of the two areas of concern, Cook Inlet and Prince William Sound. These charts are included in their entirety in Appendix A, Cook Inlet, and Appendix B, Prince William Sound. Three spill sites, three spill sizes, two environmental conditions, and two time periods are represented in Appendix A for Cook Inlet. The sites are Nikiski; the Y "1" buoy off the mouth of Kachemak Bay; and, Kennedy Entrance. At each of these sites, spills of 1 million, 9 million and 21 million gallons are modeled for typical summer and winter conditions, and for periods of 24 hours and 1 week (168 hours).

Three spill sites, three spill sizes, two environmental conditions, and three time periods are represented in Appendix B for Prince William Sound. The sites are Port Valdez; Bligh Reef; and, Seal Rocks off Hinchinbrook Entrance. At each of these sites, spills of 3 million, 11 million and 75 million gallons are modeled for typical summer and winter conditions, and for periods of 24 hours, 1 week (168 hours), and 4 weeks (672 hours). The rationale behind modeling these specific scenarios is presented in detail in Chapter II.

The purpose of these charts is to show what geographic areas are likely to be affected by a spill of a given volume, under typical climatic conditions. Thus the black area of the chart show the area the slick has covered, up to and including the time that is listed on each chart. It does <u>not</u> show the shape of the slick at that instant in time; i.e., it is not a "snapshot" of the slick. It is also important to bear in mind that this area may not be continuous. In fact, if there has been any considerable wave action over a period of time, then the slick is likely to have broken up into patches. A second related phenomenon is that the slick is usually composed of a "thick" and a "thin" slick. Transport forces move the bulk of the thick slick around trailing a sheen, or thin slick. An important corollary to this phenomenon is that much of the oil in a slick is often concentrated into a relatively small region. Many spill observations confirm that after a period of time, about 80 percent of the oil is concentrated into a thick slick area which is about 20 percent of the areal extent of the entire slick. Additionally, this thick accumulation is usually at the leading edge of a slick, thus placing cleanup efforts at a maximum distance from the spill origin.

Finally, theory predicts that warmer environmental temperatures should result in oil slicks of larger area and less thickness than colder temperatures would. This prediction is based on the fact that as the temperature falls, the viscosity of the oil increases, thus making it less susceptible to spreading forces. In practice however, this difference is rather small since the transport forces dominate soon after the oil is spilled, mitigating the effect of the spreading forces. In the cases presented here, this effect is even less noticeable since the change from winter to summer climatic conditions change several variables all at once. Not only does the temperature change from summer to winter, but also the prevailing wind speed and direction, and the current cycles change, thus making it difficult to distinguish the influence that a single variable has on the outcome.

Although all of the spill scenarios for Cook Inlet and Prince William Sound are presented in Appendices A and B, a spill from each site is shown and discussed in detail here. Again, it is most important to keep in mind that these figures show only where oil has been, up to and including the time listed. They do not show the extent or the shape of the slick at that time.

Furthermore, the importance of the concept of "typical wind and current conditions" can not be overemphasized. All of these scenarios seek to demonstrate what is most likely to happen given a spill of a certain size at a certain time of the year, either winter or summer. Under worst case circumstances, such as an extended winter storm, the size of a slick and the area it affects could be much larger than what is shown here. Conversely, if an extended period of calm were to occur after the spill, then the slick and affected area could be much smaller than what is shown. For example, while the National Response Team, in its Report to the President on the EXXON VALDEZ Oil Spill (29: 26), and the Alaska Department of Environmental Conservation both indicate that oil from the EXXON VALDEZ spill did not reach Kodiak Island until approximately 35 days after the spill occurred, residents of Ouzinkie, just off Kodiak Island, have testified to the Alaska Oil Spill Commission that they saw traces of oil there as early as 14 days after the occurrence[2]. Clearly in some ways, the EXXON VALDEZ spill was extraordinary to the extent that a very strong storm blew out of the northeast for some period, thus moving the oil further to the southwest more quickly than might have been anticipated. Therefore a typical spill scenario, similar to the EXXON VALDEZ spill in size and location, is not likely to show the slick going as far southwest as rapidly as it did in the EXXON VALDEZ case. The scenarios presented here are thought to be the best possible in the sense that they represent typical conditions that a spill is most likely to be subjected to. The scenarios account for typical winds and currents as discussed in Chapter II.

[2] Interview with Dennis Dooley, Technical Coordinator, Alaska Oil Spill Commission, November 1, 1989.

III.3.2 Cook Inlet Figure III-2 shows a 9 million gallon spill, occurring at Nikiski under typical summer conditions, after a period of 1 week (168 hours). Up to this time oil has made its way north almost to Anchorage, with the mouths of Turnagain Arm and Knik Arm just beginning to get affected. Oil has traveled completely across Cook Inlet from Nikiski to Drift River, and is just starting to contact Kalgin Island. To the south, oil has gone all the way to Kennedy Entrance and around the tip of the Kenai Peninsula. All of Kachemak Bay, including Homer and Seldovia has been hit by oil. The Barren Islands have not been impacted at this point in time, but it is probably safe to say that they would be affected shortly thereafter. Oil has not gone as far south as Shuyak Island or Shelikof Strait. Further to the west, Augustine Island and Kamishak Bay remain clear up to this point in time.

Figure III-3 shows a 9 million gallon spill originating off Kachemak Bay at the Y "1" buoy, during typical summer conditions, after a period of 1 week (168 hours). All of Kachemak Bay, including Homer and Seldovia, is quickly inundated with oil. To the south and east, oil has made its way through Kennedy Entrance and around the tip of the Kenai Peninsula. The Barren Islands have been surrounded by the slick. Oil has also reached as far south as Shuyak Island. The western extent of the slick has now filled most of Kamishak Bay including Augustine Island. The western side of Cook Inlet, from Tignagvik Point north to just past the North Foreland is touched by the slick. On the eastern side of Cook Inlet, the northern extent of the slick goes past Kenai and Nikiski and almost all the way up to Point Possession.

Figure III-4 shows a 9 million gallon spill originating at Kennedy Entrance, during typical summer conditions, after a period of 1 week (168 hours). The Barren Islands have been surrounded. To the east, oil has gone around the Kenai Peninsula, and to the south, the slick has gone as far as Afognak Island and virtually to the northern tip of Kodiak Island. The slick has entered Shelikof Strait to the north of Kodiak Island. To the west, the slick has hit Cape Douglas, Augustine Island, and part of the shoreline of Kamishak Bay. On the western side of Cook Inlet, the slick goes from Tignagvik Point north past Drift River and West Foreland to just below North Foreland. The eastern

Nikiski - 168 Hours After Spill
Spill Size = 9,000,000 Gallons
Typical Summer Wind And Current Conditions

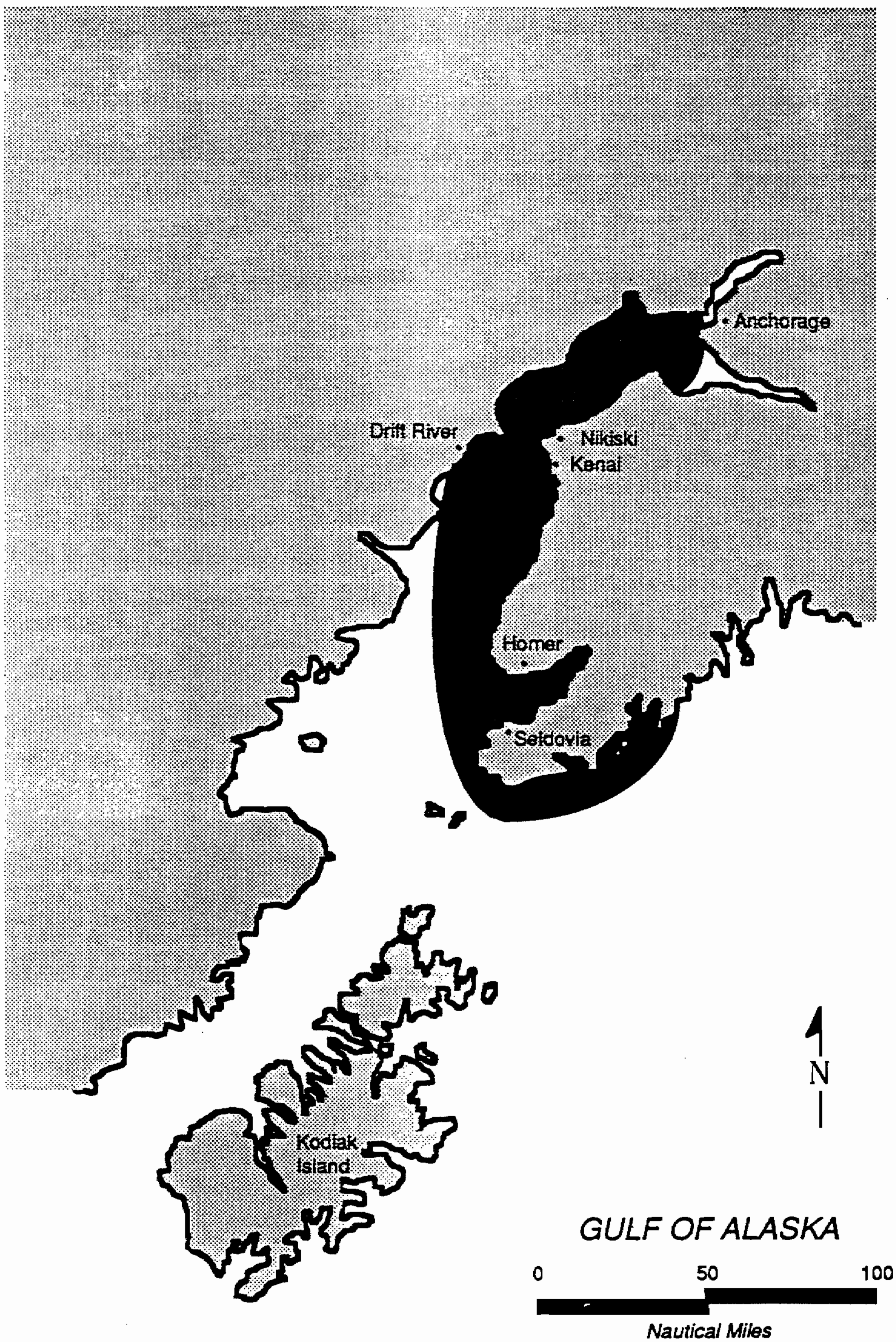


FIGURE III - 2

Kachemak Bay - 168 Hours After Spill
Spill Size = 9,000,000 Gallons
Typical Summer Wind And Current Conditions

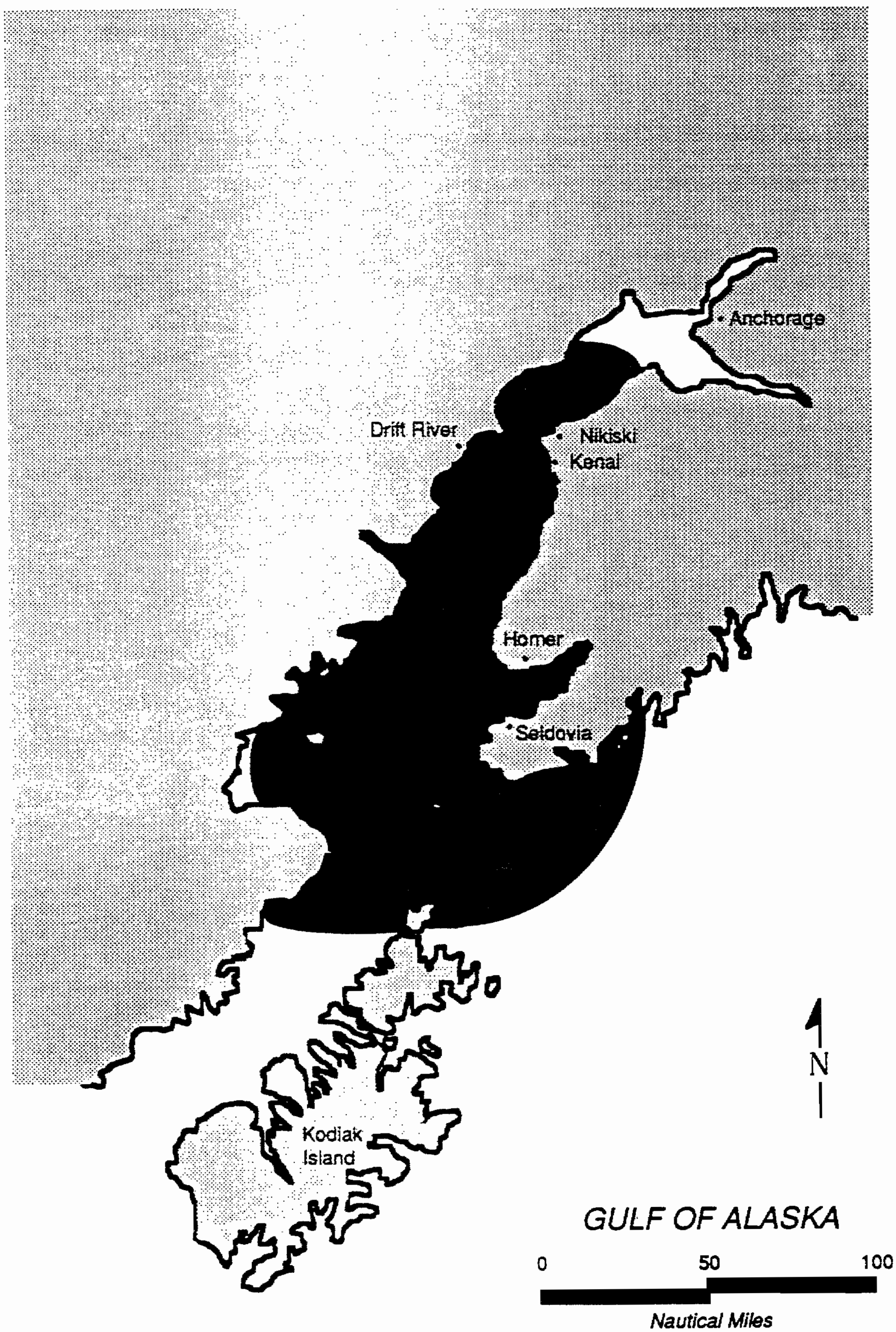


FIGURE III - 3

Kennedy Entrance - 168 Hours After Spill
Spill Size = 9,000,000 Gallons
Typical Summer Wind And Current Conditions

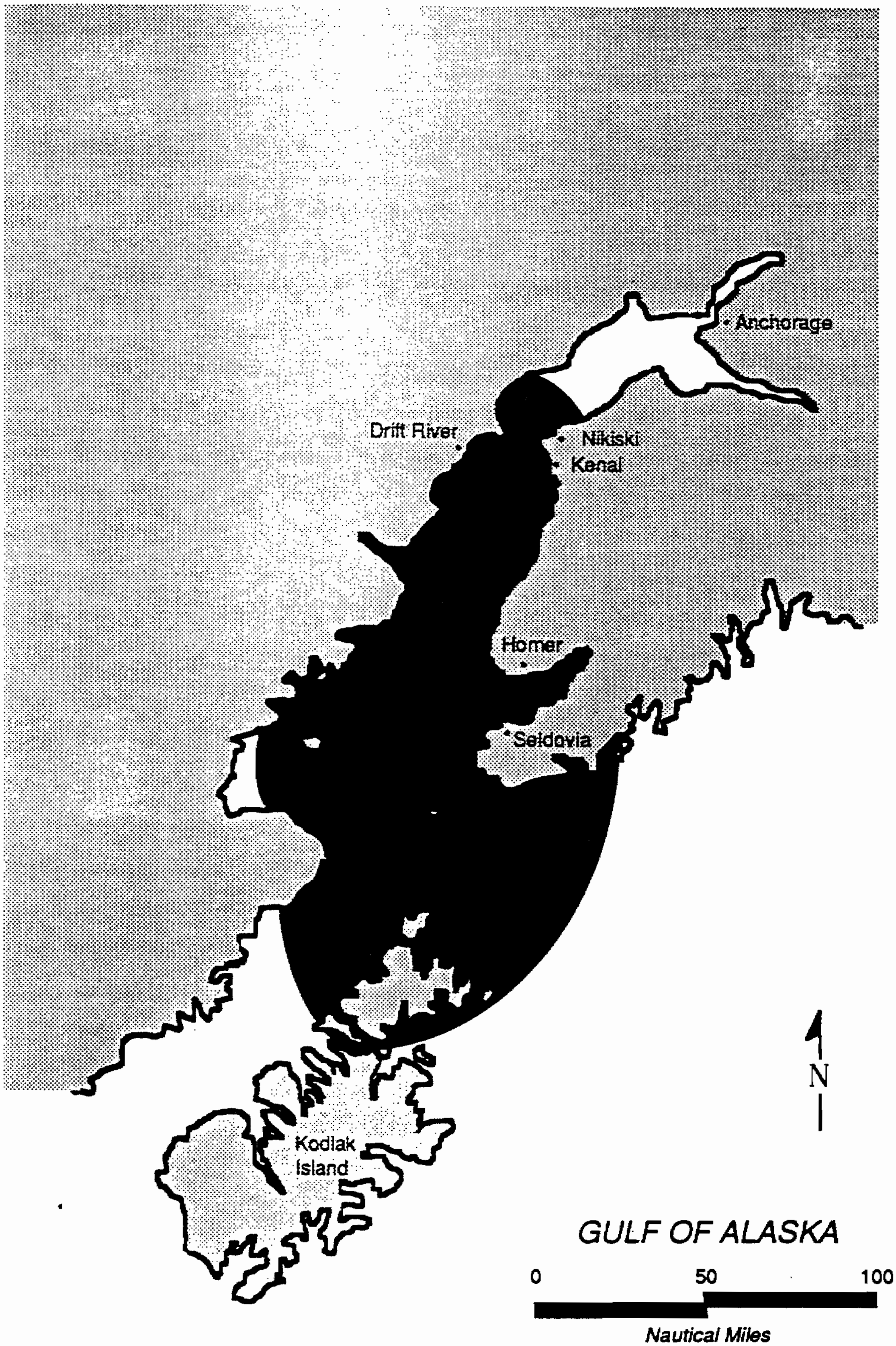


FIGURE III - 4

around the Kenai Peninsula to the south. Kachemak Bay, Homer, and Seldovia have all been impacted by the slick by this time.

The results in the remainder of the scenarios included in Appendix A are similar in many ways. Generally speaking, the larger spill volume of 21 million gallons extends slightly further in all directions for a given spill site, and the smaller volume of 1 million gallons does not extend quite as far in any direction for a given spill site as those discussed here. Although the three spill volumes cover a broad range, the differences in sizes of the slicks may not be as great as one might initially anticipate. This observation is supported by the fact that once transport forces take over and enlarge the slick faster than the spreading forces, the areal coverage of a slick becomes largely independent of volume. Of course the third dimension, thickness, does change considerably for the different spill volumes, but that is not of concern here. Also generally speaking, the typical winter spills differ from the summer spills in several ways, most notably, that they can be somewhat smaller than the summer spills. In addition, since the prevailing winds in Cook Inlet are from the northeast in winter, and from the southwest in summer, the summer spills usually have a greater north and east extent while the winter spills usually have a greater south and west extent.

III.3.3 Prince William Sound Figure III-5 shows an 11 million gallon spill originating at the Valdez terminal (Port Valdez) under typical summer conditions, after a period of 1 week (168 hours). Obviously, this slick has affected much less area after one week than any of the slicks in Cook Inlet, due primarily to weaker currents in Prince William Sound. After one week, oil has touched virtually all of the shoreline in Port Valdez, and has gone as far south as Black Point at the entrance to Tatitlek Narrows. Oil has started to go into Galena Bay and Jack Bay on the eastern side of the sound. On the western side, the slick has gone as far south as just below the entrance to Sawmill Bay. This figure also clearly demonstrates that if a spill were to occur within Port Valdez, it would greatly enhance cleanup efforts if that spill could be confined to Port Valdez and prevented from rapidly spreading over a much larger area into the open waters of Prince William Sound.

Port Valdez - 168 Hours After Spill
Spill Size = 11,000,000 Gallons
Typical Summer Wind And Current Conditions

FIGURE III - 5

Figure III-6 shows a 75 million gallon spill originating at Bligh Reef under typical summer conditions, after a period of 4 weeks (672 hours). This is the largest spill volume and the longest time period which have been modeled in this report. This slick results from a sequence of events which repeats itself for all the spills originating at Bligh Reef, and to a lesser extent, those at Port Valdez and Hinchinbrook Entrance. Prevailing easterly winds push the slick to the west, while tidal currents extend the slick north and south in the sound. Then the leading edge of the slick reaches the passages (Elrington, Bainbridge, Prince Of Wales, Knight, Latouche and Montague Strait) in the southwest corner of the sound where the strong currents push the slick into the Gulf of Alaska. Once in the gulf, the Japanese Current then transports the slick southwest along the southern side of the Kenai Peninsula until it reaches Kennedy Entrance. There, the slick "forks" with part of it continuing southwest in the Japanese Current, and the other part of it going to the northwest into Cook Inlet under the influence of the Kennedy Entrance current.

The result shown in the figure is that almost all of Prince William Sound is impacted by oil, with the exceptions of the eastern extremes of Port Valdez and Cordova, and the northwestern extreme of the Port Wells/College Fiord area. After four weeks, both sides of Montague Island and part of Hinchinbrook Island have been hit by oil, as has the entire south side of the Kenai Peninsula. Part of the slick has reached the tip of Shuyak Island, while the southeast part of Cook Inlet has also been affected. The slick has entered Kachemak Bay, and has gone as far north as just below Kenai.

Figure III-7 shows an 11 million gallon spill originating at Hinchinbrook Entrance under typical summer conditions, after a period of 4 weeks (672 hours). The mechanism described above has a similar influence here. The results are that to the east, most of Hinchinbrook Island is hit with oil. In Prince William Sound, the slick goes north to approximately the northernmost point of Knight Island, and then goes all the way to the western shore of the sound. Outside of Prince William Sound, the entire southern edge of the Kenai Peninsula is again impacted, with the slick extending to the southwest as far as the tip of Afognak Island. The slick also has turned the corner at Kennedy Entrance and has entered Cook Inlet. The entire eastern shore of Cook Inlet,

Bligh Reef - 672 Hours After Spill
Spill Size = 75,000,000 Gallons
Typical Summer Wind And Current Conditions

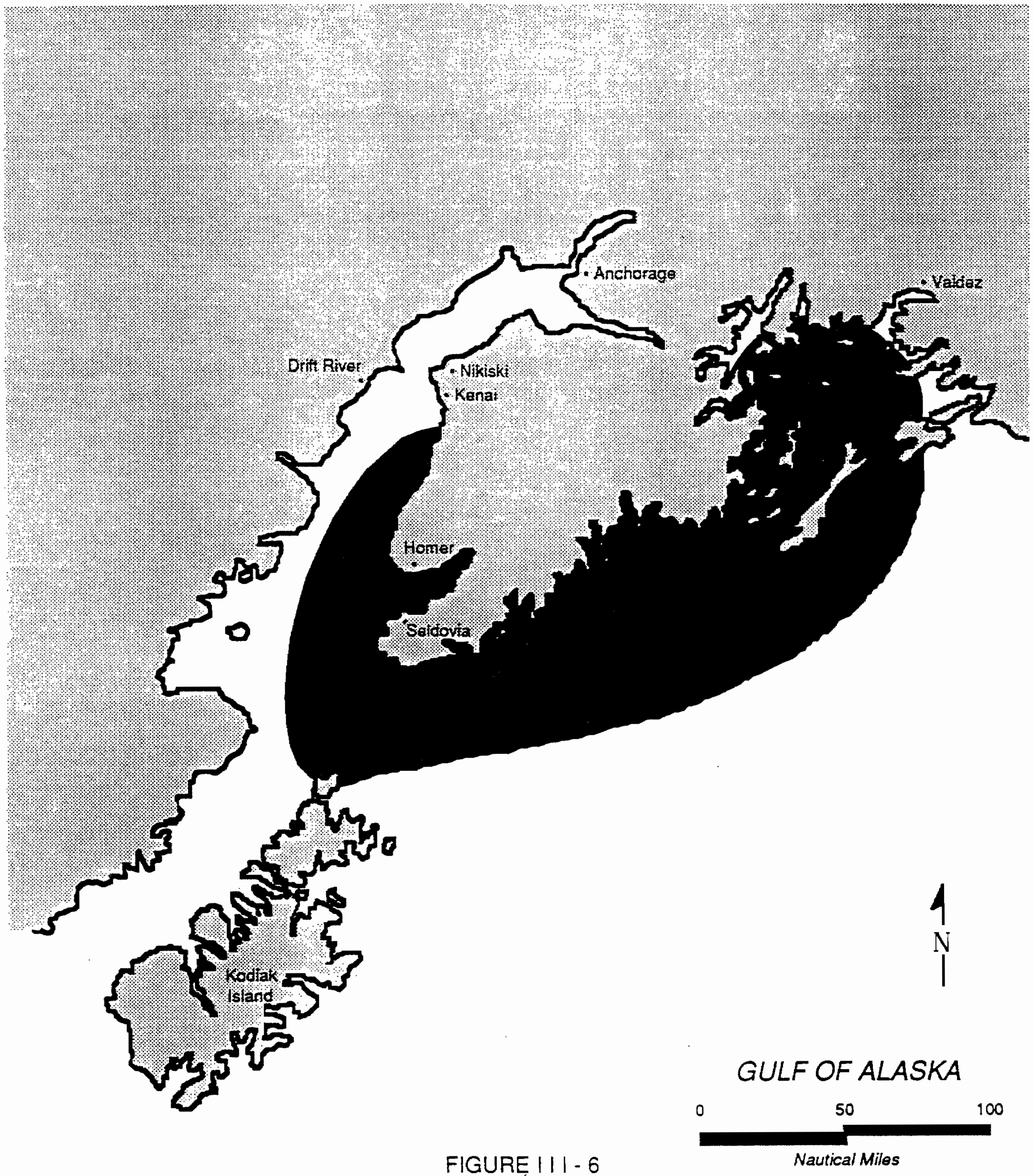


FIGURE III - 6

Hinchinbrook Entrance - 672 Hours After Spill
Spill Size = 11,000,000 Gallons
Typical Summer Wind And Current Conditions

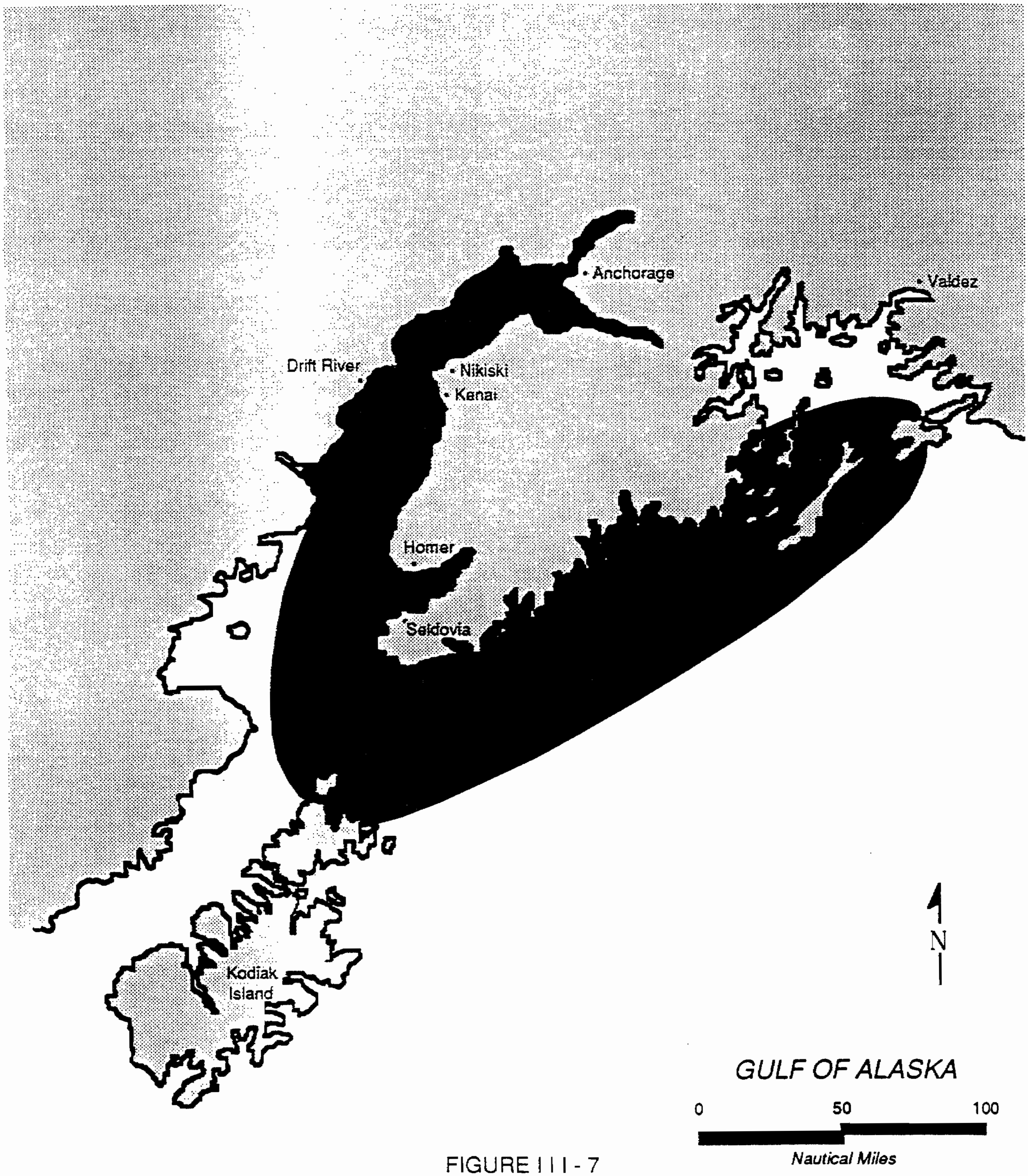


FIGURE III - 7

including Kachemak Bay, all the way up to Anchorage and into Turnagain and Knik Arms, has been affected by the slick. The slick has touched the western side of Cook Inlet from Chinitna Point northward. Kamishak Bay, Augustine Island, Cape Douglas and Shelikof Strait remain clear.

By comparison, Figure III-8 shows the same spill after only a week has passed. To the east, Hinchinbrook Island is still affected. In Prince William Sound, the slick has gone as far north as Seal Island and all the way to the west, including the western passages. Most of the southern shore of the Kenai Peninsula has been impacted by the slick, but the slick has not reached Kennedy Entrance, Cook Inlet, or Shuyak and Afognak Islands.

Several general observations can be made concerning these results and the rest of the scenarios in Appendix B. As in Cook Inlet, the range of volumes produce a range of different slick areas, but the difference in the areas is not as great as the difference in volumes. Also as in Cook Inlet, this observation is supported by the fact that transport forces dominate relatively quickly, so that the areal coverage of a slick becomes essentially independent of volume. Again, the third dimension, thickness, does change considerably for the different spill volumes, but that is not of concern here. Typical winter spills in Prince William Sound differ from the summer spills in several ways, most notably, that they are usually somewhat larger than the summer spills. This result is attributed to the fact that the prevailing winter winds are stronger and slightly more north of east than are the summer winds. These winds tend to push the slicks to the south and west more rapidly, thus more quickly starting the series of events described above which lead the slicks into the Japanese Current and into Cook Inlet. Finally, it should be noted that spills in Prince William Sound not only affect the sound itself, but they also are likely to have impact on the Kenai Peninsula, parts of Cook Inlet and parts of Kodiak, Afognak, and Shuyak Islands.

Appendix C contains the results of the model run for a spill originating offshore of southeast Alaska. The scenario is the total loss of a Prince William Sound crude carrier (75,000,000 gallons) on a voyage from Prince William Sound to Seattle in

Hinchinbrook Entrance - 168 Hours After Spill
Spill Size = 11,000,000 Gallons
Typical Summer Wind And Current Conditions

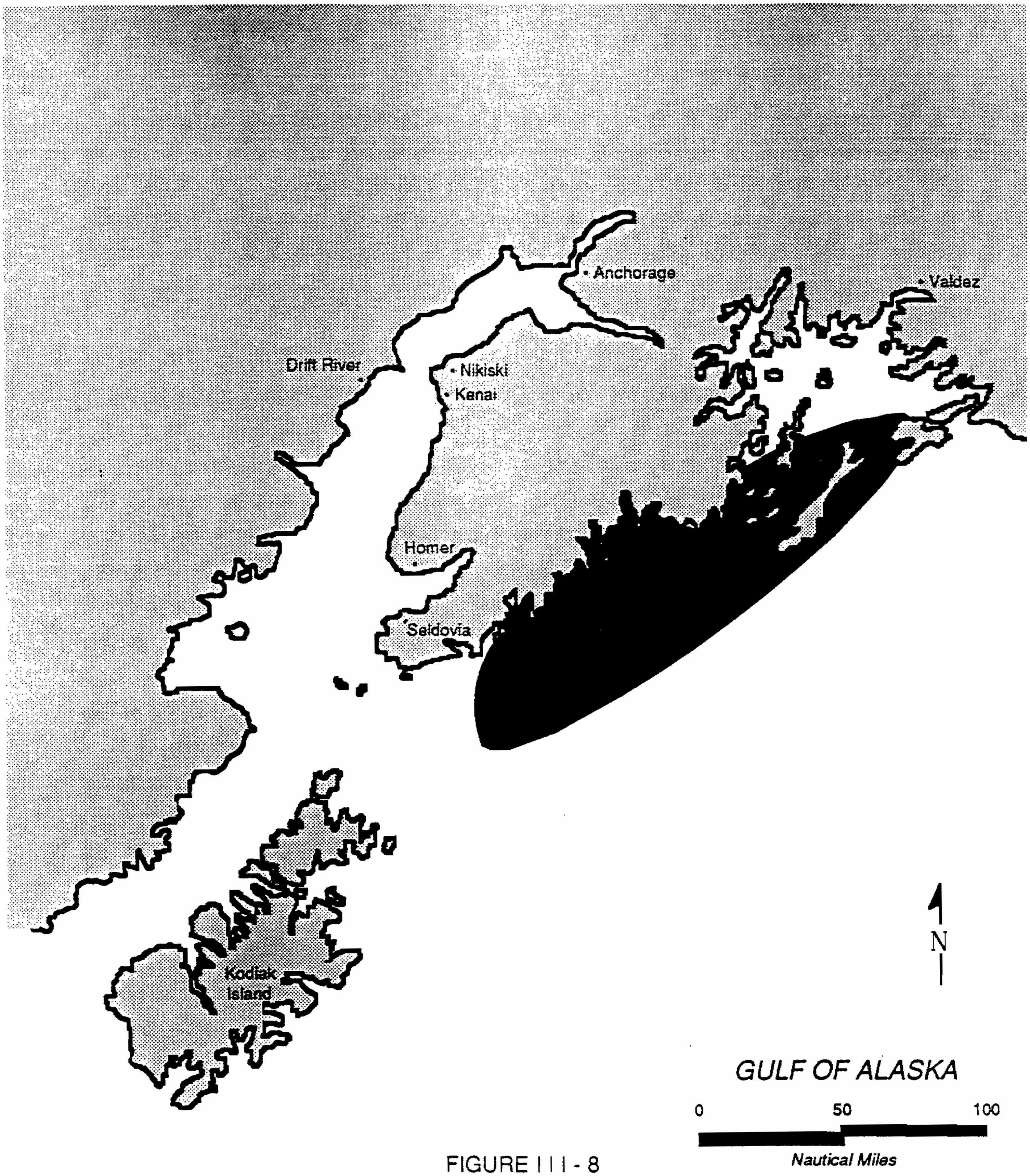


FIGURE III - 8

typical winter conditions. Two specific sites were chosen for the origin of the spill: Site 1 at Latitude 50° 00' North, Longitude 129° 15' West, and Site 2 at Latitude 50° 00' North, Longitude 130° 45' West. Site 1 is located 50 nautical miles offshore of the nearest point of land, and Site 2 is located 100 nautical miles offshore of the nearest point of land. The results of spills of both sites are shown after 24 hours and after 168 hours (one week), as is consistent with all of the other spills modeled in this report. Additionally, climatic data was available which allowed the model to be run until a period of 336 hours (two weeks). Therefore, results are also included for 336 hours, or two weeks after the spill.

The results for the spill originating at Site 1 are shown in Appendix C, pages C - 1 through C - 3. After 24 hours the slick has hit all of the western shore of Graham Island and some of its lower eastern shore. The slick has entered the Hecate Strait and is starting to hit the smaller Canadian Islands on the eastern shore of the strait. After 336 hours the slick has continued in a generally north and slightly west direction. Areas of the slick have now impacted Dixon Entrance, Prince Rupert, Clarence Strait, Ketchikan, and Prince of Wales Island. The western part of the slick has by this time hit Baranof Island and Sitka, and also Kruzof and Chichagof Islands.

By contrast, the spill originating at Site 2, also shown in Appendix C, pages C - 4 through C - 6, has a much different impact. After 24 hours, the slick is essentially the same as at Site 1; no land has been hit. After 168 hours the same 75,000,000 gallon crude oil spill has impacted only the western shore of Graham Island. Even after 336 hours, the western and northern shore of Graham Island are still the only land areas which have been directly impacted by the slick. Hecate Strait, most of Dixon Entrance, Clarence Strait, Ketchikan, Prince of Wales Island, Sitka, and Baranof, Kruzof, and Chichagof Islands are not impacted up to two weeks after the spill, provided the oil spill originates at least 100 miles offshore. An oil spill originating 100 miles offshore also allows more time to combat the spill in the open ocean with one or more of the methods discussed in Section IV of this report.

At least one major conclusion can be drawn from all of the scenarios discussed here and shown in Appendices A, B, and C. Spills of this volume are very difficult to cleanup since they cover such a large area in such a small amount of time, resulting very rapidly in major beach contamination and clearly demonstrating that while cleanup techniques must be improved, oil spill prevention must be the first line of defense. In simple terms, the preferable way to clean up a large oil spill in open Alaskan waters is to prevent that spill from occurring.

Appendix D contains the computer model validation runs which are based on the EXXON VALDEZ spill. Pages D - 1 through D - 3 of Appendix D, show the model projections of this spill after 24 hours, 168 hours (one week), and 672 hours (four weeks), respectively. Page D - 4 is a figure taken from the Presidents Report on the EXXON VALDEZ oil spill showing the actual leading edge of the spill at one week intervals. Comparison of this figure and pages D - 1 through D - 3 show that the computer model used for this report agrees closely with reality. It is important to remember that the environmental data used to produce these runs is often sketchy since wind and current data for that time period and for those areas were not thoroughly recorded. Therefore it is impossible to exactly replicate the actual EXXON VALDEZ spill. However, these figures clearly illustrate that the oil spill transport model simulated the EXXON VALDEZ oil spill well within the established standards of oil spill modeling.

CHAPTER IV - CONTINGENCY PLANNING

Section IV. 1 - Introduction

Previous chapters have discussed the potential for oil spill incidents in Cook Inlet and Prince William Sound, and the extent of the areas affected by that spill incident. This chapter will address the capabilities presently in place in Alaska for responding to the spill incident and the implications of those capabilities on potential damage occurring as a result of the spill incident. The chapter is divided into the following areas:

- Cleanup response in Cook Inlet and Prince William Sound;
- Review of selected contingency plans for Cook Inlet and Prince William Sound; and,
- Recommendations for contingency plan modifications.

Section IV.2 - Cleanup Response in Cook Inlet and Prince William Sound

This section is directed to the ability to cleanup the oil spill as a result of an oil tanker spill as described in previous chapters on Hazard Assessment and Risk Analysis. Much of the discussion is related to oil spills the size of the EXXON VALDEZ spill. These oil spills are extremely large in comparison with the more frequent smaller tanker spills and terminal spills. It must be emphasized that while contingency plans and oil spill recovery equipment may fail for large oil spills, the vast majority of oil spills are small spills. For these more frequent small spills, contingency plans and oil spill cleanup equipment have the capacity to perform satisfactorily. The discussion is divided into five areas:

- Mechanical recovery systems available in Alaska;
- Deployment of recovery systems in the specific areas of Cook Inlet and Prince William Sound;
- Other potential mechanical recovery systems;
- Other oil spill mitigation responses such as dispersants and burning; and,
- Nearshore and small spill response.

IV.2.1 Mechanical Recovery Systems Availability in Alaska Mechanical recovery of oil spilled as a result of a tank ship accident has always been considered the principal recovery technique for mitigating the effects of the spilled oil. The extent of oil transportation by water, and the offshore drilling activities in Alaska have led to the acquisition of a considerable quantity of mechanical recovery assets among various organizations within the state, most particularly the Cook Inlet Resource Organization, Alaska Clean Seas, and Alyeska. This resource base has been extensively increased since the EXXON VALDEZ spill, particularly in Valdez.

Mechanical recovery used as the principal response effort in a large spill could be quite successful, providing that the spilled oil is spreading in a relatively calm environment, that is, one that has virtually no wind, waves, or current. On the other hand, mechanical recovery is likely to be ineffective for a large spill in highly dynamic environmental conditions, that is, an environment that has high winds, high energy waves, and exceptionally high currents.

Throughout this discussion, the mechanical recovery resources will be defined as systems consisting of the skimmer itself and associated boom which is necessary to contain the oil for the skimmer to collect and pump to a storage facility. It should be noted that oil must be contained before it can be skimmed from the surface of the water in order to provide a sufficient depth of oil for the skimmers to operate. The effectiveness of skimmers in uncontained oil is generally very low. The skimming system therefore requires booms deployed in an "U" configuration ahead of the skimmer itself to concentrate the oil.

In a simplified manner, the performance of skimmer systems can be described using three variables:

- Throughput efficiency. The percentage of oil collected by the skimmer to the quantity of oil presented to and capable of being recovered by the skimmer;
- Recovery efficiency. The percentage of oil recovered to the total volume of liquids recovered; and,

- The encounter rate. This is the amount of oil that is available to the skimmer system for collection. It is the product of the swath of the system (including its booms), the speed of the skimming system through the water, and the thickness of oil.

Normal expected operating practice would be to maintain an encounter rate at least equal to the skimming capacity of the system by varying the swath width and/or speed of encounter (slick thickness being beyond the control of the system). A system performing as envisioned would operate at 100% throughput and recovery efficiency and recover as much oil as it encounters up to the limit of its capacity.

In actual experience, however, the performance of a skimmer system is almost always less than ideal. Environmental conditions, the properties of the spilled oil, the current speed of the water relative to the skimmer height and distance differentials between the skimmer and a storage facility, mechanical inefficiencies, and operator competence and/or options, all contribute to a degradation of the ideal situation.

Typical values of efficiency based on published tests are:

- Throughput efficiency - 40 to 60%; and,
- Recovery efficiency - 40 to 90%.

Skimming system performance degrades quickly as a function of sea state with six foot waves being the limit for recovery for virtually all skimmers. As an example, fullscale basin test on the USCG Offshore Skimming Barrier provided the following data on recovery efficiency as a function of wave height:

- Calm waters - approximately 100% recovery efficiency;
- One foot waves - 75% of recovery efficiency; and,
- Two foot waves - 50% of recovery efficiency.

It is relatively simple to understand, on the basis of the above limited discussion, the potential difference between "nameplate" performance and actual performance during a spill event. However, rather than assume the various scenarios that may degrade performance, it is preferable to quantify the ideal performance as a baseline. This is the procedure that will be followed in this section.

The mechanical recovery resources presently available in Alaska are described in Table IV - 1, along with the organizations which own them. Three factors are considered for each of the skimming systems:

- Pumping capacity of the skimmer expressed in barrels per hour. The numbers presented are those provided by the manufacturer and are normally related to "nameplate" skimming capacity. It can normally be assumed that the pumping capacity is with minimal head, which can be a significant factor in actual operation.
- Skimming capacity of the skimmer expressed in barrels per hour. Investigative studies and field experience has shown that actual performance of a skimmer is substantially less than "nameplate" capacity. Discussion of various tests for a wide variety of skimmers is provided in Appendix E, "Oil Spill Skimmers," and shows performance capabilities for those skimmers. As a rule of thumb, skimmer capacity has been equated to one-third of the pumping capacity for this analysis.
- Effective areal coverage expressed in square nautical miles per hour. This is a calculated figure that relates skimmer capacity to the encounter rate of the skimming system. Encounter rate is the amount of oil that the skimming system encounters over time. It is determined by the width of the swath of the system - the distance between the ends of the collecting boom deployed in a "U" configuration - times the speed of the system through the water while skimming times the thickness of the oil in the slick. By holding speed through the water constant for all systems as skimming effectiveness diminishes with speeds over three-quarter knot, and also holding the thickness of oil constant, the capacity of the system can be related to its required swath and thus areal

TABLE IV - 1 . LOCATION AND CAPACITIES OF MAJOR OIL SPILL RECOVERY ASSETS IN ALASKA

EQUIPMENT	MAXIMUM PUMPING CAPACITY (bbl/hr)	ESTIMATED SKIMMING CAPACITY (bbl/hr)	EFFECTIVE (a) AREAL COVERAGE (nm^2/hr)
Cook Inlet Response Organization			
Lockheed 3100	536	179	0.008
ODI VOSS	1070	357	0.017
Outrigger VOSS	1070	357	0.017
DESMI-250	470	157	0.007
Komara 12K	76	25	0.001
Alaska Clean Seas			
FRU	660	220	0.010
Halliburton VOSS	660	220	0.010
Sock	370	123	0.006
TRANSVAC	171	57	0.003
Walosep	251	84	0.004
Alyeska			
Marflex DSV	4200	1400	0.064
Seaskimmer 50	628	209	0.010
Weir Skim Vessel	4200	1400	0.065
Marko V	357	119	0.006
Others			
Walosep	251	84	0.004
Komara 12K	76	25	0.001

(a) Based on a speed of skimming of 0.7 knots and an average oil thickness of 1 millimeter coverage in square nautical miles per hour. This figure is important in comparison with the spreading rate of the oil from the spill incident.

Tables IV - 2, IV - 3, and IV - 4 show typical deployment schemes for the skimming systems described above. With the exception of the dedicated skim vessels of Alyeska and the Lockheed 3100 of CIRO, the systems are based on the use of "vessels of opportunity" such as the offshore supply vessels in Cook Inlet and various fishing vessels.

<u>IV.2.2 Oil Spill Response in Cook Inlet</u> Using data from Table IV - 1 and oil slick spreading characteristics from Chapter III, it is possible to estimate the amount of oil that could be recovered from the 1,000,000, 9,000,000, and 21,000,000 gallon spills in Cook Inlet by comparing the areal extent of the spill with the effective areal coverage of the mechanical recovery equipment. This estimate is provided numerically in Table IV - 5 for CIRO response assets alone and for CIRO assets augmented by response assets from Alaska Clean Seas and Alyeska. The cleanup effort is shown graphically for the 1,000,000 gallon spill in Figure IV - 1. It is apparent from these tables and figure that the spreading of the oil quickly overcomes the ability of the recovery systems to clean the oil up. The need to obtain the assets of Alaska Clean Seas and Alyeska quickly is also plainly shown. Without those assets, offshore recovery is negligible when compared to the area affected.

The above figures assume that the skimming system is operating in near ideal conditions. These assumptions of ideal conditions include the following: the system is operating from a vessel whose design features are fully compatible with the skimming system and which has been modified to accept the skimmer; and, that sufficient storage for recovered oil is available and can be accessed by the skimming systems. At the present time, neither of these assumptions are true for Cook Inlet. The vessels to be used to deploy the skimmers are, with the above noted exceptions, vessels of opportunity with untrained (in oil spill response) crews, and untested deployment capabilities. The storage capacity for the response systems is through the use of rubber bladders which have a total capacity of approximately 800 barrels (or 32,000

TABLE IV - 2
RESPONSE CAPABILITY AND SYSTEM DEPLOYMENT USING CIRO RECOVERY SYSTEMS

RECOVERY SYSTEM	ENCOUNTER RATE (NM2 / HR)	PUMPING CAPACITY (BBL / HR)	SKIMMING CAPACITY (BBL / HR)
Lockheed 3100, operating with 500 ft. of boom towed by 2 ft. Hurricane inflatable boats. 31 ft. boat pulling 3600 gal. bladder tank.	0.008	536	179
Offshore Devices Skimming System mounted on supply boat plus a Hyde Vac skimmer. 4600 gal. storage bladder tank carried on deck.	0.017	1070	357
Outrigger Weir Skimming System mounted on supply boat plus a Hyde Vac skimmer. 4600 gal. storage bladder tank carried on deck.	0.017	1070	357
Sweeping boom - 500 ft. of containment boom deployed in a "U" towed by 2 34 ft. boats. Boat in pocket of "J" has a DESMI-250 skimmer and also tows a 4000 gal. bladder tank.	0.007	470	157
3 60 ft. fishing vessels towing containment boom in a "U" configuration, 2 boats on the ends of the boom with the third in the pocket recovering oil with a DESMI - 250 skimmer and towing a 3600 gal. bladder tank.	0.007	470	157
3 60 ft. fishing vessels towing containment boom in a "U" configuration, 2 boats on the ends of the boom with the third in the pocket recovering oil with a KOMARA 12K skimmer and towing a 4000 gal. bladder tank.	0.001	76	25

TABLE IV - 3
RESPONSE CAPABILITY AND SYSTEM DEPLOYMENT
USING ALASKA CLEAN SEAS RECOVERY SYSTEMS

RECOVERY SYSTEM	ENCOUNTER RATE (NM2 / HR)	PUMPING CAPACITY (BBL / HR)	SKIMMING CAPACITY (BBL / HR)
LCM or 60 foot fishing vessel equipped with Halliburton Fast Response Unit, pumping to a 4400 gal. (105 bbl) bladder tank on board.	0.010	660	220
LCM or 60 foot fishing vessel equipped with Halliburton Skimming Barrier, a 4400 gal. (105 bbl) bladder tank on board.	0.010	660	220
LCM or 60 foot fishing vessel with 500 ft. of boom towed in a "U" configuration; LCM equipped with a Walosep skimmer, pumping to a 4400 gal. (105 bbl).	0.004	251	84
LCM or 60 foot fishing vessel with 500 ft. of boom towed in a "U" configuration; LCM equipped with a TRANS VAC and a 4400 gal. (105 bbl) bladder tank on board.	0.003	171	57

TABLE IV - 4
RESPONSE CAPABILITY AND SYSTEM DEPLOYMENT
USING ALYESKA RECOVERY SYSTEMS

RECOVERY SYSTEM	ENCOUNTER RATE (NM2 / HR)	PUMPING CAPACITY (BBL / HR)	SKIMMING CAPACITY (BBL / HR)
" GEORGIA BAY / RICHMOND BAY" DSV equipped with 2 MARFLEX swepping arms; 143,000 bbl storage capacity.	0.064	4200	1400
"ENERGIZER" storage barge with 73,000 bbl storage capacity + FRAMO vessel lightering system.	-	4000	-
"LIBERTY SERVICE" WRV, 1 Vikoma 10 Weir Boom Skimmer and 2 20 ft. boats to deploy the skimmer. 3510 bbl storage capacity.	0.065	3900	1400
ERV, deploys 3000 ft. of Expandi boom and uses 2 ViKOMA Seaskimmer 50's for recovery. 3910 bbl storage capacity.	0.020	1256	418
MARCO Class V used with 1000 ft. of boom towed by 2 fishing vessels of opportunity. Storage capacity of 30 bbl on board plus 2500 gal. (60 bbl) in a towed dracone (made available from Alaska Clean Seas, Prudhoe Bay).	0.006	357	119

TABLE IV - 5
RECOVERABLE SPILLED OIL
VERSUS SPILL RESPONSE CAPABILITY
COOK INLET

HOURS AFTER SPILL	SPILL SIZE (In gallons)			CUMULATIVE SPILL RESPONSE EFFECTIVE AREAL COVERAGE (In nm^2)		
	1,000,000	9,000,000	21,000,000	CIRO ONLY	CIRO PLUS ACS	CIRO +ACS +ALYESKA
	AREAL COVERAGE (In nm^2)					
0	0	0	0	0	0	0
24	1.8	7.9	13.8	0.3	0.3	0.3
48	7.9	14	25	0.6	0.8	2.2
72	19	22	37	0.9	1.3	4.1
96	36	32	57	1.2	1.8	6.0
120	45	46	81	1.5	2.3	1.8
144	59	108	112	1.8	2.8	9.7
168	75	172	179	2.1	3.3	11.5

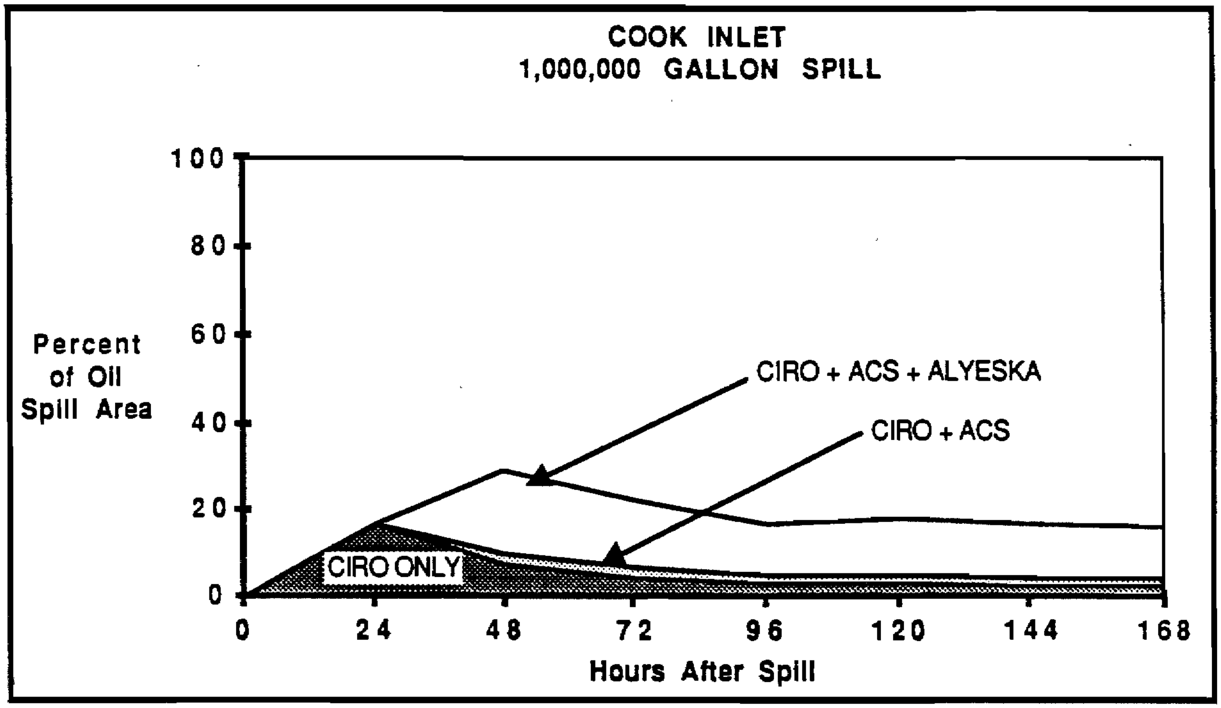


FIGURE IV - 1 SPILL RESPONSE SYSTEM AREAL COVERAGE CAPABILITY AS PERCENT OF SPILL AREAL EXTENT gallons). Nearly all of the tank capacity for the planned response effort is provided by these towable floating tanks, generally called dracones. This presents a number of problems. The emptying of dracones filled with a highly viscous product is a major problem which hampered efforts in Valdez. Additionally, some sort of support vessel is required to empty the dracones and that vessel has not yet been identified. Finally, the time necessary to empty the dracones takes time away from skimming, further limiting the response effort. Providing barge space with oil/water separation capability is absolutely essential to any measure of spill response success in Cook Inlet. There can be no effective spill response effort without provision for storage and disposal of the recovered oil. Without the addition of the Alyeska capability, the response system in Cook Inlet would shut down in the first day.

The figures showing expected rates of mechanical recovery also assume ideal response conditions. Conditions in Cook Inlet are not likely to be ideal for spill response. First, there is the problem of tides and currents. Cook Inlet has a tidal range of 15 to 30 feet with currents that go up to 8 knots on a diurnal cycle. This causes problems in sweeping broad areas with containment booms to increase the quantity of oil encountered by the skimmers. Containment booms generally fails to contain oil in currents greater than 0.7 knots perpendicular to the boom at which point the oil collecting in the boom passes under the boom skirt and continues in the current stream. Slack water with currents less than 0.7 knots occurs for less than three hours in a 24 hour period in Cook Inlet. Due to this current, existing practices of deploying boom and recovery systems would be ineffective in Cook Inlet. Instead, the recovery systems would have to "chase" the oil slick, maintaining a 0.5 to 1 knot speed differential from the slick. This would not be the ideal response effort as the effort is limited to following the oil slick as it moves rather cleaning up according to planned directions, but in Cook Inlet no other method has an opportunity to be successful.

High currents also mean that booms cannot be anchored to protect sensitive areas or to provide a permanent barrier for the response effort. Anchored booms would either fail physically or be carried away. High currents also mean that it is probably not possible to put a protective containment boom around a leaking tanker. The boom would either fail to contain the oil or be carried away, or both.

The high currents in Cook Inlet also produce a current shear zone in the center of the inlet. The shear zone is a place where floating debris collects, and, when oil is spilled, where the oil can collect also. Although there is not a seaweed and kelp problem in Cook Inlet, there is always a large quantity of drift wood, ranging in size from small pieces to logs 60 feet long. This will present a real problem for most mechanical recovery systems.

The next problem with spill response in Cook Inlet is ice. The spill response plans described so far only apply to open water. For Cook Inlet, this means from about April to November, although the ice season is highly variable depending on the severity of the winter. Some years the Inlet remains nearly ice free, but in others ice may occur early and be very persistent.

Shipping in Cook Inlet generally continues all year regardless of the ice. The fifteen oil rigs keep the ice broken up with the movement in the current, and the environmental dynamics of current and high tide tend to make ice cover a mass of flowing pieces rather than continuous cover. As a result, large ships, such as petroleum tankers, continue to operate all year, except perhaps for a week at a time when ice conditions are most severe. Although the tankers continue to move in ice, the smaller vessels that might be used for spill response may not. The large offshore supply vessels can continue to operate and the large 65 foot fishing vessels can operate in some ice conditions, but the other small vessels, including the majority of the fishing fleet, cannot operate in the ice. Given the additional problems of the inability to collect oil with booms in ice and the lack of support vessels, the response effort will be severely limited from November through April.

Although spilled oil will not spread as fast in broken ice as it will on open water, it will, nevertheless, be transported by currents with the ice. As a result, oil that is not recovered will continue to be transported with currents all winter and will be released over a wide area in spring. At breakup, this oil will appear as a sudden spill over a broad area rather than just from a point source.

The extreme environmental conditions in Cook Inlet, tides of 30 feet and currents of 8 knots, cause spreading to occur so rapidly that effective response with mechanical recovery is not likely to be successful for any spills larger than a few thousand barrels of oil.

Burning as a method of spill response in Alaska has been the subject of heated discussion for at least the past decade. Generally accepted practice for response teams has been to try mechanical recovery first since it is safer and easier. However, consideration of Table IV - 5 leads one to the conclusion that in this case burning may be the only option available for an effective response. The oil will move out in the dynamic environment so fast that mechanical recovery can never hope to recover it fast enough. The On Scene Coordinator will be quickly driven to the conclusion that he must burn the heavy accumulations, mechanically recover around the edges and in the outlying areas, and disperse the thin slicks and sheens before they hit the beach.

One of the big problems in burning is making the decision, and for Cook Inlet, it must be made very quickly in order to be effective. The decision to burn must also be made quickly because of the condition of the oil. As the oil spreads out to a slick that is less than 3 mm thick, or as it emulsifies, it may not be possible to burn. As a water-in-oil emulsion (generally called "mousse") develops to the point that the water is more than 10% of the final mixture, the spill probably will not burn. The probability of oil forming a mousse quickly depends on the oil type and the environmental conditions. Prudhoe Bay crude has a tendency to form mousse quickly while Cook Inlet crude is not nearly as likely to become emulsified.

Wave action, stormy weather, and high currents can also make oil go to mousse quickly. The Prudhoe Bay crude spilled in Prince William Sound probably could have been burned for the first two or three days when weather conditions were calm; however, later wind and waves whipped it up into mousse that was 60 to 80% water.

This oil would not have burned. The environmental conditions in Cook Inlet would tend to emulsify the oil fairly quickly.

IV.2.3 Oil Spill Response in Prince William Sound Spill response capability for Prince William Sound has improved tremendously since the Exxon Valdez spill. Before the spill there was only an inner harbor response capability consisting of three MARCO skimming vessels ranging in size from 28 feet and 3 tons to 50 feet and 17 tons. Although these vessels are good harbor skimmers, they have only limited capability in Prince William Sound.

Since the Valdez spill eight major, seagoing, response vessels have been added. This force includes three escort vessels, one weir boom response vessel, one integrated tug/barge dedicated skimming vessel, an integrated tug/barge for lightering operations, and two large storage barges.

First consider the escort vessels. These ships range in size from 207 feet long with a displacement of 2158 tons to 209 feet long with a displacement of 2750 tons. Response capability, therefore, has been upgraded from harbor boats to seagoing vessels that are basically larger than the standard World War II 2,200 ton destroyers. Further, these escort response vessels (ERV's) are equipped with 7,600 feet of containment boom and two high capacity skimmers that can be deployed by eight ton hydraulic cranes. Each ERV has a 20 foot work boat that can be used to deploy the containment boom in a skimming configuration.

These escort vessels are the first line of defense against oil spills. The new Alyeska Contingency Plan specifies that every laden tanker en route from the Terminal to Hinchinbrook Entrance will be accompanied by two escort vessels, at least one of which will be an ERV. Current policy is that the SERVES (Ship Escort Response Vessel) Group will escort laden tankers from Seal Rocks (the entrance to the channel) outbound and partially laden tankers from Seal Rocks inbound.

The escort program provides the transitting vessels with an additional margin of safety in several ways. First, the escorts provide a check on the tanker's navigation. Second, the escort can help the tanker avoid or deal with some of the hazards to navigation, such as icebergs. And third, the escort vessel is available to immediately begin containing and recovering oil in the event of an accident that results in a spill.

Response capability has also been greatly enhanced by the addition of four barges to the Valdez inventory. Two of these units are tug/barge combinations and one of these combinations is also a response unit. Adding barges to the Valdez force is an extremely important change because the availability of storage space for recovered oil is one of the most important elements of a successful spill response effort.

One of the tug/barge combinations, the "Georgia Bay/Richmond Bay" unit, is designated as a Dynamic Skimming Vessel (DSV). In this case the barge is equipped with two Marflex Sweeping Arm weir skimmers. The Marflex skimmers are similar to the Dutch Hydrovac/"Cosmos" units and are probably the most effective add-on skimmer that could be provided for a barge. These skimmers would be routinely used with 100 feet of containment boom attached to each with the potential of an additional 1600 feet of containment boom deployed separately. (A typical sweeping arrangement is shown in figure 502.2-3, page 500-7 of the Alyeska Contingency Plan.) The Marflex system has a tremendous capacity to recover oil; however, the oil comes in as an oil/water mixture. This system could be enhanced considerably by having an on-board oil/water separator to process the mixture as it comes aboard. This would mean that the stored product would be a very high percent oil and relatively clean water would be going over the side. The oil/water separator may not be effective when the spilled oil becomes highly viscous or emulsified, but the system could be rigged so that the separator would be by-passed in these conditions and separation could occur by pumping off the bottom of the storage tanks.

Although offshore environmental conditions are generally severe in Alaska, the conditions in Prince William Sound are not as severe as in Cook Inlet. Particularly, the Prince William Sound area is not troubled by extremely high tides and currents.

Further, there is no problem with sea ice in the area. Most of the ice problem is with icebergs that come off the Columbia Glacier. These icebergs are a danger to navigation, especially in the spring.

Prince William Sound has a serious problem with floating debris that clogs skimmers and pumps. The biggest problem is with sea weed, particularly the variety known locally as "pop weed". The weed clogs skimmers and sometimes makes pumping the recovered product almost impossible. The weed also decays in the recovered product, which causes additional problems. There is not much drift wood in the form of debris except when unusually high tides remove wood from the shoreline.

Waves are generally not a big problem to spill response except in storm conditions. Because there is not much fetch in Prince William Sound, waves are short and generally not a problem for skimming oil. There can be some problem with short waves causing splashover in containment booms.

Alyeska has most of the spill response capability in the area, so using equipment from other areas results in only a marginal improvement in spill response performance. As in other areas, prompt response is most important, so the potential effectiveness of borrowed equipment is further degraded.

The effectiveness of the oil spill recovery assets within Prince William Sound are formidable, and are superior to those at any port in the United States. However, the characteristics of the oil spill spreading under the influence of current and wind can overwhelm most response operations. Table IV - 6 and Figure IV - 2 show the capabilities of the Prince William Sound response equipment as opposed to the spreading of the oil spill. Although the comparison is superior to that seen in the Cook Inlet spill scenarios, the recovery response does not mitigate the spill to the extent that substantial onshore cleanup is not required even in the smallest major spill. As was to be expected, the loss of an entire tank ship completely overwhelms the system.

TABLE IV - 6
RECOVERABLE SPILLED OIL
VERSUS SPILL RESPONSE CAPABILITY
PRINCE WILLIAM SOUND

HOURS AFTER SPILL	SPILL SIZE (In gallons)			CUMULATIVE SPILL RESPONSE EFFECTIVE AREAL COVERAGE (In nm^2)	
	3,000,000	11,000,000	75,000,000	ALYESKA	ALYESKA +CIRO +ACS
	AREAL COVERAGE (In nm^2)				
0	0	0	0	0	0
24	3.8	9	32	2.1	2.1
48	8.4	17	58	4.2	4.7
72	20	25	91	6.3	7.3
96	36	38	133	8.4	9.9
120	65	67	188	10.5	12.5
144	108	115	262	12.6	15.0
168	167	172	360	14.7	17.7

ASSUMPTIONS:

(1) Alyeska recovery assets are deployed immediately and are able to skim 18 hours a day

(2) CIRO and Alyeska assets arrive in time to start skimming at beginning of day 2 of the spill and can operate 6 hours per day

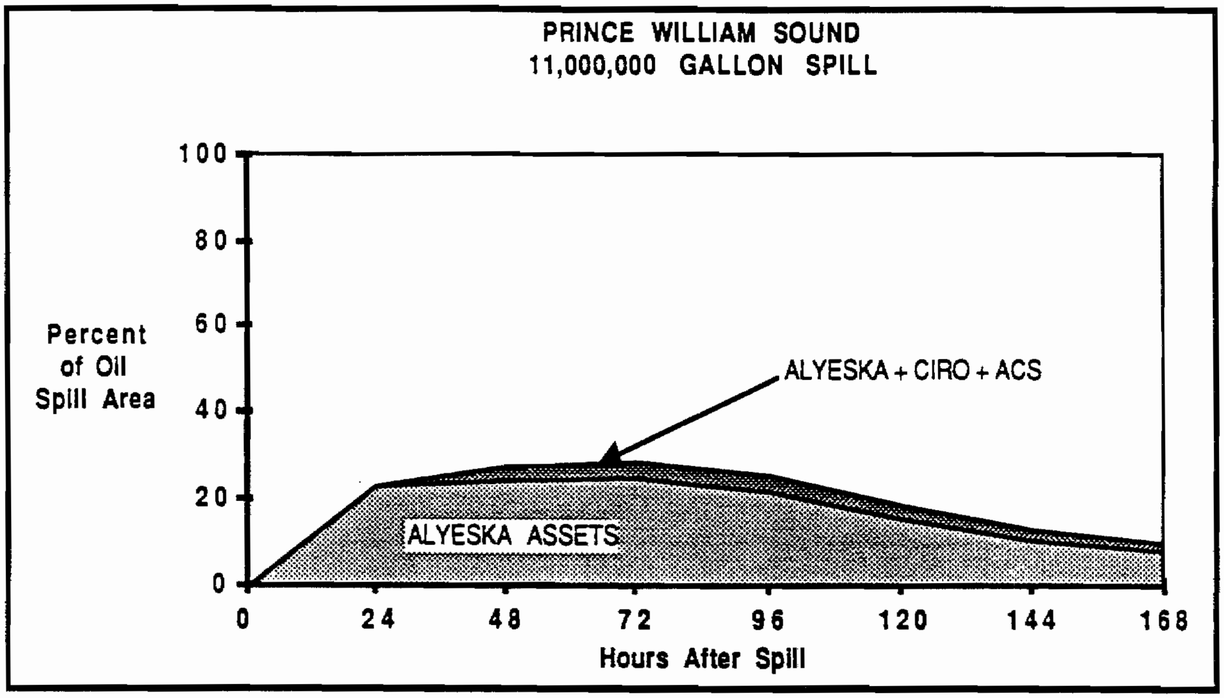


FIGURE IV - 2 SPILL RESPONSE SYSTEM AREAL CAPABILITY AS PERCENT OF SPILL AREAL EXTENT

IV. 2.4 Other Systems for Spill Response

Use of Skimming Systems from Other Governmental Agencies The U.S. Coast Guard and the U.S. Navy have extensive inventories of sea going spill response equipment that can be requested in a spill emergency. This equipment can be requested through established procedures and flown to the spill site. This equipment was very important to the response effort in Valdez and its use and deployment will be a major consideration in any large spill. The USCG equipment is similar in performance to the ODI equipment already in the CIRO inventory while the USN equipment is based on the Marko V unit presently in use by Alyeska. Two major considerations in the deployment of these assets are: the length of time required to request the units and fly them to the area of the spill site; and, the need for support vessels to effectively deploy the systems. The requirement for support vessels limits the usefulness of these systems as those assets are already in short supply. The request time issue can be adequately handled in contingency planning scenario development which would identify decision points and preplanning agreements necessary as a result of that identification.

Netting Oil Over the past several years there has been some interest (particularly in Europe) in using fishing boats with special netting to gather in and recover highly viscous oil. These techniques have been tried and have been fairly successful. The nets are used to encircle the oil, pull it alongside, then either draw it on board with the netting to deposit it in holds, or recover it along side with conventional skimmers.

Although this technique shows promise of success, there are some problems.

- The oil to be recovered must be highly viscous so that it doesn't go through the netting;
- The fishing boats must be equipped with special netting designed for this operation;
- The fishing boats must be supplied with some high capacity skimmers; and,
- The fishing boats must have storage space for the recovered oil. This may

mean storing it in the fish holds, in onboard bladder tanks, or towable bladder tanks.

Use of Dredges as Response Vessels With the additions of a skimming suction head to the dredging unit, dredges show tremendous potential for being fitted out to be highly effective, large scale oil skimmers. There are dredges in the Netherlands that have been specially constructed so that they can be immediately pressed into service as high capacity skimmers. There is also engineering data available that shows how to adapt existing dredges to be used for spill response.

There are no dredges permanently stationed in Alaska. There are some commercial dredges that operate near Anchorage in the summer, but they are not maintained in the area. The Corps of Engineers does not maintain dredges in Alaska. They have dredges on the West Coast of the lower 48, and these could be called into service in an emergency. However, calling a dredge from California is not an "early response" but only a cleanup measure after the spill scenario is well developed.

In addition, the Corps does not have a mission of oil spill response. They will not be specially equipped for skimming and oil/water separation because their primary mission is dredging. The Corps of Engineers have studied the problem and they know what needs to be done, but they have no mandate or budget for making alterations to vessels for spill response. As a result, dredges are not likely to be used in any other capacity than disaster relief in a very large spill.

Potential Skimmer for Ice Wartsila Marine of Finland has combined with LORI to develop a device called an "ice cleaner". This system is an independent ice breaker bow-barge that is pushed ahead of a large work boat or tug. The LORI brushes recover pooled oil and clean oiled ice. The system capacity may be very large, but in ice the encounter rate may be very low. On the other hand, since oil is contained by the ice in winter, time is available to recover oil slowly. This device shows great potential for spill recovery in broken ice and should be considered for winter operations in Cook Inlet.

Specially Designed Barges A major requirement in oil spill response is the availability of barges in which to store the recovered product. Most barges that are available as "vessels of opportunity" are too large to tow behind a skimming system without a large tug, and when they are empty, the pumping lift is often more than 20 feet to start to fill the barge. In addition, the viscosity of the recovered oil makes it difficult to empty the barge to other vessels. Heating coils and openable hatches are features that may be required for the barges to operate effectively and continuously. Storage systems must be designed in concert with skimming systems to allow maximum performance of the recovery operation.

Increased Use of Local Vessel of Opportunity Among those with experience with the Valdez spill, opinion is mixed regarding the likely effectiveness of vessels of opportunity. Some spill response professionals believe that vessels of opportunity don't work out very well. Small fishing boats were used to tow containment boom in the Valdez spill, but they were not used with skimmers. Even larger fishing boats, those in the 60 to 70 foot class, may have problems because they don't have the stability to put a tank on deck. Towable tanks (dracones) are not always an improvement either because they are easier to fill than to empty. Dracones are particularly hard to pump out when they are filled with highly viscous oil or debris. Dracones are filled very quickly and emptied slowly. In some cases in the Valdez spill they were taken to Seattle to be emptied.

In spite of these problems, vessels of opportunity are being considered for a greater role in the response effort. A group in Cordova is presently classifying vessels into three types so that they can be assigned tasks and used quickly in an emergency. They are being classified according to size, H.P., and communications equipment. Initially they were just considered for pulling boom, but the larger vessels, 60 to 70 feet long, could also be used for skimming. There are plans to provide a way to line their fish holds, possibly with bladder tanks, for storing oil. They can do some skimming, probably with a Komara 12K size skimmer or with the comparable Hoyle Marine T12 disc skimmer. Each pair of vessels could tow about 500 feet of containment boom in a

"J" configuration with a skimmer for oil recovery on the boat in the pocket. As an alternative, each vessel could be fitted with a jib to deploy a skimming boom along side to collect oil for skimming and storage.

Although the vessels of opportunity do not show a tremendous increase in response capability, they may be quite effective in the long term cleanup effort after the oil becomes scattered . The larger skimmers look attractive in calculating oil encounter rates, but they are not very maneuverable. Large skimmers show a high capacity for a very small number of units; however, after the oil becomes scattered, a large number of more maneuverable, shallow draft vessels may be more effective than a few high capacity units. As a result, the usefulness of vessels of opportunity may not be adequately shown strictly by encounter rates and skimming rates. Their advantages may be more in their numbers and versatility.

IV.2.5 Other Spill Mitigation Measures With the general inability of mechanical removal systems to cope with oil at sea, processes that do not involve the physical removal of the oil from the water as oil become more extensively discussed as alternatives. The main processes that are involved include the dispersal of the oil by chemical means, the burning of the oil on site, and bioremediation.

Chemical Dispersants The use of chemical means to disperse the oil into the water is probably the most controversial issue in the field of response to oil spilled on water. The National Academy of Science (NAS) has recently completed an exhaustive study of the use of dispersants. Of particular interest to this study was the reiteration that dispersants must be applied at the early stages of the spill as oil becomes less dispersible as its viscosity increases. The NAS study concludes that "Dispersants are most effective for oil viscosities less than about 2,000 cSt, and almost no dispersion occurs over 10,000 cSt."

In general, a dispersant sprayed onto an oil slick is intended to reduce the cohesiveness of the slick so that the oil is broken into small droplets by wave action and water current and the resulting oil droplets are dispersed into the water column and diluted to low concentrations. The operational advantages of using a dispersant include:

- Their simplicity in use as opposed to booms and skimmers and the obviation for handling recovered oil or emulsions;
- Their utility and effectiveness in all sea states; and,
- Their faster response time and their ability to treat more oil per unit of time than mechanical means, particularly if aerial application is utilized.

The use of dispersant has, however, been limited due to two factors: its toxicity and corresponding effect on marine life; and, its effectiveness. Toxicity has been a major factor in the hesitation to use dispersants; however, recent evidence indicates that dispersants cause little damage above that by untreated oil. The significant concern focuses now on whether current formulations of dispersants are effective in combating spilled oil. Most studies indicate the effectiveness at somewhere between 10% and 30% and only under certain conditions.

As with mechanical recovery, dispersants cannot be viewed as an end all to the oil spill problem. They are part of the overall strategy to limit the ecological damage arising from the spill incident, and should be deployed when their use results in the least overall environmental damage of the options available.

Dispersants can be applied by either fixed wing aircraft, helicopters, or systems installed on a vessel. The major consideration that is involved in applying the dispersant is to achieve a relatively uniform application on the oil without undue wind drift losses.

Large aircraft have been equipped with spray boom and interior storage and are most useful for large spills because of their range, capacity, speed, and potential for areal coverage. However, due to the controversy regarding dispersant use, the fixed wing assets are not readily available, although Conair out of Canada does have a fleet of six planes. The Airborne Dispersant Delivery System is a unit developed for deployment on a C-130 commercial aircraft and is the only system that does not require a permanent installation as it can be used with almost any available C-130 aircraft. Logistics are not trivial for aircraft deployment as civilian aircraft, normally in competitive trade, must be relied on.

The application of dispersants from vessel platforms has some distinct advantages such as selective spraying on the leading edge of the slick to mitigate further spreading. The major disadvantage, as with helicopter systems, is the low volume of dispersant they can carry and their relatively short range.

In-situ Burning In-situ burning is defined as the process of burning an oil spill on land or water. Since the early 1970's many tests have been conducted in Alaska and Canada to evaluate the effectiveness of this technique as an oil spill countermeasure .

In order for oil on water to burn, the slick must be relatively fresh and at least 3 mm thick. Since the volatile components in the oil begin to evaporate as soon as the spill occurs, the potential for in-situ burning decreases with time. Fresh oil slicks on any surface which have sufficient thickness can be ignited by matches, burning rags, air deployable igniters, and lasers. The field tests suggest that up to 90 percent of an oil spill can be removed from the water surface by in-situ burning. However, depending on wind speed and temperature, as much as 50 percent of an oil slick can evaporate in 24 hours or less. Once this occurs, it may be impossible to ignite the oil remaining on the water surface. In-situ burning produces a tarry residue which could be difficult to cleanup. Under optimum burn conditions, about 10 percent of the oil will remain on the water as burn residue. In addition, the burning creates black smoke which could violate air quality control regulations and present a health hazard for nearby communities.

Bioremediation Bioremediation is the use of microbes to biodegrade spilled hydrocarbon molecules in place. The microbes could be naturally occurring in the spill area or they could be non-indigenous naturally occurring or engineered microbes, and nutrients could be added to enhance their activity. Bioremediation is potentially the least damaging and least costly cleanup option. However, cleanup times are very long and significant scientific and practical application issues must be addressed. The effect on local habitat by increased microbe creation, both indigenous and non-indigenous, must be studied in depth to ensure the cure is not worse than the disease. This is a new but burgeoning area that should be carefully monitored for its great potential.

IV.2.6 Nearshore and Small Spill Response The previous discussion in this section has focussed on the large spill and on the recovery of spilled oil in open waters. The calculations have shown that mitigation efforts in open water probably will not be totally successful. In fact, historical experience, including the EXXON VALDEZ, tends to lead to a pessimistic view of those efforts, particularly for the large spill incident. However, these factors should not lead planners to conclusions that on-water recovery efforts are not worth pursuing; rather, it should lead to the need to fight the oil spill from a variety of levels with efforts initiated at the onset of the spill and not when resources are in danger of damage later in the spill timeline.

Recognizing that economic and environmental resources will be affected in almost every case, the responders to an oil spill must act early in the spill to ensure that those resources are protected to the extent possible. While large response equipment is being used in open waters to minimize the amount of oil that will impact on shorelines. Other response assets must be directed to prevent the oil from entering/impacting environmentally/economically sensitive areas with nearshore protection schemes. This action requires two prior analyses to be successful:

- First, the identification of environmental/economic resources that should/must be protected; and,
- Second, the identification of response equipment that is specifically designed to this protective mode, and a response strategy that incorporates that equipment.

Implicit in the first requirement is the development of methodologies that will allow for a definitive agreement on the value of a particular resource and the value of that resource vis-a-vis some other resource. A system of prioritization of economic and environmental resources is required within which trade-off analyses can be performed with some equanimity of stakeholder interest. This is an intrinsically difficult task as it includes conflicts regarding short term and long term effects, economic versus environmental priorities, and the effect of societal disruption. A significant limiting factor in the development of this prioritization is the feeling that it cannot be done unless one knows where the oil spill is going and what resources that the spill may affect and the potential seasonality of those resources. This is an untenable limitation, as an ad hoc decision making apparatus becomes unwieldy and emotional resulting in lags in decision making. With the wide availability of various computer hardware and software, this decision analysis should be able to be completed prior to the event.

Response systems for nearshore protection and recovery have different characteristics than that associated with open water recovery. While open water recovery relies on few large skimmer systems capable of recovering large amounts of oil, the nearshore strategy probably consists of many small systems of exclusionary devices and skimmers for smaller concentrations of oil. Typical systems might include:

- Fishing vessels equipped with small, suction-type skimmer deployed from a mast/boom structure with onboard storage (bladders, flexible tanks, etc.) that operate within an exclusionary boom or within a bay to which oil has been diverted;
- Permanent weir systems that can be used like an adjustable dike to prevent oil from entering sensitive stream areas;
- Multiple boom structure allowing diversion and collection of oil; and,
- Permanent placement or storage of response equipment at sensitive areas for quick response without transportation logistical considerations at the time of the spill.

Similarly, the pessimistic view of large scale cleanup efforts should not extend to all spill events. It was noted earlier that the vast majority of spill events are small in size and do not tend to overwhelm the response system. They are normally of short duration, and can be handled with existing personnel and, particularly in Prince William Sound, equipment is available and capable of containment and cleanup with little damage except under extraordinary circumstances for these small spills.

Section IV.3 - Review of Selected Contingency Plans for Cook Inlet and Prince William Sound

The events following the grounding of the EXXON VALDEZ and subsequent spilling of oil into Prince William Sound showed that the oil industry and the State and Federal governments were not well prepared to respond to a major oil spill. Alyeska's contingency plan in place at the Valdez terminal was, for a variety of reasons, inadequate to the task of coping with this spill, as exemplified by the almost immediate turning over of the responsibility of the recovery effort by Alyeska to Exxon. In hindsight, this inadequacy was probably inevitable as the contingency plan was designed to react to small spills, such as spills at the terminal, and not specifically targeted at the large spill. Indeed, a spill larger than 1000 barrels was considered such an unlikely event, that the only reference to that potential was the short discussion on a 200,000 barrel spill scenario.

A review of the major contingency plans in effect for the areas of Cook Inlet and Prince William Sound indicates that a planning document does not exist to react to a major spill event in Alaska. Recent improvements in the Alyeska plan alleviate many of the shortcomings that were apparent in the EXXON VALDEZ spill. The completion of additional sections of the Appendix in that plan, such as scenario development and a Decision Guide, may provide a more useful document. However, the stated intent, within the Alyeska plan, to turn the spill response over to the ship owner as soon as possible is troubling when attempting to evaluate the spill response plan, when the duration of the spill will undoubtedly exceed the plan's lifespan.

Four contingency plans were reviewed as to their applicability to act as decision documents in the event of an oil spill. These plans are:

- United States Coast Guard: COTP Western Alaska Pollution Response Plan;
- Regional Response Team: Alaska Region Oil and Hazardous Substance Pollution Contingency Plan;
- Alaska Department of Environmental Conservation: Alaska Oil and Hazardous Substances Pollution Contingency Plan; and,
- Alyeska Pipeline Company: Tanker Spill Prevention and Response Plan for Prince William Sound.

Each plan was reviewed with respect to the generally accepted elements required for successful contingency planning; specifically:

- Purpose of the contingency planning document;
- Goals/priority(s) of the contingency plan;
- Response resource identification, such as equipment stockpiles and ownership;
- Identification of sensitive environmental and economic resources;
- Prioritization of those resources in terms of their relative importance;
- Allocation of response resources as a function of credible spill events and the prioritization of economic and environmental resources;
- Organization that is intended to carry out the plan;
- Training requirements for individuals involved in carrying out the plan; and,
- Identification of the credible spill event(s).

The results of the review are presented in Table IV - 7. Not unexpectedly, none of the plans fulfilled all of the criteria. Of the plans, only the Alyeska plan is directed at response and cleanup of oil spilled as a result of a tanker accident in specific waters. Each of the other plans dictate how the respective organizations will function in the event, not how oil will be recovered or assets/resources protected.

TABLE IV - 7 COMPARISONS OF SELECTED CONTINGENCY PLANS

PLAN	PURPOSE	GOALS/PRIORITIES	RESPONSE RESOURCE IDENTIFICATION	IDENTIFICATION OF ENVIRONMENTAL/ ECONOMICAL (E/E) RESOURCES	PRIORITIZATION OF E/E RESOURCES	ALLOCATION OF RESPONSE RESOURCES TO CREDIBLE SPILL EVENT	ORGANIZATION	TRAINING	CREDIBLE SPILLS IDENTIFIED
COTP Western Alaska Pollution Response Plan	To provide guidance to COTP personnel in the event that an oil spill occurs within the COTP Western Alaska Area	One: Safety of Life Two: Safety of Vessel/Facility and Cargo Three: Elimination of pollution source to preclude involvement of beaches and shorelines Four: Diversion/Exclusion/ Dispersion; protection of shoreline, particularly areas of greatest ecological concern Five: Beach cleanup	U.S. Coast Guard Resources only	No	No	No	Small spills handled within internal organization - larger spills utilize Emergency Task Forces which escalate in size depending on severity of spill	Spill response with contractors to be carried out one a year USCG Marine Safety School to conduct simulated spill every 18 months	No. High Risk are identified with risk source but no volume or impact associated
Alaska Region Oil and Hazardous Substance Pollution Contingency Plan	To provide for a coordinated and integrated response by agencies of the Federal Government	Provide an advising body to the On Scene Coordinator Coordinate all input from Regional Response Team agencies Provide resources and other available assistance	Regional Data Base	No	No	No	Regional Response Team made of individuals from various federal agencies and a state representative	-	No
Alaska Oil and Hazardous Substances Pollution Contingency Plan	To provide for a coordinated and integrated response by the Department of Environmental Conservation (DEC) during a spill emergency. Provides a framework within which DEC's duties and responsibilities are carried out	Provide for containment and cleanup of spills of oil discharges of unknown origin Require the maximum practicable use of private services and resources Insure that cleanup is initiated and adequate Identify the source, cause, and responsible party Protect the public Protect Alaska's natural resources	DEC resources only but identifies industry organizations	No	No	No	-	Provides guidelines for the type of training required	No
Tanker Spill Prevention and Response Plan for Prince William Sound (Alyeska)	To establish a base case program for oil spill protection, preparation, and response	Provide measures to reduce the risk of a major tanker incident Prepare for the spill event with equipment Respond to an oil spill event Prevent uncontrolled spread of oil Increase potential recovery rate in open waters Minimize shoreline impact Protect sensitive shoreline impact Minimize ecological impact from beach cleanup	Alyeska Resources	Yes	Sensitivity of resources by month provided No methodology for prioritization	Nameplate capabilities of equipment provided not related to actual expected performance or to spill size	Dedicated spill response organization of up to 150 personnel	Required training courses and exercises not yet developed (in process)	No

By way of definition, contingency planning can be described as "a behaviorally or scientifically designed approach of decision-making predicated on an event that is of possible but uncertain occurrence" and "the determination, in advance of a specific situation, of the optimum course of action consistent with established goals."

The contingency plans now in place do not follow the above definition. Rather they are administrative in nature, and while the information provided within them is of significant value in the response, that information is advisory and not action-oriented. These plans do not transfer easily into the decision-making process of oil spill response efforts if those efforts are substantially different from routine tasks. The present system has worked successfully in the past due to the fact that most oil spills are small in size and of limited duration. The present plans have proven valuable in the past and must not be discarded because of their insufficiency in major spill events.

Section IV.4 - Contingency Planning for the Major Spill

The major spill event requires a different approach to response efforts and contingency planning because of the following unique factors:

- The increased complexity of the event in terms of resources, management, and manpower;
- The increased complexity of the event in terms of duration, area covered, and potential environmental sensitivities; and,
- The compressed time frame in which decisions must be made and resources deployed or techniques utilized or initiated.

Among the key elements that are required for the major spill event contingency planning are:

- Prioritization of economic and environmental sensitivities. This is the goal-setting criteria described in the definition above;

- Clear understanding of the events that may occur and the relative probability of their occurrence;
- Generation of credible scenarios with credible conclusions including the description of the potential environmental conditions, the response options, the tactical problems, and critical concerns of the response and impact;
- Development of decision-making and decision analysis approach predicated on the credible scenario event. This approach requires: the identification of information requirements; the identification of response requirements and constraints; and, the prediction of optimum response effort and its implication for prevention activities;
- Allocation and deployment of resources based on the prioritization and on anticipated decisions developed during the contingency decision/creation process;
- Development of training based on the credible event with inclusion of all individuals that are expected to be involved; and,
- Development of a set of procedures which will ensure the creation of an organization capable of responding to the anticipated event. The organization created is an outcome of the anticipated demands of the events and the decisions that will have to be made.

The structure of the contingency plan for a tanker spill needs to address all the various stages of the required response. The COTP Western Alaska plan lists five priorities in order of importance:

- Priority One: Safety of life;
- Priority Two: Safety and vessel/facility and cargo;
- Priority Three: Elimination of pollution source to preclude involvement of beaches and shorelines;
- Priority Four: Diversion/Exclusion/Dispersion; protection of the shoreline, particularly areas of greatest ecological concern; and,
- Priority Five: Beach cleanup.

It appears logical that this structure could be used with the one basic change: each of the priorities should be the number one priority of some group or organization within the overall organizational structure. This would allow a multi-faceted response to the spill event with independent colinear operations.

The contingency plan should be based, as discussed above, on credible events and directed to the response solution to those events. By its nature, the credible event is related to a specific location or body of water and the contingency plan should also focus on this specific location. The Report to the President on the EXXON VALDEZ spill talked about conflicting contingency plans. This could be alleviated with a focus on specific bodies of water and the inclusion of all parties - state, federal, industry, other stakeholders - and their roles or priorities within one plan. At the very least, one plan should be developed for Cook Inlet, Prince William Sound, and the North Slope with others developed as they become more involved in the marine transportation and exploration of oil.

Section IV.5 - Summary

The above discussions on the recovery of oil in the open waters following a spill event point out the difficulties that are encountered in the spill of oil from a tankship at sea. The spilled oil is not a compact object, but is affected by physical processes and the effects of wind and current. Recovery systems cannot operate according to textbook practices, but must "chase" the spill with concurrent loss in effectiveness. The analysis of oil recovery described above is very optimistic in that it assumes that the recovery system operates near to optimum effectiveness, that is, that the recovery system collects all the oil that it encounters and that it only collects oil and no water in the skimming process. This has been clearly shown to be invalid in many studies. Actual experience has indicated performance in the area of 20 to 60 per cent of that described and even less with lower concentrations of oil.

Because oil from a very large spill spreads and is transported away from the spill site so quickly, spill response using locally available equipment is likely to recover a relatively low percent of the spilled oil. This means that an effective response effort must be launched immediately so that a substantial amount of oil can be recovered before extensive spreading and transport occurs. Further, in the case of a large spill, plans must be made to obtain additional equipment from outside sources quickly to augment the mechanical recovery effort.

Since a massive oil spill is so difficult to recover using mechanical devices, other response alternatives must also be considered to prevent large quantities of oil from going ashore. Two major alternatives to mechanical recovery are dispersants and burning. Much has been written on the relative merits of each of these alternatives and the adverse effects that their use promulgates. The one thing that is clear, however, in considering either of these alternatives, is that they must be used in the very early stages of the spill or they will not be effective.

The problems involved in responding to a very large spill that still beg a solution should not deter the effort to effectively respond to small and moderate size spills. A well organized response effort can be very successful in responding to these spills. Further, effective response to these spills can prevent substantial environmental impact to sensitive areas. Continuing to strive to achieve a high level of effectiveness in mechanical recovery will both prevent significant environmental impact and will also improve response techniques and equipment so that they will be more effective in the largest spills.

Potential decision-makers must develop programs based on credible spill events and develop a structure of response that allows the response to occur in independent colinear operations. An encompassing contingency plan based on credible spill events and on specific bodies of water and including state, federal, industry, and other stakeholders in its planning and execution is mandatory for future spill mitigation efforts.

CHAPTER V - IMPROVED TANKER DESIGN

Section V.1 - Introduction

The grounding of the EXXON VALDEZ on Bligh Reef in Prince William Sound and the subsequent spilling of over ten million gallons of Alaska North Slope crude, in less than five hours, suggests that the construction of oil tankers be re-examined with respect to a design which could reduce both the number and magnitude of oil spills. This section of the report will focus on engineering subsystems in ship design - many of which are in use, but not required, on today's modern tankers.

Specifically, improvements in tanker design will be suggested in the following areas:

- Double Hulls;
- Centralized Bunker Tanks;
- Automated Cargo Control System;
- Auxiliary Thrusters;
- Precise Navigation Display System; and,
- Improved Lifeboats.

Section V.2 - Double Hulls

Oil tankers with double hulls have cargo and bunker tanks surrounded with a complete and protective second hull. Double hulls are required on chemical tankers and gas carriers to provide the maximum amount of protection to the cargo tanks. This design provides the highest probability of surviving damage, either from a collision or grounding, with no loss of cargo. The arrangement provides spaces both below the cargo tanks and on the sides solely for the carriage of ballast water when the tanker is in the ballast condition. These tanks are empty when the tanker is loaded. In the loaded condition, the empty ballast tanks also act as the first line of defense in the event of structural damage to the cargo tanks. Therefore, double hulls, in addition to providing the highest probability of preventing oil spills, also act to reduce the magnitude of an oil spill in the event of damage to a cargo tank by containing oil released from the inner cargo tanks.

Title 46 of the Code of Federal Regulations, Subpart 153.230 defines a type I double hull; whereas, Subpart 153.231 defines a type II double hull. In general terms, a type I double hull requires the spacing between the inner and outer bottom to be 1/15 of the beam of the vessel or 19.7 feet, whichever is smaller. In the case of the EXXON VALDEZ with a beam of 166 feet, this would equate to a spacing of 11.06 feet. With respect to the spacing between the inner and outer sides of a type I double hull vessel, Subpart 153.230 requires 1/5 of the beam or 37.74 feet, whichever is smaller. Again using the EXXON VALDEZ as an example, the minimum distance would be 33.2 feet. While this type I double hull is the most effective design with respect to reducing oil pollution from collisions, groundings and rammings, it results in a 25 to 30 percent loss of cargo carrying capacity due to the excess ballast capacity between the inner and outer hulls. This loss in carrying capacity would require an increase in the number of tankers to transport the same volume of oil with an attendant increase in the number of tanker accidents.

In reviewing the requirements for a type II double hull; as specified, in Subpart 153.231, the spacing between the inner and outer bottom is exactly the same as a type I double hull (1/15 of the beam of the vessel or 19.7 feet, whichever is smaller); however, the minimum required spacing between the inner and outer sides is reduced to 76 centimeters or approximately 30 inches. In the case of the type II double hull, the designer does <u>not</u> have sufficient space to meet the ballast requirements. A design between a type I double hull with excess ballast capacity and a type II double hull with insufficient ballast capacity could be considered. This type II (modified) double hull design would use the ballast capacity as presently required by the International Maritime Organization (IMO) and the U.S. Coast Guard (USCG) and adjust the separation between the inner and outer hulls so that the tanker carries only the required ballast capacity. With only the required ballast between the inner and outer hulls, the cargo carrying capacity is <u>not</u> affected.

Since both the type I double hull and the type II double hull require a minimum distance between the inner and outer bottom of 1/15 of the beam of the vessel or 19.7 feet, whichever is smaller, it appears logical that the type II (modified) double ull tanker should start with a double bottom, as required for the type I and type II double hulls. By starting with the IMO required ballast volume and subtracting the volume required for the double bottom, the volume remaining for each side can be determined. The calculations reveal that the minimum distance between the inner and outer sides is nearly 1/15 of the tanker's beam, or the same separation as the double bottom. In other words, a suggested design for a compromise double hull oil tanker would be a type II (B/15) design with a minimum separation between the inner and outer hulls of 1/15 of the beam of the vessel or 6.56 feet (2.0 meters), whichever is larger. The 6.56 feet (2.0 meters) minimum separation is necessary to maintain the effectiveness of the two hulls in preventing the release of cargo.

Would this oil tanker be as effective in protecting the environment as a type I double hull? The answer with respect to groundings is <u>yes</u>. The answer with respect to high-energy collisions is <u>no</u>. However, since the cargo carrying capacity is <u>not</u> reduced, the overall number of oil tankers or traffic density will <u>not</u> increase. In addition, with the suggested Alaska Vessel Monitoring System (AVMS), vessel traffic separation lanes and designated anchorages in both Prince William Sound and Cook Inlet, the probability of a high-energy collision could be reduced through operational control of these vessels in Alaskan waters. Figure V - 1 is a schematic of a nominal 70,000 deadweight ton crude carrier with a B/15 double hull for operations in Cook Inlet. Figure V - 2 is a schematic of a nominal 250,000 deadweight ton crude carrier with a B/15 double hull for operations in Prince William Sound.

Section V.3 - Centralized Bunker Tanks

Any oil tanker will normally transport crude oil one way and return to the loading port in the ballast condition. It is, however, important to recognize that in addition to transporting crude oil one way , the oil is handled twice (loaded and discharged) and

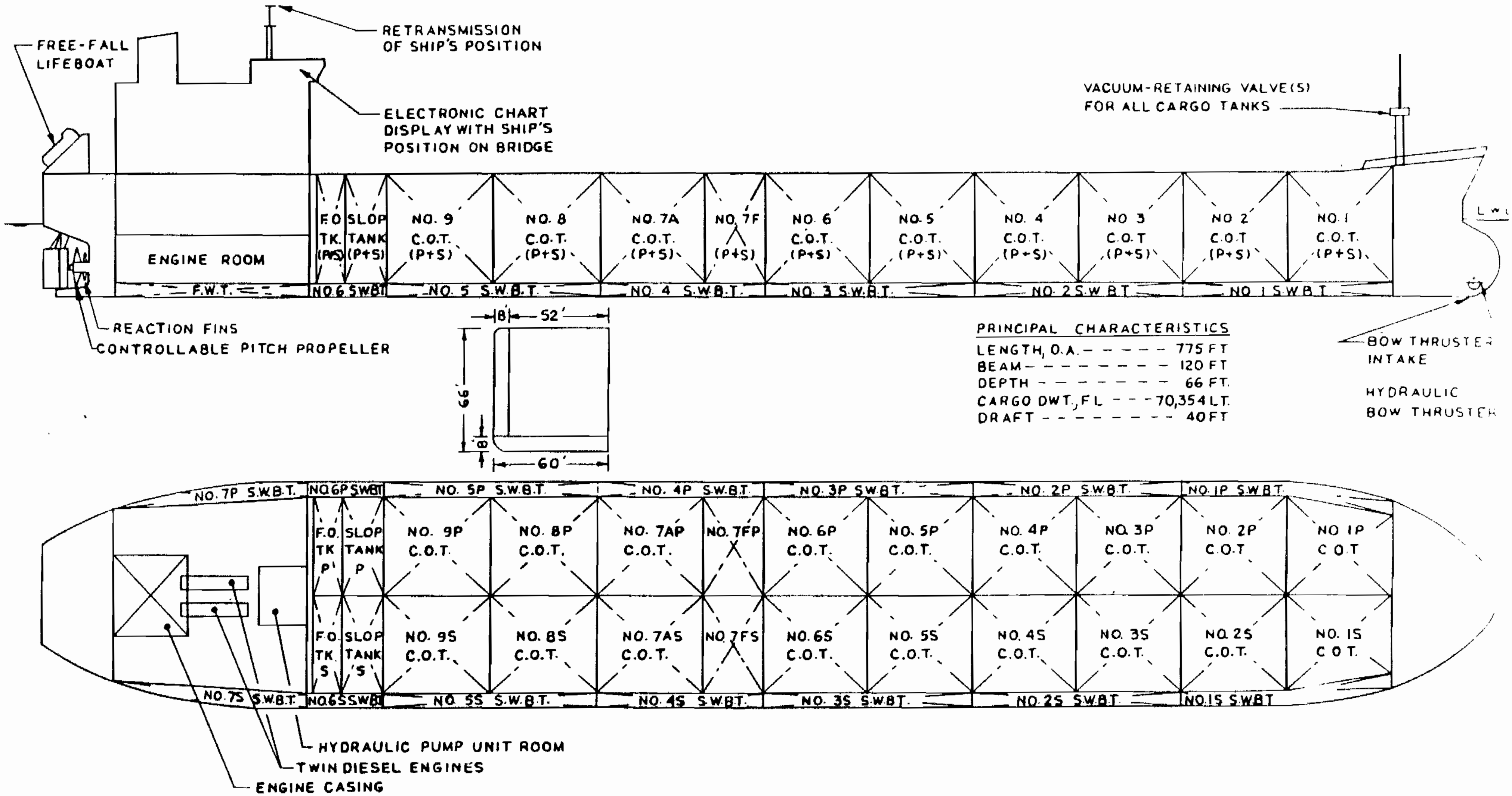


FIGURE V - 1

70,000 DWT CRUDE CARRIER

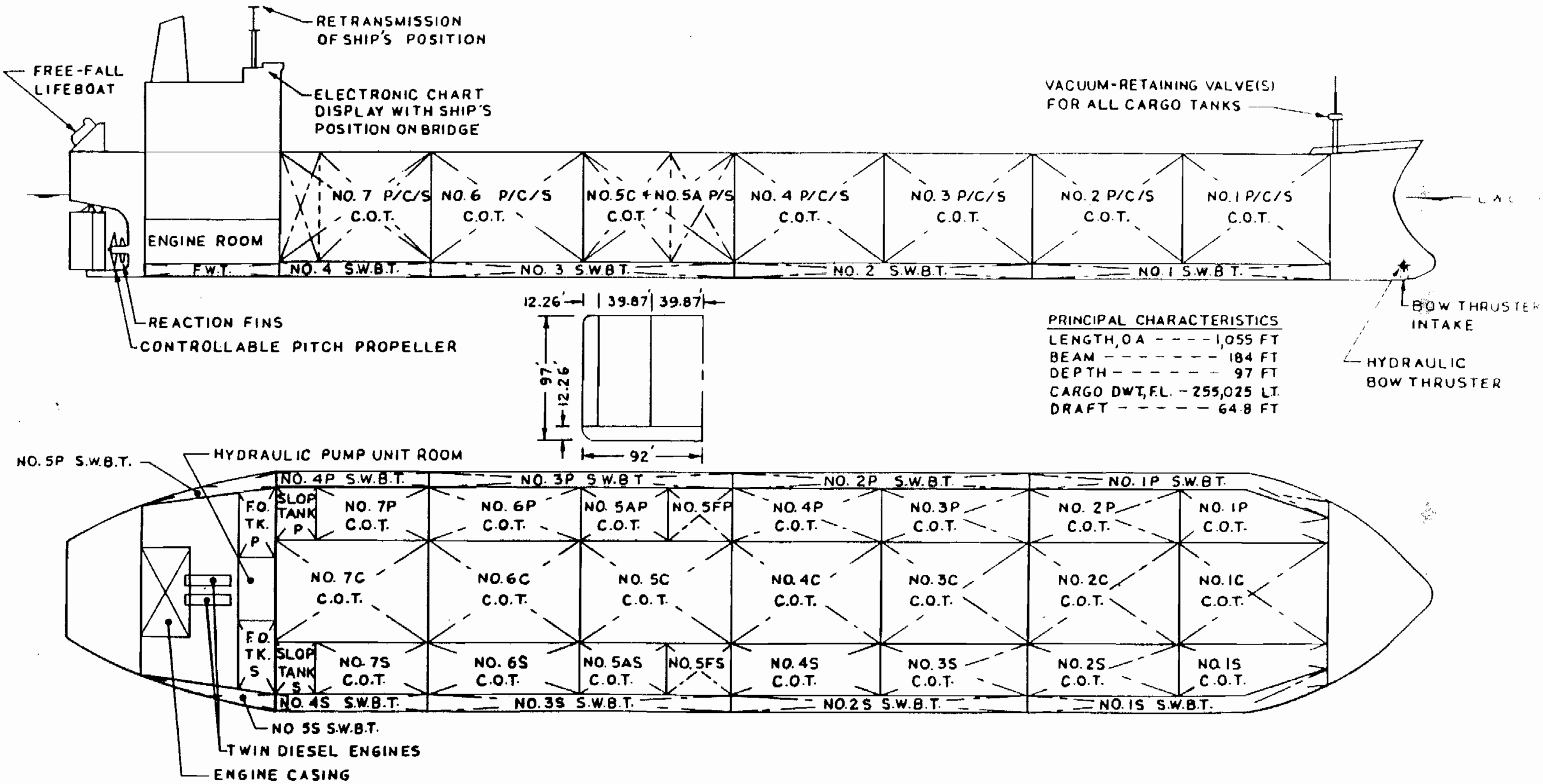


FIGURE V - 2

250,000 DWT CRUDE CARRIER

that the ship's bunker tanks contain fuel oil on both legs of the trip. Specifically, the bunker capacity of a crude carrier can exceed 1,000,000 gallons. This 1,000,000 gallons of bunker capacity is one of the reasons that while the Alaska Oil Spill Commission's primary concern should be with a loaded tanker, a tanker in ballast should not be disregarded.

The increased efficiency of the today's diesel engine has led to today's lower exhaust gas temperatures and thus to a decrease in the performance of the exhaust gas boilers. The steam generated by these boilers is essential for heating the fuel bunkers. If fuel is stored in tanks with sides in contact with the sea, then the amount of available steam is not sufficient for heating purposes, and expensive fuel has to be burnt in the oil-fired boiler to balance the shortage. However, if the fuel tanks are installed in a central position in the ship, forming block tanks whose sides are not in contact with the sea, then even the reduced amount of steam produced by the exhaust gas boiler is enough to heat the fuel.

The block tank system means more than just energy saving. In this case fuel economy measures coincide with measures to reduce oil pollution. The four bunker tanks are arranged athwartships, above the inner bottom and between the inner sides. In a fashion similar to the cargo tanks, the spaces directly below in the double bottom and outboard in the double sides would be used exclusively for ballast water. An elevated overflow tank is installed in the center of the tanks. Since all stiffeners of the tanks are placed outside, the tanks have smooth sides and floors, a point which is relevant to fuel deterioration.

Another advantage is the simplification of the pipeline systems. The filling line of the bunker tanks is a single line in the athwartship direction with manifolds on both ship's sides, and one connection to each of the tanks directly through the deck. The overflows of the tanks are connected with short bends to the central overflow tank. Overfilling of the tanks is reduced due to their position and the overflow tank. Tank level alarms and remote control, pressure actuated valves are provided in both the cargo handling system and the bunkering system.

Space is provided below the center tanks in which the remote controlled fuel transfer pumps are located. The fuel oil from the tanks flows into these pumps which in turn deliver it via a pressure pump directly to the engine room. This avoids suction problems and the installation of a pipe duct in the double bottom can be avoided.

The block tanks simplify not only the fuel system but also the ballast system. Since the ballast tanks surrounding the centralized bunker tanks have the same trimming moment as the bunker tanks, trim adjustments for fuel consumption are a direct one to one ratio.

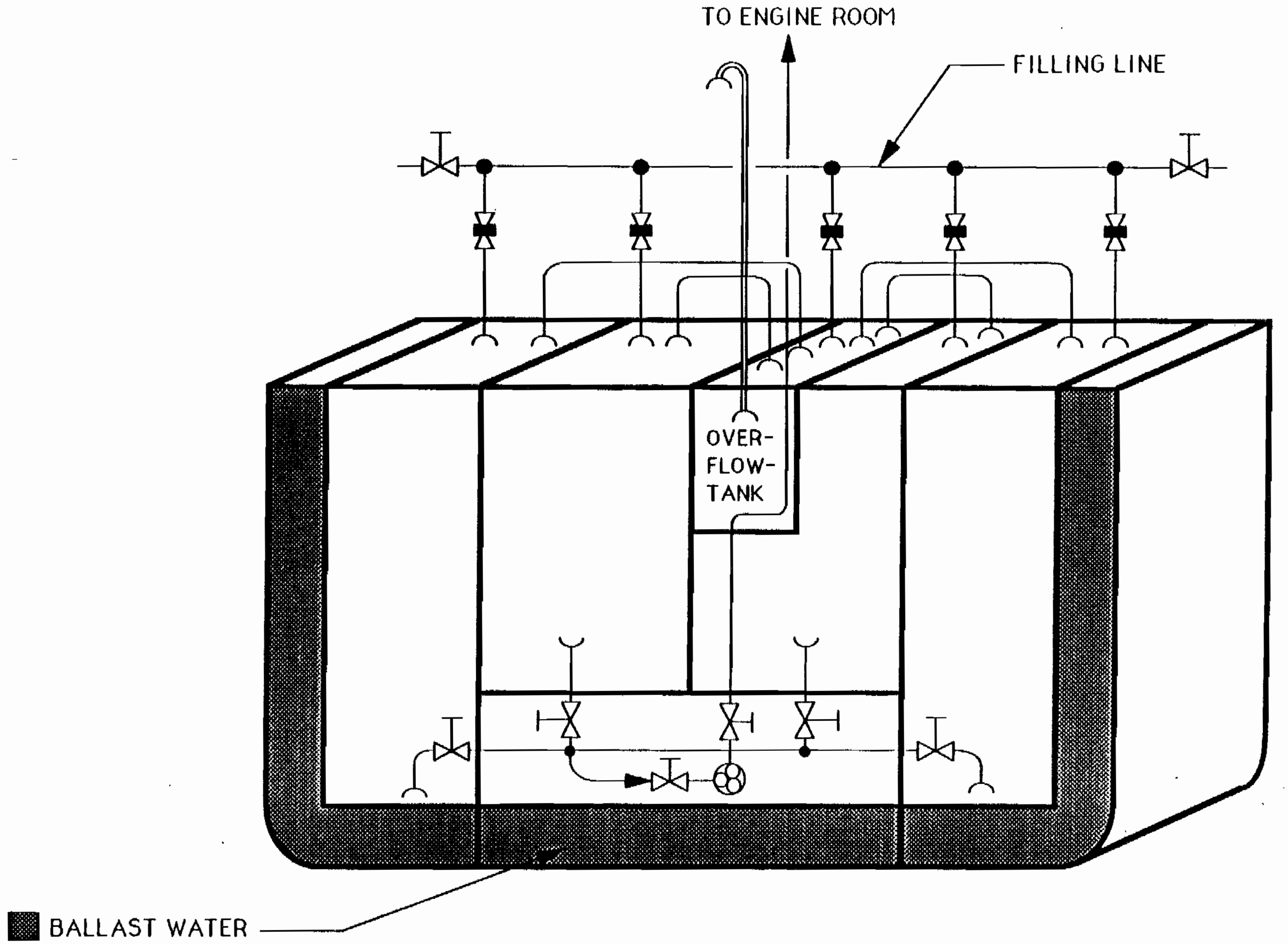
Today's shipboard bunkering and fuel problems can be solved, in a large part, with centralized bunker tanks. Figure V - 3 illustrates the centralized bunker tanks; furthermore, this arrangement protects the environment by reducing the probability of oil spills from collisions and groundings due to the double hull configuration.

Section V.4 - Automated Cargo Control System

An automated cargo control system will increase ship safety, decrease vessel turnaround time, reduce paperwork requirements, and decrease the probability of an oil spill. With this type of system, many existing problems are solved by using state-of-the-art system technology. Basically, data and control signals are transmitted between a cargo control console, two central computers and various system subpanels.

The cargo control console replaces all conventional tanker's remote control mimic board. The system includes multiple color cathode ray tube's (CRT'S), Operation Keyboards and one main system Keyboard. Having this hardware, the operator will be able to monitor the following functions simultaneously.

- Ballast piping valve lineup;
- Ballast and bunker tank levels;



CENTRALIZED BUNKER TANKS

FIGURE V - 3

- Cargo piping and vacuum-retaining valve status;
- Cargo and ballast pump status; and,
- Cargo tank levels.

By having multiple CRT'S, the operator can give the option to view drafts, trim and stress, cargo venting/IGS system lineup and scheduling information.

The cargo operations keyboards will help the operator perform the task of manually opening and closing valves, and control the speed of cargo, ballast and bunker transfer pumps. By having three keyboards, the operator will be able to control various systems simultaneously on the different screens. Special functions such as loading plan simulations, onboard calculations, and engine room flooding calculations, will be able to be performed under "Systems Keyboard", which has full alphanumeric capability.

Each computer on the main cargo system can independently perform all operations in which the subpanels provide an additional level of redundancy. For example, if the control for the cargo is lost, the operator has the capability to control all cargo related systems directly from the subpanels. In the backup mode, the operator can manually control all valves and pumps in a conventional manner.

In automatic mode, the system is designed to control the discharge or loading of the ship. For instance, when discharging in automatic control mode, the operator either inputs a new discharge plan or specifies a previously saved discharge plan. The simulation also provides a complete schedule for cargo, ballast and bunker transfer. If the simulation is acceptable, the operator will engage the system to automatically line up the cargo lines and start the pumps. From this point on, the system gradually increases the overall cargo pumping rate until either the maximum present discharge manifold pressure, maximum present transfer rate, or the cargo pump system capability is reached. The system then automatically monitors the manifold pressure or transfer rate, and controls the system to maximize the discharge rate throughout the operation. At the same time, pumping rates for each cargo tank are also individually controlled such that all tanks will finish up at exactly the same time (or subsequently if so desired by the operator). Automatic ballasting, crude oil washing, stripping and line draining operations are also provided.

During automatic operations, the operator must acknowledge certain key steps before the computer will proceed. Examples of computer controlled actions which must first be acknowledge by the operator include, opening of manifold valves, starting cargo or ballast pumps, closing tank fill valves, and initiating crude oil washing, stripping and line draining sequences.

The system also provides the following alarm-monitoring and error-checking functions, which are essential for maximizing safety:

- Comparison of actual cargo transfer rates to present limits;
- Comparison of actual manifold pressures to present limits;
- Comparison of actual measured vessel draft and trim to that calculated by the on-line system;
- Display of "time to full" or "time to empty" warning messages for all cargo and ballast tanks;
- Calculation of longitudinal trim and stress;
- Comparison of actual valve lineup to desired valve lineup; and,
- Displays the status of the cargo tank vacuum-retaining valves.

In order to reduce paperwork requirements, the system can automatically generate most of the documentation required for every voyage. The onboard computer in the vessel control center can transfer data to a shoreside computer for Customs, Immigration or the company's needs through onshore satellite communication (SATCOM), to further expedite vessel clearing. Figure V - 4 is a graphical representation of the automated cargo control system.

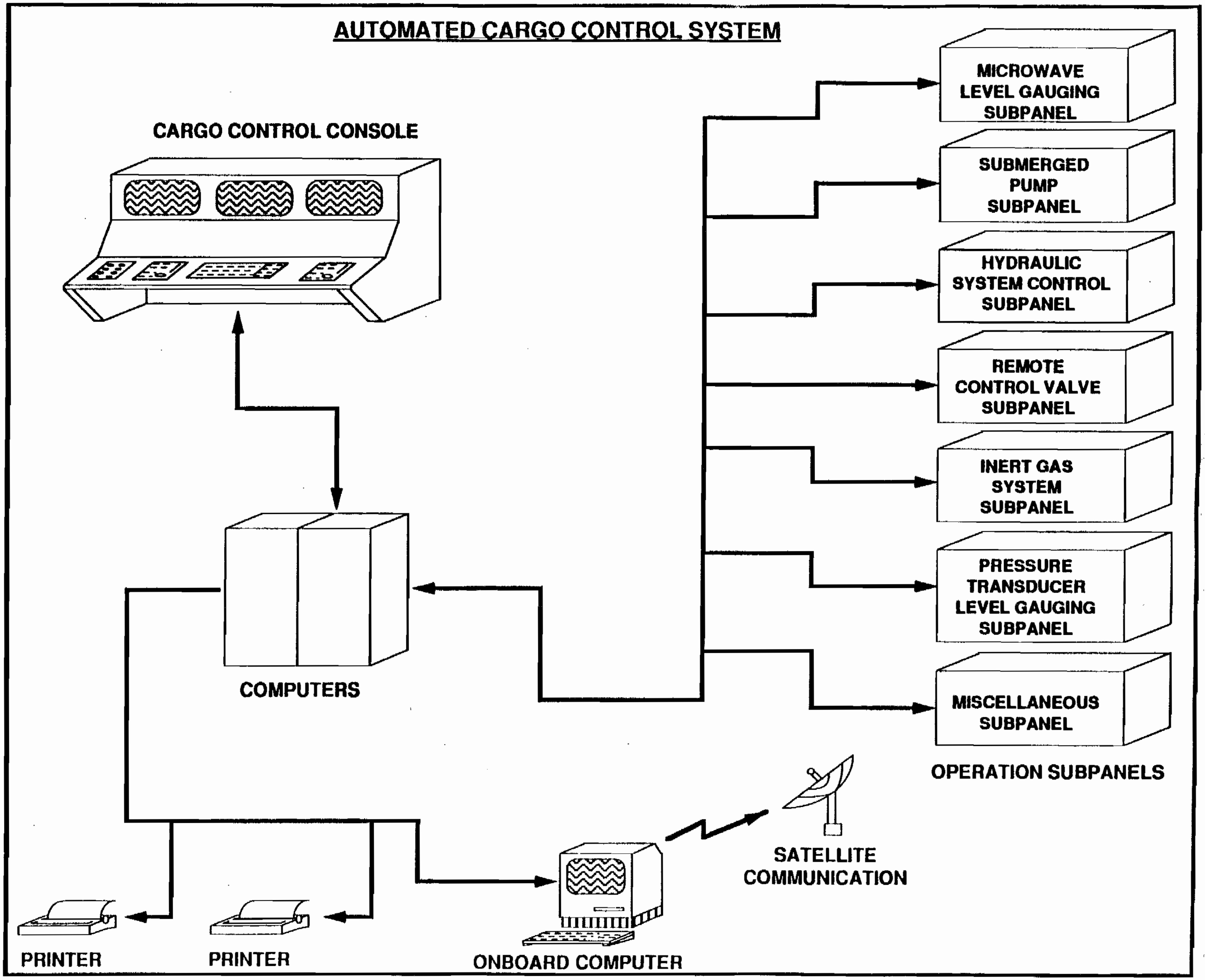

AUTOMATED CARGO CONTROL SYSTEM
CARGO CONTROL CONSOLE
COMPUTERS
MICROWAVE LEVEL GAUGING SUBPANEL
SUBMERGED PUMP SUBPANEL
HYDRAULIC SYSTEM CONTROL SUBPANEL
REMOTE CONTROL VALVE SUBPANEL
INERT GAS SYSTEM SUBPANEL
PRESSURE TRANSDUCER LEVEL GAUGING SUBPANEL
MISCELLANEOUS SUBPANEL
OPERATION SUBPANELS
SATELLITE COMMUNICATION
PRINTER
PRINTER
ONBOARD COMPUTER

FIGURE V - 4

Section V.5 - Auxiliary Thrusters

Berthing accidents account for approximately five percent of tanker oil spills and the magnitude of these oil spills is generally much smaller than the oil spills resulting from collisions or groundings. However, they occur in locations which suffer from frequent spills. Location, frequency and magnitude must all be considered when evaluating the effects of oil on water and marine life.

Figure V - 5 illustrates the turning moments versus speed of a 70,000 deadweight ton Cook Inlet tanker. With the rudder alone, at a full 35 degrees, it is shown that the turning moment at nine knots is approximately 43 million foot pounds; whereas, the turning moment at two knots is less than 4 million foot pounds - a reduction of over 90 percent. It is also shown that a 1500 BHP auxiliary thruster develops an average of 12 million foot pounds at berthing speeds - speeds below two knots. By combining the forces produced by the ship's rudder and the auxiliary thruster, a combined average turning moment of nearly 15 million foot pounds is produced at speeds below two knots. This is nearly four times the moment from the rudder alone.

The auxiliary thruster is hydraulically powered and designed for ice operations. The thruster's intake is at the bottom of the tanker and the port and starboard discharge nozzles are above the intake. This design varies from the standard single tunnel thruster which tend to become ice bound on the intake side of the thruster. This auxiliary thruster also acts as a backup device in the event of the loss of the propeller since the discharge nozzles are directed 15 degrees aft of the perpendicular to the centerline of the tanker. This means that an oil tanker with twin diesel engines powering a single propeller could lose one engine and the propeller and still drive the hydraulic unit with the remaining engine. The auxiliary thruster would increase the tanker's resistance in the water by approximately one percent at 14 knots. This added resistance would equate to a speed loss of approximately 0.05 knot.

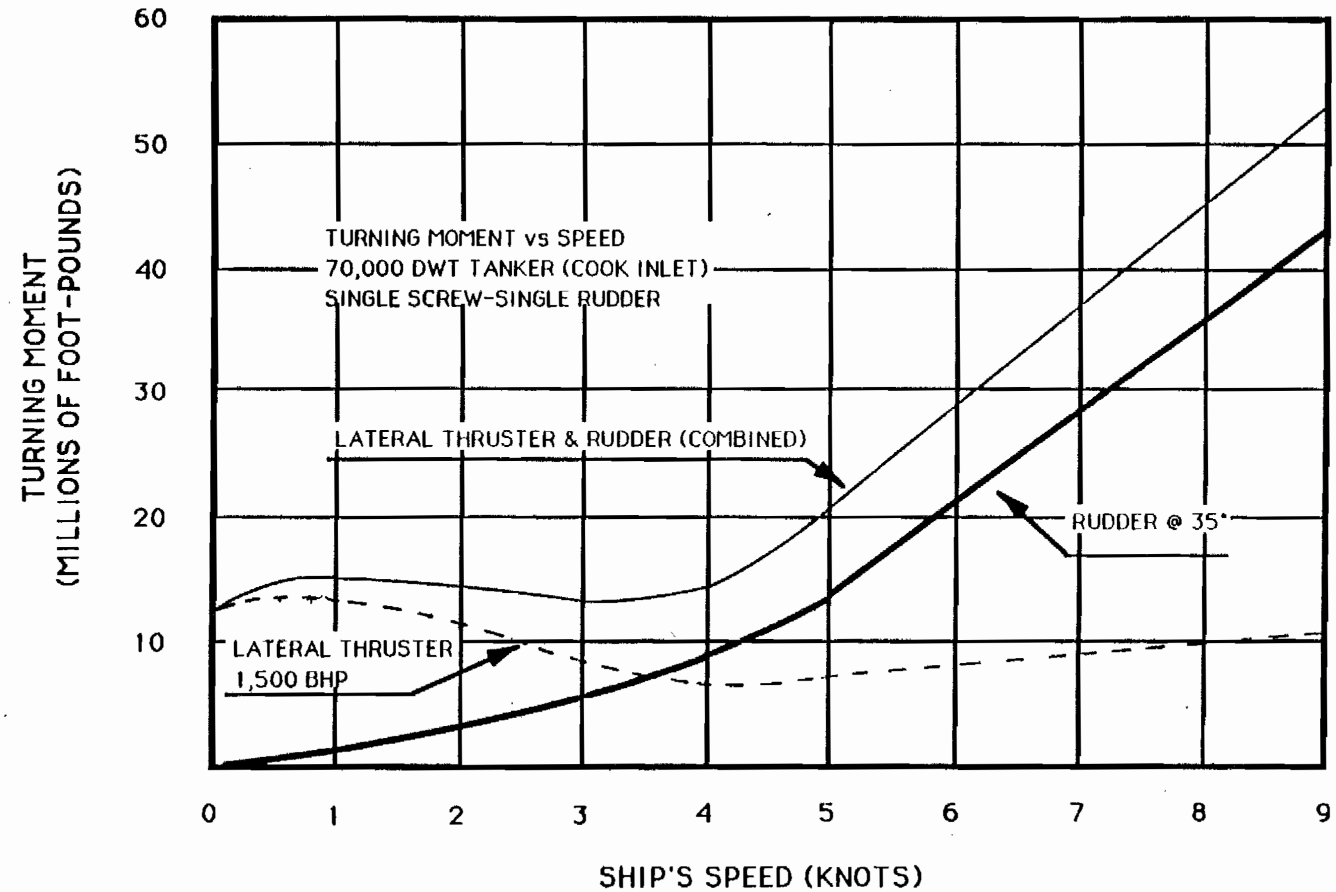

TURNING MOMENT vs SPEED
70,000 DWT TANKER (COOK INLET)
SINGLE SCREW-SINGLE RUDDER
LATERAL THRUSTER & RUDDER (COMBINED)
RUDDER @ 35°
LATERAL THRUSTER
1,500 BHP
TURNING MOMENT
(MILLIONS OF FOOT-POUNDS)
SHIP'S SPEED (KNOTS)
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9

FIGURE V - 5

Section V.6 - Precise Navigation Display System

A precise navigation display system is a computerized navigation and piloting system intended for use aboard vessels that navigate in harbors, along shores and coastal waters. It combines accurate positioning, radar and electronic charts on a single multi-color display, usable in full daylight without a hood. Its electronic charts are accurate replica of NOAA charts, stored internally in its own memory, including various scales and areas of coverage. Pre-computed routes for all intended journeys are maintained, usable as an aid to piloting along the way, and in maneuvering in harbors.

The system consists of a shipboard computer of medium performance, available off-the-shelf, a color monitor and a special control box. It can obtain radar targets for its display from a digital radar, and positioning from LORAN-C, GPS, and/or a satellite navigation system. A digital, raster scan radar, a gyrocompass or fluxgate compass, and a LORAN-C receiver capable of connection to the computer are integral parts of the system.

The electronic charts of the system form the background of its displays. Various scales can be selected, and they change automatically as the vessel moves along its track. The chart displays contain accurately placed aids to navigation, including buoys, fixed lights, and day beacons. Shorelines, channel edges, major depth contours, principal hazards and obstructions are all incorporated on the charts. A symbol representing the vessel moves in accordance with position determined by LORAN-C or GPS. A track of the vessel's previous positions is maintained, and can be recorded. Radar images of other vessels, buoys and other aids to navigation, and the shoreline are combined with the electronic chart, and tracks of moving vessels are visible. Radar echoes from buoys indicate whether or not they are at their charted locations. The charts can be used for voyage planning; setting waypoints automatically plots track lines and labels them with the courses and distances between the selected points. Labeled tracklines can be recorded for subsequent and repeated use. The bearing, and distance and time to reach selected buoys or waypoints can be continuously displayed. Any position can be entered and marked on the chart display. The ships position is continuously displayed and can be color coded with respect to being in safe waters.

Section V.7 - Improved Lifeboats

An oil tanker operating in Alaska waters could be equipped with free-fall lifeboats. Free-fall lifeboats are completely enclosed, easily accessible from the stern of the tanker and designed for use in rough seas or seas covered with burning oil. These lifeboats are launched in a free-fall mode from a ramp. They are equipped with a radio to transmit position data by an integrated navigation memory system. Distress signals are automatically transmitted on shipping and air distress frequencies. These free-fall lifeboats are already used extensively in the North Sea and have recently been fitted on two merchant vessels in the United Kingdom. The use of improved lifeboats would encourage the tanker's crew to stay with the ship in the event of a severe casualty. By staying with the ship until the last possible moment, the crew might be able to prevent an oil spill or minimize the amount of oil spilled in the waters of Prince William Sound or Cook Inlet.

Section V.8 - Cost of Improved Tankers

Figure V - 6 illustrates the increased cost of improved tankers based on the improved 70,000 deadweight ton Cook Inlet crude carrier and the improved 250,000 deadweight ton Prince William Sound crude carrier. Both of these crude carriers incorporate the engineering subsystems discussed within this section, with cost data verified by U.S. shipyards, and are governed by the following factors:

- Single ship bid from U.S. shipyard (Nov. 1989) with a 1992 delivery;
- Service speed is 14 knots;
- Designed for ice operations in Cook Inlet/Prince William Sound;
- Main propulsion - diesel engine(s); and,
- Hydraulic unit for auxiliary thruster and cargo pumps.

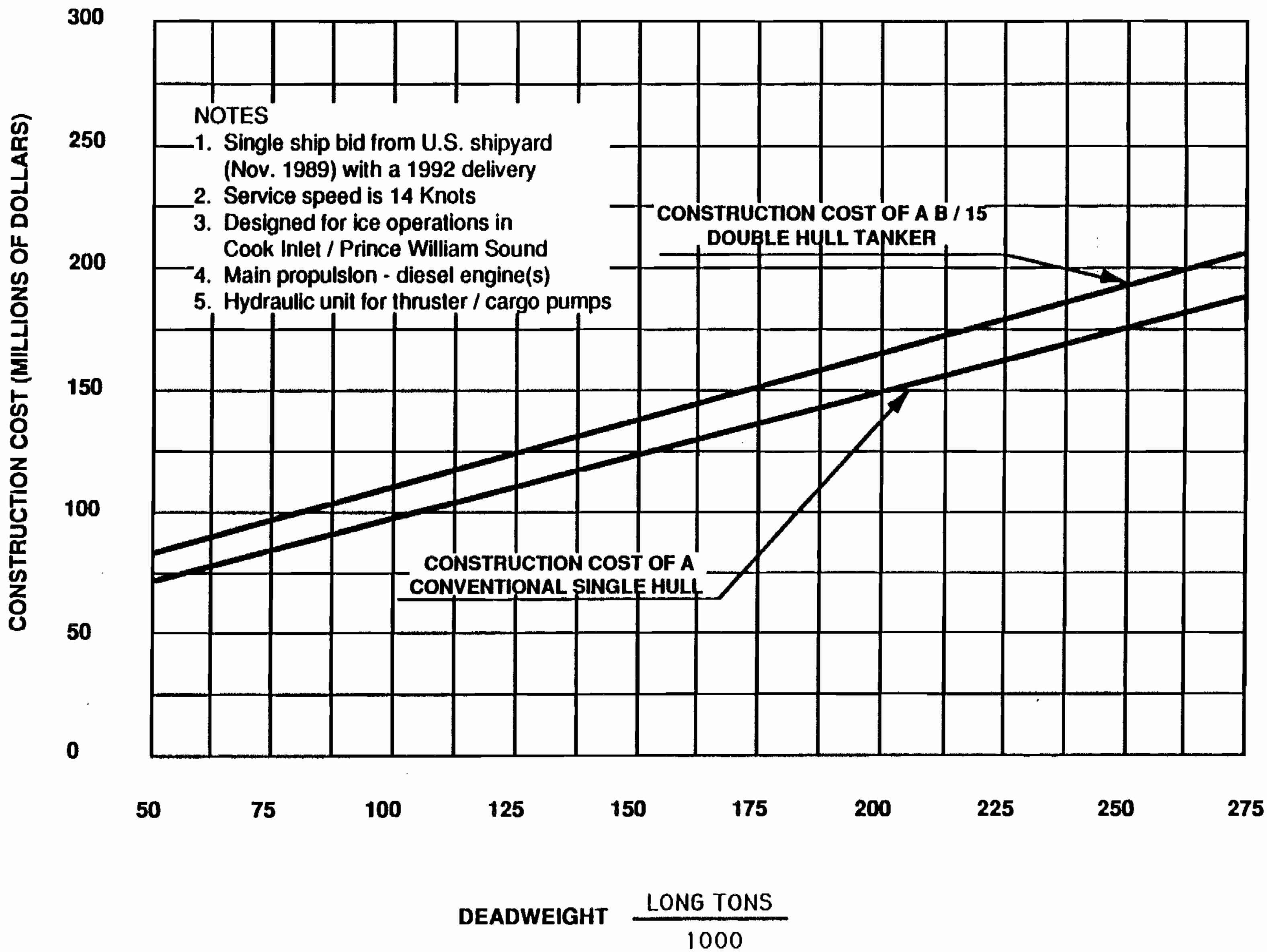

NOTES
1. Single ship bid from U.S. shipyard (Nov. 1989) with a 1992 delivery
2. Service speed is 14 Knots
3. Designed for ice operations in Cook Inlet / Prince William Sound
4. Main propulsion - diesel engine(s)
5. Hydraulic unit for thruster / cargo pumps
CONSTRUCTION COST OF A B / 15 DOUBLE HULL TANKER
CONSTRUCTION COST OF A CONVENTIONAL SINGLE HULL
CONSTRUCTION COST (MILLIONS OF DOLLARS)
0
50
100
150
200
250
300
50
75
100
125
150
175
200
225
250
275
DEADWEIGHT LONG TONS / 1000

FIGURE V - 6

Figure V - 6 also shows that the construction cost of a 70,000 deadweight ton, single hull tanker, is approximately 85 million dollars, whereas the cost of an improved B/15 double hull tanker (separation between the inner and outer hulls is the tanker's beam divided by 15), of the same deadweight, is 93 million dollars. This 8 million dollar increase in construction cost equates to a cost increase of 9.4 percent for the Cook Inlet crude carrier.

From the same graphic, it is shown that the cost of a 250,000 deadweight ton, single hull tanker, is approximately 175 million dollars, whereas the cost of an improved B/15 double hull tanker, of the same deadweight, is approximately 192 million dollars. The computed cost increase of 17.2 million dollars equates to a cost increase of 9.8 percent for the Prince William Sound crude carrier.

CHAPTER VI - SYSTEM EFFECTIVENESS AND ECONOMIC ANALYSIS

Section VI.1 - Introduction

This chapter will discuss the modifications required within Cook Inlet and Prince William Sound to provide a substantially increased level of safety for those ports and the economic impact of those modifications. The discussion will include:

- A description of the modifications to be implemented and their costs; and,
- The effect those modifications will have on the safety of the port.

Section VI.2 - System Modifications

The determinations of specific system modifications have been developed in the following manner:

- Analysis of marine transportation systems elements, corresponding deficiencies, and potential mitigating solutions;
- Analysis of recommendations presented to the Alaska Oil Spill Commission through public submittal; and,
- Analysis of suggestions developed by Commission members as a result of submittals and personal investigations.

The modifications for improving the safety of the ports have been divided into three groups, categorized in terms of the time factor of their implementation.

Group I modifications are those that can be expected to be implemented in the near or immediate future. They include the following:

- Mandatory drug and alcohol testing;
- Training for emergency operations and high-risk navigation areas;
- Port restrictions/Port closure system;

- Two person watchstanding requirement;
- Improved loading/unloading procedures;
- Local involvement in spill cleanup/prevention; and,
- Spill response equipment coordination.

Group II Modifications are those which rely on systems which are more or less available at the present time, but whose acquisition and/or installation, and therefore effectiveness, will occur over an intermediate time frame. These systems include:

- Vessel monitoring system;
- Mandatory traffic lanes and traffic separation scheme;
- Mandatory designated anchorages;
- Emergency response and pollution control vessels; and,
- Improved loading/unloading designs.

Group III modification is the requirement for improved tanker design which is expected to occur over an extended period of time as new tankers are constructed.

Potential costs for the implementation of the system modifications are given for each modification in terms of either: cost per vessel; one time acquisition cost; development costs; and/or annual costs. The costs were developed using the following assumptions:

- Personnel costs are based on a person-year of $100,000 which includes base pay and overhead costs;
- Acquisition costs of equipment are based on published prices for the equipment or systems or similar equipment or systems; and,
- Development costs, analysis costs and policy costs are based on costs for similar completed projects.

VI.3.1 Mandatory Drug and Alcohol Testing Drug and alcohol testing for all personnel involved in tanker operations, including state pilots, will be initiated. The primary effort will be directed towards compliance with applicable regulations promulgated by the U.S. Coast Guard and other agencies authorized to regulate shipping. In addition, each terminal operator will be responsible for insuring that testing is performed on any vessel personnel entering their terminal facilities whenever reasonable cause exists to suspect intoxication. Test results showing a blood-alcohol content in excess of 0.04 will result in denial of access to the terminal facility.

The program will require random testing procedures and record maintenance activities to ensure that all personnel sailing in Alaskan waters are participants. The voluntary cooperation of terminal operators may prove unwieldy in the face of shipper pressure when enforcement affects the ability of a ship to sail on schedule. It is likely that the State will be required to take an active role in the implementation and enforcement of drug and alcohol testing, with the associated personnel and test procedure costs that would result from that involvement.

Potential Costs It is possible to define various situations under which the State might be involved in the drug and alcohol testing program in concert with federal agencies and commercial entities. Without exact knowledge of the operations of other agency programs, it is difficult to forecast any shared program costs. However, an estimate can be derived from costs that would be incurred by the system as a whole. The following is an estimate of those costs:

• Testing costs at a local hospital/clinic - Per ship ($100/person)	$4,000 per year
• Database development and maintenance- One-half man-year	$50,000 per year
• Periodic terminal investigation- One-half man-year	$50,000 per year

VI.3.2 Training for Emergency Operations, and High-risk Navigation Areas Accidents usually develop through relatively long sequences of changes and errors. Each of the large number of causal factors present in an accident situation offers the potential for correction - elimination of any one of those factors will usually interrupt the sequence of events and prevent the accident from occurring. The operator's ability to detect a situation going awry as early as possible must be improved in order to minimize accidents. In order to promote the recognition of errors, ship operators should occasionally be exposed to accident situations in a training environment. This training would reinforce the ship operator's knowledge in these situations of potential recovery and contingency actions.

Training in accident situations should be required of all deep draft shiphandlers on a periodic basis. Various schools in the continental U.S. and elsewhere have developed training programs emphasizing this type of training and they are regularly used by ship operators to improve their skills. In addition, the State could develop its own training facility in conjunction with its university complex to provide the necessary training within the State. The training would emphasize the team training concept adopted by most schools and utilize real-time simulation facilities which are becoming reasonably inexpensive with the proliferation of microprocessor technology. It is envisioned that the training course would consist of a five-day course limited to four to five individuals in each class to maximize interaction and hands-on training.

Potential Costs The costs involved would include the following:

• Acquisition and installation of the simulator-	$300,000
• Courseware development -	$100,000
• Instructor -	$100,000/year
• Student -	$500/course

VI.3.3 Port Restrictions/Port Closure System Environmental conditions within Cook Inlet and Prince William Sound are sometimes unsafe for tanker operations. The U. S.

Coast Guard has the authority, to close the port or to restrict traffic within the port when it feels that conditions create an undue risk to navigation. This modification proposes to formalize the circumstances that lead to the decision to close or to restrict the port through two changes to the present method. The first would be to systematically determine the minimum environmental conditions that must exist before traffic is allowed to transit the port. The methodology of setting this minimum criteria can take a number of paths, either as sophisticated as real-time simulation or as straightforward as developing consensus among shipping interests.

The second change would be the appointing of a "state harbormaster", a civilian with extensive experience in shipping in the local area, such as a senior state pilot, who would, in conjunction with the Coast Guard, apply the criteria for closing or restricting the port. Either the Coast Guard or the state harbormaster would be able to close the port or to restrict operations within the port.

Potential Costs The costs of this program are expected to be minimal. Port closure/restriction criteria can be quickly developed due to the close interaction among shipping industry personnel and the acknowledged importance of improving the safety of the marine transportation system. It is expected that the harbormaster post would be combined with other duties, such as within the Vessel Monitoring System, to minimize that cost. An annual report of port closure/port restriction should be required. An estimated total cost should not exceed $10,000 annually.

VI.3.4 Two Person Watchstanding Requirement Standard practice within the shipping industry is to provide two qualified watchstanders on the bridge and in the engine room during transits of restricted waters. The rationale for that practice is very clear in that, at such times, it is not possible for one individual to absorb all the information required, perform calculations on that information - both manual and intuitive, and take the correct action in a timely fashion to maneuver the vessel in a safe manner. Among the major causes of accidents involving human error is the inability, for a variety of reasons including faulty information, inexperience, and poor perception, to correctly interpret the situation that the vessel is encountering and to take effective action in time. Two qualified watchstanders can divide the information and calculation load and provide support for correct and timely decision-making. The standard practice is, therefore, well established. However, history has proved that either the standard practice is disregarded at times, or the definition of restricted waters is subject to opinion. The requirement that there be two qualified watchstanders on the bridge and a licensed engine room officer along with a QMED in the engine room at any time a tank ship is north of Kennedy Entrance and Hinchinbrook Entrance should be made mandatory.

The preferred bridge watchstanders would be a state pilot and qualified shipboard individual. It is understood as discussed in Chapter II, that the state pilot is not able to board the incoming vessel until some time after the boundary line suggested above has been crossed. Prior to the boarding of the pilot, the requirement would be for two qualified individuals from the ship's complement.

Multiple watchstanders would provide an additional element of safety. In the event of incapacitation of one of the individuals, the other would be able to operate the vessel while assistance was forthcoming. Further, in an emergency situation, additional trained hands are already functioning in a backup or assist mode to take on some of the added tasks during those critical periods.

Potential Costs It is possible that the extended voyage time required by the boundaries of mandated requirements exceed that of "standard practice". Two hours of additional overtime are estimated to be required to meet this proposed standard. The estimated cost is $350 per voyage per ship.

VI.3.5 Improved Loading/unloading Procedures Oil spills resulting from the loading and unloading of cargo historically account for a large percentage of all oil spills. The oil industry is continually seeking improvements in the procedures by which oil is transferred, and in the development of training programs and methodology to improve the performance of the individuals involved in oil transfer. Annual reviews of terminal practices should be undertaken to ensure that the terminals are instituting programs on a regular basis to provide the highest level of training and subsequent performance.

Potential Costs Annual review of loading and unloading procedures and training is estimated to consume one person-month per year at a cost of approximately $10,000. No increase in training cost is expected as improved training would replace existing efforts. The initiation of improved procedures would probably result in an economic benefit to the system.

VI.3.6 Local Involvement in Spill Cleanup and Prevention The lack of a qualified workforce in a response effort may hinder the situation greatly, as did occur in the EXXON VALDEZ spill. Having state of the art equipment but not having the personnel to operate that equipment detracts significantly from the effort. Local organizations and communities have a vested interest in the response effort and should be trained and equipped to assist in all phases of the response effort. The Alyeska Contingency Plan includes the establishment of Community Response Centers which will be trained and equipped by Alyeska to assist in the spill response. This type of organization should be expanded to include participation throughout the spectrum of spill response. Similar arrangements of organization exist in Alaska in accordance with the Incident Command System for natural disasters. This arrangement could reasonably be expected to function in oil spill response as well. It is expected that these organizations would be trained and organized by, and in conjunction with, oil industry spill organizations and that they would participate in spill response exercises.

Implementation of this modification will require the following steps:

- Determining where these community groups and organizations fit within the response organization, based on credible scenarios of the spill event, and specifically defining the goals of their utilization, their allocation to specific priorities, and their reporting and information responsibilities;
- Identification of community groups and organizations;

- Determination of training costs, organizational maintenance costs, and the source of funding for those costs;
- Development of a training curriculum and schedule; and,
- Determination of the training organization.

Potential Costs The costs for developing the local organization participation fall into four categories and are estimated as:

• Training program development	$100,000
• Training coordinator	$100,000/year
• Training sessions	
Offshore response training	
Two days/year/100 boats	$50,000/year
Onshore cleanup training	included in training coordinator
• Annual spill response exercise	$50,000/year

VI.3.7 Spill Equipment Coordination The ability to obtain and deploy resources quickly has been shown to be critical to the mitigation of damage due to the spill event. The spreading of the oil slick was shown in Chapter IV to quickly overwhelm the oil spill response effort in the event of a major spill. The acquisition of large, capable spill recovery systems, particularly those which can operate independently with onboard storage is very costly, and unfortunately becomes cost-effective only on the occasion of a major spill event. Alyeska's commitment in acquiring response resources since the EXXON VALDEZ spill probably could not be borne by any other port in the U. S. without significant public participation or industry wide acquisition.

Alaska has unique problems in bringing response assets to bear on a spill incident, not the least of which is its distance from significant stores of equipment. The airport structure in the Cook Inlet area is superior to that existing in Valdez, affording better access to worldwide equipment, but the deployment of outside equipment is still probably to be measured in days rather than hours after the spill event. Even with rapid acquisition of equipment from outside the state, limited resources for deployment, such as deployment vessels and storage facilities, would prevent its effective use. The owners of oil spill response equipment in Alaska should consider an oil spill in Alaska waters to be an industry problem, and enter into cooperative agreements that ensure that spill response equipment is made available to the spill event and not limited to a specific area.

It is probable that the state of Alaska, and possibly the federal government, would have to become a party to such an industry agreement in order to allow for the release of equipment from its dedicated use without the halting of other activities. Alyeska, for instance, has committed to have a certain amount of resource equipment on hand and in a state of readiness at all times that the port is operating. The release of any part of that equipment may force the port to shut down as its commitment has been breached. The State would have to concur with the release of that equipment, while leaving the port of Valdez open to traffic. Specific agreements spelling out the circumstances under which that series of events can occur, along with safeguards for continued safe and ensured operations, should be quickly sought out and implemented.

In addition, the state of Alaska should pursue enhanced procedural methods for obtaining and utilizing Federal spill response assets. Currently, certain triggering events must occur prior to the deployment and use of these assets. Those triggering events must be identified prior to the spill event and facilitating agreements must be developed to ensure acquisition and deployment immediately upon notification of a spill event. This is not a problem unique to Alaska, but one which concerns all coastal states. The occurrence of a major spill should immediately put these assets on notice, and it should initiate the process of transporting these assets to the event site.

<u>Potential Costs</u> The basic concepts involved in this proposed modification could be expected to consume one-half man-year of government staff time.

Section VI.4 - Group II Modifications

VI.4.1 Vessel Monitoring System The development of a Vessel Monitoring System (VMS) would provide a direct management tool in ensuring that vessels entering and transitting a port area follow transit patterns that lead to safe passage. Under the proposed system, both onshore and shipboard watchstanders would be able to monitor the ship's progress relative to predetermined shipping lanes and, potentially, other traffic. The system uses the LORAN-C information on the vessel and transmits that information to both a land based monitoring station and to electronic navigation equipment aboard the ship. The information so transmitted would be displayed on computer graphic screens which would show the ship's position on the screen along with other pertinent data on the ship's transit. Two way communication via the data screen would be possible as well as alarms relating to predicted movement and associated risk. Other sensor input, such as direct gyro read-out and integration with digital radar, also could be possible.

The VMS would consist of a shoreside module and an individual ship module, and is pictorially described in the block diagram in Figure VI - 1. The shoreside module would be located in existing facilities in Cook Inlet and Valdez and would include the following items:

- A LORAN-C Surveillance System to automatically receive the position, and sensor information from all vessels of interest. The transmit interval for each vessel can be changed to any interval so that interrogations could be made more frequently when conditions warrant, and less frequently at other times.
- A Graphic Display System that provides vessel trackline and sensor information based on the vessel's transmitted information. The trackline is displayed on a electronic chart of the port area along with other pertinent information including projected track. Decision management software will be available to provide early warnings of potential deviations from safe transit patterns and to record the trackline and maneuvering for future interrogation and study and as potential training exercises.

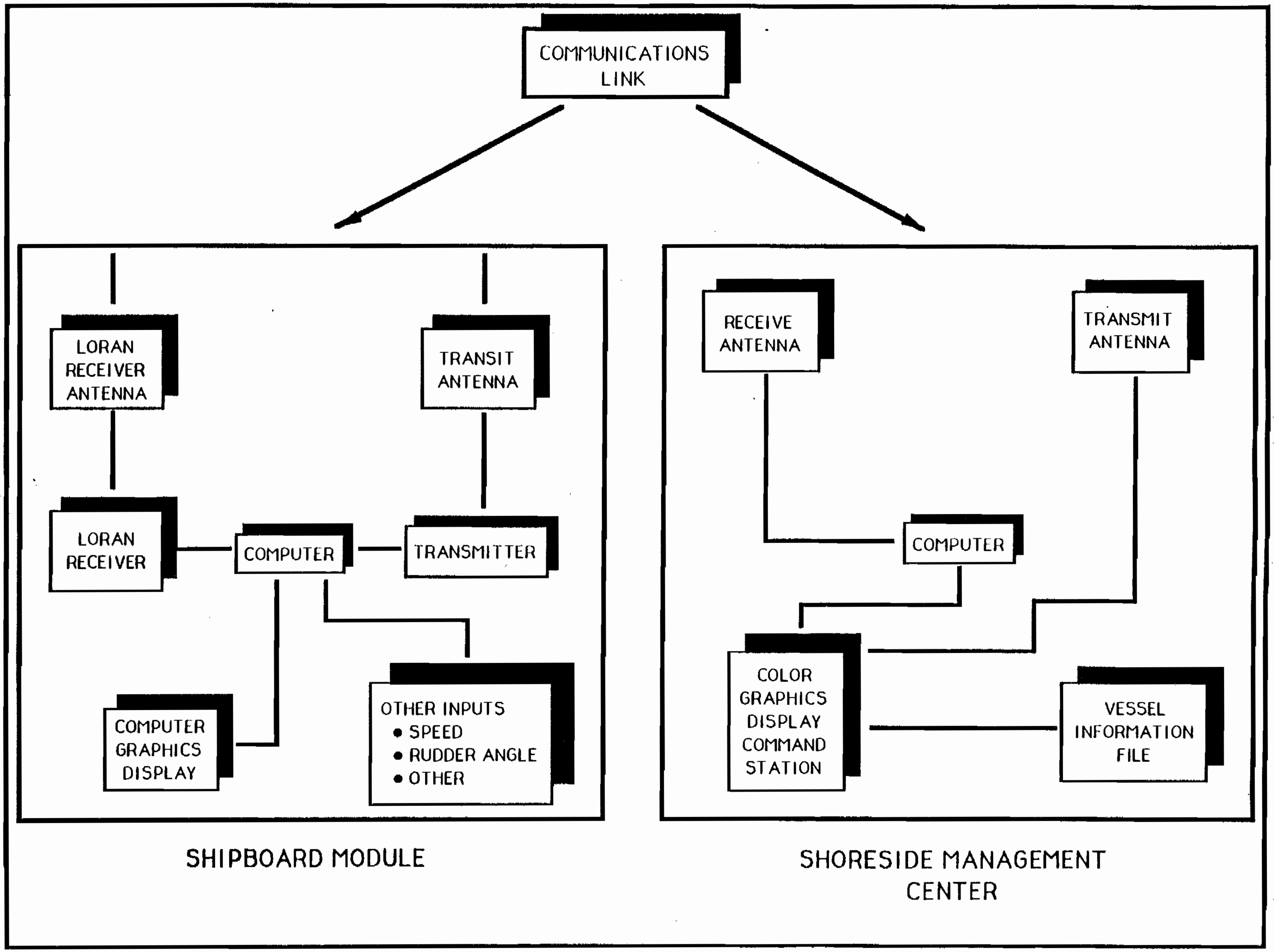


FIGURE VI - 1 VESSEL MONITORING SYSTEM

The vessel module will consist of a LORAN-C receiver, a transceiver communications system for transmitting the LORAN-C signal and other sensor information, and a graphic display computer for control, interface, storage, and display in conjunction with electronic navigation chart software. A fuller description of the system is given in Chapter V.

Each ship that enters Cook Inlet and Prince William Sound would be required to have a vessel module onboard. Similar systems are becoming commonplace at sea as an aid to the navigation of vessels, improving performance without additional manpower.

The shoreside or base station would be manned by experienced deep draft mariners on a twenty-four hour basis. These individuals would be civilian employees of the Coast Guard, and they would be required to undergo significant training in the operation of the VMS as well as having extended emergency and accident scenario training. This training would enhance their ability to sense intuitively when the situation is starting to go awry.

Potential Costs

• Shoreside Station	
VMS System	$400,000
Watchstanders	
Four watchstanders with one Officer In Charge	$500,000/year
Operating Cost	$50,000/year
• Vessel Module	$30,000/vessel

VI.4.2 Mandatory Traffic Lanes and Designated One-way Traffic Areas Traffic lanes for inbound and outbound traffic should be designated based on preferred passage routes that are deemed to provide the highest level of safe passage. In areas where traffic separation is not possible due to width of channel or high risk of navigation, one way traffic areas should be designated. These lanes have been designated for Prince William Sound, and similar configurations should be developed for Cook Inlet.

Passage using these traffic lanes should be mandatory to and from the port area for deep draft vessels, unless specific instructions to the contrary are given by the VMS on a vessel by vessel basis. The traffic lanes will be an integral part in the active monitoring role of the VMS and casual use would result in ineffective performance and degradation in the level of safety within the respective port.

Potential Costs The establishment of the traffic separation scheme in Cook Inlet would be largely administrative in nature but may require the performance of a systems study prior to its implementation. Costs for that study should be no more than $30,000 unless simulation is required. An in depth simulation study would be possible for less than $100,000 if that alternative is required. State costs for administrative expenditures for implementing the traffic schemes and for instituting mandatory requirements should not exceed one-half man-year.

VI.4.3 Designated Anchorages Designated safe anchorages should be determined to ensure that the risk of an anchored ship being hit by a transitting ship deviating from the channel is minimized. These anchorages should also minimize the risk of a ship going aground while anchored or while going to or from the anchorage. U.S. Coast Guard designation will be required, and, depending upon survey information, additional surveys may be required for those areas.

Potential Costs The provision of designated anchorages should be accomplished with a minimal cost, in the area of $50,000 depending on survey requirements. It is unknown at this time if this cost is within current budgets or will require separate funding.

VI.4.4 Emergency Response and Pollution Control Vessels The ability to have vessels available and equipped to react to a vessel accident adds substantially to the safety of a port area. That vessel's ability to function as an immediate pollution response vessel, in the event of a spill resulting from an accident, will have a significant mitigating effect on the damage resulting from the spill. Three of these vessels have already been deployed in Prince William Sound and are presently being used as escort vessels. The addition of these vessels to the Prince William Sound operating procedures has raised the safety of that port demonstrably by providing additional navigational guidance, offering expeditious towing assistance, and having on-site containment boom and oil recovery devices.

Similar capability should be provided in Cook Inlet. Emergency response/pollution control vessels could be provided in a standby mode, with one vessel in northern Cook Inlet in the vicinity of Nikiski and one in southern Cook Inlet in the vicinity of Kachemak Bay. As an alternative, a vessel could be assigned to actively escort every crude carrier in Cook Inlet, similar to operations now occurring in Prince William Sound.

Potential Costs The following are the estimated costs for providing the emergency response and pollution control vessels:

• Vessel acquisition costs	
Two vessels at $3,000,000 each	$6,000,000
• Pollution response equipment	
$500,000 per vessel	$1,000,000
• Annual operating cost for two vessels	$2,200,000

VI.4.5 Improved Loading and Unloading Facility Design It is expected that all the facilities in Cook Inlet and Prince William Sound will update their loading facilities as new and improved designs are developed. The concepts of those designs are presented in Chapter V and can be seen to offer an increased level of spill prevention. The incorporation of these designs are felt to be part of the continual maintenance and upgrading of the facilities in question and that potential costs will be part of that budgetary consideration.

Section VI.5 - Group III Modifications

The Group III modifications involve changes to the present design of tank ships to take advantage of improvements in the vessel's capability to minimize the probability of an accident and to mitigate the effects of a spill incident if an accident occurs. A complete discussion of that design is provided in Chapter V. Improvements in the proposed tanker design include the following:

- Double hull construction with separation between the inner and outer hulls of 1/15 of the beam of the vessel or 6.56 feet (2.0 meters) whichever is greater;
- Centralized bunker tanks;
- Automated cargo control system;
- Auxiliary thrusters;
- Precise navigation display system; and,
- Improved lifeboats.

<u>Potential Costs</u> The additional cost for a tanker built to the standards of the design described in Chapter V are:

• 70,000 DWT tanker for Cook Inlet	$8,000,000
• 250,000 DWT tanker for Prince William Sound	$17,200,000

Section VI.6. - Cost Analysis of Group Modifications

The costs associated with the modifications discussed above are presented in summary in Table VI - 1 for Cook Inlet and Table VI - 2 for Prince William Sound. The costs are divided into the following categories:

- Acquisition cost - the initial cost of obtaining equipment, facilities, and regulatory changes and management procedures to allow implementation of the system modification;

TABLE VI - 1 COSTS ASSOCIATED WITH COOK INLET MARINE TRANSPORTATION SYSTEM MODIFICATIONS

SYSTEM MODIFICATION	ASSOCIATED COSTS				
	Acquisition Costs	Annual Operating Costs	Vessel Specific Costs	Cost per Barrel	Cost per Gallon
GROUP I					
Mandatory Drug and Alcohol Testing Emergency and High-risk Navigation Area Training Port Restrictions/Port Closure System Two Person Watchstanding Requirement Improved Loading/Unloading Procedures Local Spill Cleanup/Prevention Involvement Spill Response Equipment Coordination	$550,000	$420,000	$25,000	$0.020 (a)	$0.001
GROUP II					
Vessel Monitoring System Traffic Separation Lanes with One-Way Traffic Designated Anchorage Areas Emergency Response/Pollution Control Vessels Improved Loading/Unloading Designs	$7,400,000	$2,750,000	$30,000	$0.147 (a)	$0.003
GROUP III					
Improved Tanker Design			$8,000,000	$0.043 (b)	$0.001
TOTAL COSTS	$7,950,000	-$3,170,000	$8,055,000	$0.210	$0.005

(a) Based on 26,000,000 barrels oil throughput per year in Cook Inlet
(b) Based on 26,000,000 barrels annual tonnage carried by 75,000 DWT tanker

TABLE VI - 2 COSTS ASSOCIATED WITH PRINCE WILLIAM SOUND MARINE TRANSPORTATION SYSTEM MODIFICATIONS

SYSTEM MODIFICATION	ASSOCIATED COSTS				
	Acquisition Costs	Annual Operating Costs	Vessel Specific Costs	Cost per Barrel	Cost per Gallon
GROUP I					
Mandatory Drug and Alcohol Testing					
Emergency and High-risk Navigation Area Training					
Port Restrictions/Port Closure System					
Two Person Watchstanding Requirement	$550,000	$420,000	$25,000	$0.001 (a)	$0.000
Improved Loading/Unloading Procedures					
Local Spill Cleanup/Prevention Involvement					
Spill Response Equipment Coordination					
GROUP II					
Vessel Monitoring System					
Traffic Separation Lanes with One-Way Traffic					
Designated Anchorage Areas	$7,400,000	$2,750,000	$30,000	$0.007 (a)	$0.0002
Emergency Response/Pollution Control Vessels					
Improved Loading/Unloading Designs					
GROUP III					
Improved Tanker Design			$17,200,000	$0.056 (b)	$0.0013
TOTAL COSTS	$7,950,000	$3,170,000	$17,255,000	$0.064	$0.0015

(a) Based on 639,000,000 barrels oil throughput per year in Prince William Sound
(b) Based on 43,750,000 barrels annual tonnage carried by 250,000 DWT tanker

- Annual operating costs - the yearly costs that will be incurred to maintain and/or operate the system modification;
- Vessel specific costs - those costs which will affect each vessel utilizing the port area for the transport of oil;
- Cost per barrel - the above costs calculated on a per barrel basis. Acquisition costs have been annualized at interest rate of 12 percent and an economic life of 15 years; and,
- Cost per gallon - the costs calculated on a per gallon basis.

Table VI - 1 shows that the cost of the system modifications for Cook Inlet is $7,950,000 for the acquisition of the systems with an annual operating cost of $3,170,000. Vessel costs will be $8,055,000 per vessel for the vessels incorporating the design described in Chapter V. The overall cost will be $0.21 per barrel or about one-half cent per gallon.

In Prince William Sound, acquisition costs and operating costs are $7,950,000 and $3,170,000 respectively, with the vessel specific costs increasing to $17,255,000 due to the larger size of tank vessel that transits those waters. Prince William Sound's larger oil throughput results in a cost per barrel of $0.064 and per gallon of $0.0015.

Section VI.7 - System Effectiveness

The system modifications discussed above will result in a significant reduction in oil spills within the port systems. The reduction associated with each modification was developed using the methodology described below.

VI.7.1 Effectiveness Methodology

As discussed in Chapter Two, Hazard Assessment, oil spills from tankers result from six types of accidents: collisions, groundings, rammings, structural failures, breakdowns, and fires and explosions. The system modifications discussed above can reduce the occurrence of one or more of these accident types depending on the particular effect of the modification. For instance, "Designated Anchorages" would have an effect on rammings and groundings but not on the other accident types, while "Improved Tanker Design" affects all accident types.

The procedure for applying the system modifications factors is shown in Figure VI-2. The distribution of spill incidents is derived from worldwide tanker spill incidents as described in Section II.6. The modification is then compared to these spill incidents by accident type to determine if the modification has an effect or not. If the modification has an effect, that effect is quantified and that spill incident data reduced accordingly for that accident type. Quantification of the effect was determined through interrogation of the extensive literature of systems and engineering analysis of vessel accidents, and real-time simulation of vessel operations. This process continues through all accident types and system modifications for each group, and the results are then aggregated by group. These results are presented in Figure VI -3 which shows the oil spill incidents remaining after application of each group system modification. Figure VI - 4 provides the same information by spill incident type.

Table VI - 3 provides the results of the effectiveness methodology in tabular form aggregated by group. As can be seen from that table, Group I modifications will have an effectiveness of 14 percent in reducing accidents, while Group II modifications have a combined effectiveness of 41 percent. The effectiveness of improved tanker design is found to be 55 percent. The cumulative reduction in oil spills due to the combination of the three groups is approximately 77 percent. These reductions are shown graphically in Figure VI - 5 which also provides some guidance in the time frame in which those reductions take place. Group I modifications are expected to affect the oil spill rate in the immediate future, while Group II and Group III modifications will take place over a longer time period as systems are acquired and installed and new vessels constructed and placed in service.

Applying the modification factors to the historical spill rates developed in Chapter II, it is possible to project the reduction in spill incidence rate per port call and in the recurrence interval between spills for each port area. Table VI - 4 shows the projected

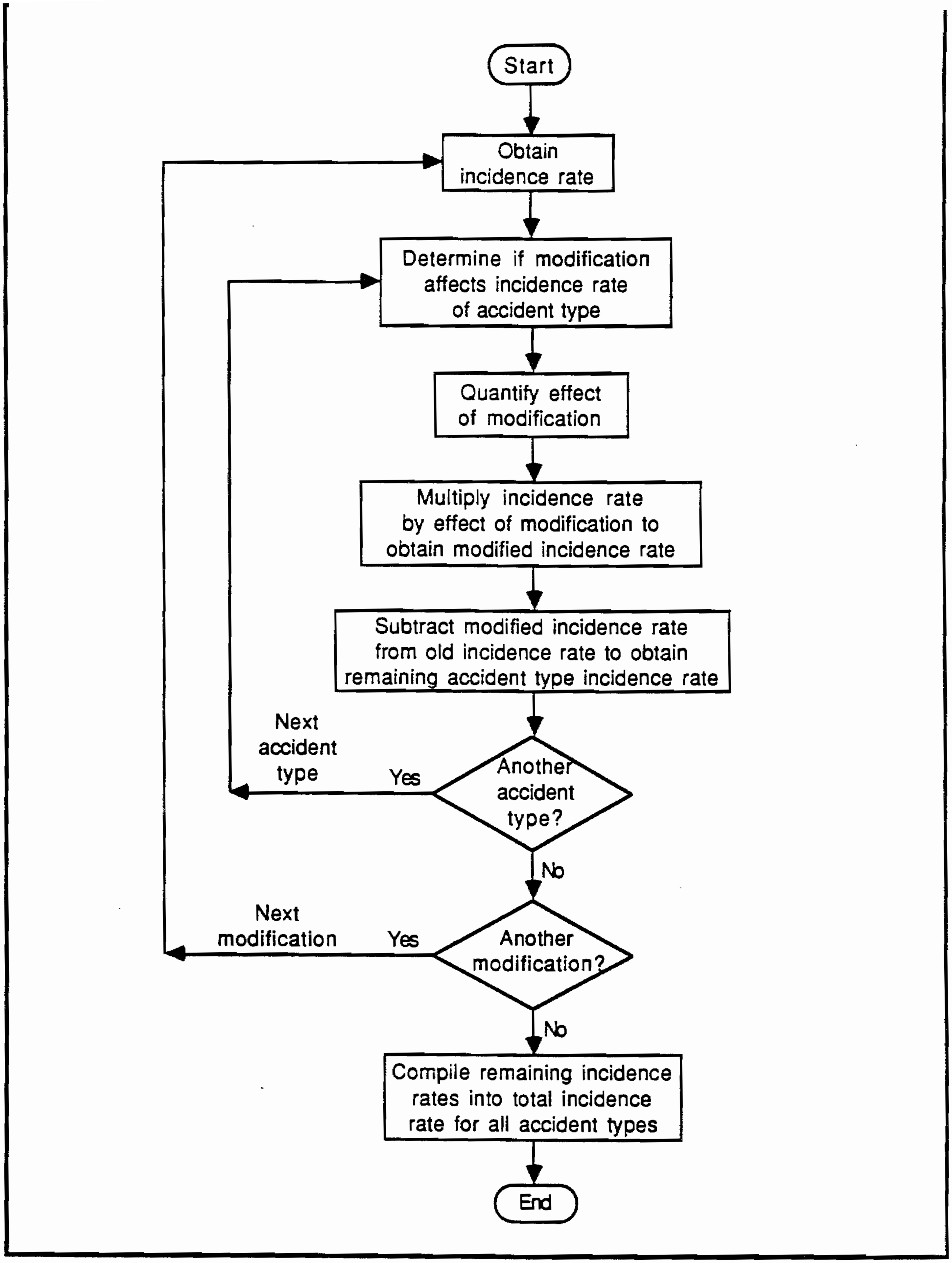
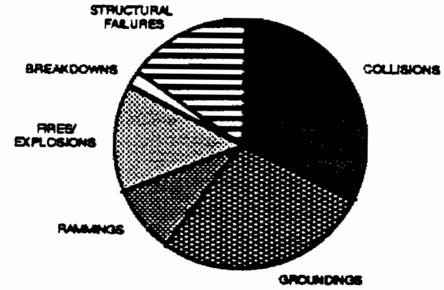
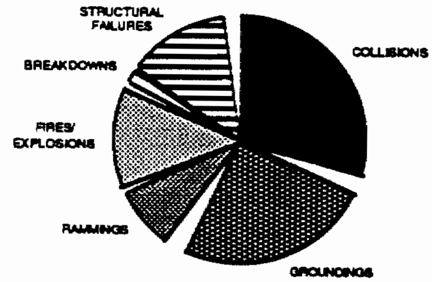


FIGURE VI - 2 EFFECTIVENESS METHODOLOGY

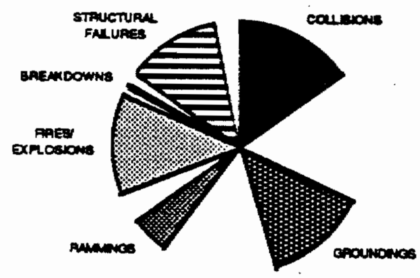
EXISTING



GROUP I MODIFICATIONS



GROUP I and II MODIFICATIONS



GROUP I, II and III MODIFICATIONS

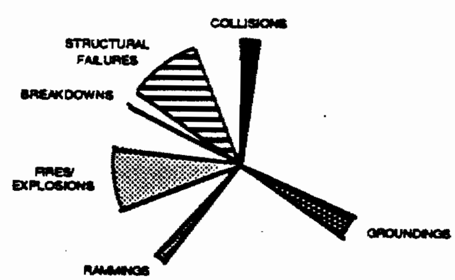
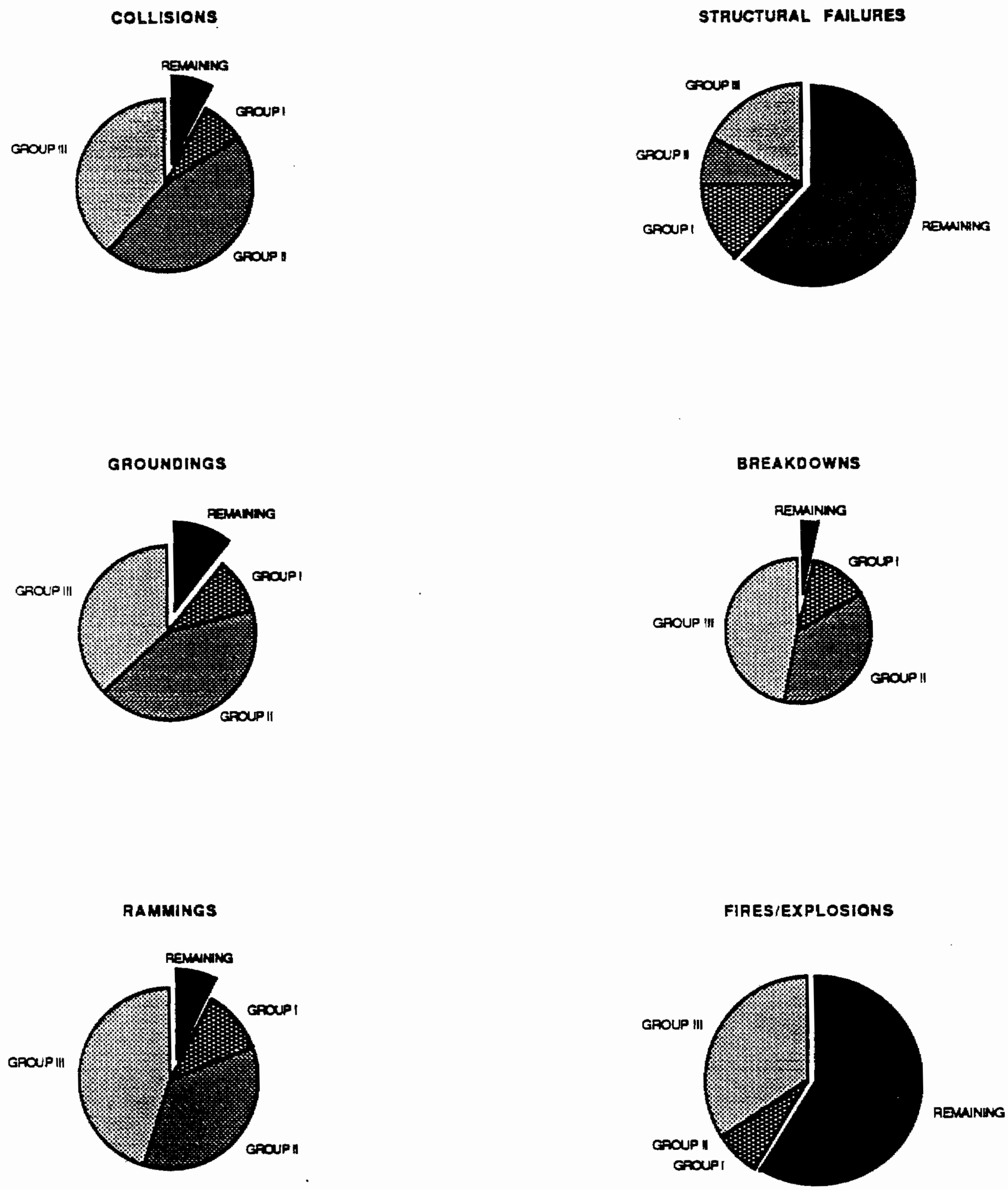


FIGURE VI - 3 TOTAL OIL SPILLS REMAINING AS RESULT OF GROUP MODIFICATIONS



NOTE: Each circle represents 100% of incidents for the specific accident type. Remaining refers to spill incidents remaining after application of system modifications.

FIGURE VI - 4 REDUCTION IN SPILL INCIDENTS BY ACCIDENT TYPE DUE TO SYSTEM MODIFICATIONS

TABLE VI - 3 OIL SPILL REDUCTION DUE TO MARINE TRANSPORTATION SYSTEM MODIFICATIONS

SYSTEM MODIFICATION	REDUCTION IN OIL SPILLS (per cent)	CUMULATIVE REDUCTION (per cent)
GROUP I		
Mandatory Drug and Alcohol Testing Emergency and High-risk Navigation Area Training Port Restrictions/Port Closure System Two Person Watchstanding Requirement Improved Loading/Unloading Procedures Local Spill Cleanup/Prevention Involvement Spill Response Equipment Coordination	14	14
GROUP II		
Vessel Monitoring System Traffic Separation Lanes with One-Way Traffic Designated Anchorage Areas Emergency Response/Pollution Control Vessels Improved Loading/Unloading Designs	41	49
GROUP III		
Improved Tanker Design	55	77

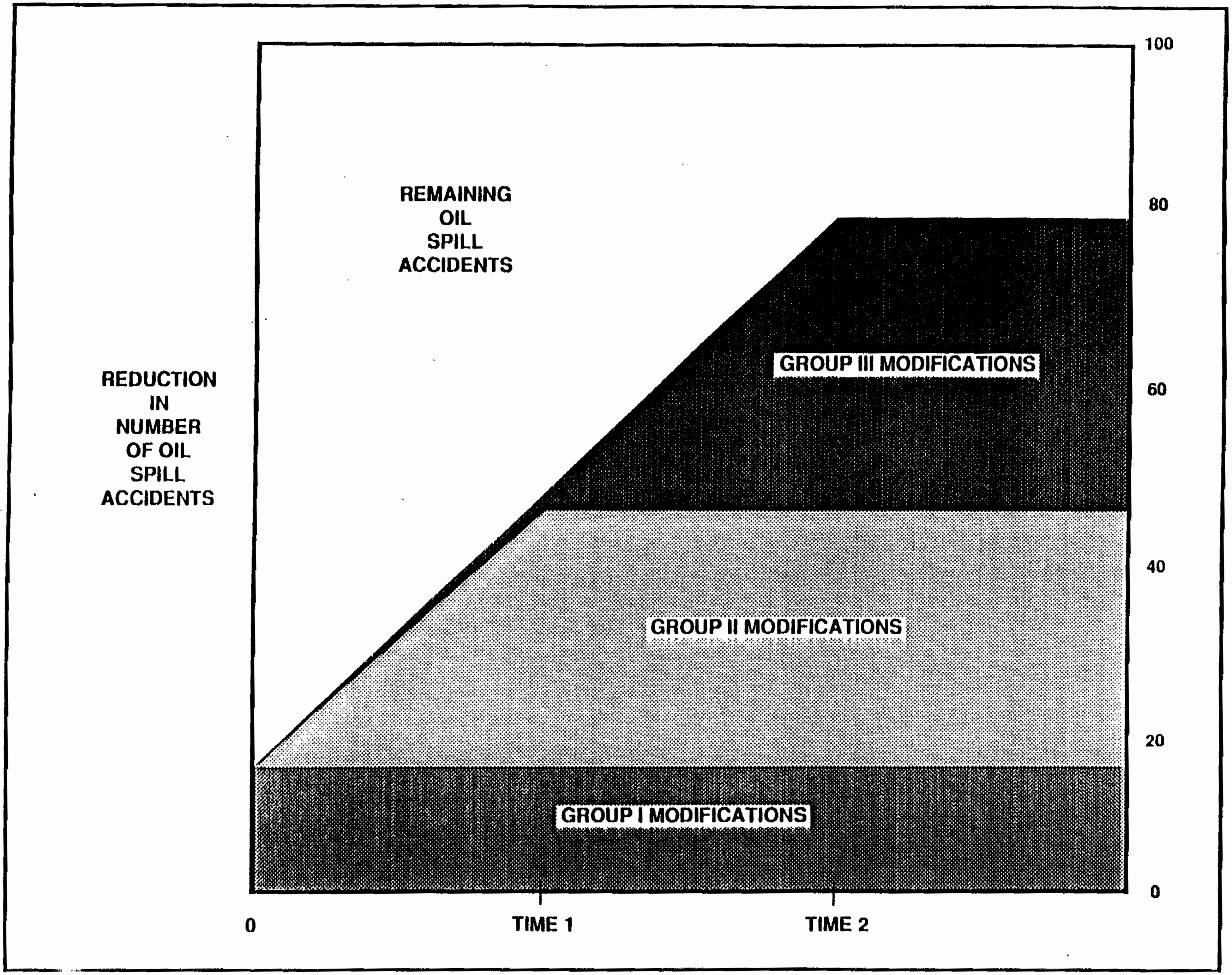


FIGURE VI - 5 EFFECTS OF SYSTEM MODIFICATIONS ON THE REDUCTION OF OIL SPILL ACCIDENTS

TABLE VI - 4 PROJECTED SPILL PROBABILITIES AND RECURRENCE INTERVALS
COOK INLET - GROUP I MODIFICATIONS

LOWER SPILL LIMIT (GALLONS)	300	1,000,001	9,000,001	300
UPPER SPILL LIMIT (GALLONS)	1,000,000	9,000,000	21,000,000	21,000,000
MEAN INCIDENCE RATE (SPILL/PORT CALL)	0.00224	0.000209	0.0000767	0.00252
NUMBER OF PORT CALLS PER YEAR	171	171	171	171
PROBABILITY OF 1 OR MORE OCCURRENCES/YEAR	0.32	0.035	0.013	0.35
RECURRENCE INTERVAL (YEARS)	2.6	28	76	2.3

spill probabilities for Cook Inlet as a function of Group I system modifications, for spills in the three spill ranges determined in Chapter II, as well as for all spills above 300 gallons. The table shows that the incidence rate for oil spills will decline for all spill events to 0.00252 per port call from 0.00293 per port call, and that the corresponding recurrence interval between spills declines to 2.3 years from 2.0 years. Table VI - 5 similarly shows the effect of the combined Group I and Group II modifications on Cook Inlet, with a mean incidence rate of 0.00149 spills per port call and a recurrence interval of 3.9 years. Lastly, Table VI - 6 shows similar calculations for all proposed system modifications, with mean incident rate of 0.00067 per port call and a recurrence interval of 8.7 years.

Tables VI -7, VI - 8, and VI - 9 show the results of applying the system modifications to Prince William Sound. Table VI - 7 shows that the incidence rate for oil spills in Prince William Sound due to Group I modifications will decline for all spill events to 0.000844 per port call from 0.000981 per port call, and that the corresponding recurrence interval between spills declines to 1.3 years from 1.1 years. Table VI - 8 similarly shows the effect of the combined Group I and Group II modifications, with a mean incidence rate of 0.000498 spills per port call and a recurrence interval of 2.2 years. Lastly, Table VI - 9 shows similar calculations for all proposed system modifications, with mean incident rate of 0.000224 per port call and a recurrence interval of 5.0 years.

Figure VI - 6, VI - 7, and VI - 8 show the improvement in port safety, and the increase in cost per barrel of oil transported to achieve that safety, for the port areas of Cook Inlet and Prince William Sound. Port safety is equated to reduction of oil spills due to marine transportation system modifications. Increased cost and improvement in port safety are shown for the effects of Group I modifications, Group I and Group II modifications combined, and Group I, II, and III modifications combined. The figure shows that a 77 percent improvement in port safety can be achieved in Cook Inlet for a cost of $0.21 per barrel with an associated cost of $0.064 per barrel in Prince William Sound. It should be emphasized that the increased cost and reduction in risk impact different groups of people, with the benefits of risk reduction - economic,

TABLE VI - 5 PROJECTED SPILL PROBABILITIES AND RECURRENCE INTERVALS
COOK INLET - GROUPS I and II MODIFICATIONS

LOWER SPILL LIMIT (GALLONS) UPPER SPILL LIMIT (GALLONS)	300 1,000,000	1,000,001 9,000,000	9,000,001 21,000,000	300 21,000,000
MEAN INCIDENCE RATE (SPILL/PORT CALL)	0.00132	0.000124	0.0000453	0.00149
NUMBER OF PORT CALLS PER YEAR	171	171	171	171
PROBABILITY OF 1 OR MORE OCCURRENCES/YEAR	0.20	0.021	0.0077	0.22
RECURRENCE INTERVAL (YEARS)	4.4	47	130	3.9

TABLE VI - 6 PROJECTED SPILL PROBABILITIES AND RECURRENCE INTERVALS
COOK INLET - GROUPS I II, and III MODIFICATIONS

LOWER SPILL LIMIT (GALLONS)	300	1,000,001	9,000,001	300
UPPER SPILL LIMIT (GALLONS)	1,000,000	9,000,000	21,000,000	21,000,000
MEAN INCIDENCE RATE (SPILL/PORT CALL)	0.000593	0.0000556	0.0000204	0.000669
NUMBER OF PORT CALLS PER YEAR	171	171	171	171
PROBABILITY OF 1 OR MORE OCCURRENCES/YEAR	0.097	0.0095	0.0035	0.11
RECURRENCE INTERVAL (YEARS)	9.9	110	290	8.7

TABLE VI - 7 PROJECTED SPILL PROBABILITIES AND RECURRENCE INTERVALS
PRINCE WILLIAM SOUND - GROUP I MODIFICATIONS

LOWER SPILL LIMIT (GALLONS)	300	3,000,001	11,000,001	300
UPPER SPILL LIMIT (GALLONS)	3,000,000	11,000,000	75,000,000	75,000,000
MEAN INCIDENCE RATE (SPILL/PORT CALL)	0.000747	0.0000739	0.0000236	0.000844
NUMBER OF PORT CALLS PER YEAR	896	896	896	896
PROBABILITY OF 1 OR MORE OCCURRENCES/YEAR	0.49	0.064	0.021	0.53
RECURRENCE INTERVAL (YEARS)	1.5	15	47	1.3

TABLE VI - 8 PROJECTED SPILL PROBABILITIES AND RECURRENCE INTERVALS PRINCE WILLIAM SOUND - GROUPS I and II MODIFICATIONS

LOWER SPILL LIMIT (GALLONS)	300	3,000,001	11,000,001	300
UPPER SPILL LIMIT (GALLONS)	3,000,000	11,000,000	75,000,000	75,000,000
MEAN INCIDENCE RATE (SPILL/PORT CALL)	0.000440	0.0000436	0.0000139	0.000498
NUMBER OF PORT CALLS PER YEAR	896	896	896	896
PROBABILITY OF 1 OR MORE OCCURRENCES/YEAR	0.33	0.038	0.012	0.36
RECURRENCE INTERVAL (YEARS)	2.5	26	80	2.2

TABLE VI - 9 PROJECTED SPILL PROBABILITIES AND RECURRENCE INTERVALS
PRINCE WILLIAM SOUND - GROUPS I, II, and III MODIFICATIONS

LOWER SPILL LIMIT (GALLONS)	300	3,000,001	11,000,001	300
UPPER SPILL LIMIT (GALLONS)	3,000,000	11,000,000	75,000,000	75,000,000
MEAN INCIDENCE RATE (SPILL/PORT CALL)	0.000198	0.0000196	0.00000627	0.000224
NUMBER OF PORT CALLS PER YEAR	896	896	896	896
PROBABILITY OF 1 OR MORE OCCURRENCES/YEAR	0.16	0.017	0.0056	0.18
RECURRENCE INTERVAL (YEARS)	5.6	57	180	5.0

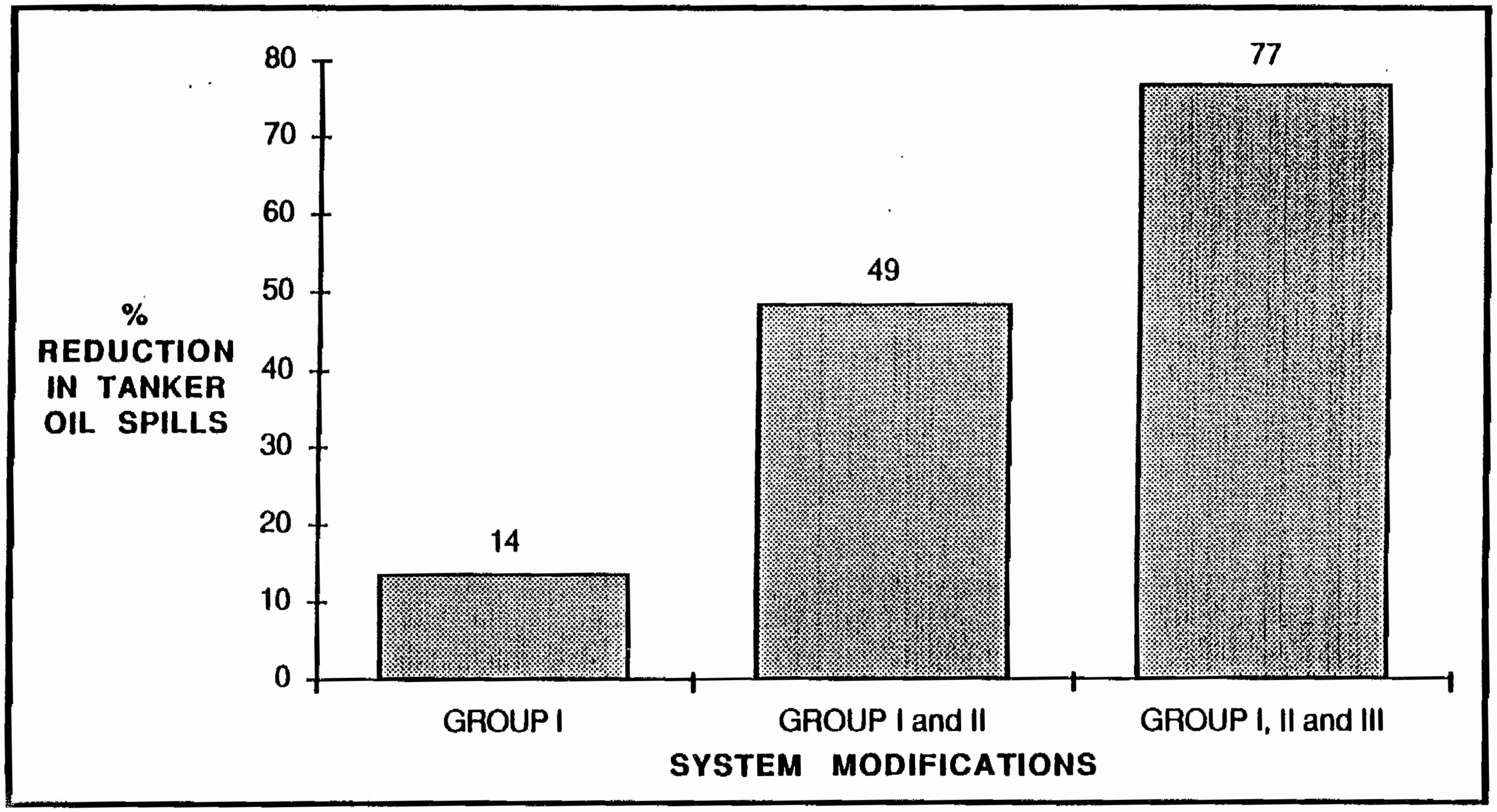


FIGURE VI - 6 REDUCTION IN TANKER OIL SPILLS
DUE TO MARINE TRANSPORTATION SYSTEM MODIFICATIONS

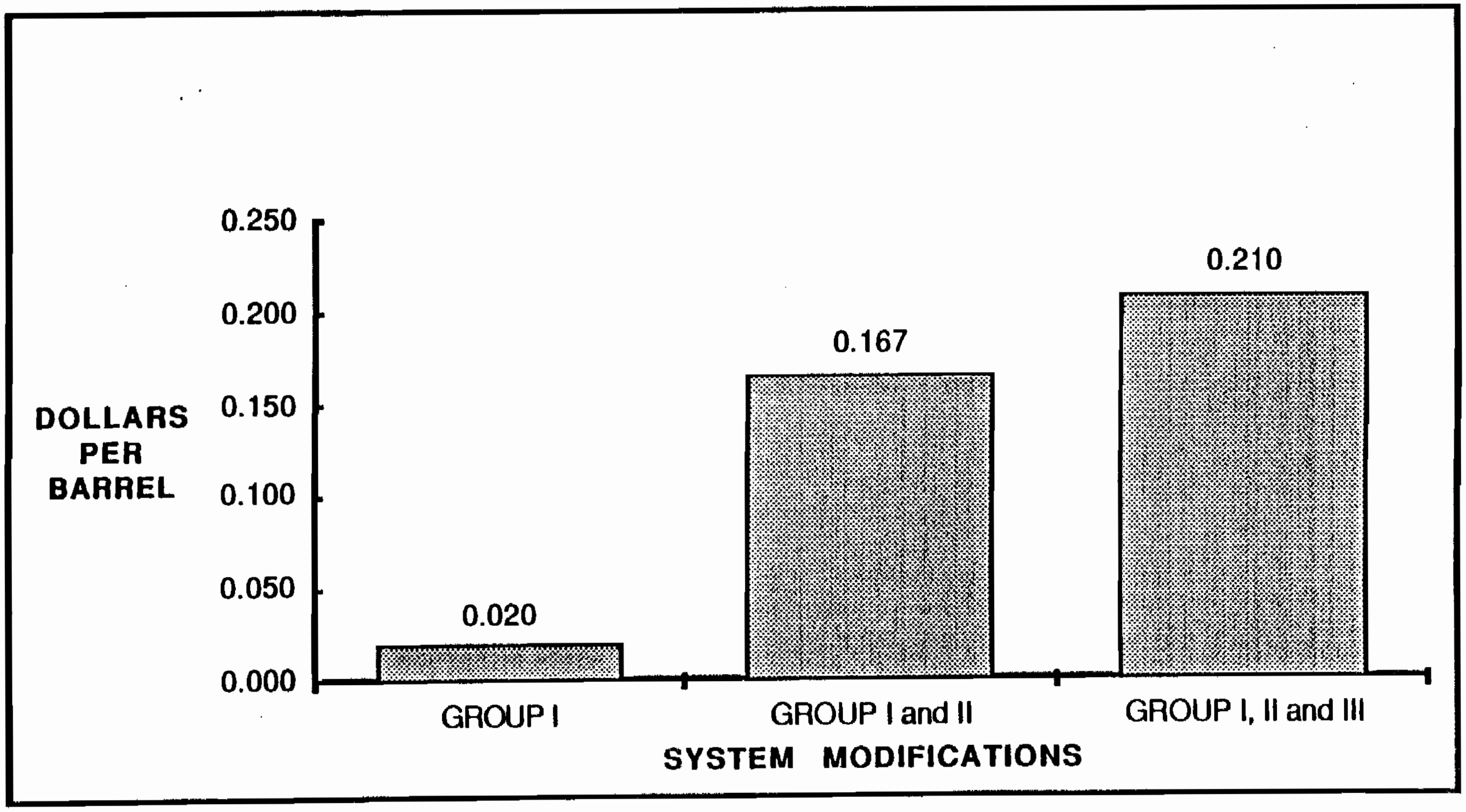


FIGURE VI - 7 COST OF MARINE TRANSPORTATION SYSTEM MODIFICATIONS PER BARREL FOR COOK INLET

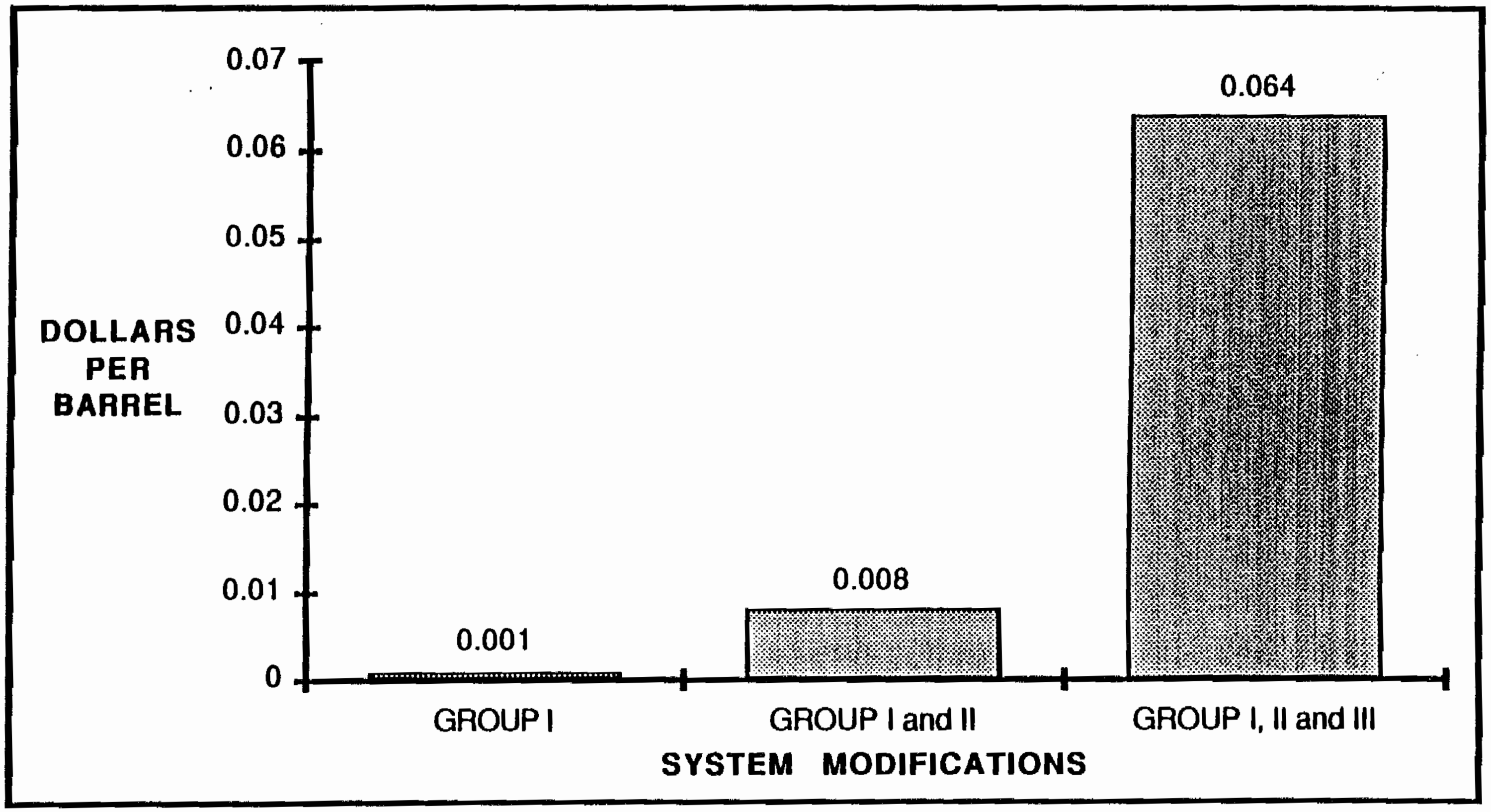


FIGURE VI-8 COST OF MARINE TRANSPORTATION SYSTEM MODIFICATION PER BARREL FOR PRINCE WILLIAM SOUND environmental and social - being shared by groups that may or may not carry the burden of the costs. The above discussion indicates that a substantial reduction in risk is achievable with a comparably small increase in cost.

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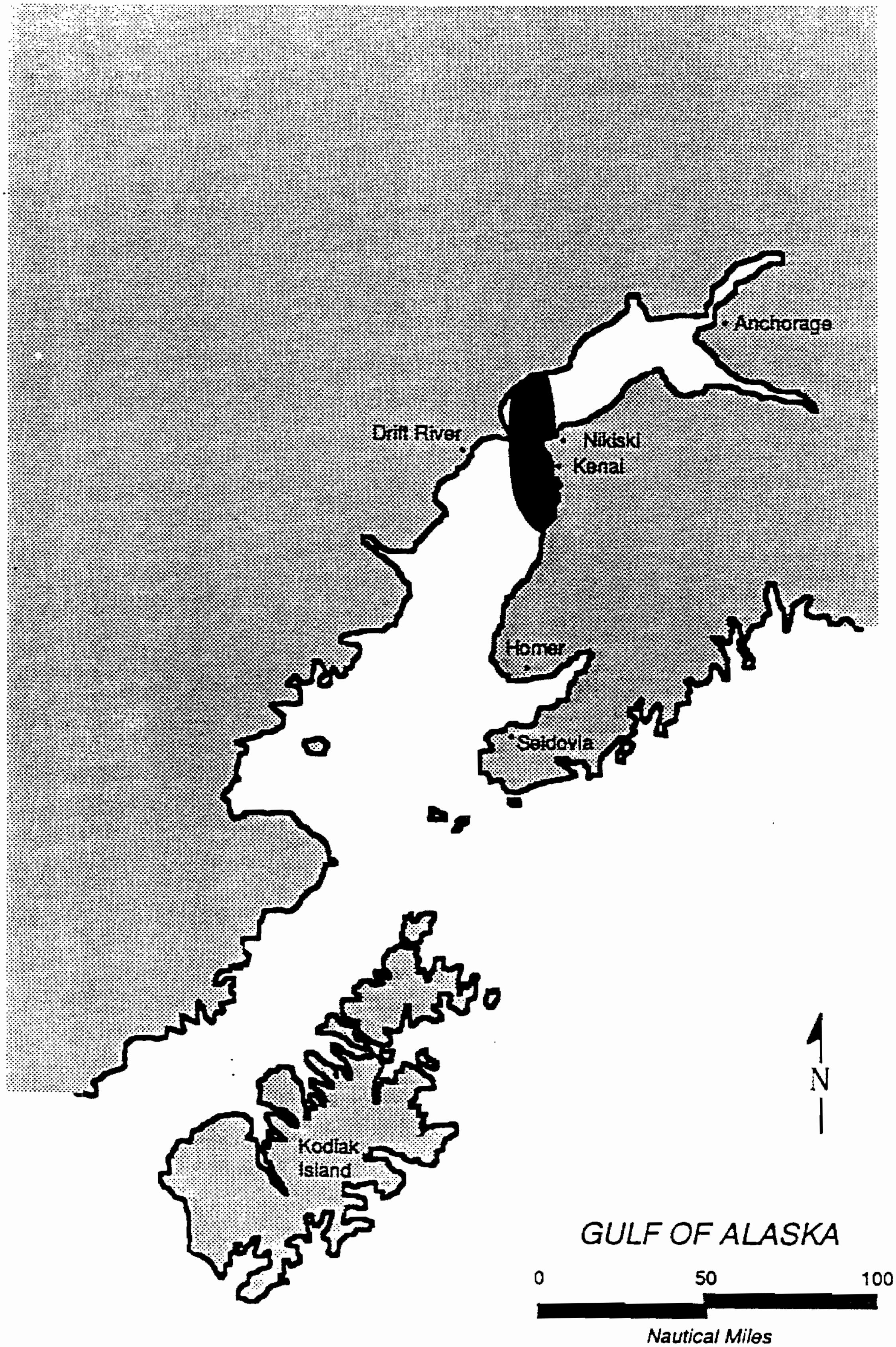
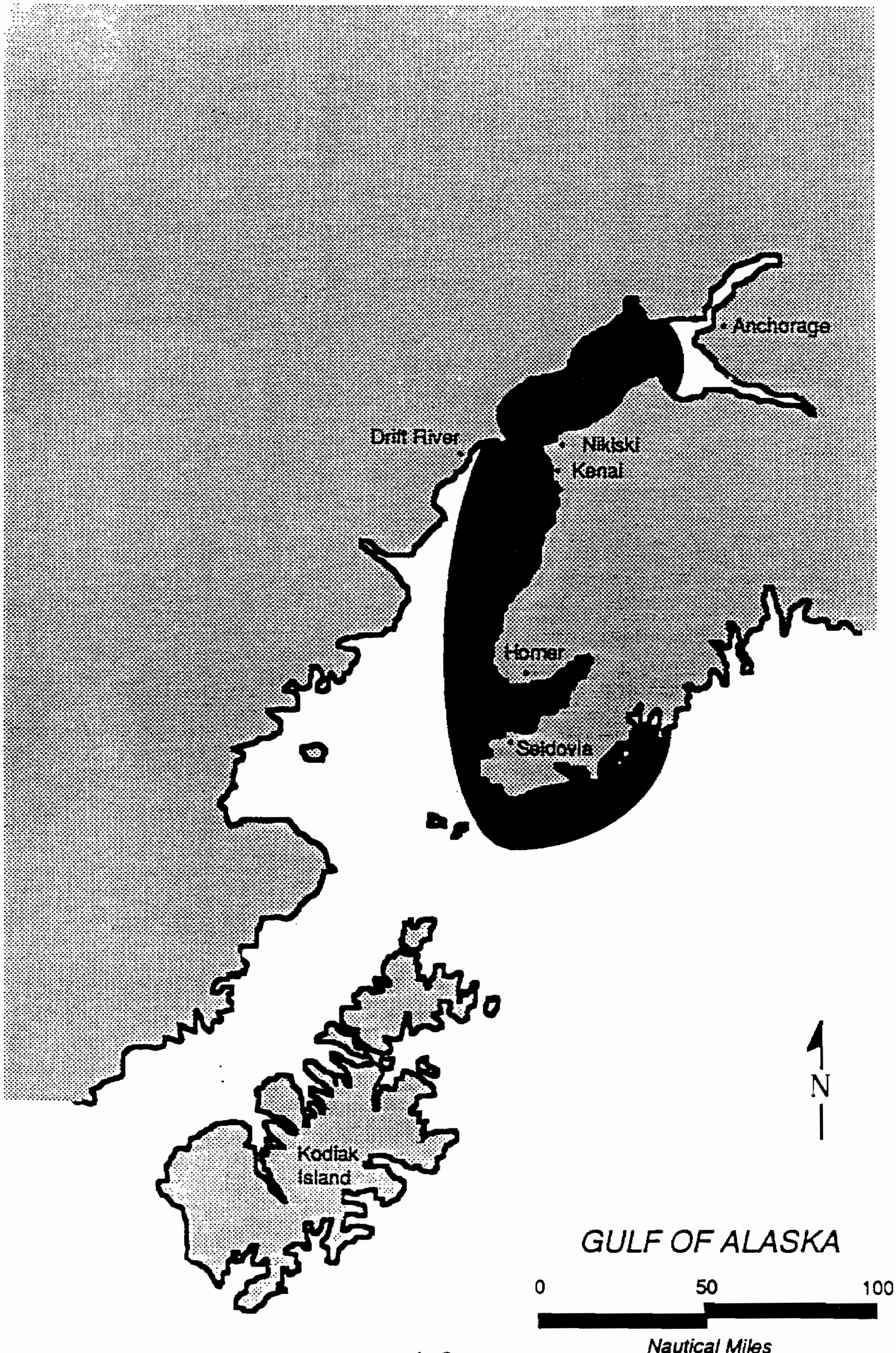
APPENDIX A

COOK INLET OIL SPILL PROJECTIONS

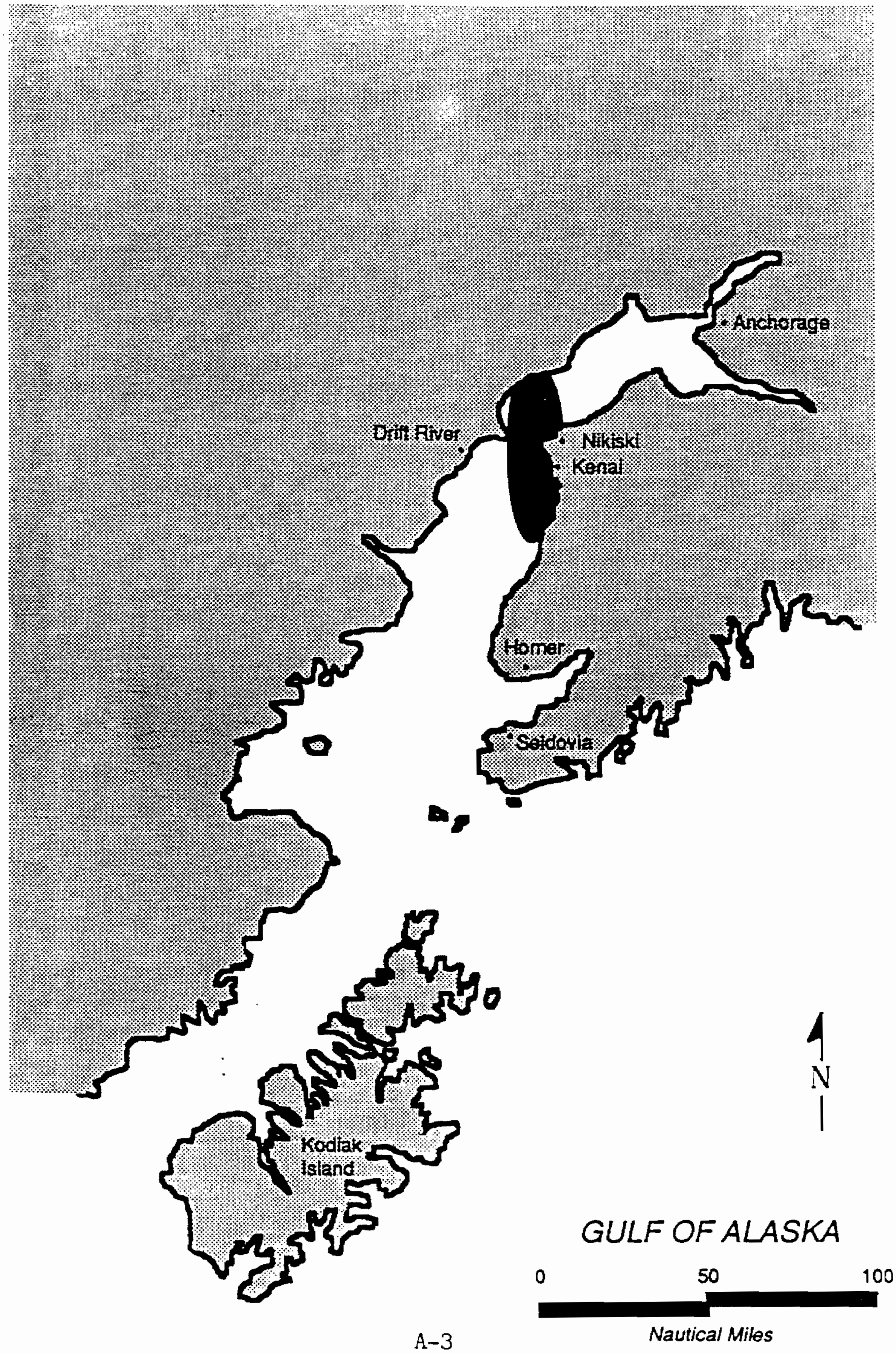
Nikiski - 24 Hours After Spill
Spill Size = 1,000,000 Gallons
Typical Summer Wind And Current Conditions



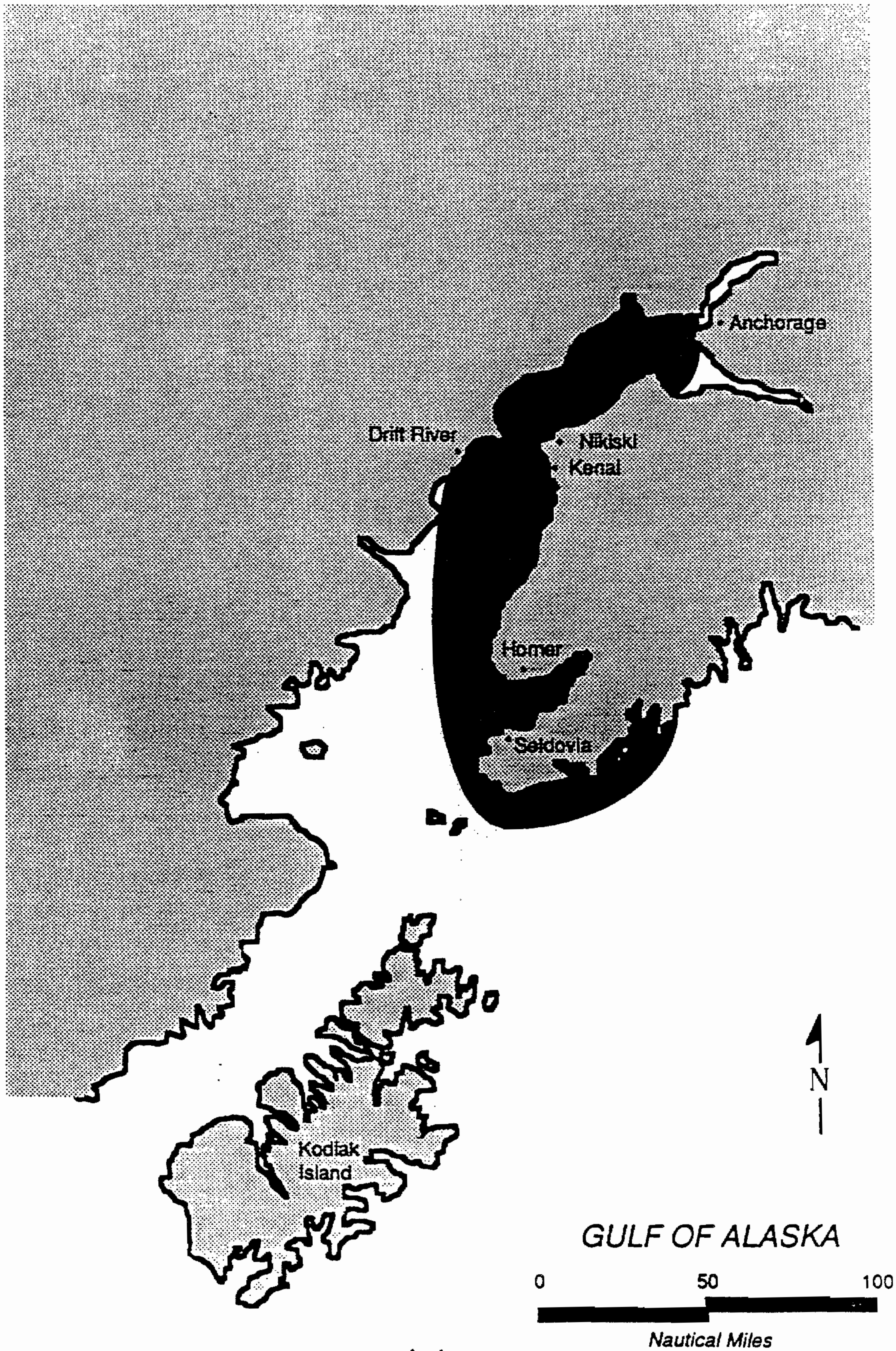
Nikiski - 168 Hours After Spill
Spill Size = 1,000,000 Gallons
Typical Summer Wind And Current Conditions



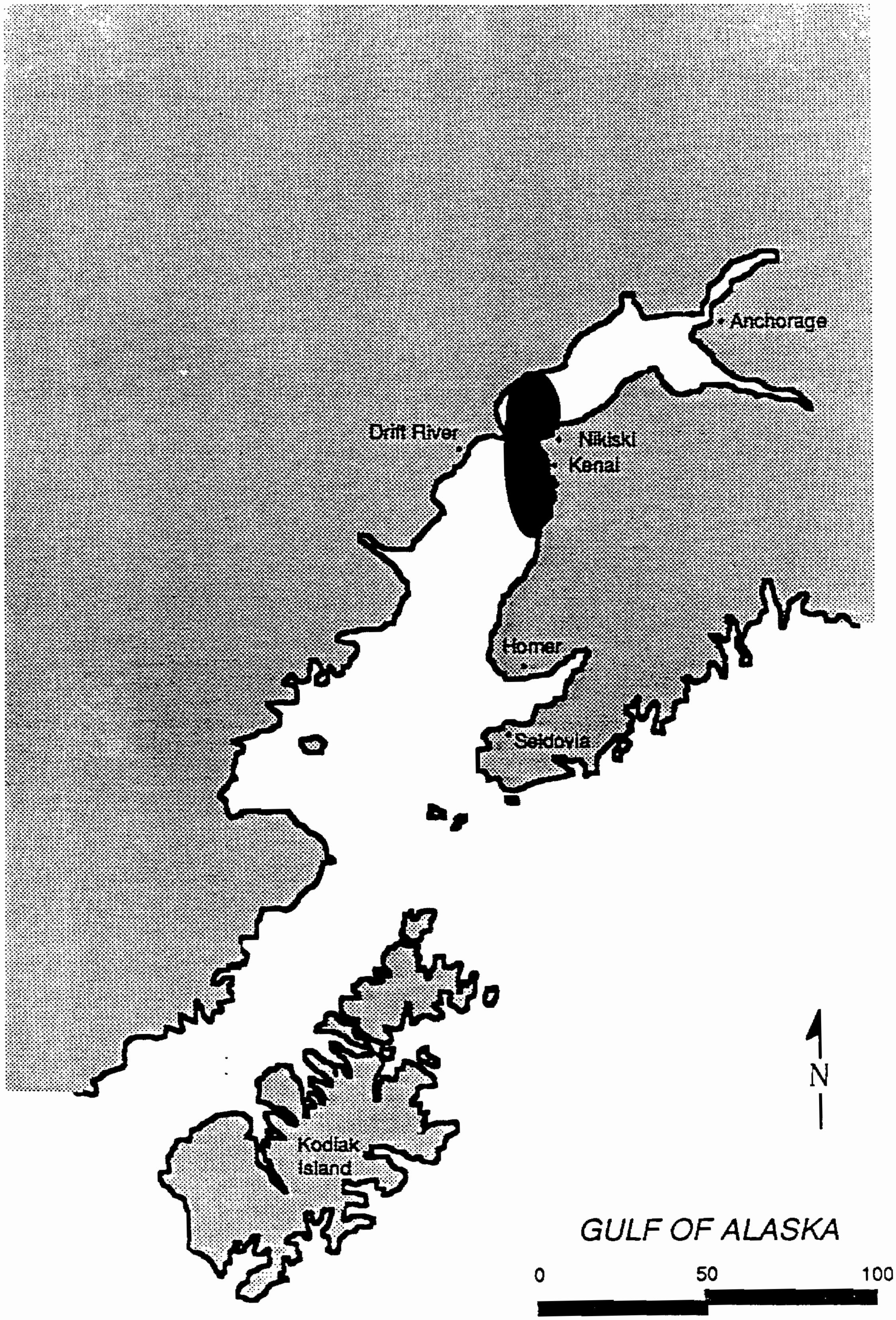
Nikiski - 24 Hours After Spill
Spill Size = 9,000,000 Gallons
Typical Summer Wind And Current Conditions



Nikiski - 168 Hours After Spill
Spill Size = 9,000,000 Gallons
Typical Summer Wind And Current Conditions



Nikiski - 24 Hours After Spill
Spill Size = 21,000,000 Gallons
Typical Summer Wind And Current Conditions



Nikiski - 168 Hours After Spill
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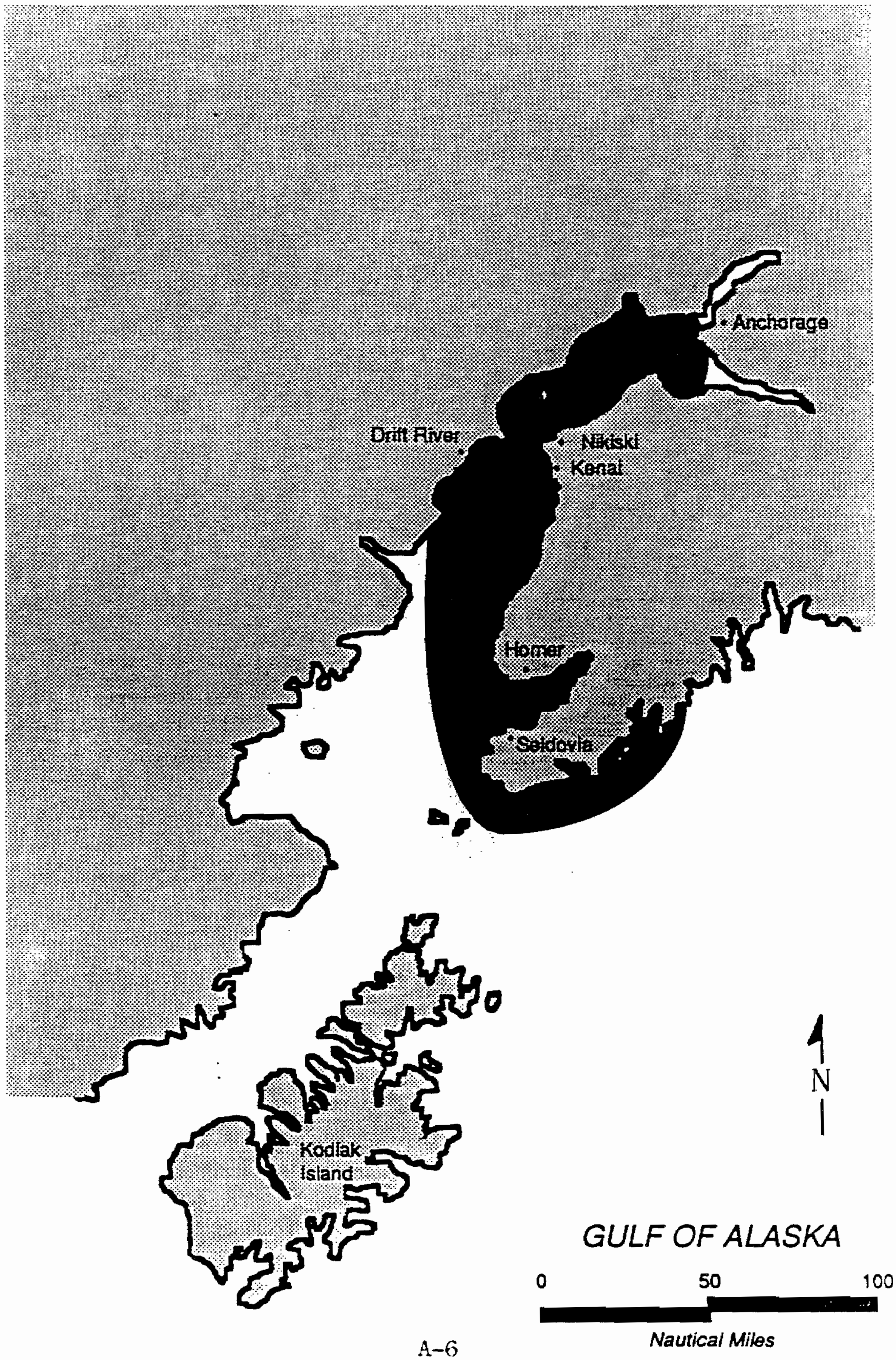
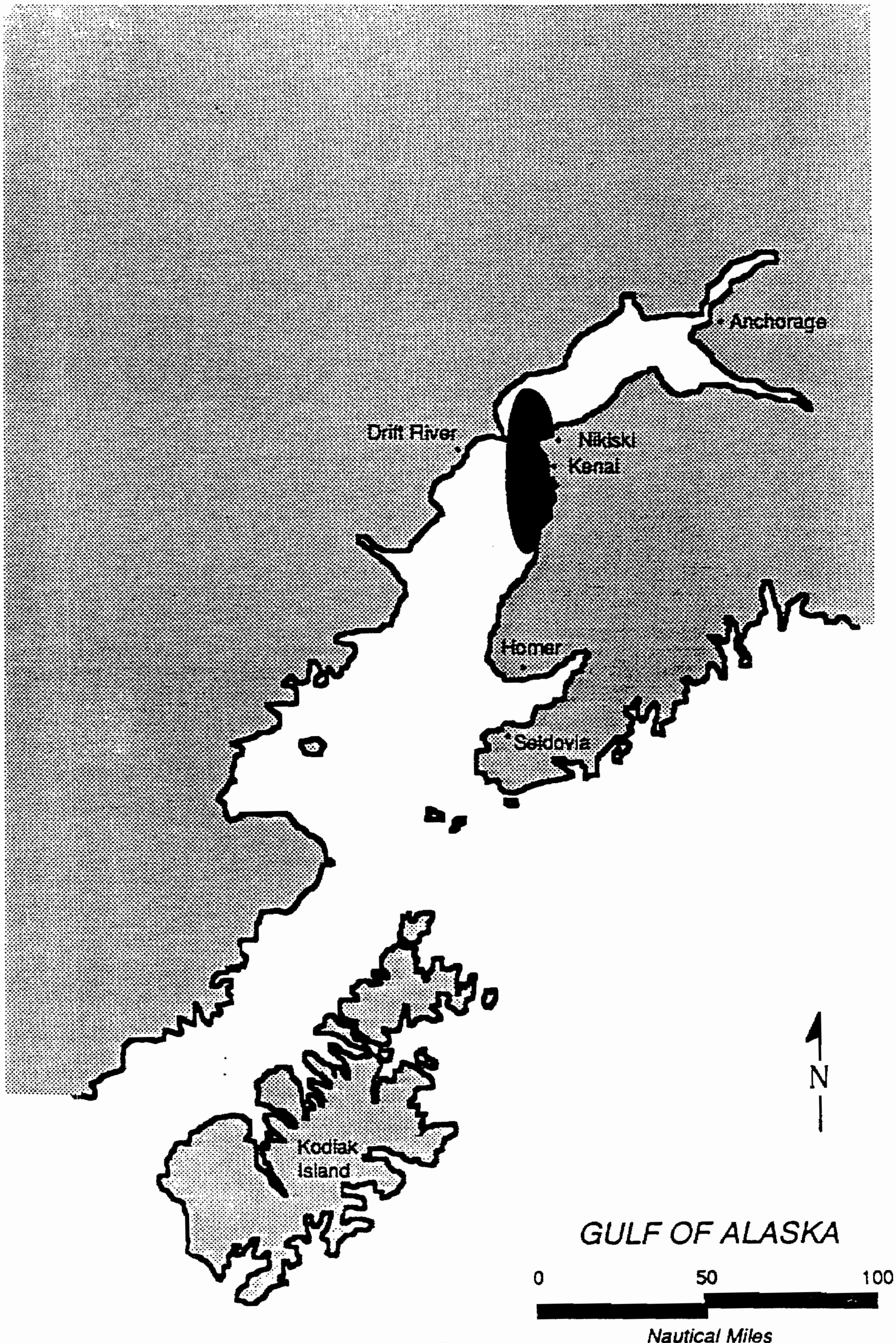
Typical Summer Wind And Current Conditions



Nikiski - 24 Hours After Spill
Spill Size = 1,000,000 Gallons
Typical Winter Wind And Current Conditions



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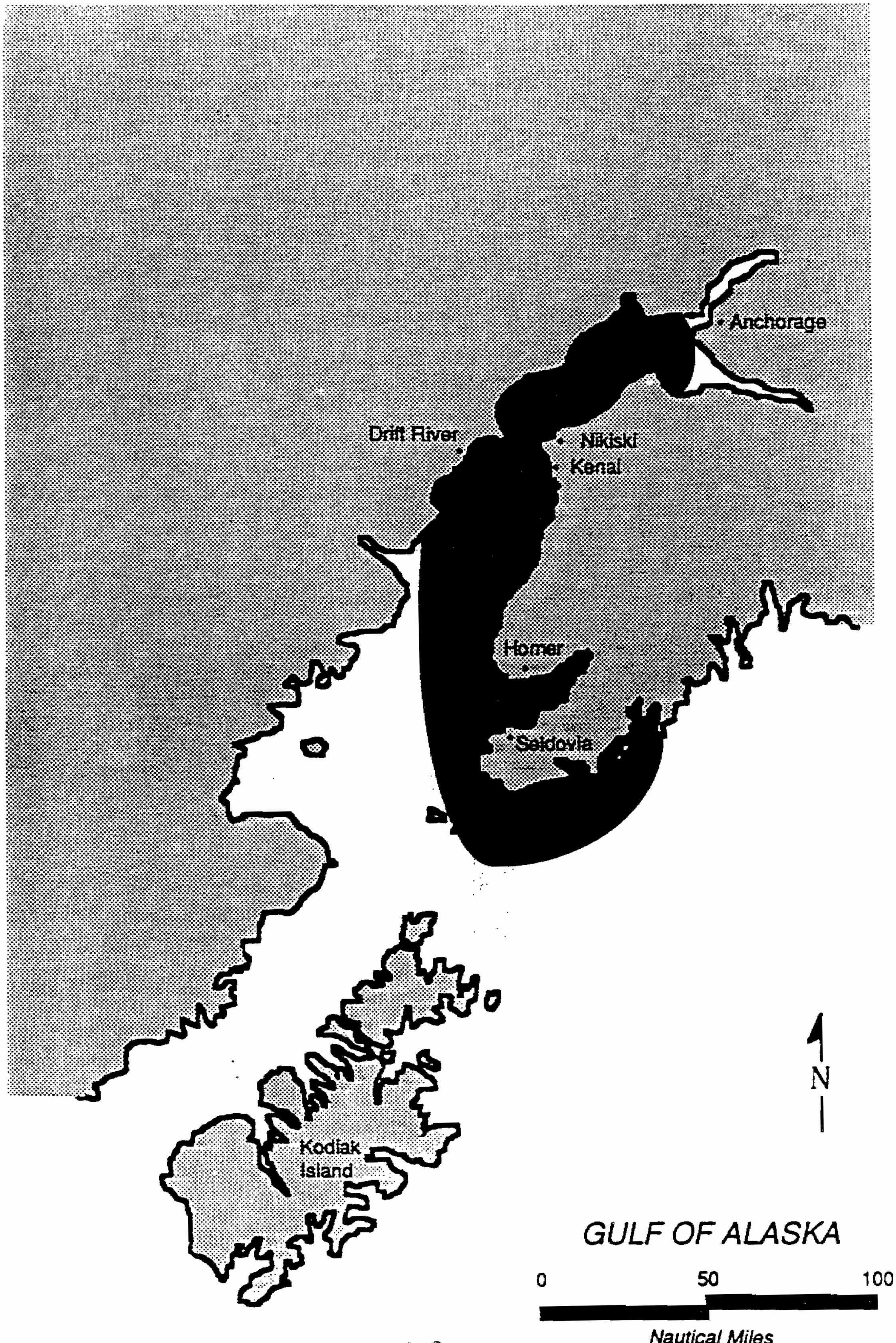
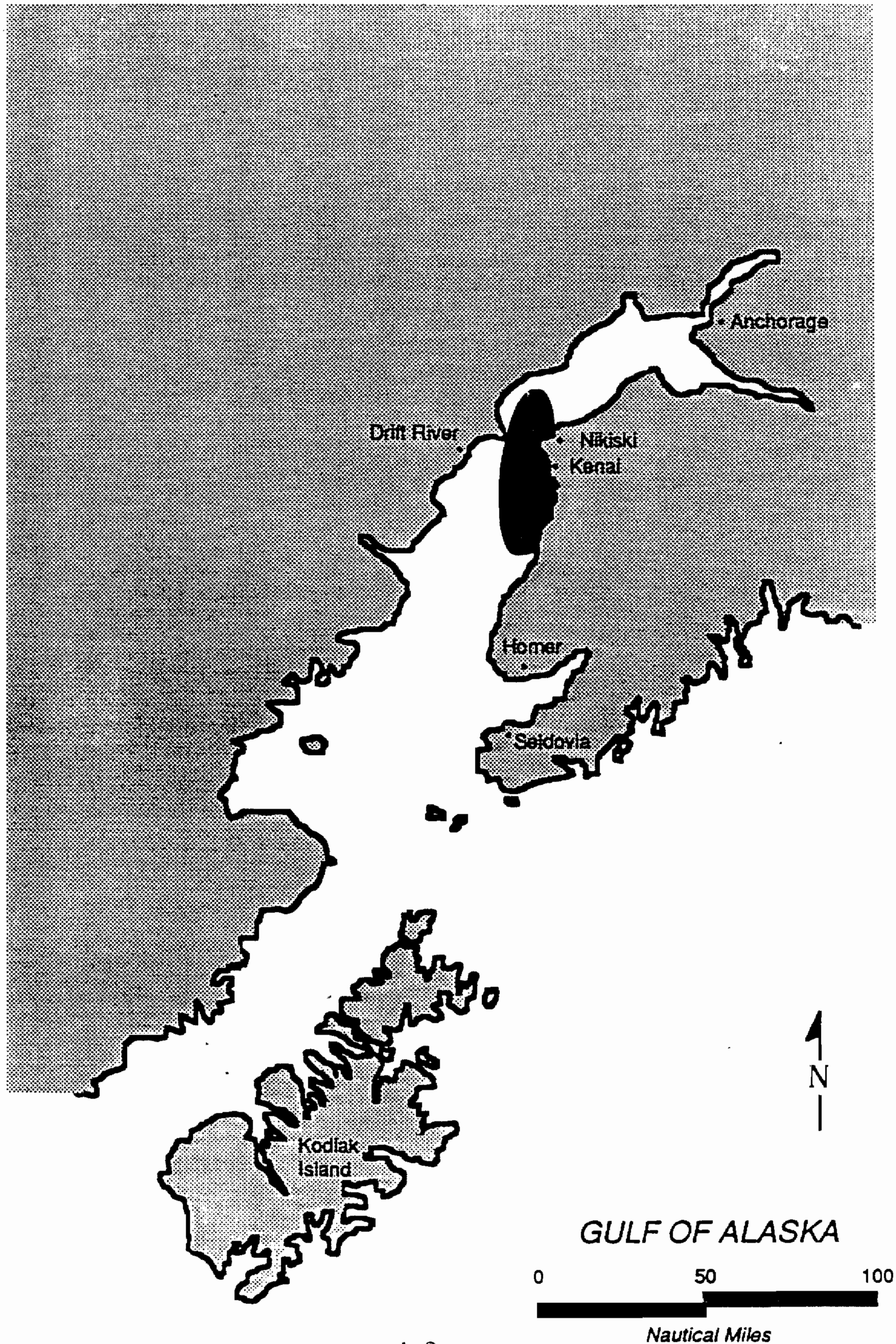
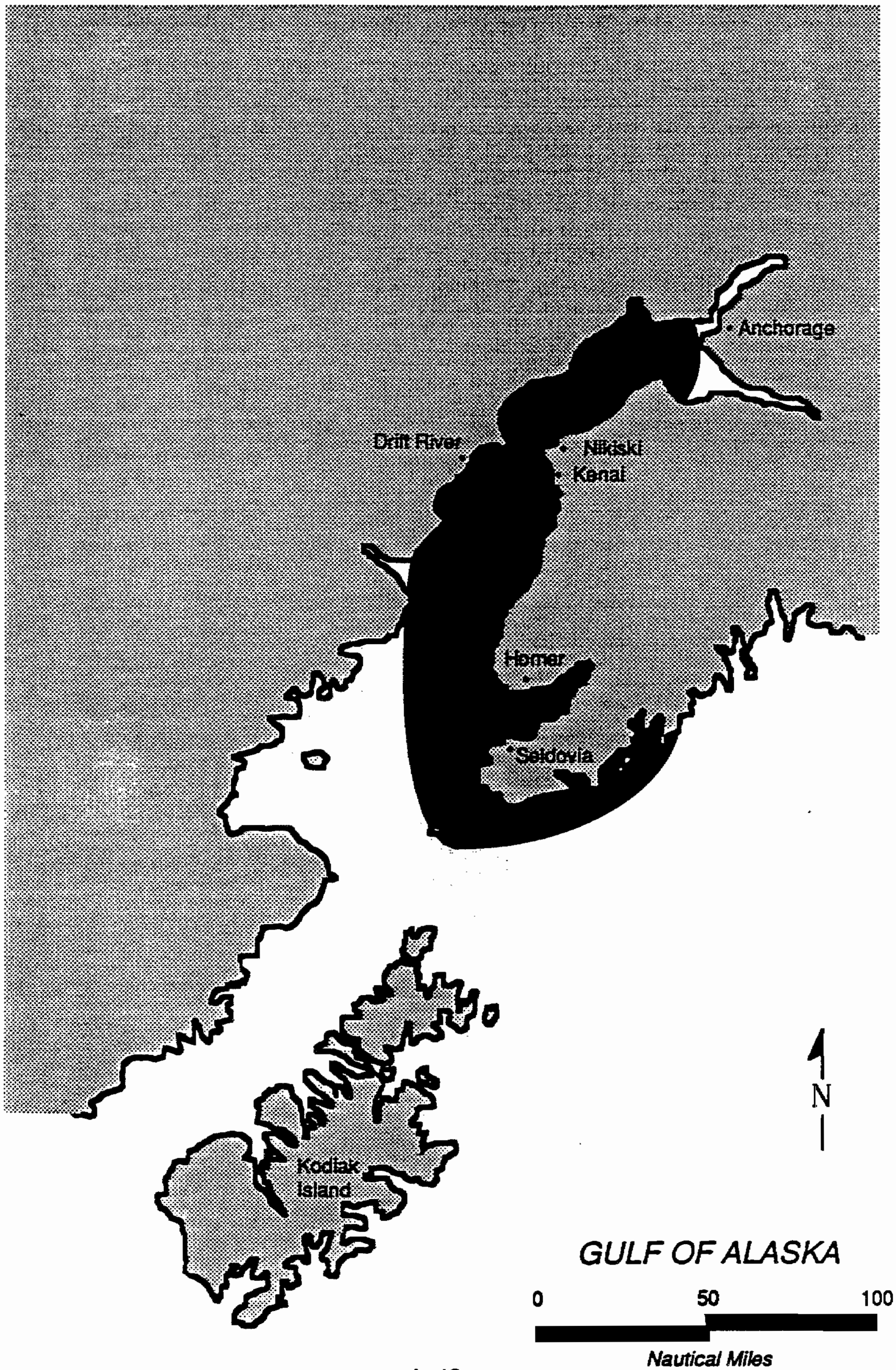
Spill Size = 1,000,000 Gallons
Typical Winter Wind And Current Conditions



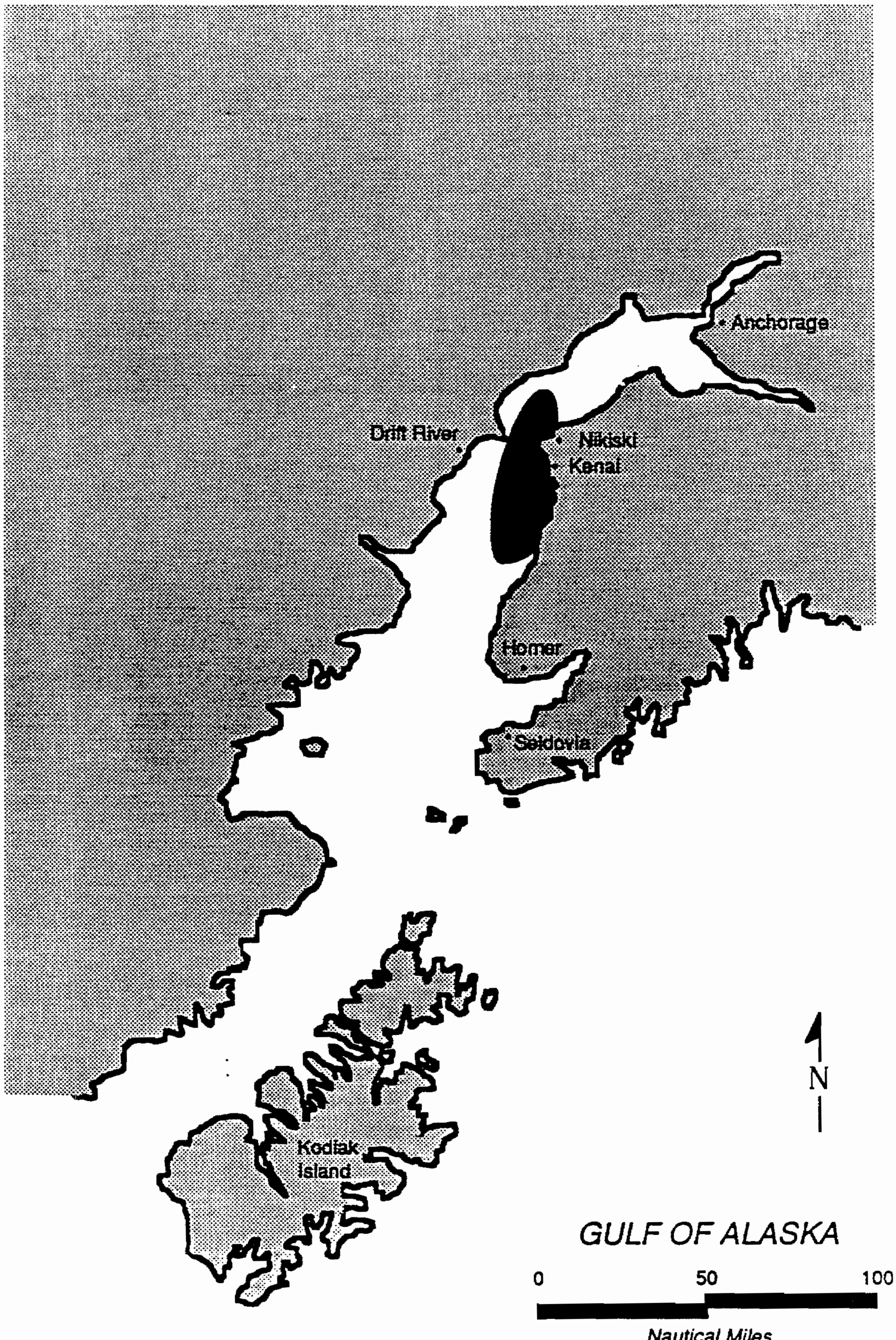
Nikiski - 24 Hours After Spill
Spill Size = 9,000,000 Gallons
Typical Winter Wind And Current Conditions



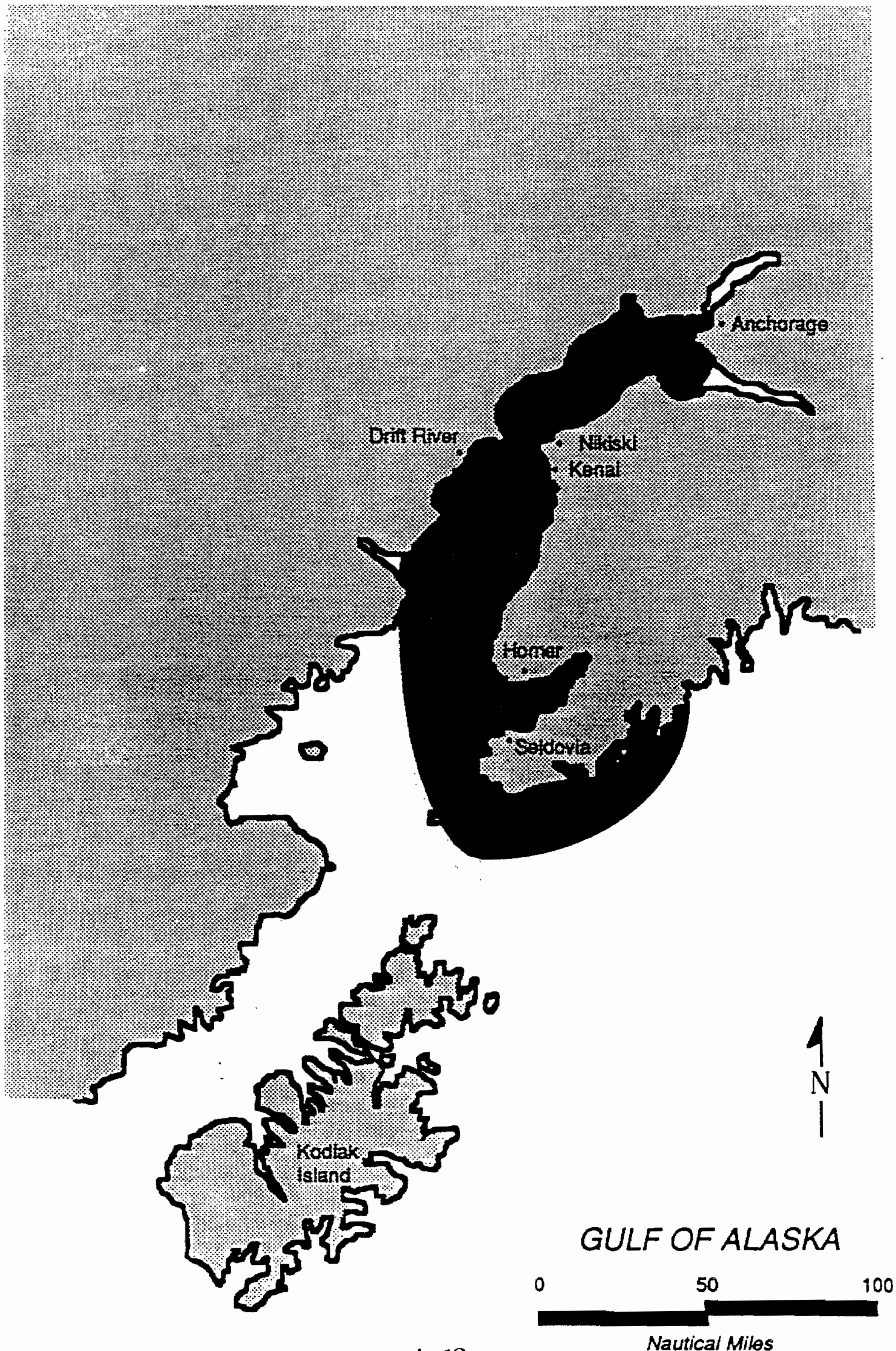
Nikiski - 168 Hours After Spill
Spill Size = 9,000,000 Gallons
Typical Winter Wind And Current Conditions



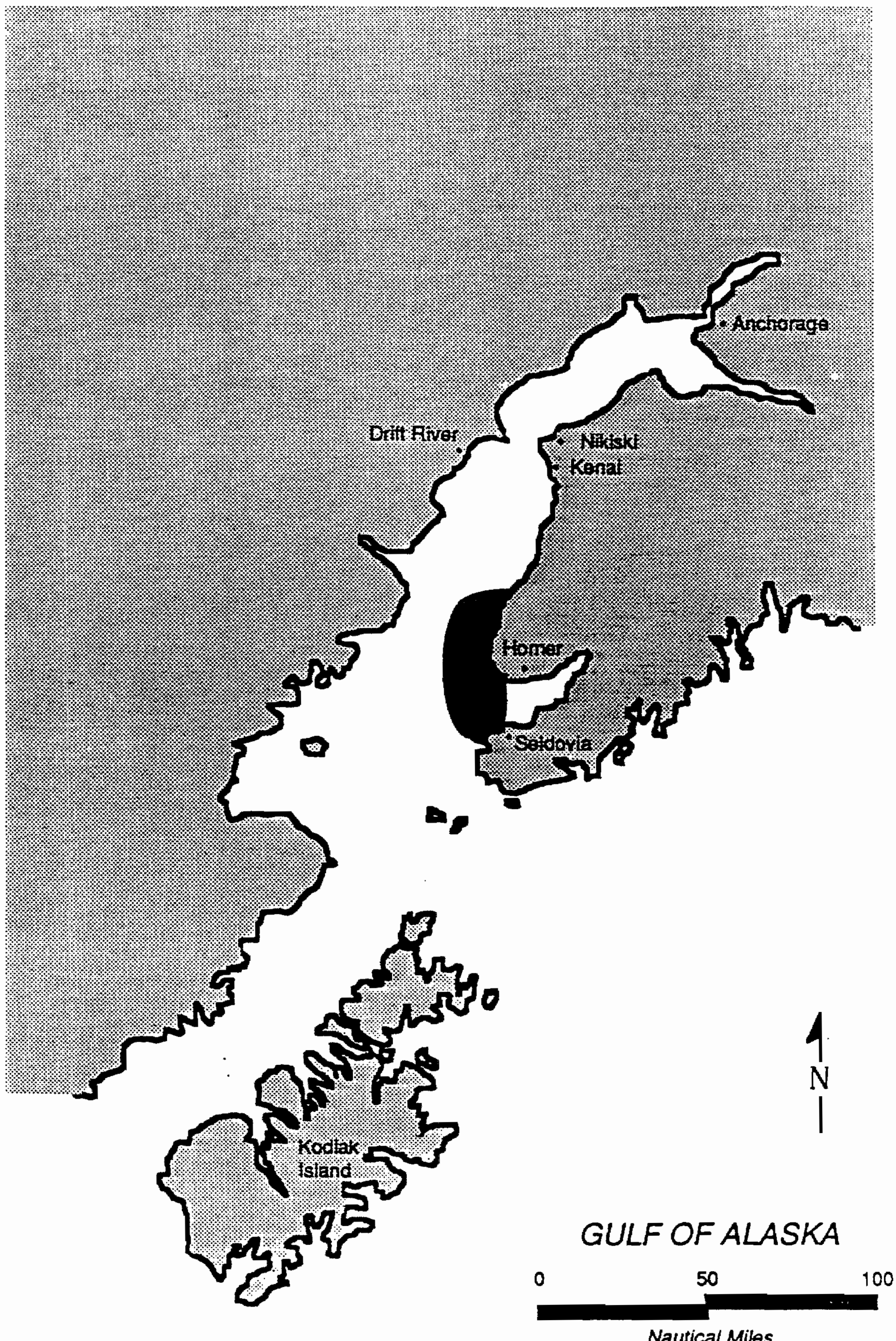
Nikiski - 24 Hours After Spill
Spill Size = 21,000,000 Gallons
Typical Winter Wind And Current Conditions



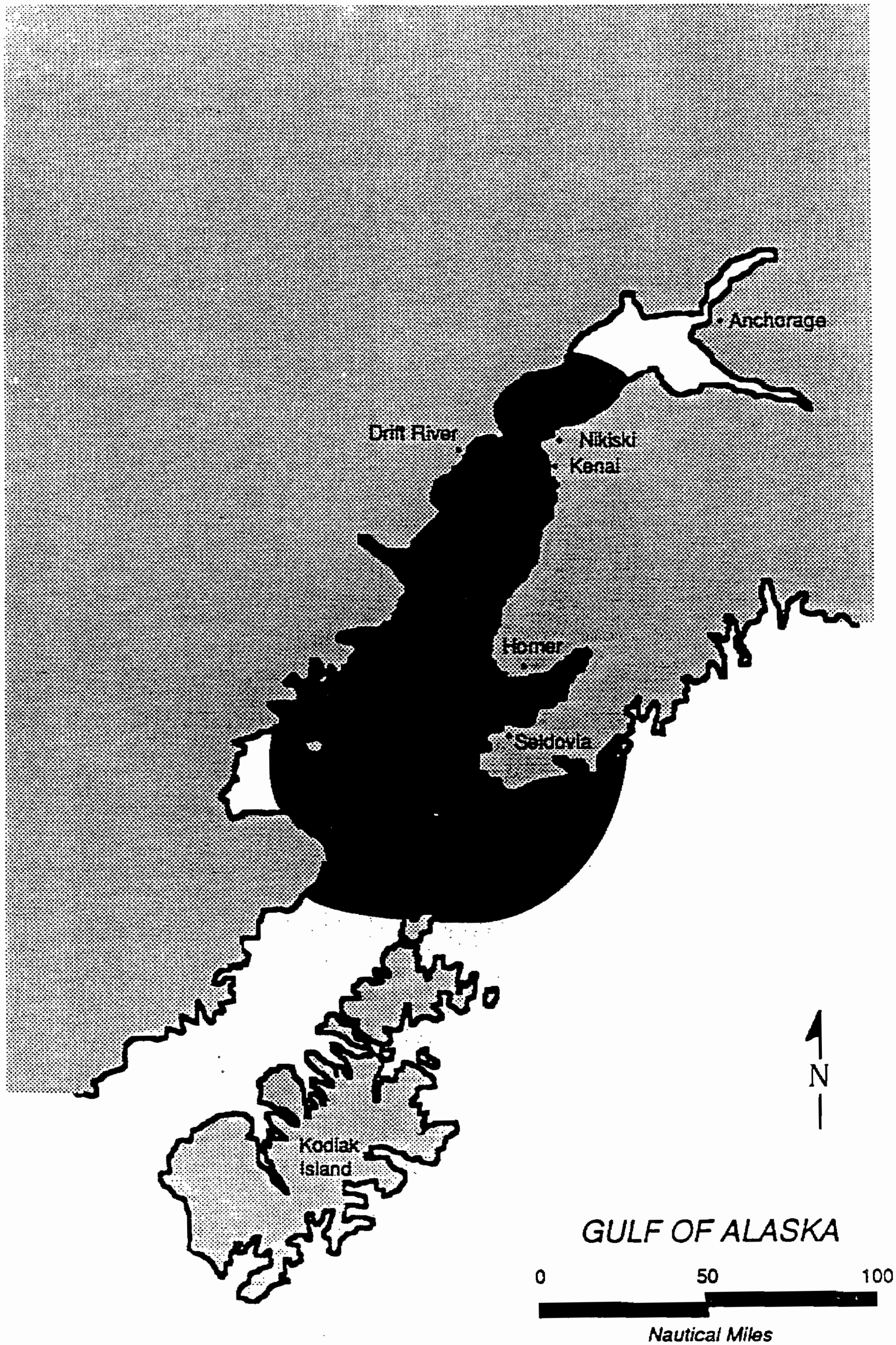
Nikiski - 168 Hours After Spill
Spill Size = 21,000,000 Gallons
Typical Winter Wind And Current Conditions



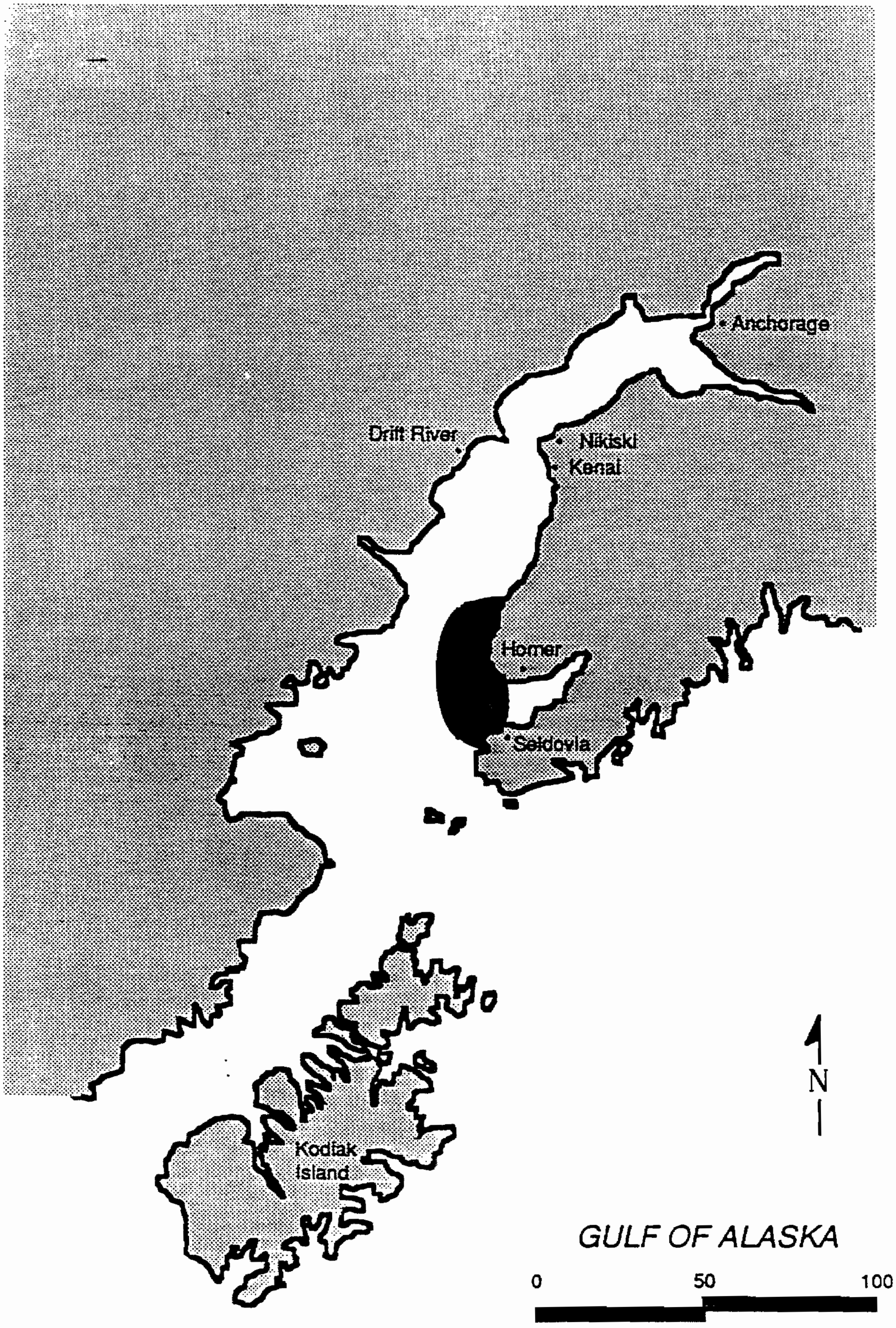
Kachemak Bay - 24 Hours After Spill
Spill Size = 1,000,000 Gallons
Typical Summer Wind And Current Conditions



Kachemak Bay - 168 Hours After Spill
Spill Size = 1,000,000 Gallons
Typical Summer Wind And Current Conditions



Kachemak Bay - 24 Hours After Spill
Spill Size = 9,000,000 Gallons
Typical Summer Wind And Current Conditions



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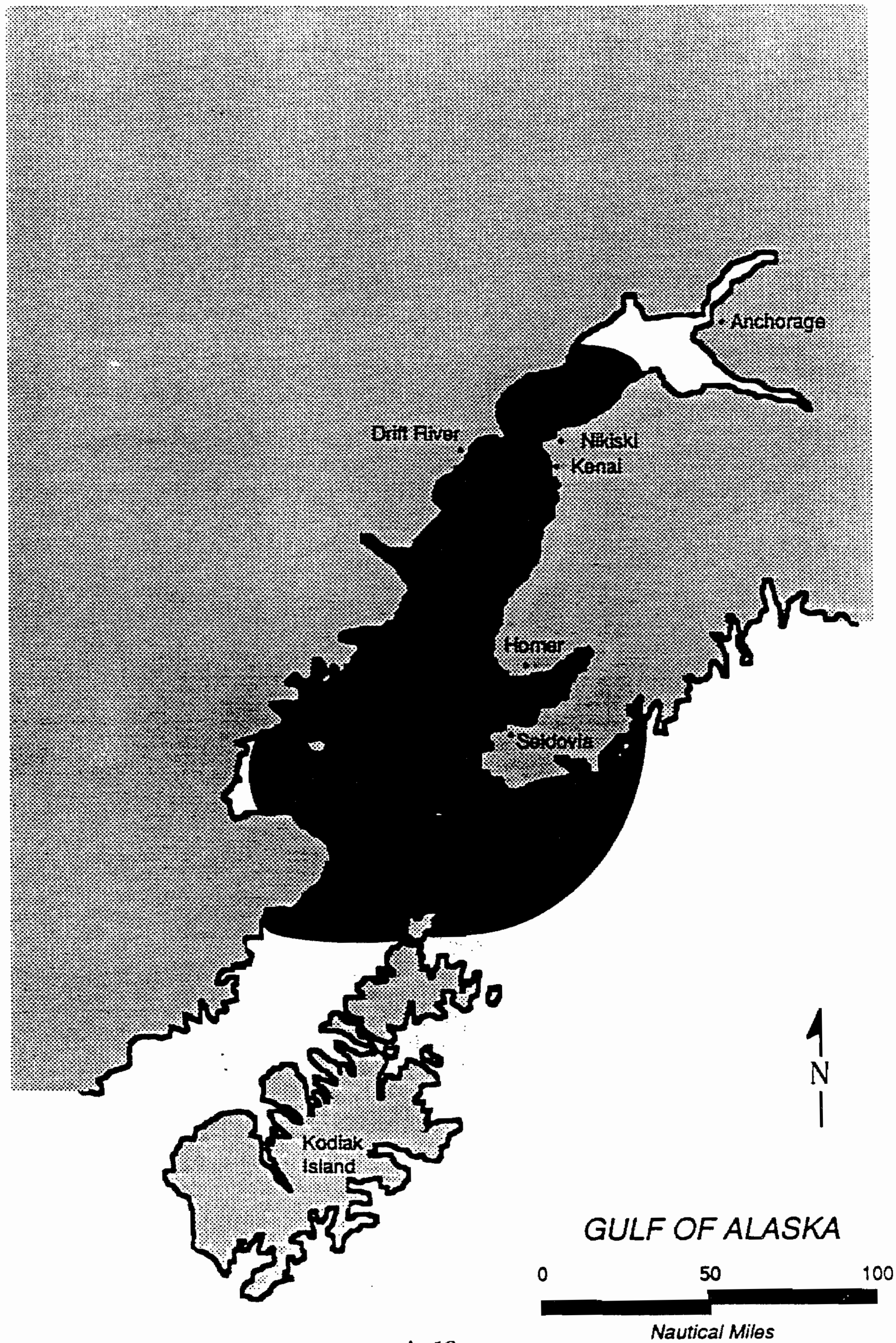
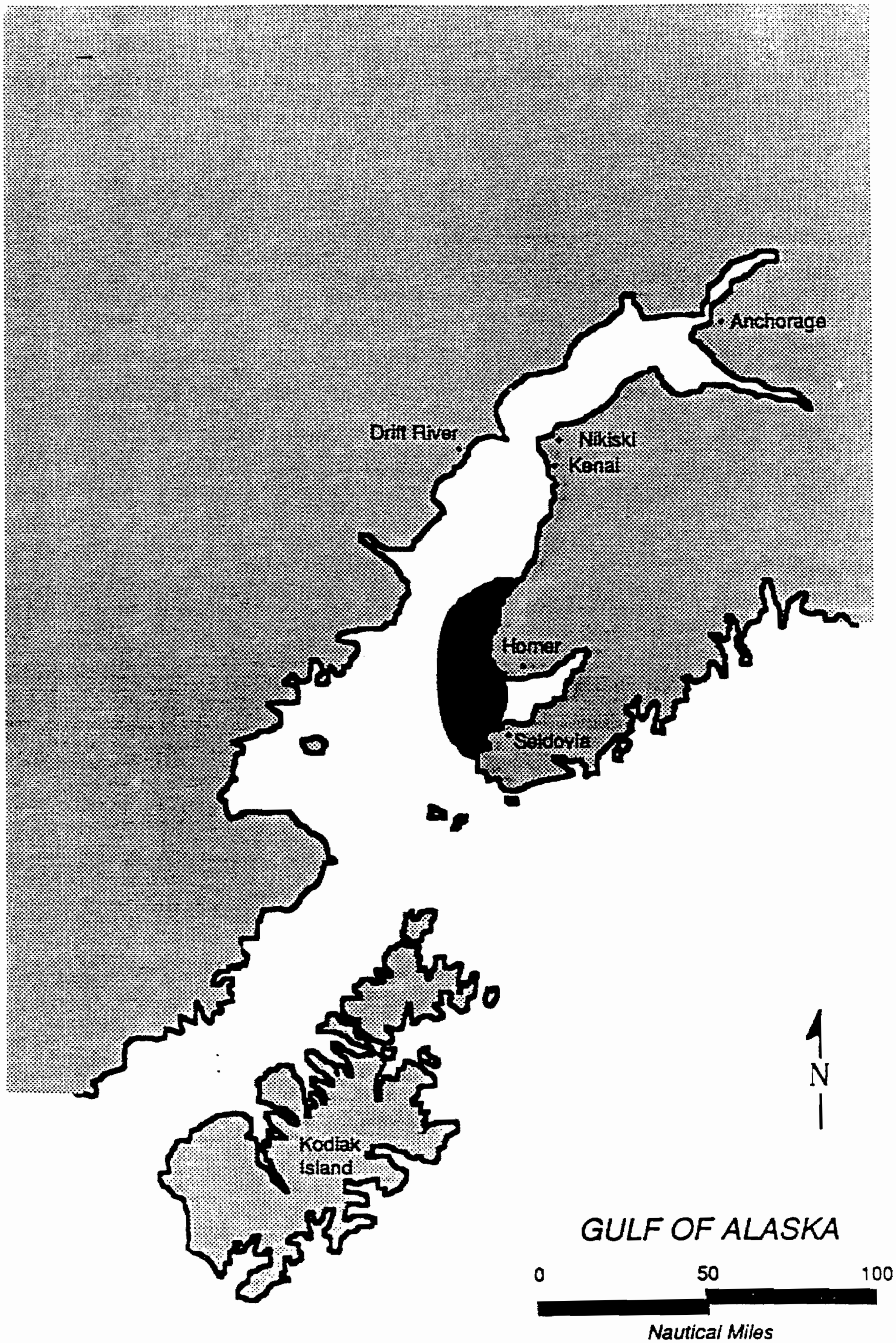
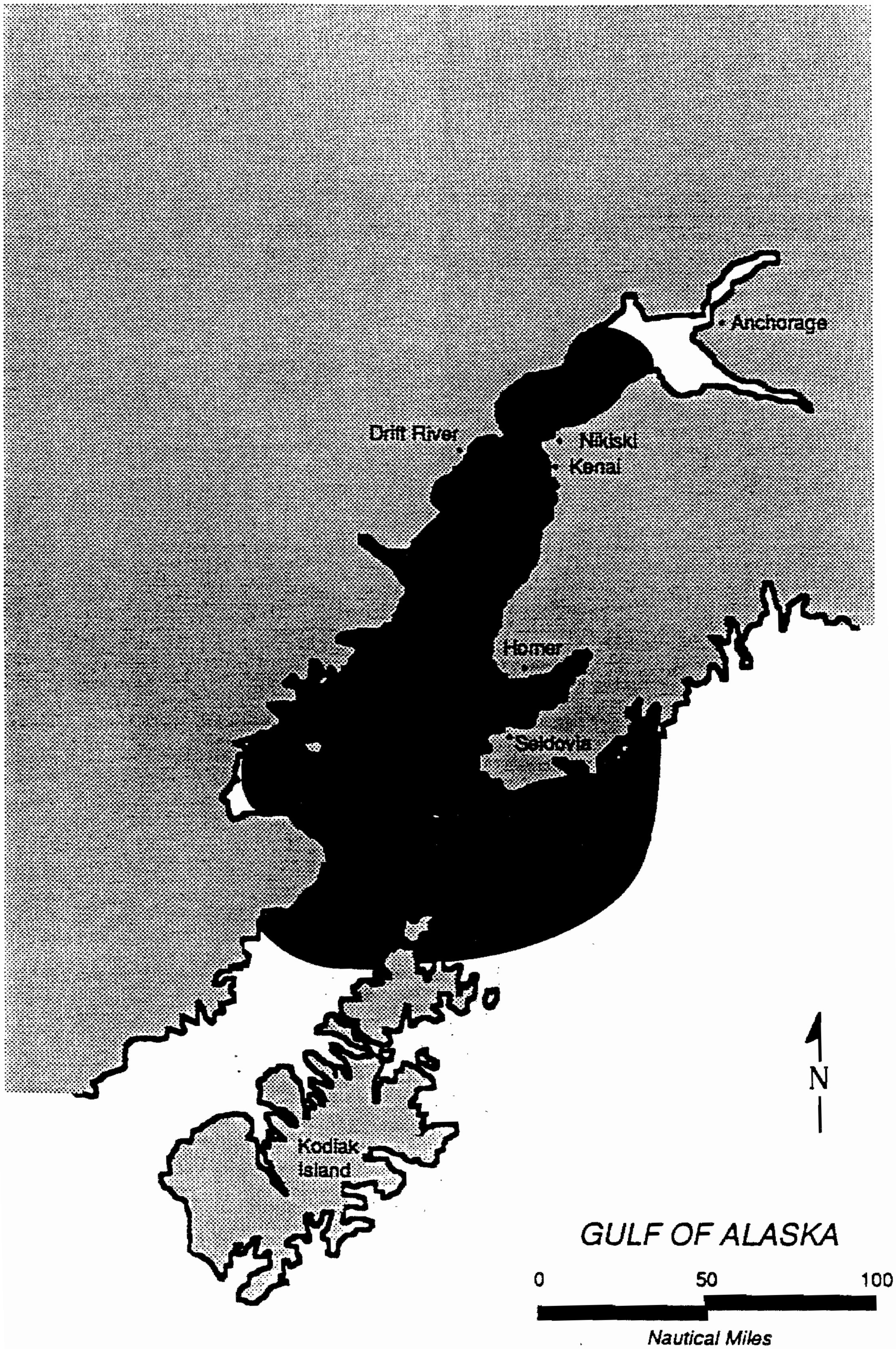
Spill Size = 9,000,000 Gallons
Typical Summer Wind And Current Conditions



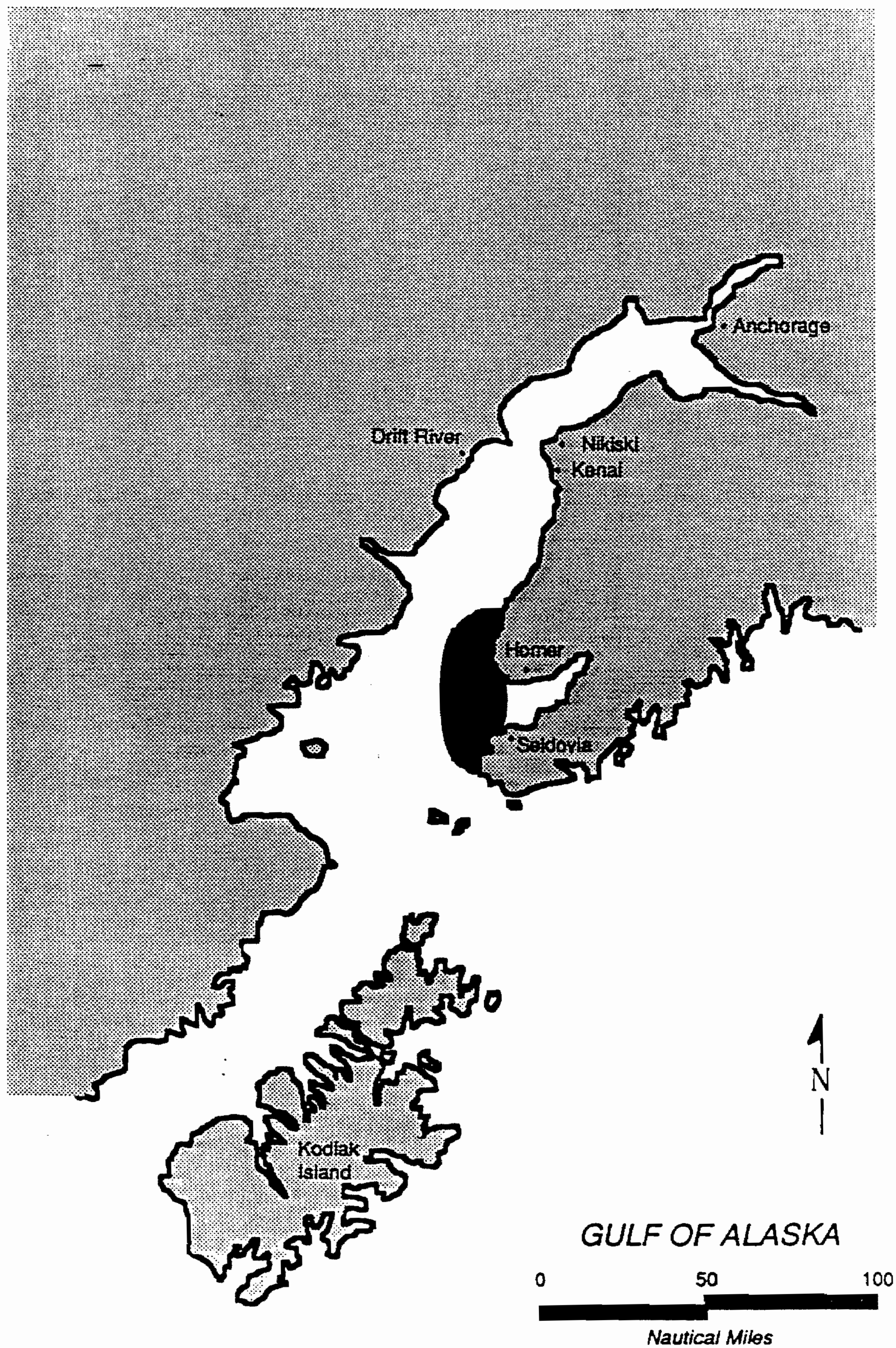
Kachemak Bay - 24 Hours After Spill
Spill Size = 21,000,000 Gallons
Typical Summer Wind And Current Conditions



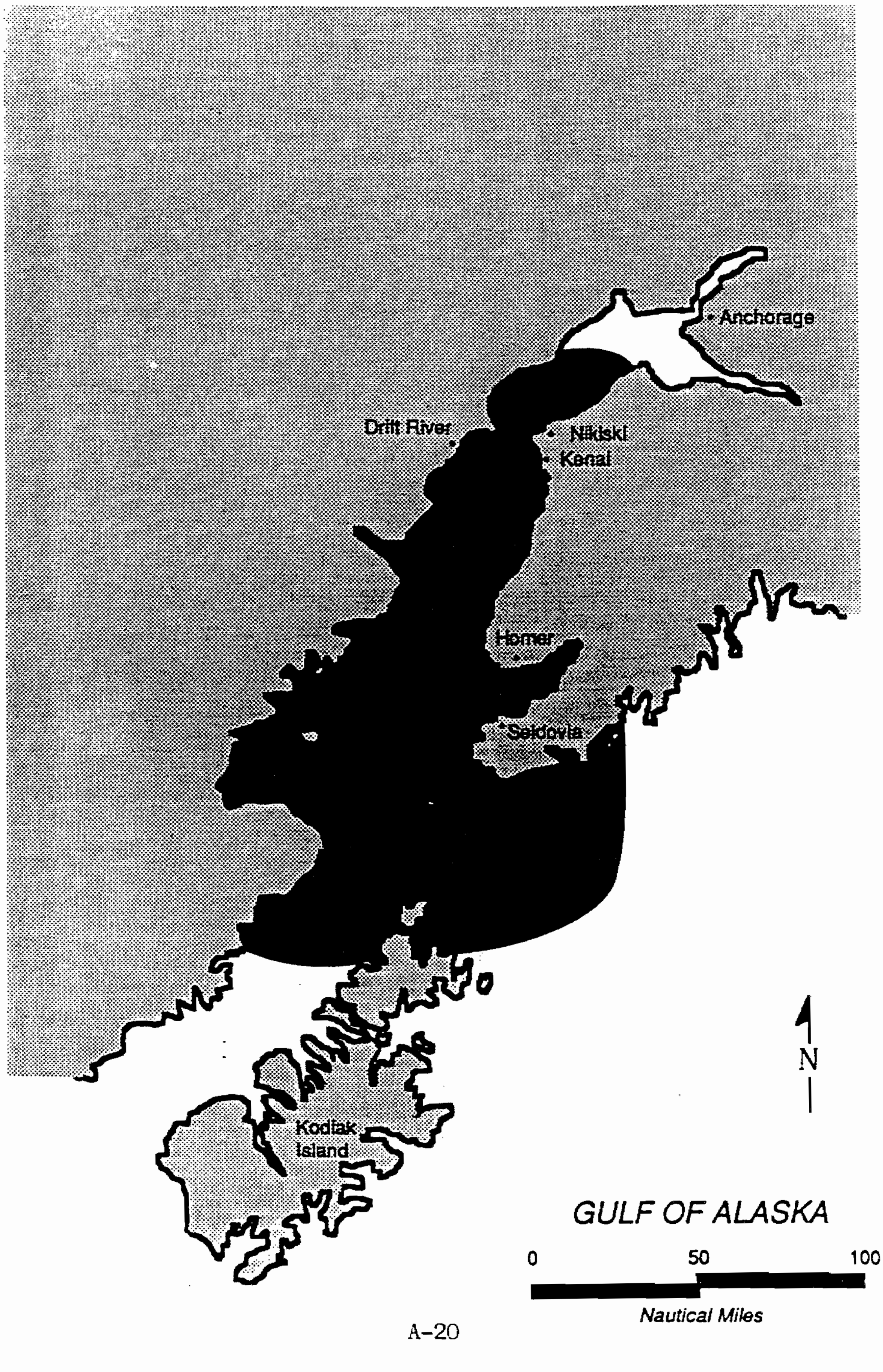
Kachemak Bay - 168 Hours After Spill
Spill Size = 21,000,000 Gallons
Typical Summer Wind And Current Conditions



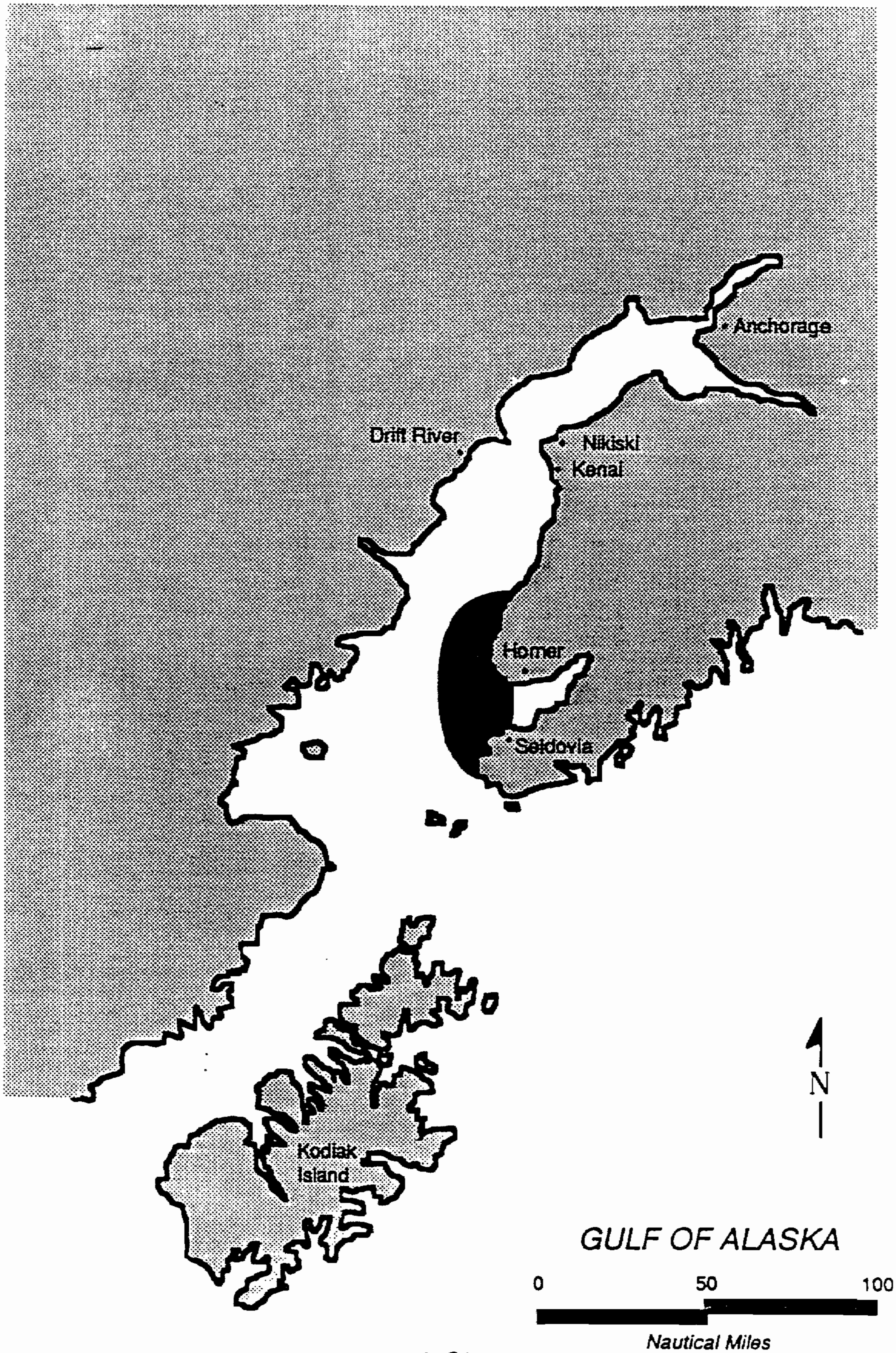
Kachemak Bay - 24 Hours After Spill
Spill Size = 1,000,000 Gallons
Typical Winter Wind And Current Conditions



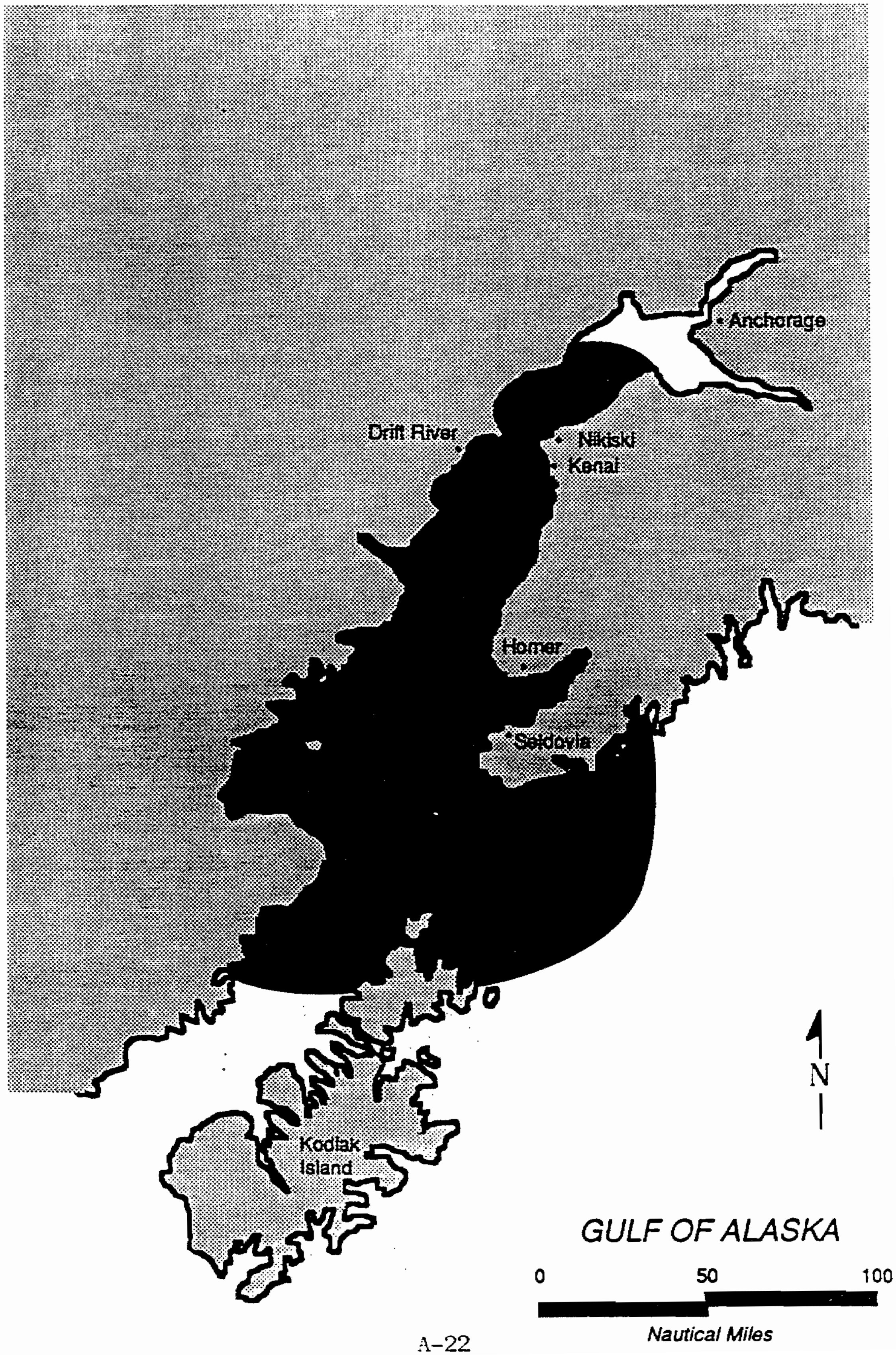
Kachemak Bay - 168 Hours After Spill
Spill Size = 1,000,000 Gallons
Typical Winter Wind And Current Conditions



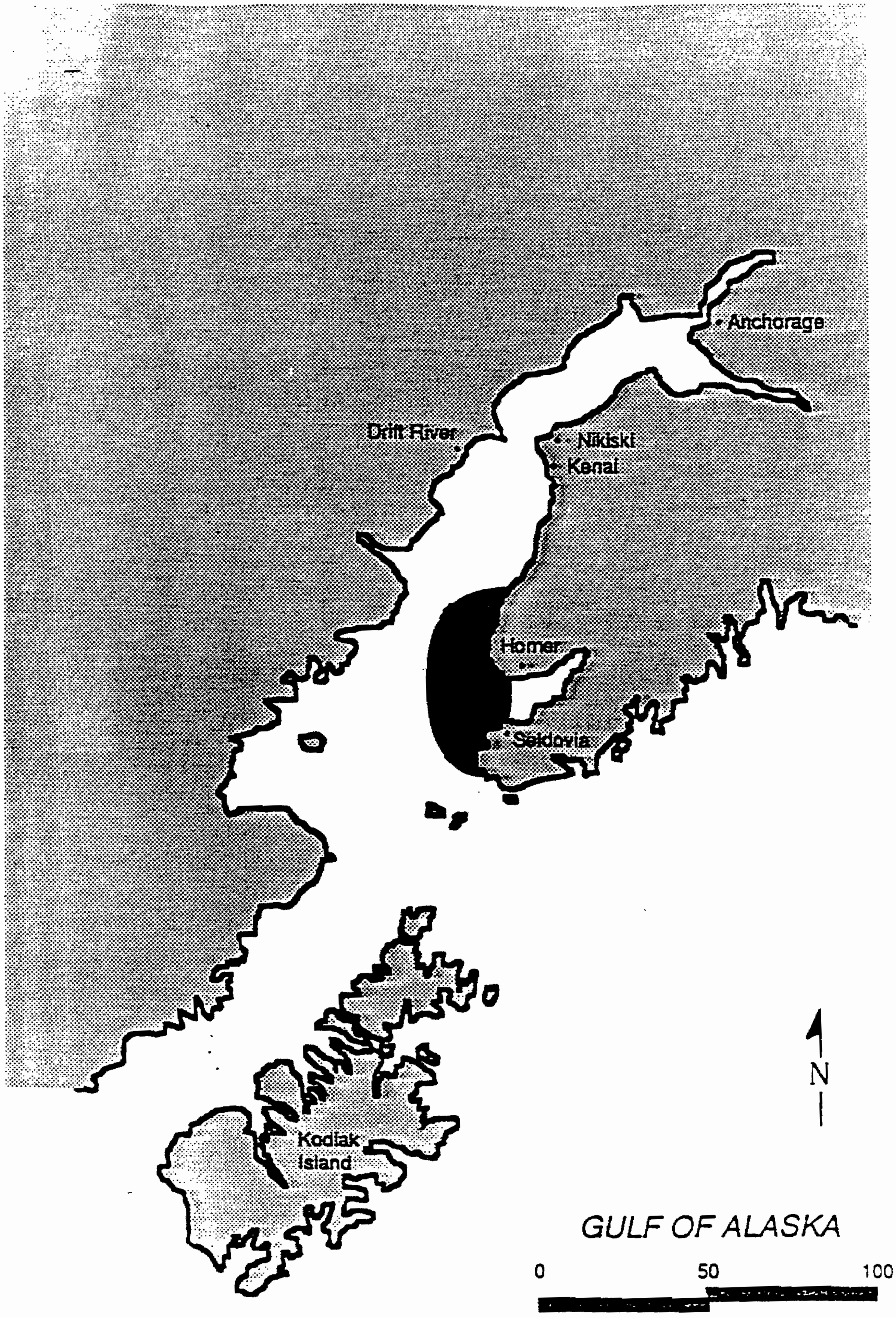
Kachemak Bay - 24 Hours After Spill
Spill Size = 9,000,000 Gallons
Typical Winter Wind And Current Conditions



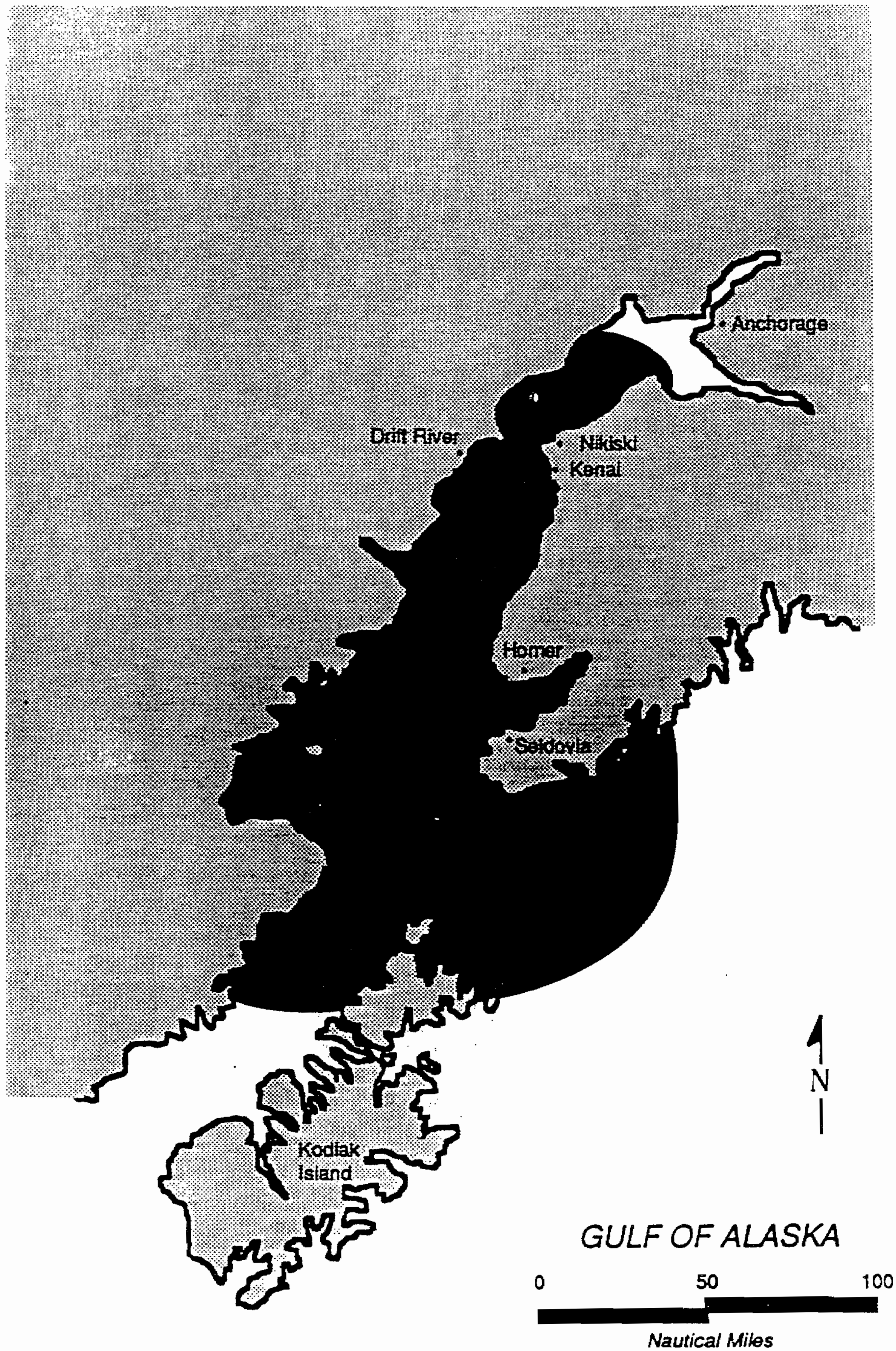
Kachemak Bay - 168 Hours After Spill
Spill Size = 9,000,000 Gallons
Typical Winter Wind And Current Conditions



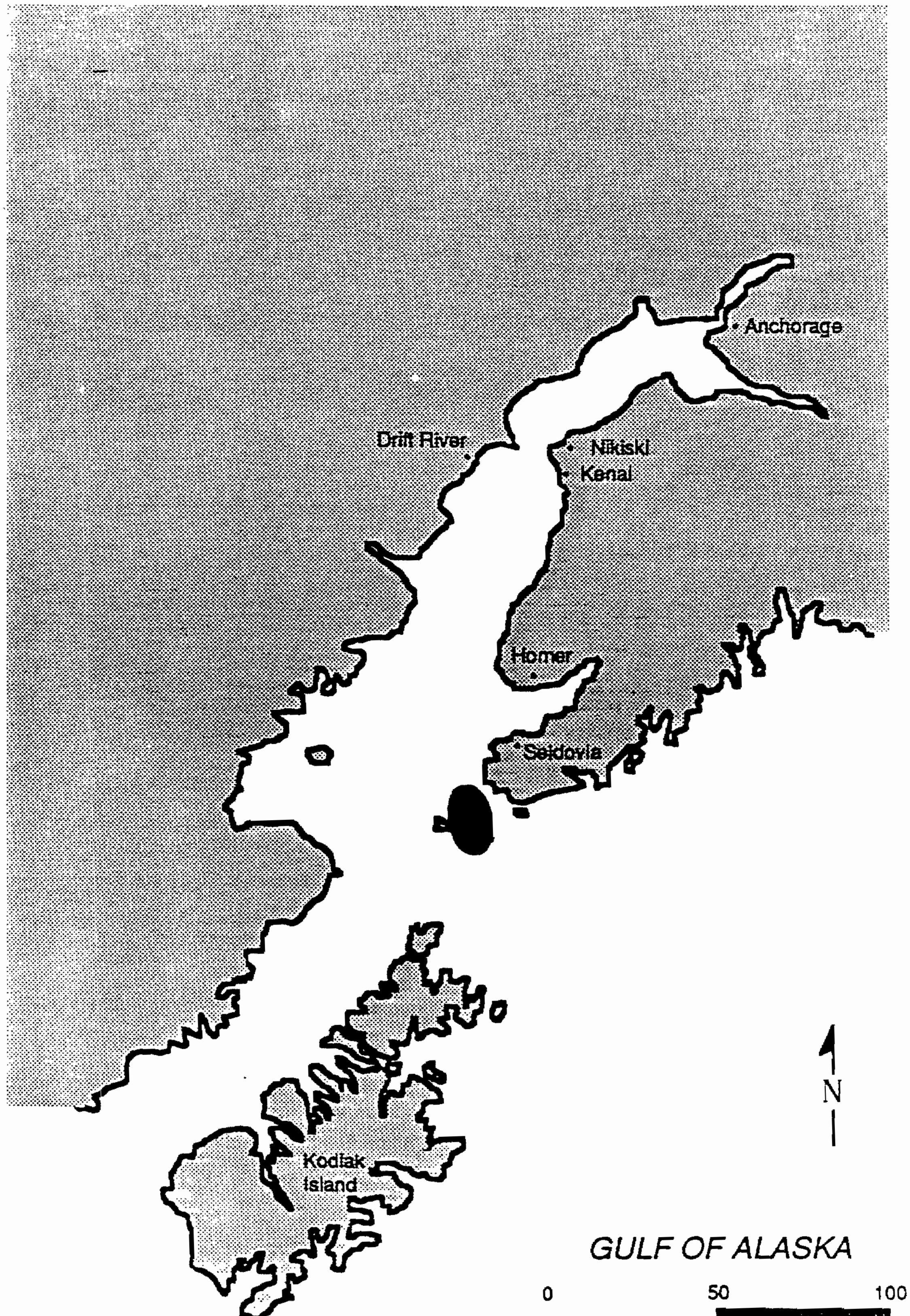
Kachemak Bay - 24 Hours After Spill
Spill Size = 21,000,000 Gallons
Typical Winter Wind And Current Conditions



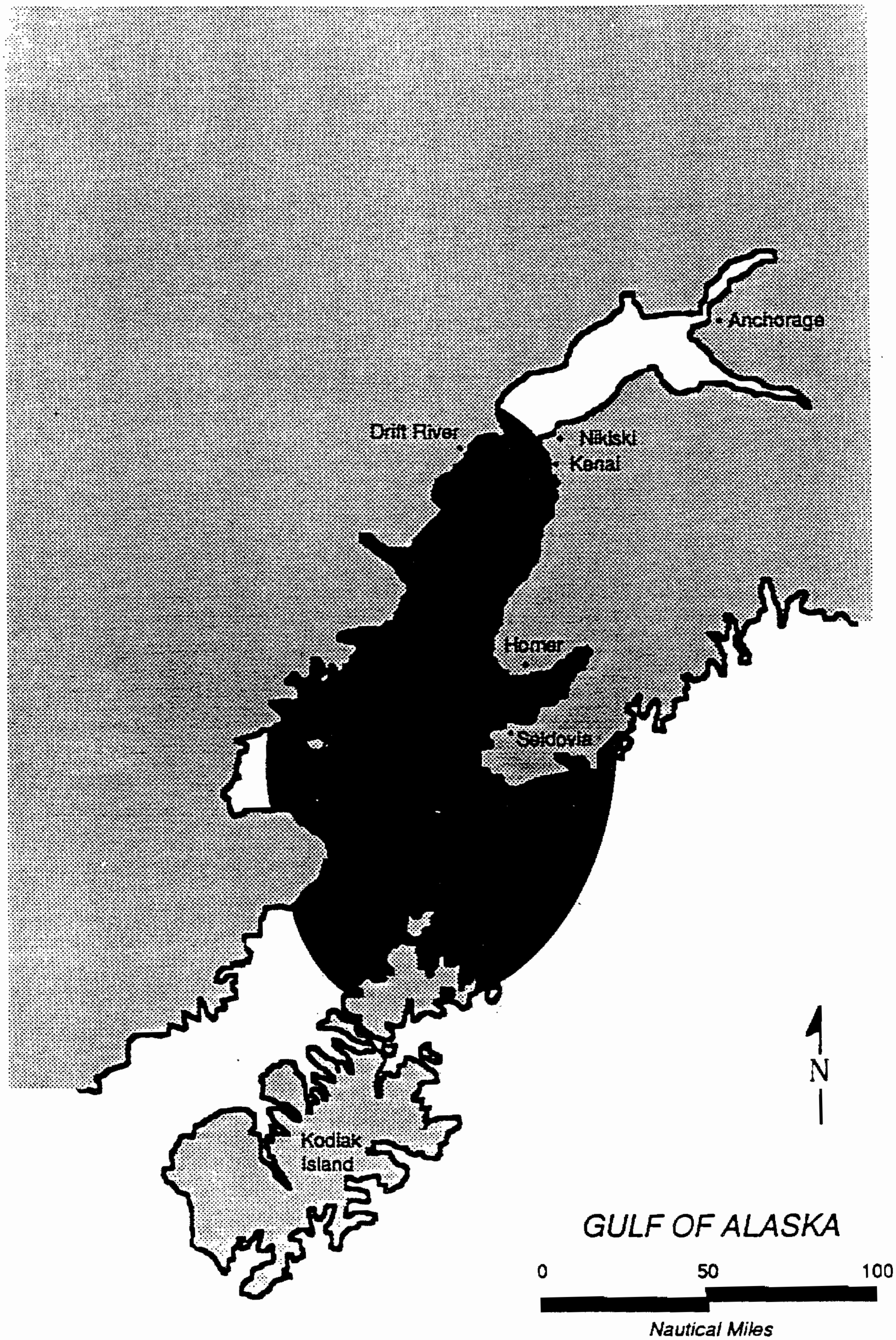
Kachemak Bay - 168 Hours After Spill
Spill Size = 21,000,000 Gallons
Typical Winter Wind And Current Conditions



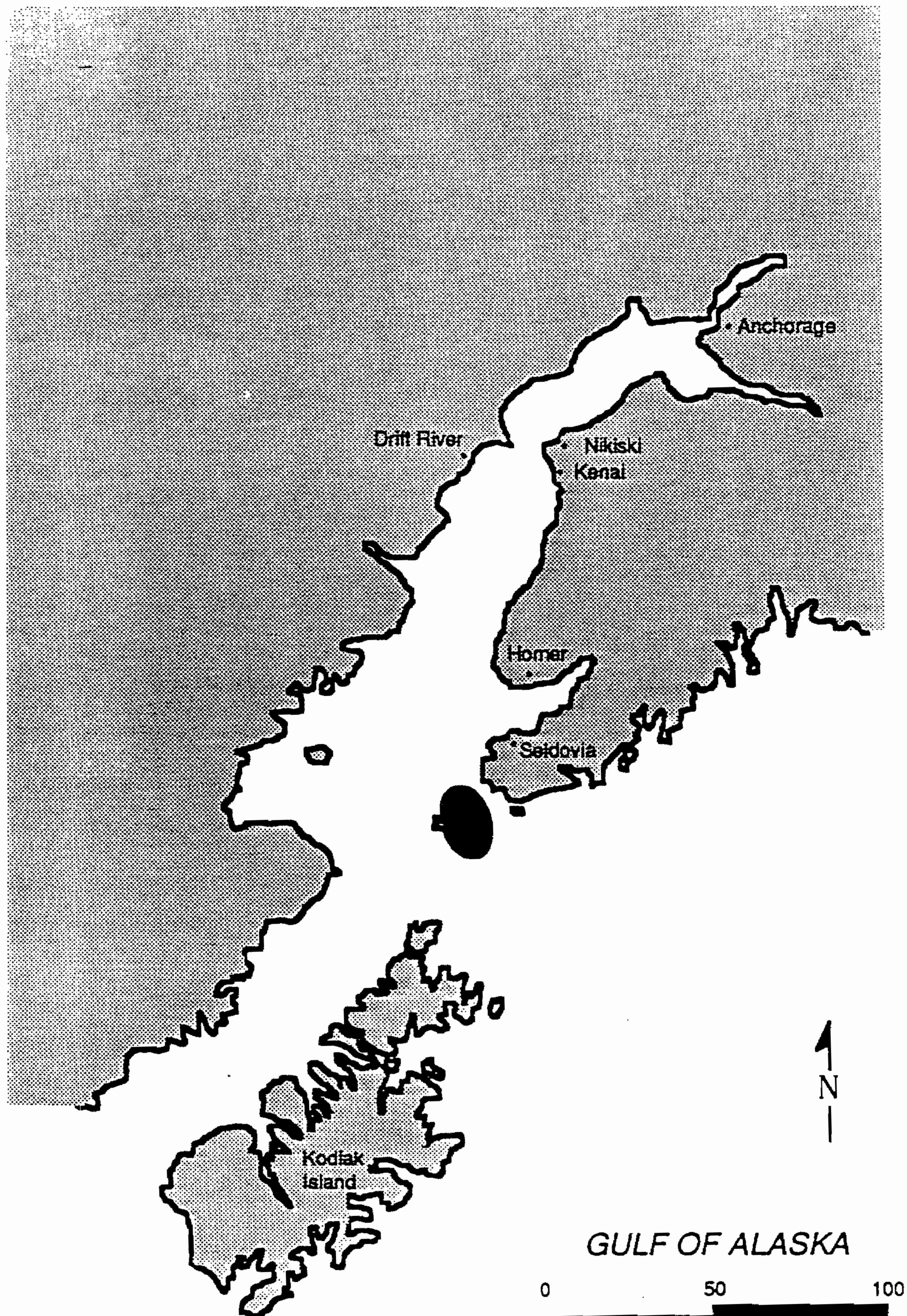
Kennedy Entrance - 24 Hours After Spill
Spill Size = 1,000,000 Gallons
Typical Summer Wind And Current Conditions



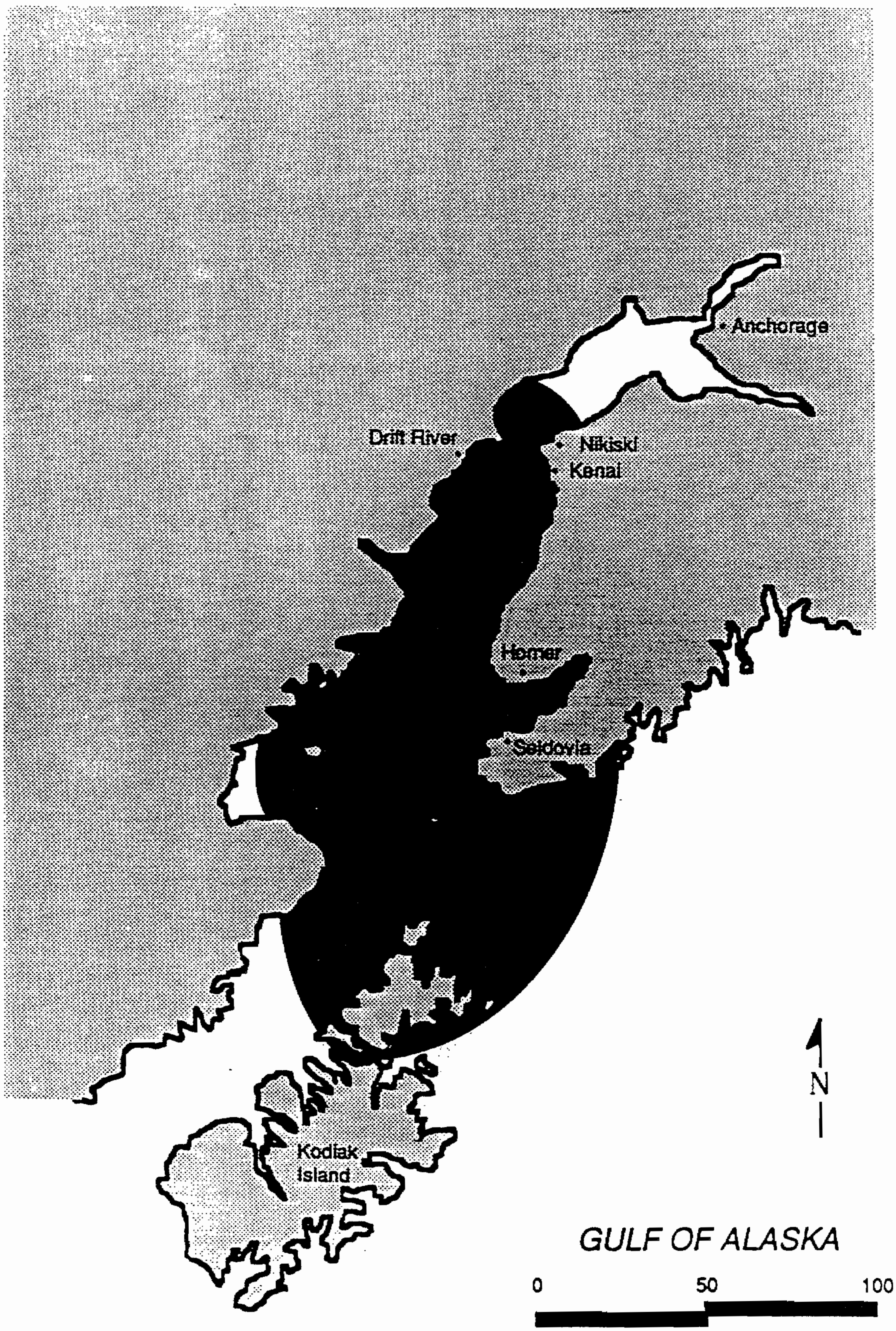
Kennedy Entrance - 168 Hours After Spill
Spill Size = 1,000,000 Gallons
Typical Summer Wind And Current Conditions



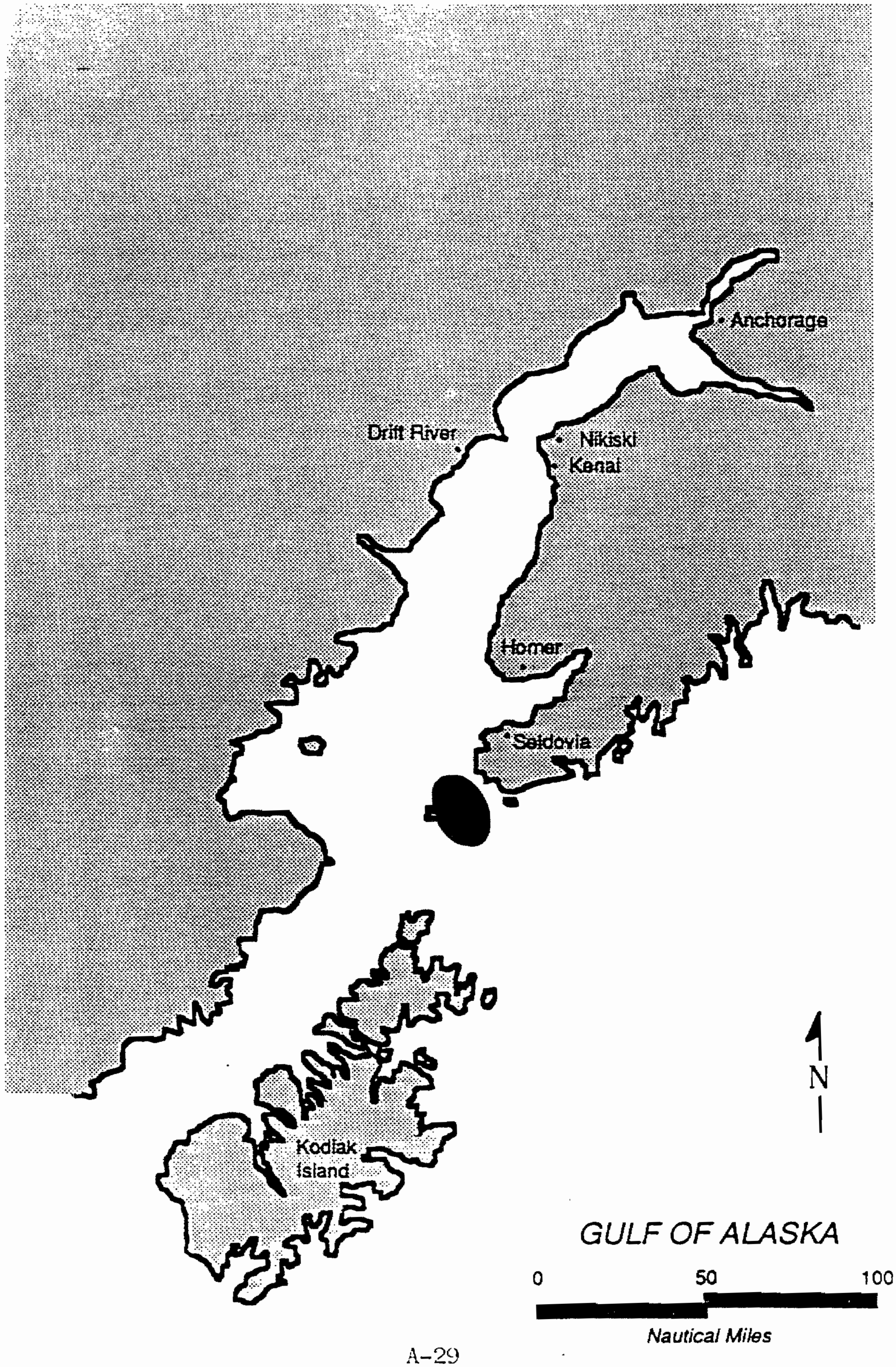
Kennedy Entrance - 24 Hours After Spill
Spill Size = 9,000,000 Gallons
Typical Summer Wind And Current Conditions



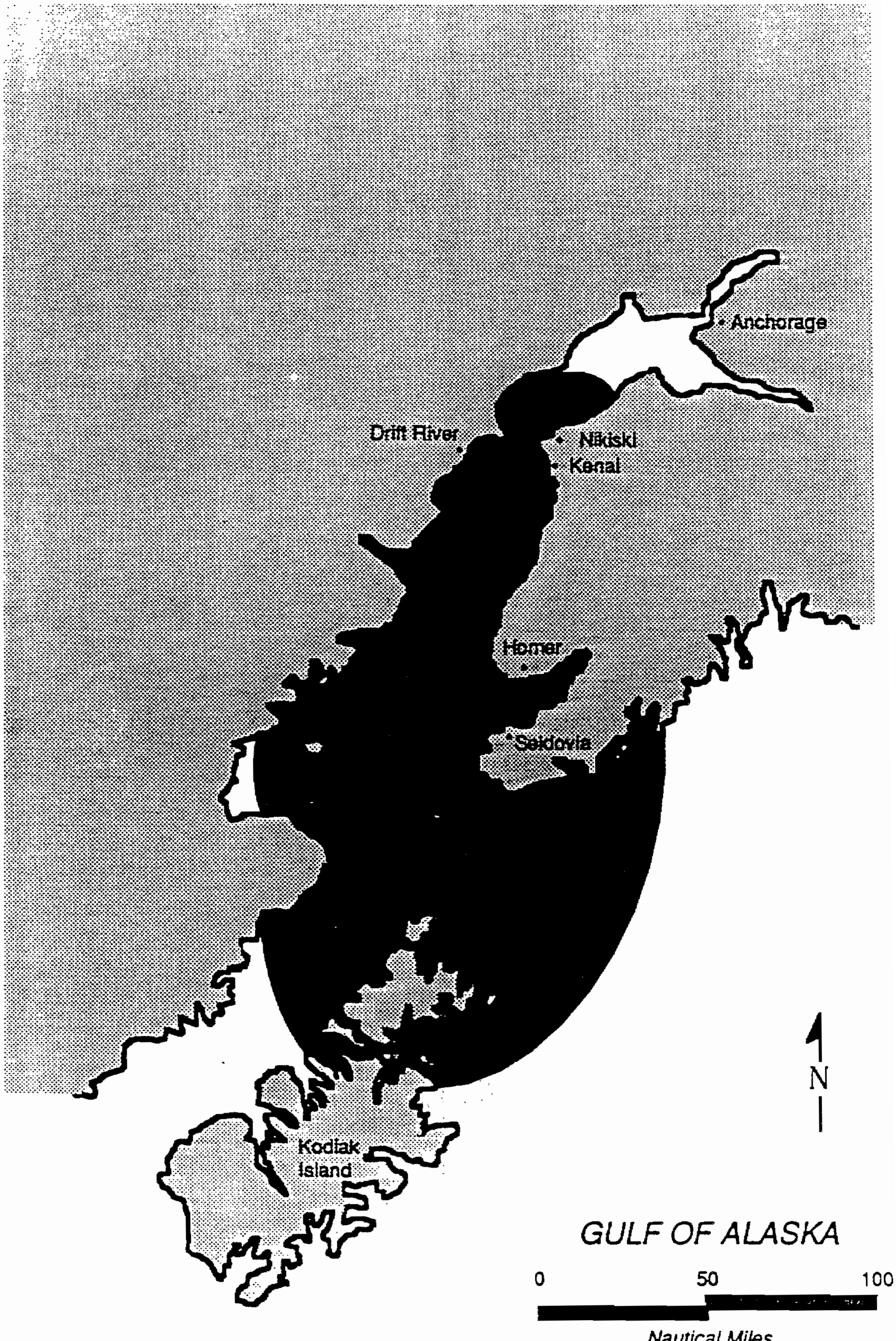
Kennedy Entrance - 168 Hours After Spill
Spill Size = 9,000,000 Gallons
Typical Summer Wind And Current Conditions



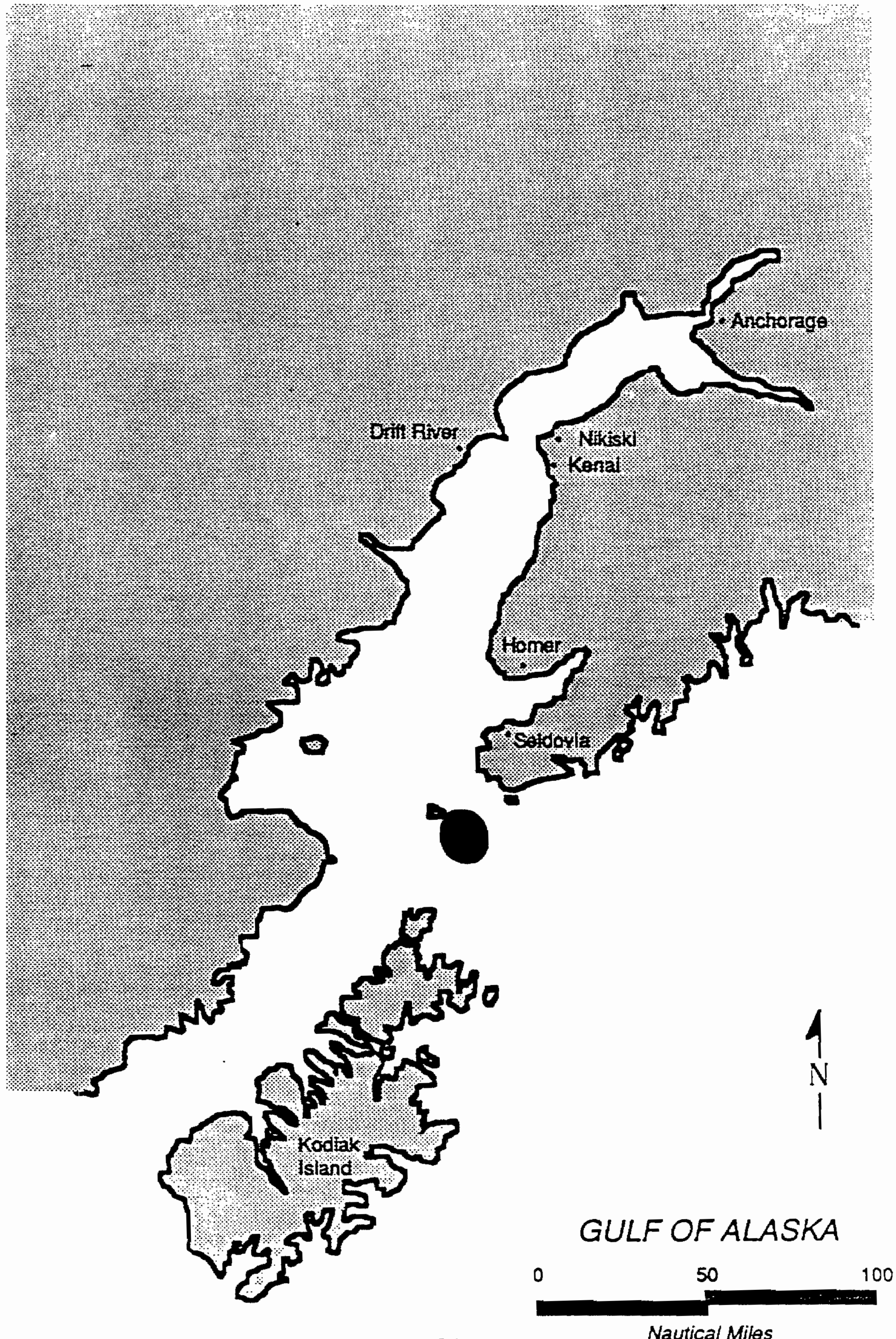
Kennedy Entrance - 24 Hours After Spill
Spill Size = 21,000,000 Gallons
Typical Summer Wind And Current Conditions



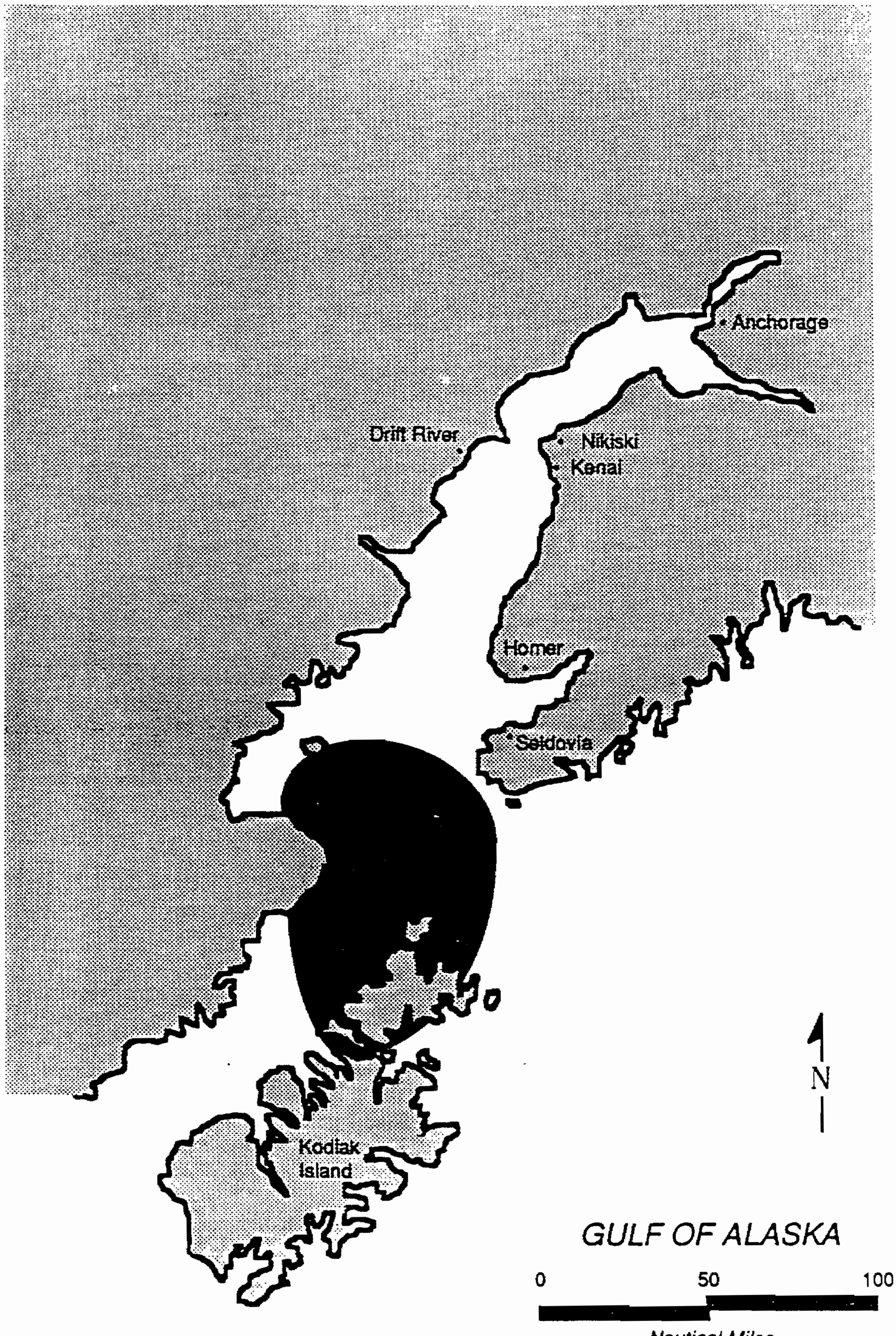
Kennedy Entrance - 168 Hours After Spill
Spill Size = 21,000,000 Gallons
Typical Summer Wind And Current Conditions



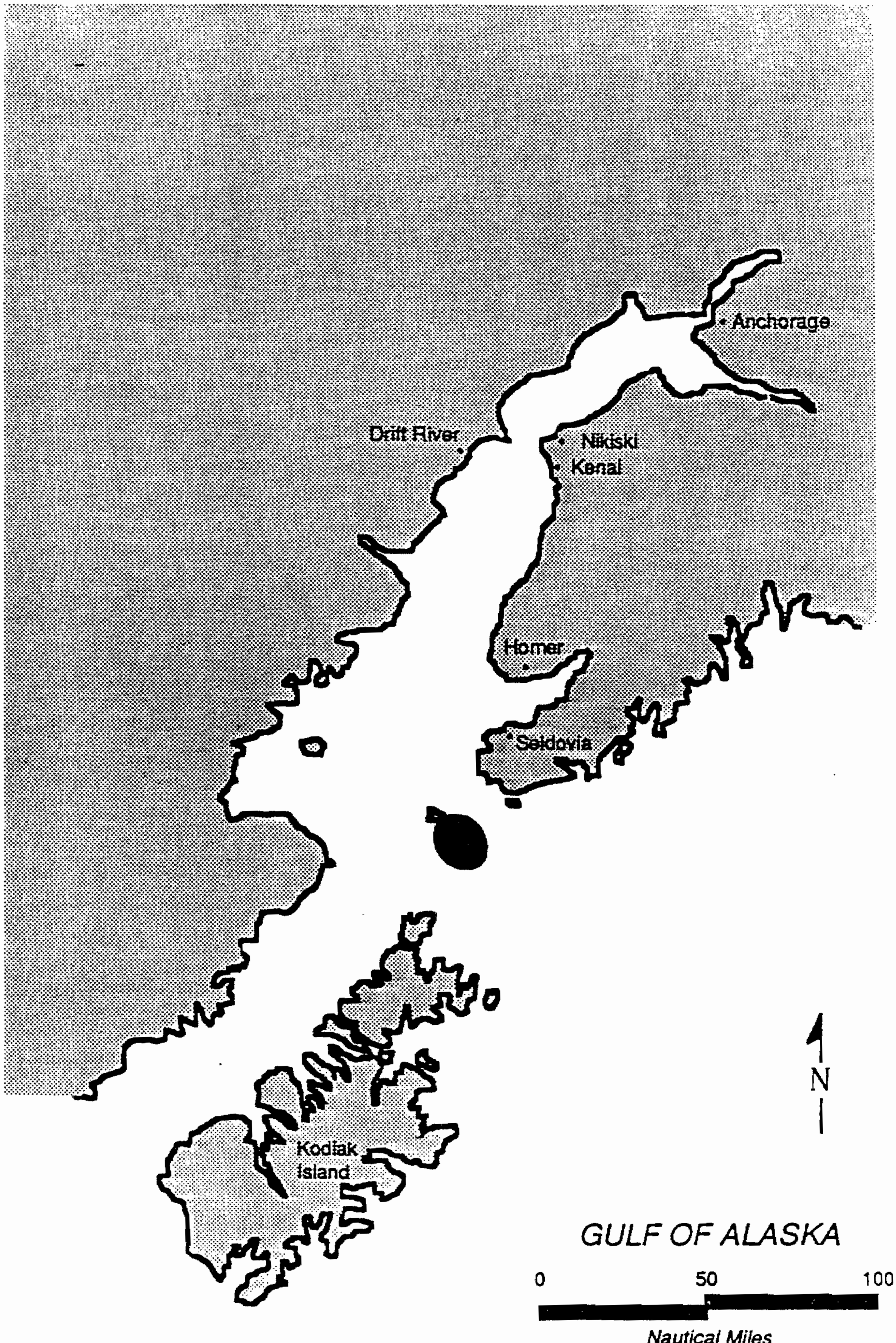
Kennedy Entrance - 24 Hours After Spill
Spill Size = 1,000,000 Gallons
Typical Winter Wind And Current Conditions



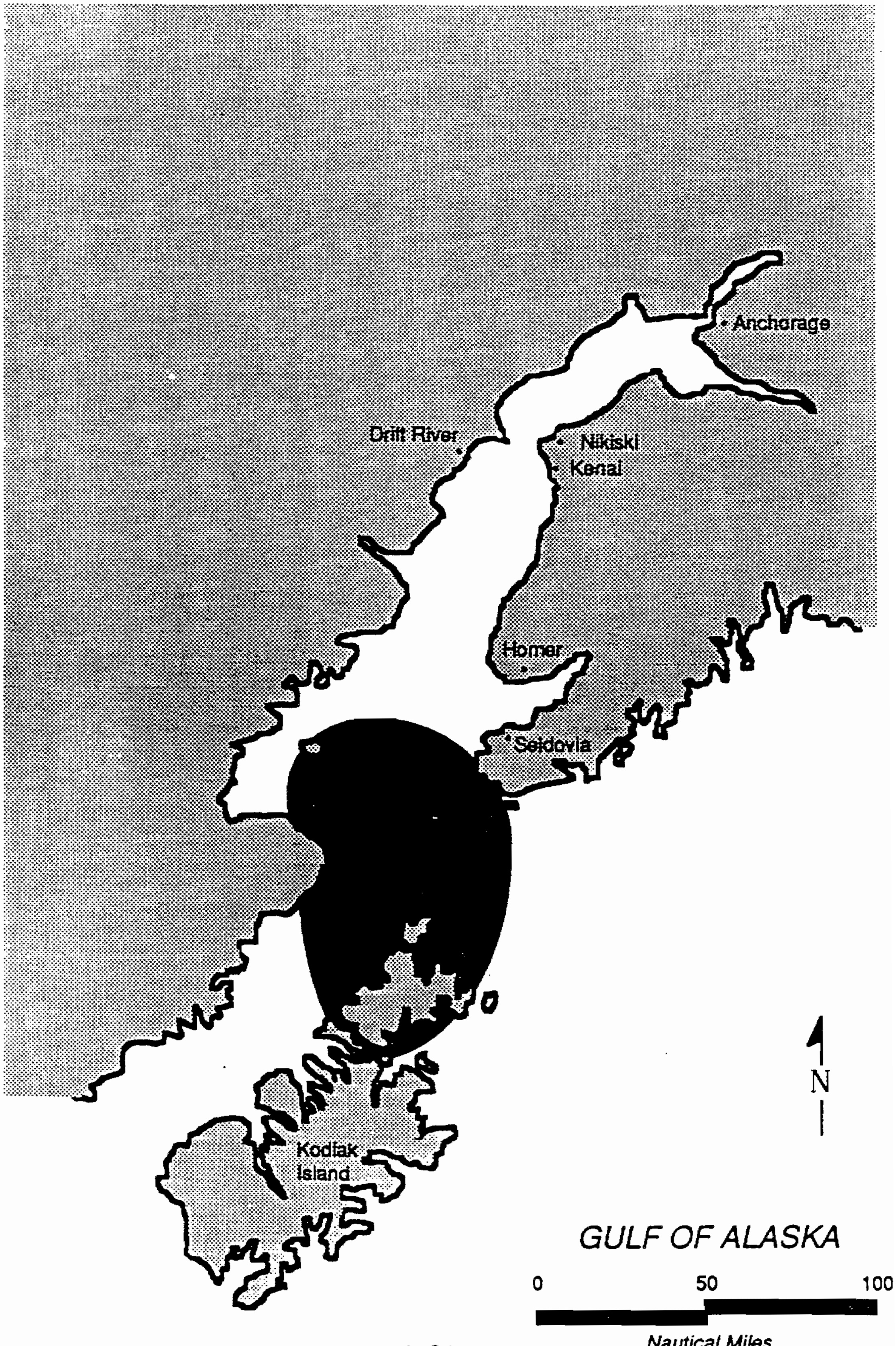
Kennedy Entrance - 168 Hours After Spill
Spill Size = 1,000,000 Gallons
Typical Winter Wind And Current Conditions



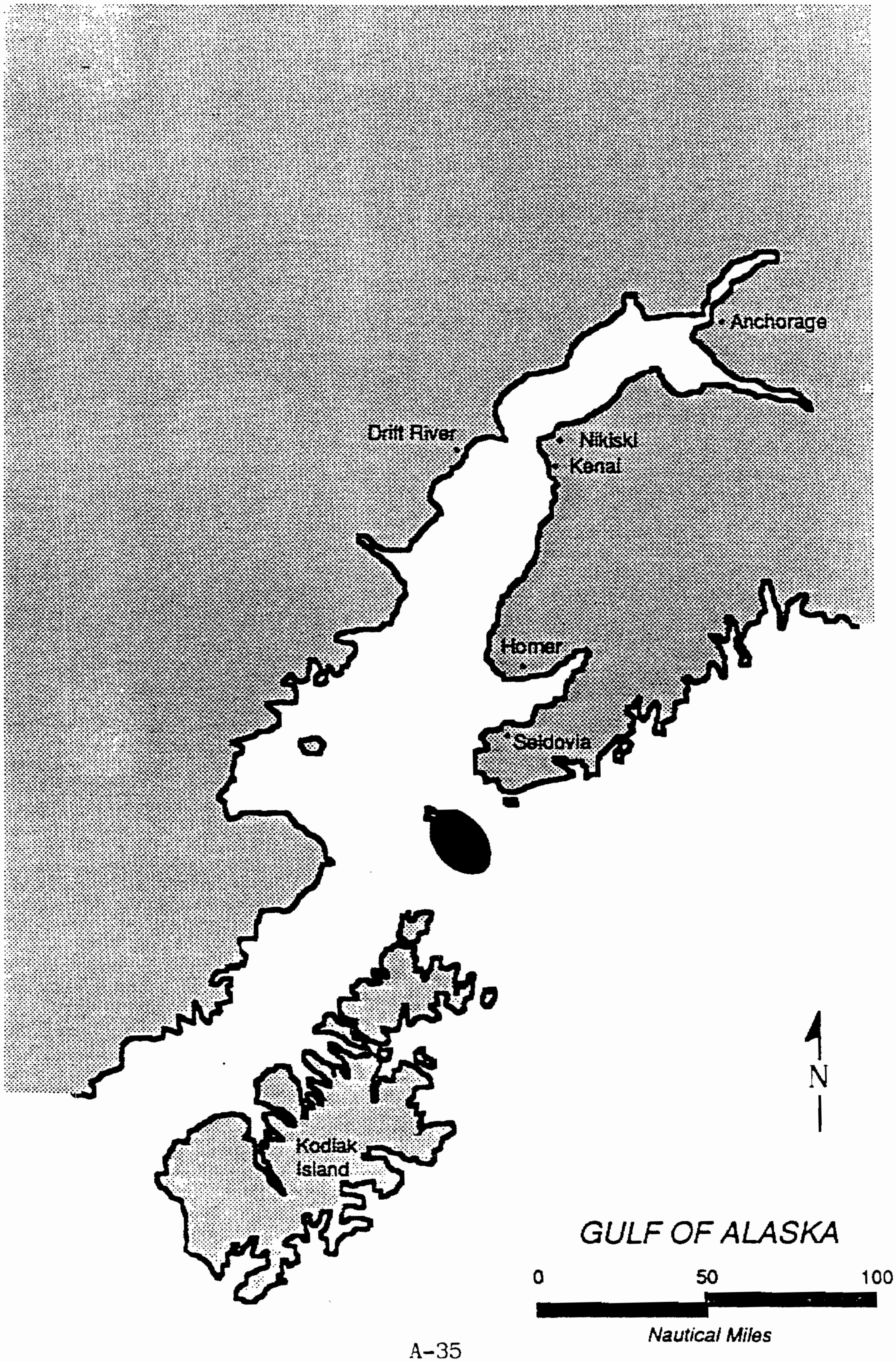
Kennedy Entrance - 24 Hours After Spill
Spill Size = 9,000,000 Gallons
Typical Winter Wind And Current Conditions



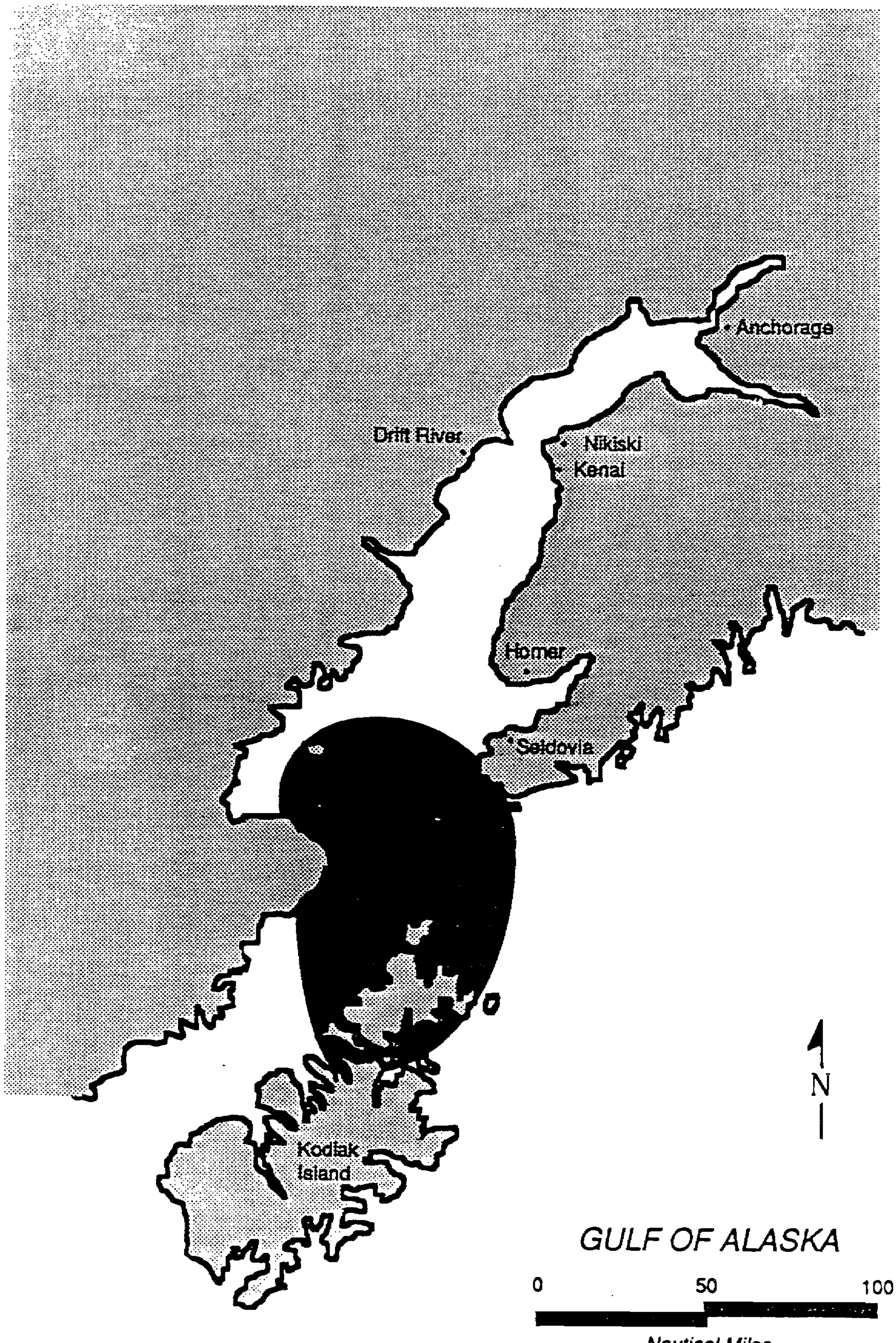
Kennedy Entrance - 168 Hours After Spill
Spill Size = 9,000,000 Gallons
Typical Winter Wind And Current Conditions



Kennedy Entrance - 24 Hours After Spill
Spill Size = 21,000,000 Gallons
Typical Winter Wind And Current Conditions



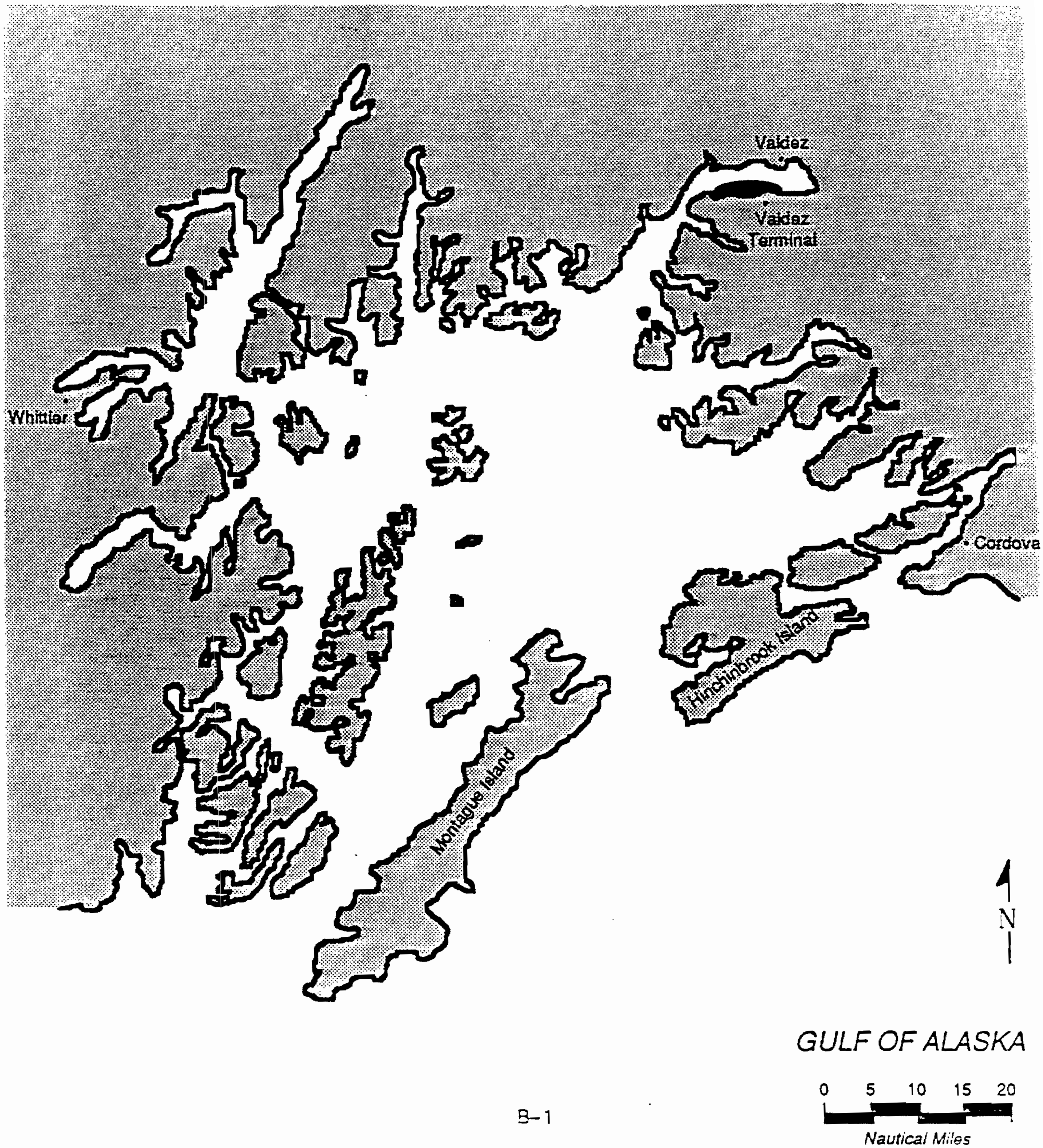
Kennedy Entrance - 168 Hours After Spill
Spill Size = 21,000,000 Gallons
Typical Winter Wind And Current Conditions



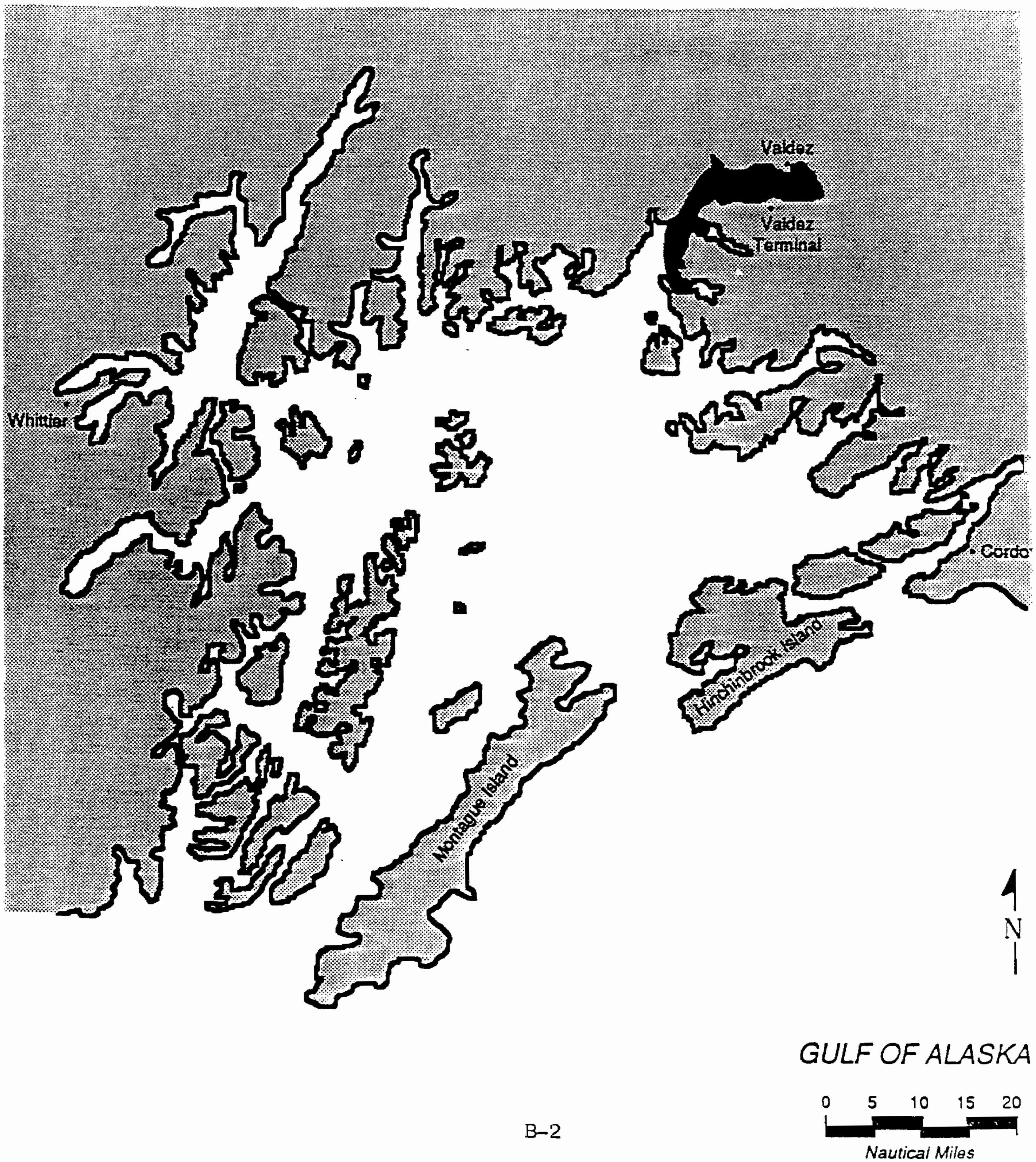
APPENDIX B

PRINCE WILLIAM SOUND OIL SPILL PROJECTIONS

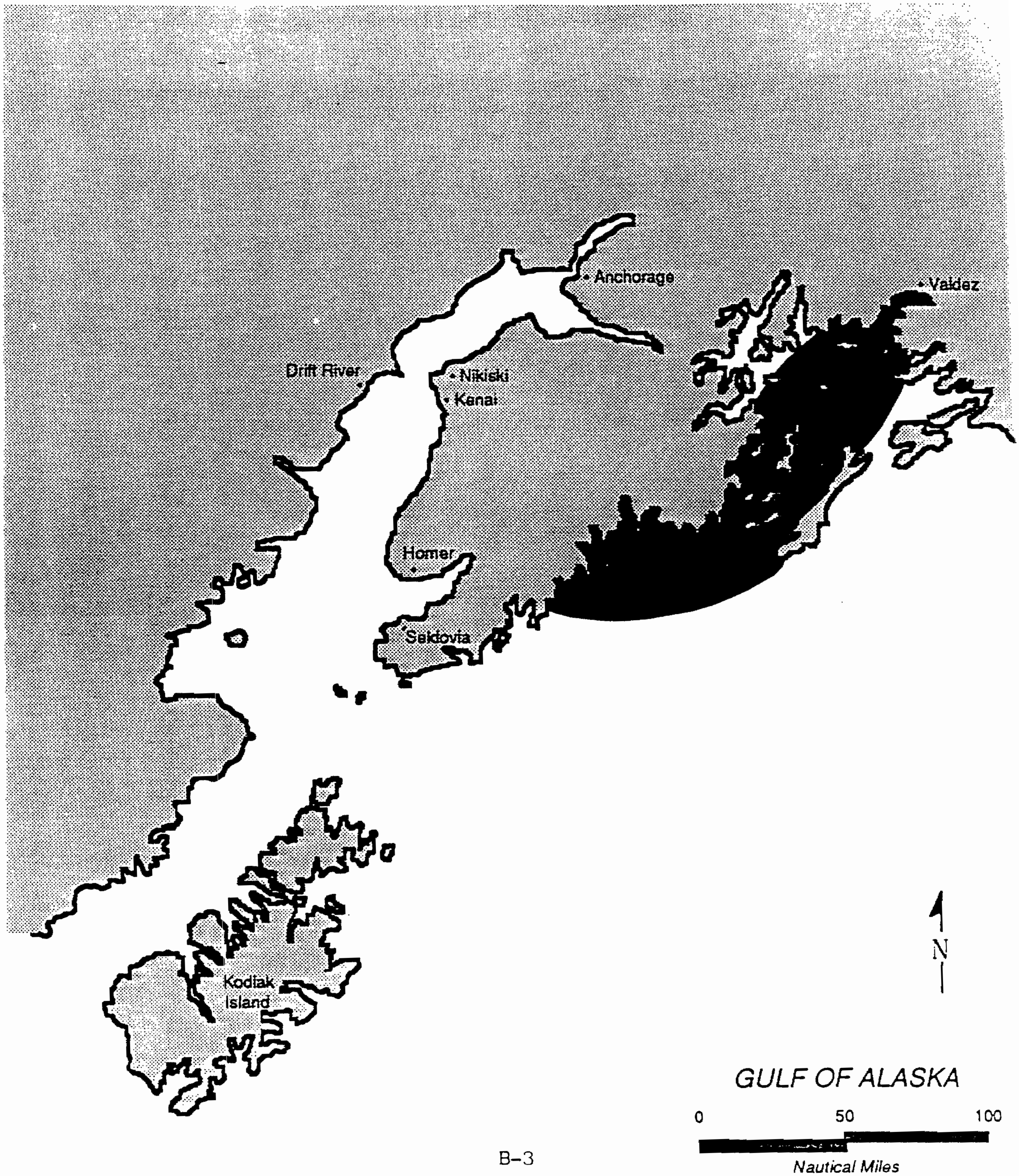
Port Valdez - 24 Hours After Spill
Spill Size = 3,000,000 Gallons
Typical Summer Wind And Current Conditions



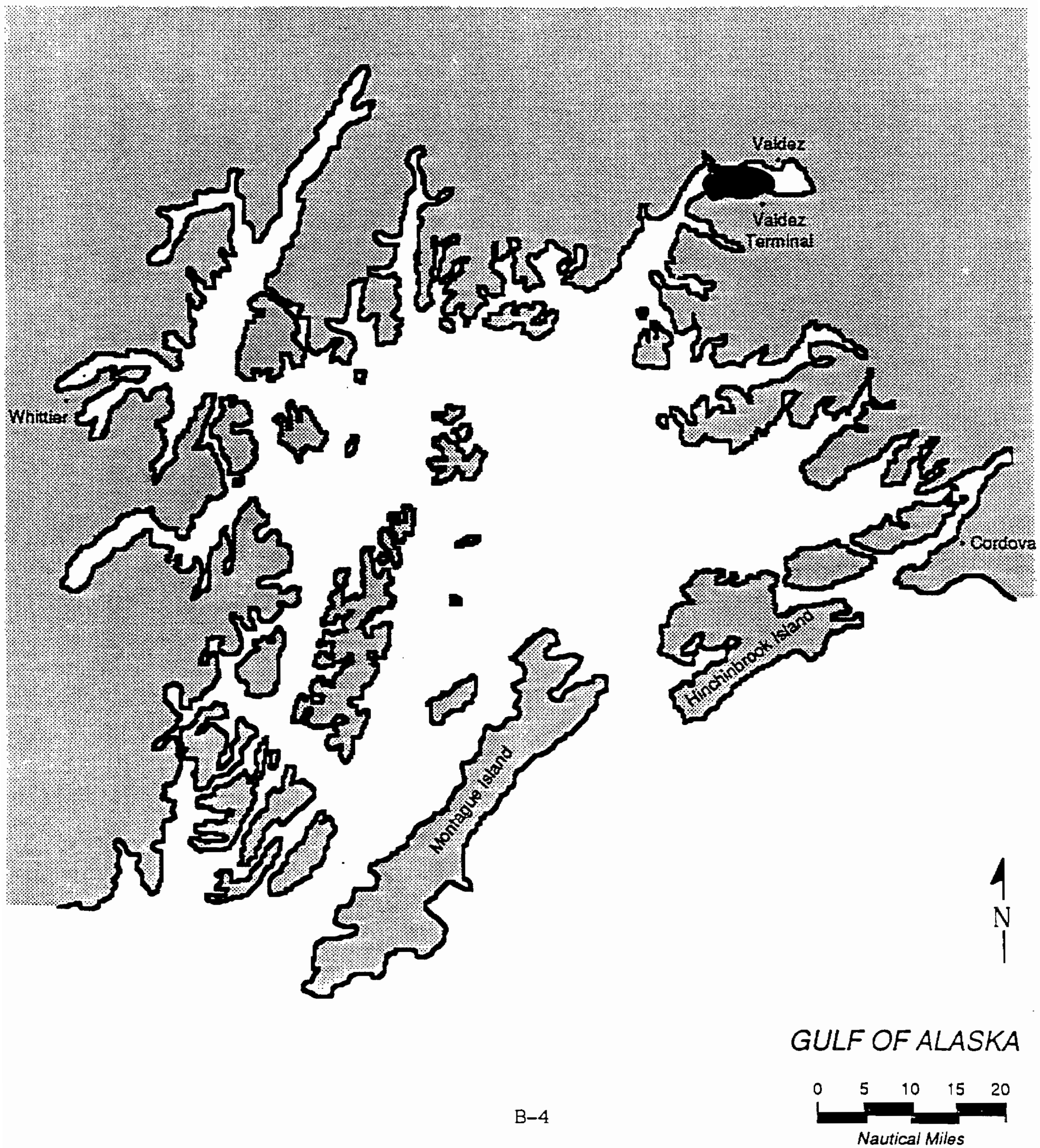
Port Valdez - 168 Hours After Spill
Spill Size = 3,000,000 Gallons
Typical Summer Wind And Current Conditions



Port Valdez - 672 Hours After Spill
Spill Size = 3,000,000 Gallons
Typical Summer Wind And Current Conditions

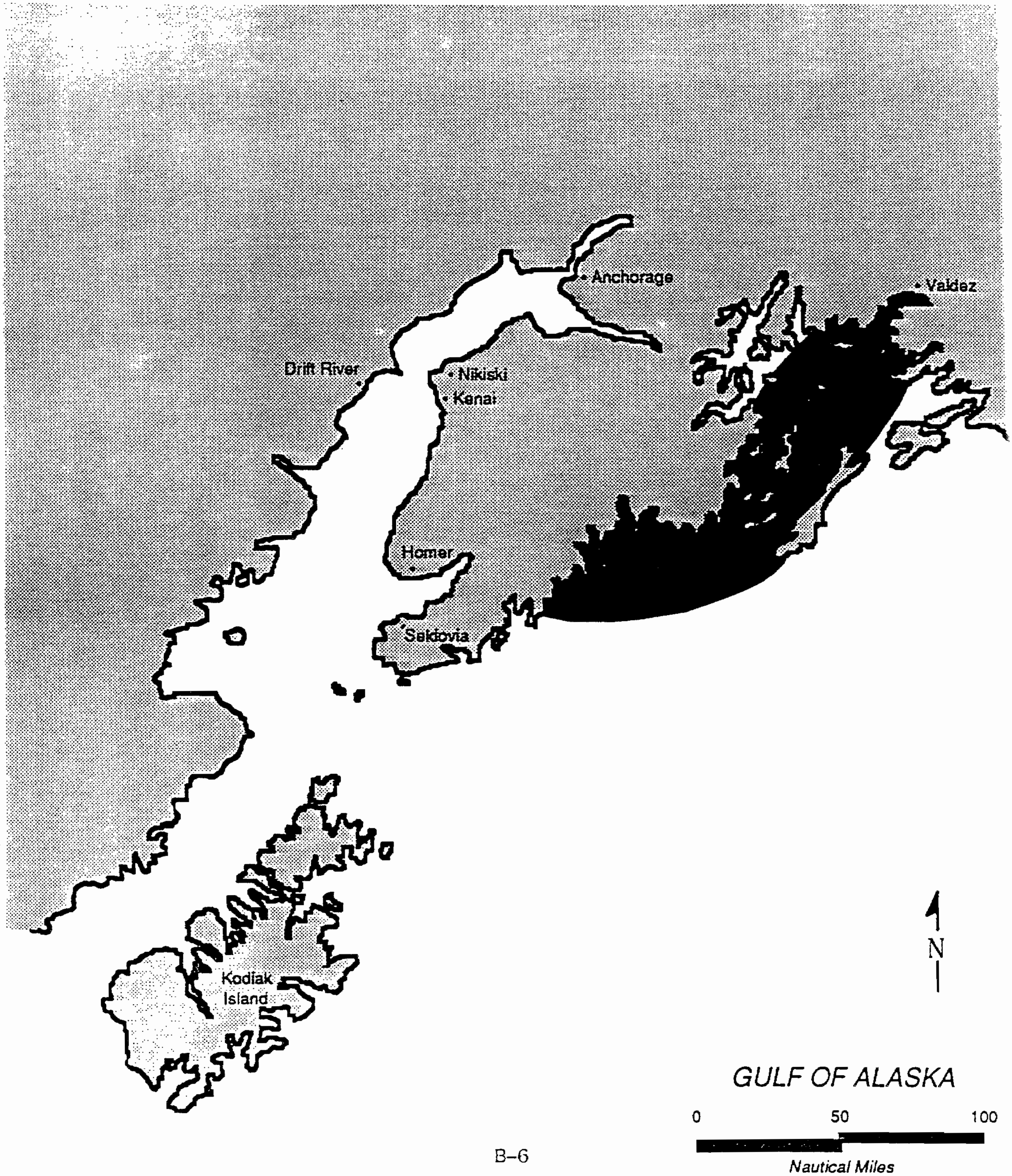


Port Valdez - 24 Hours After Spill
Spill Size = 11,000,000 Gallons
Typical Summer Wind And Current Conditions

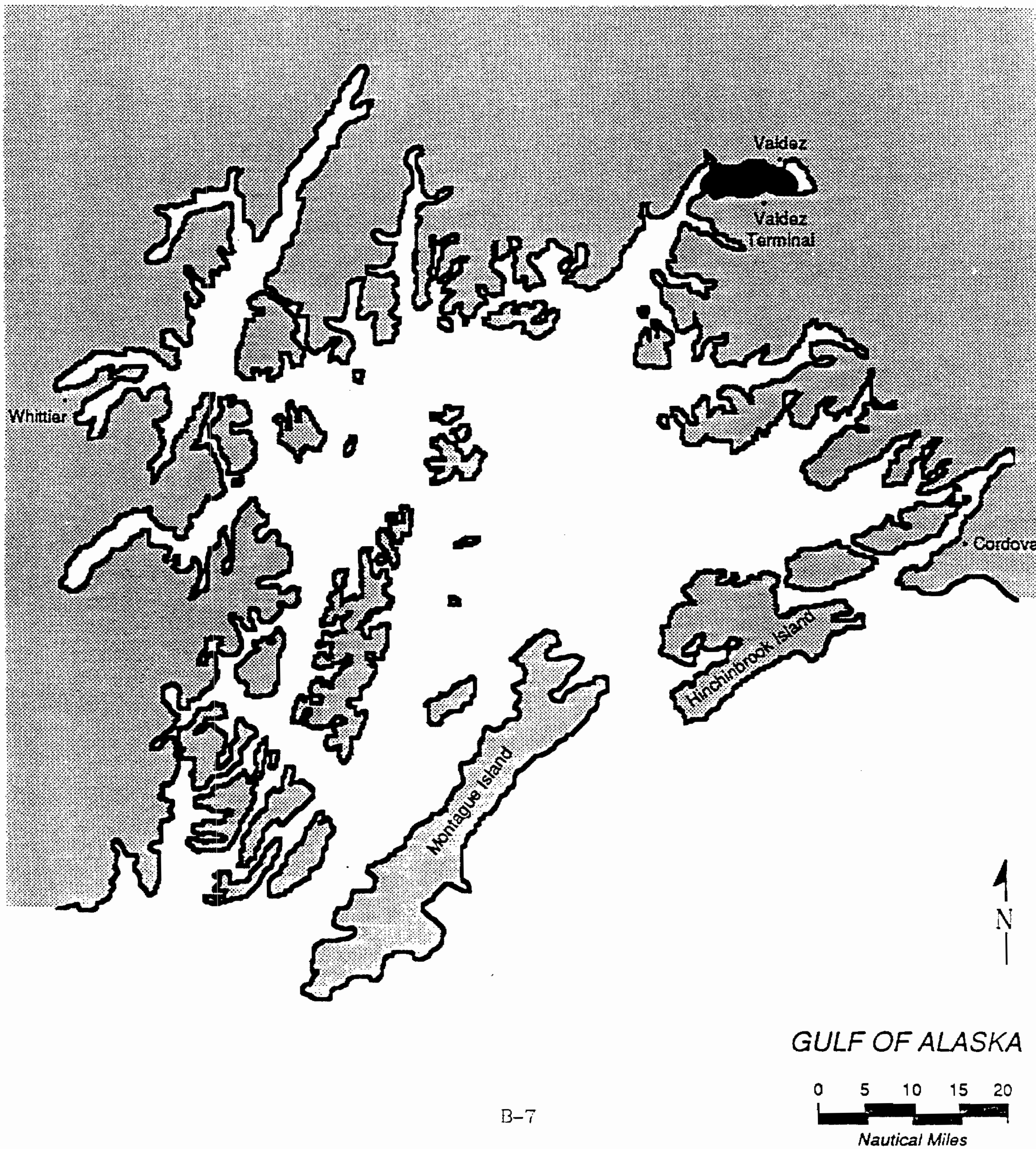


Port Valdez - 168 Hours After Spill
Spill Size = 11,000,000 Gallons
Typical Summer Wind And Current Conditions

Port Valdez - 672 Hours After Spill
Spill Size = 11,000,000 Gallons
Typical Summer Wind And Current Conditions

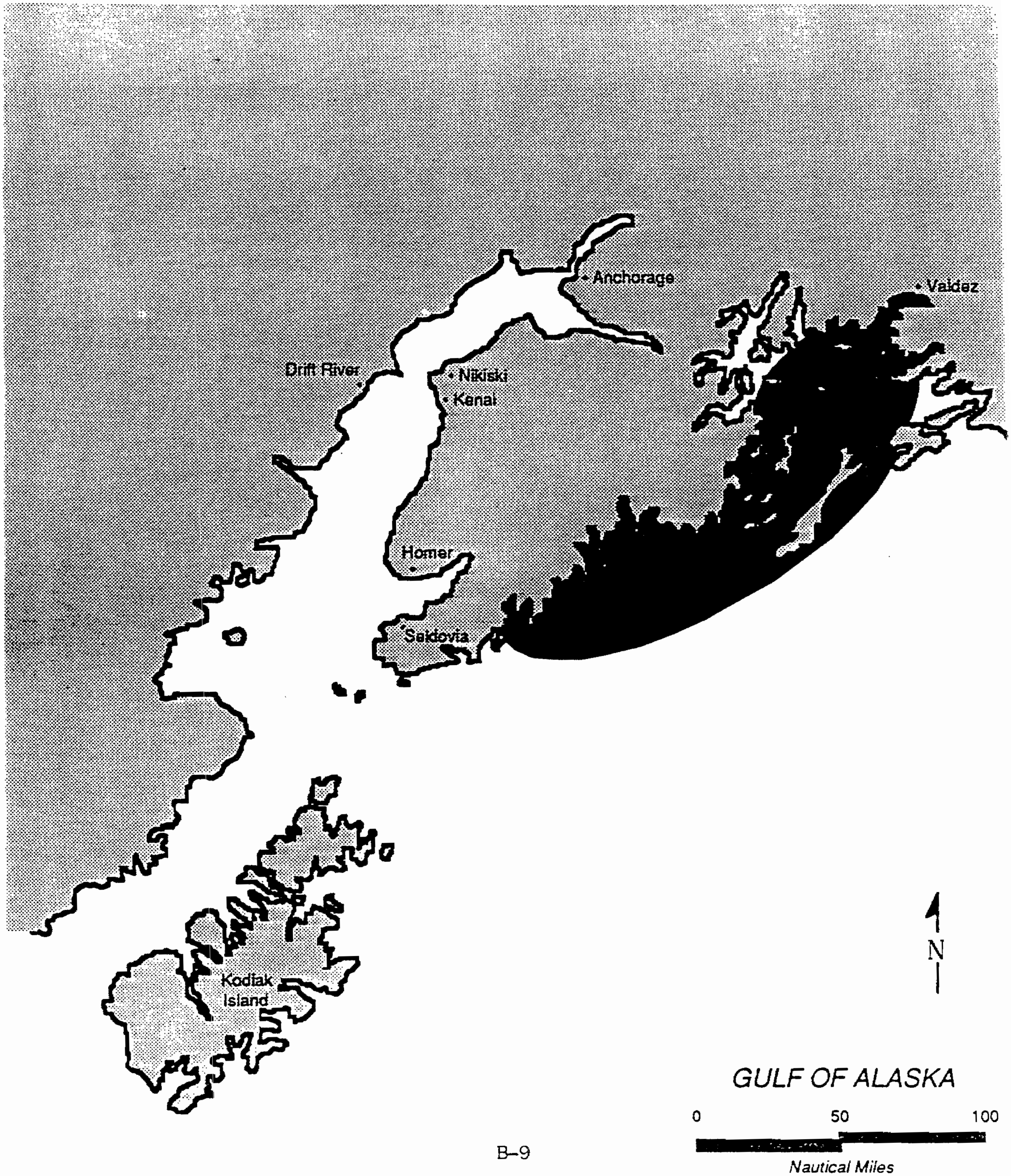


Port Valdez - 24 Hours After Spill
Spill Size = 75,000,000 Gallons
Typical Summer Wind And Current Conditions

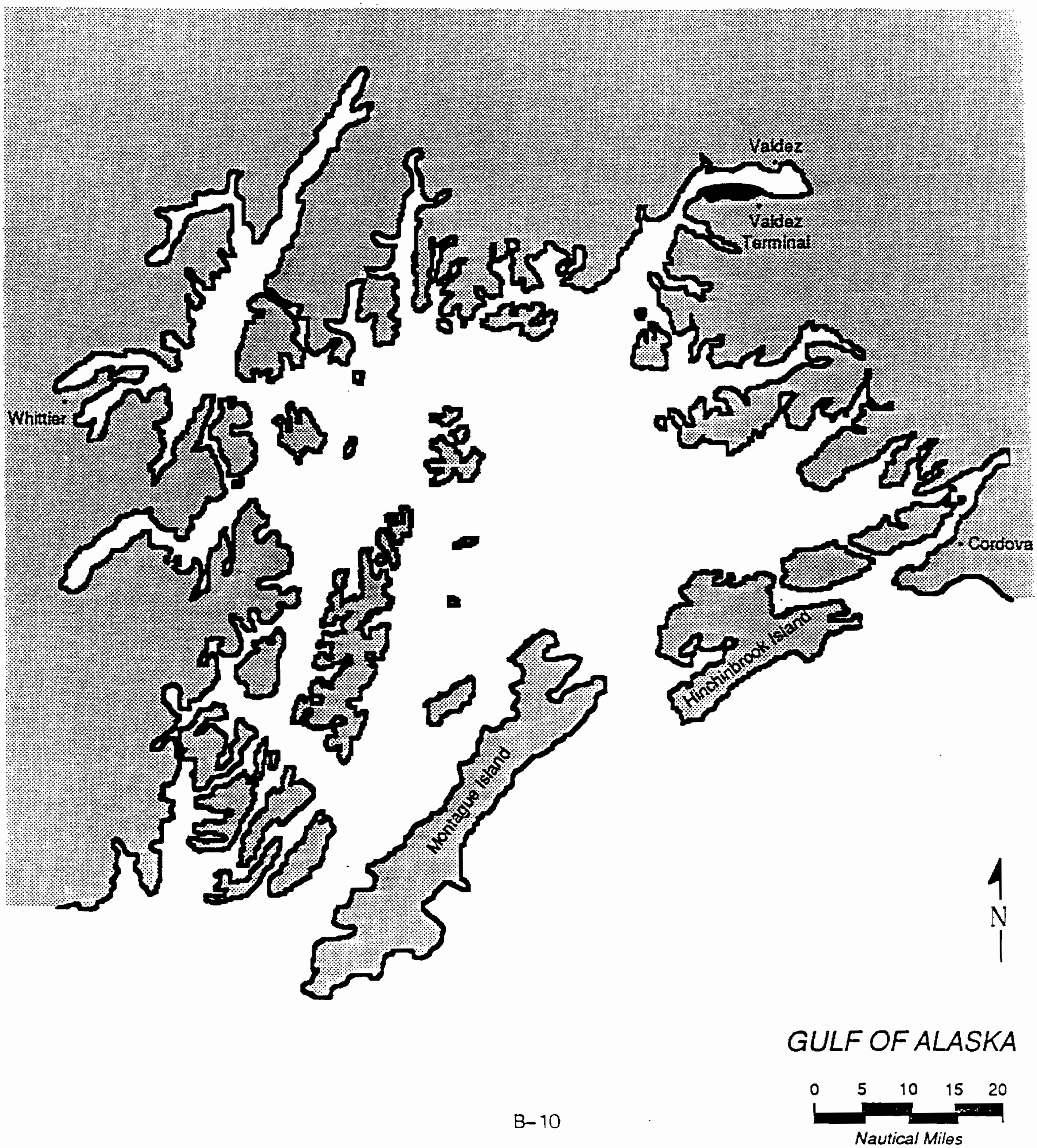


Port Valdez - 168 Hours After Spill
Spill Size = 75,000,000 Gallons
Typical Summer Wind And Current Conditions

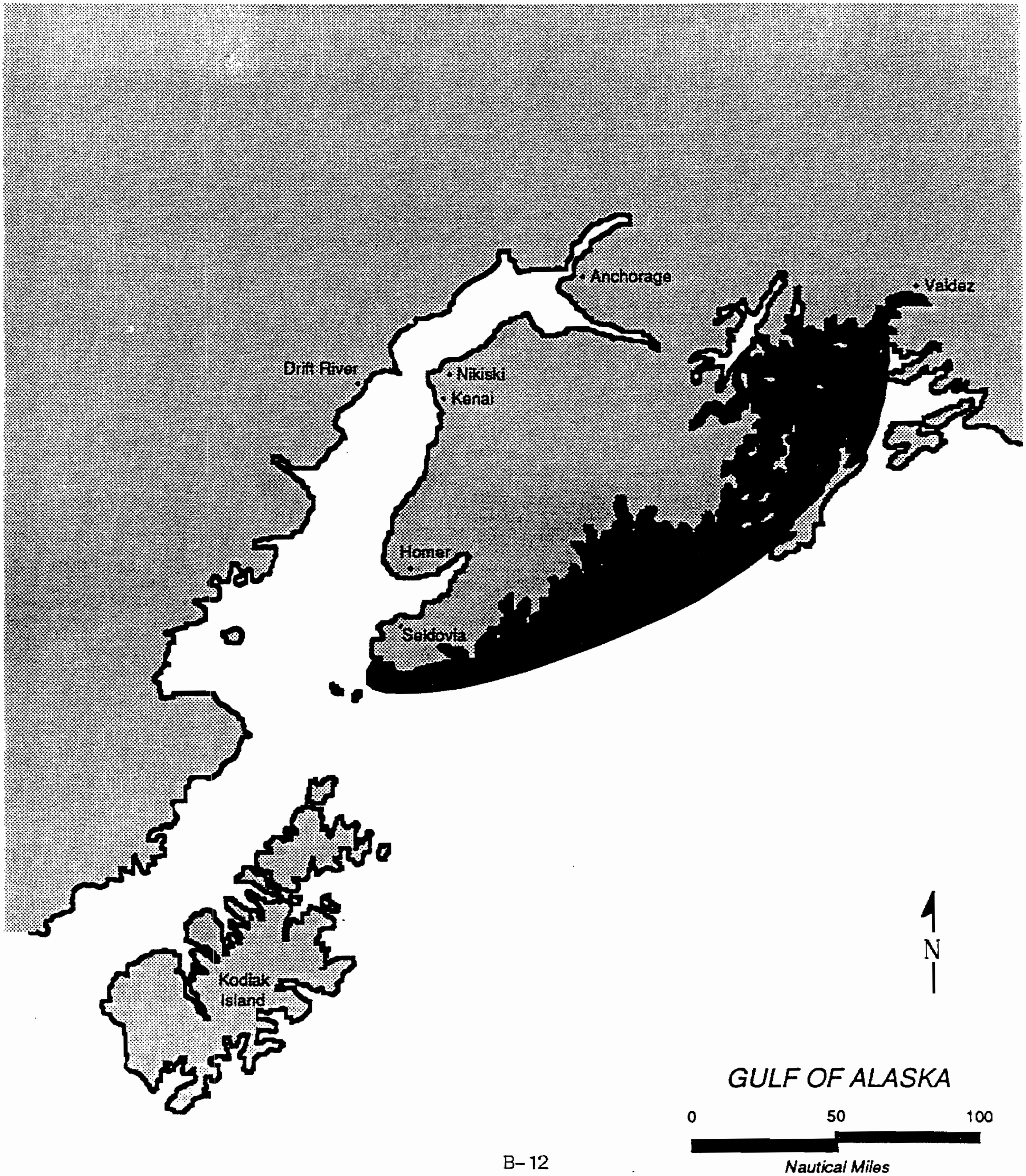
Port Valdez - 672 Hours After Spill
Spill Size = 75,000,000 Gallons
Typical Summer Wind And Current Conditions



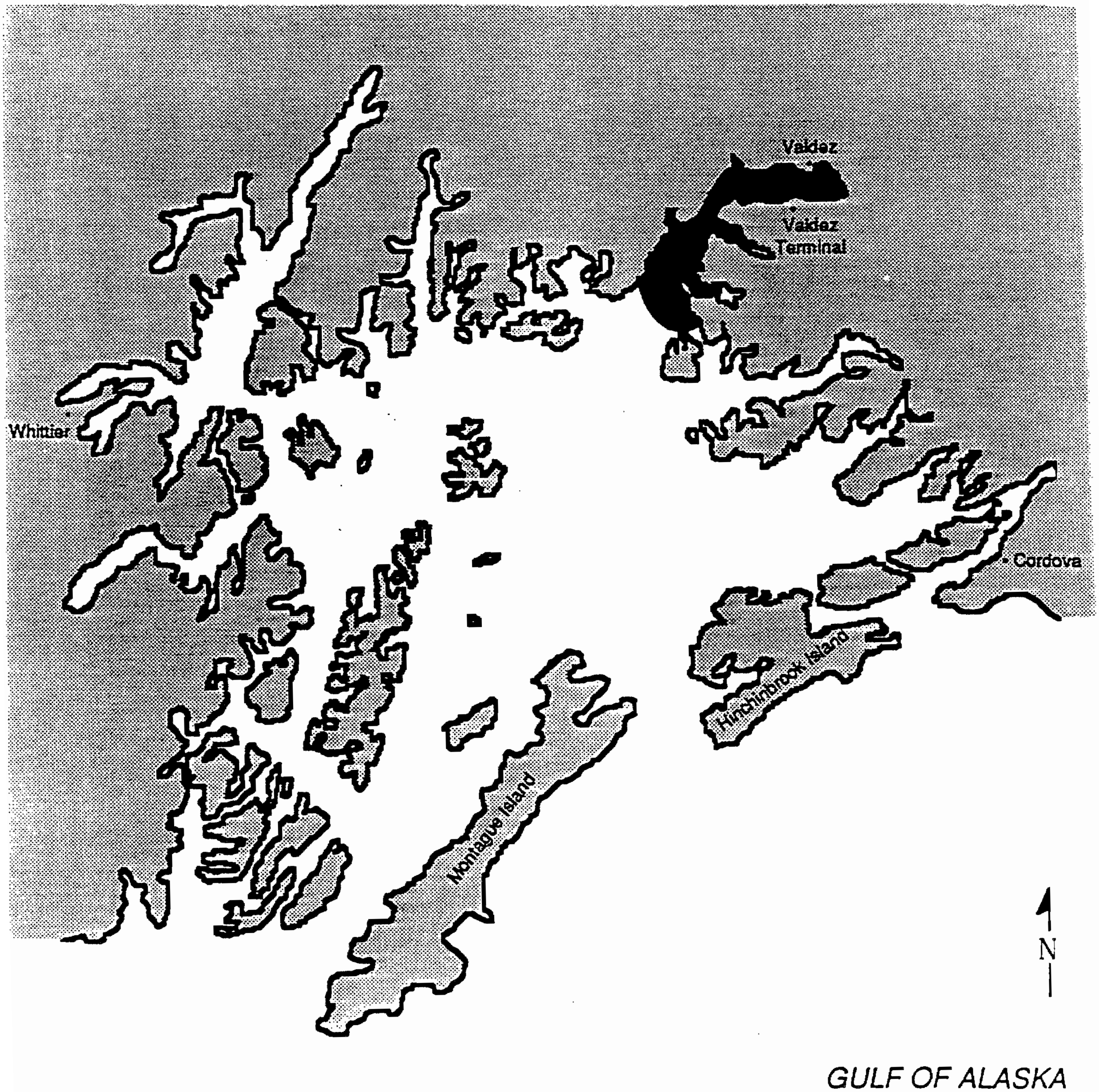
Port Valdez - 24 Hours After Spill
Spill Size = 3,000,000 Gallons
Typical Winter Wind And Current Conditions



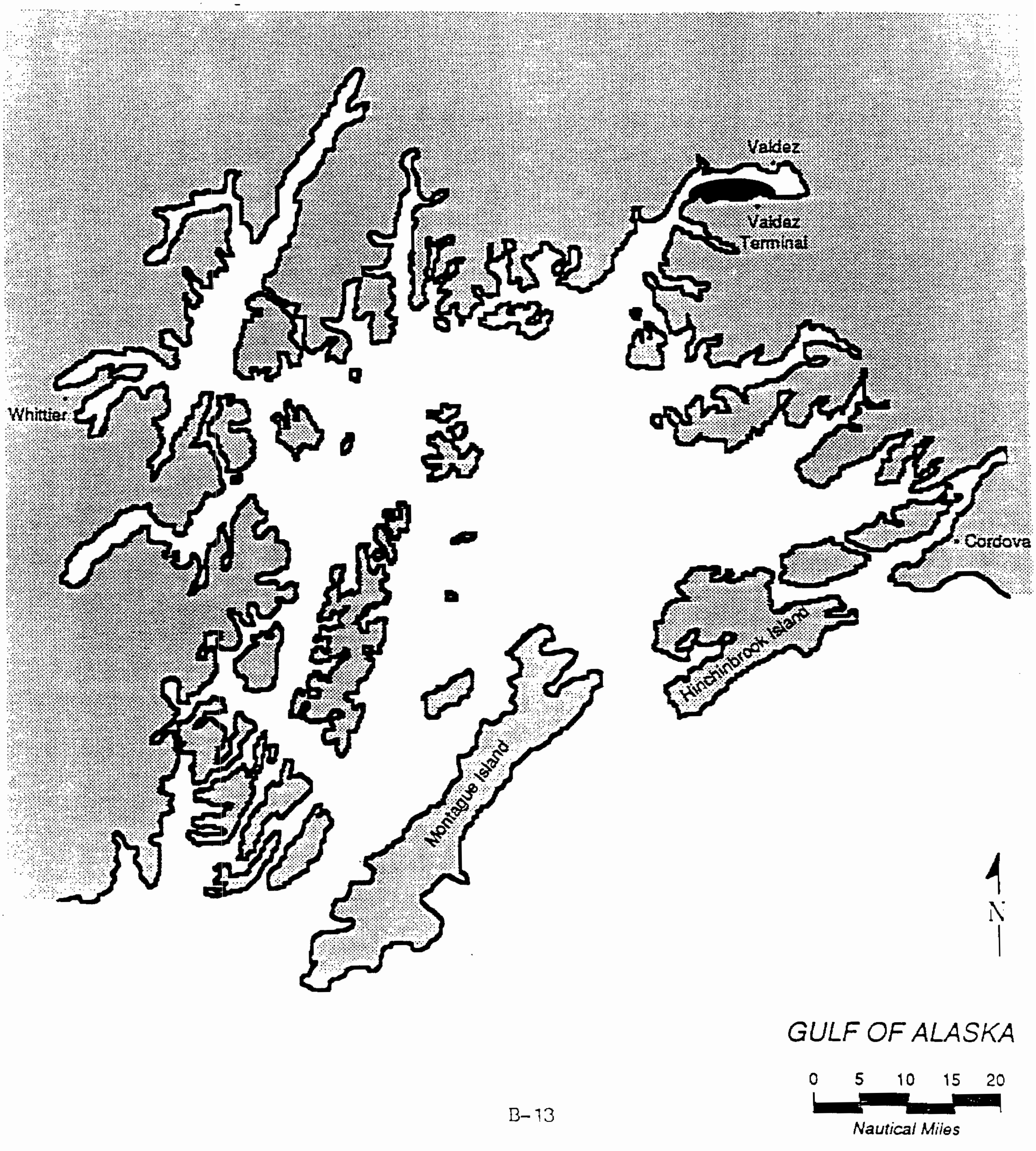
Port Valdez - 672 Hours After Spill
Spill Size = 3,000,000 Gallons
Typical Winter Wind And Current Conditions



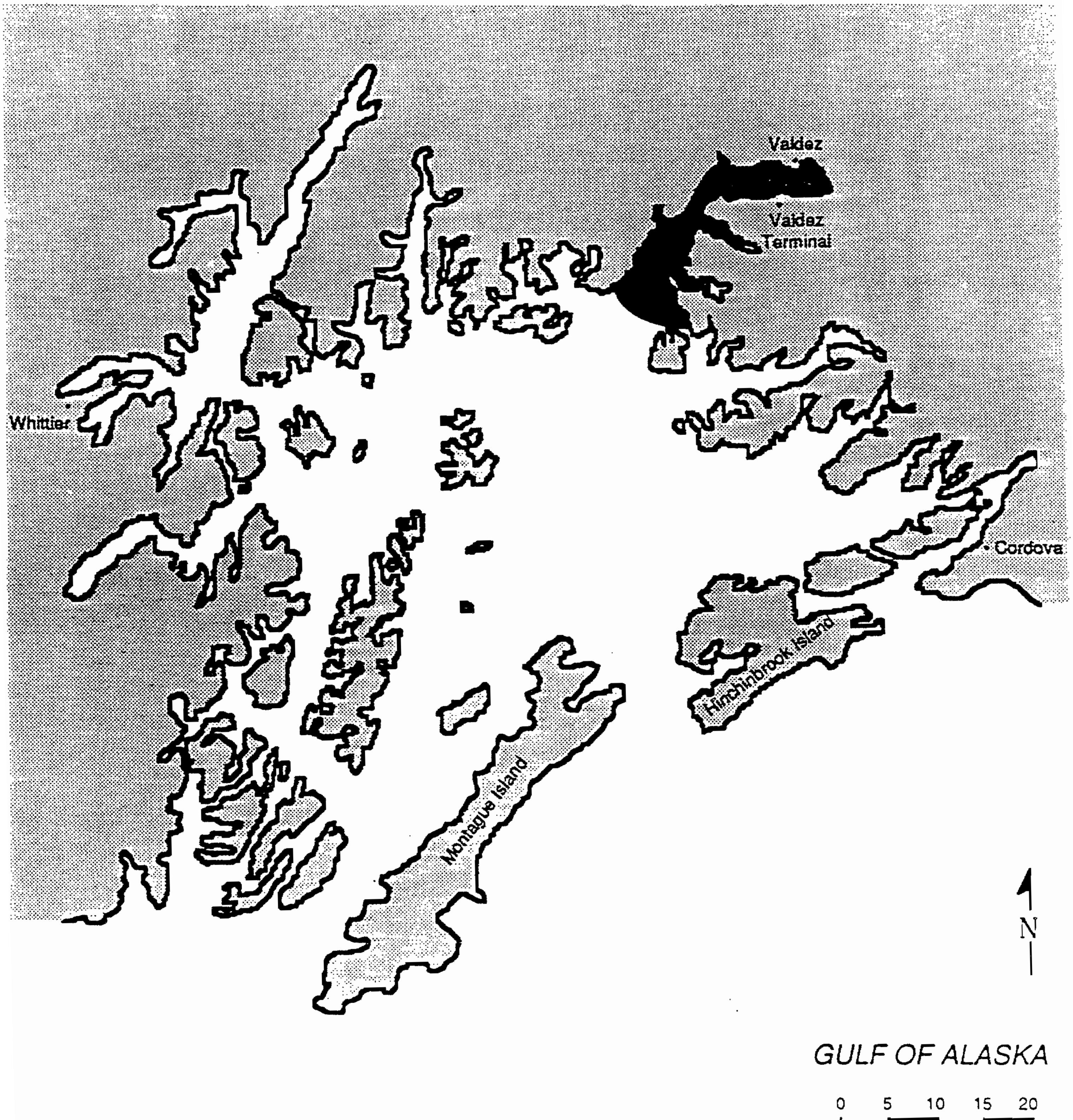
Port Valdez - 168 Hours After Spill
Spill Size = 3,000,000 Gallons
Typical Winter Wind And Current Conditions



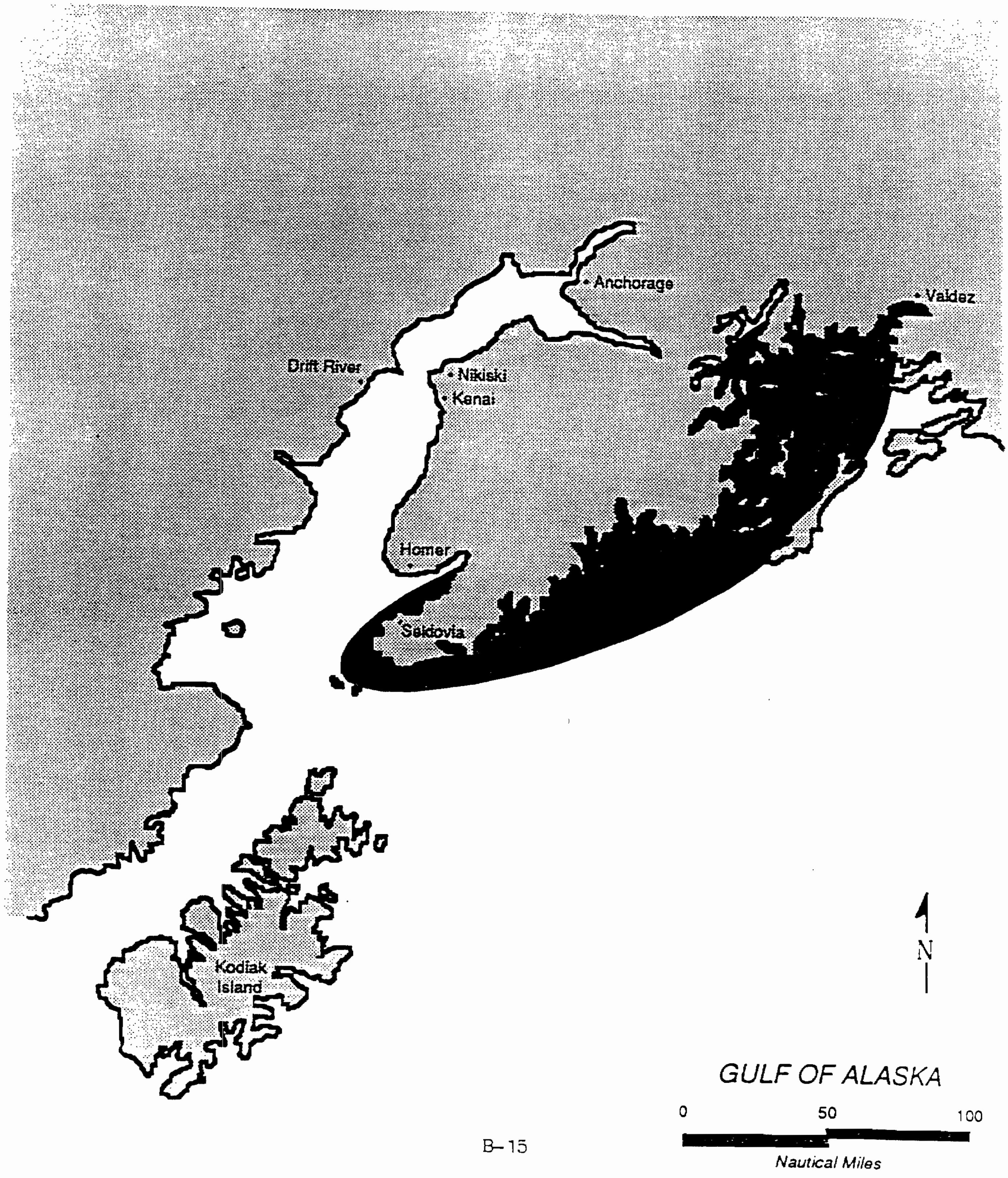
Port Valdez - 24 Hours After Spill
Spill Size = 11,000,000 Gallons
Typical Winter Wind And Current Conditions



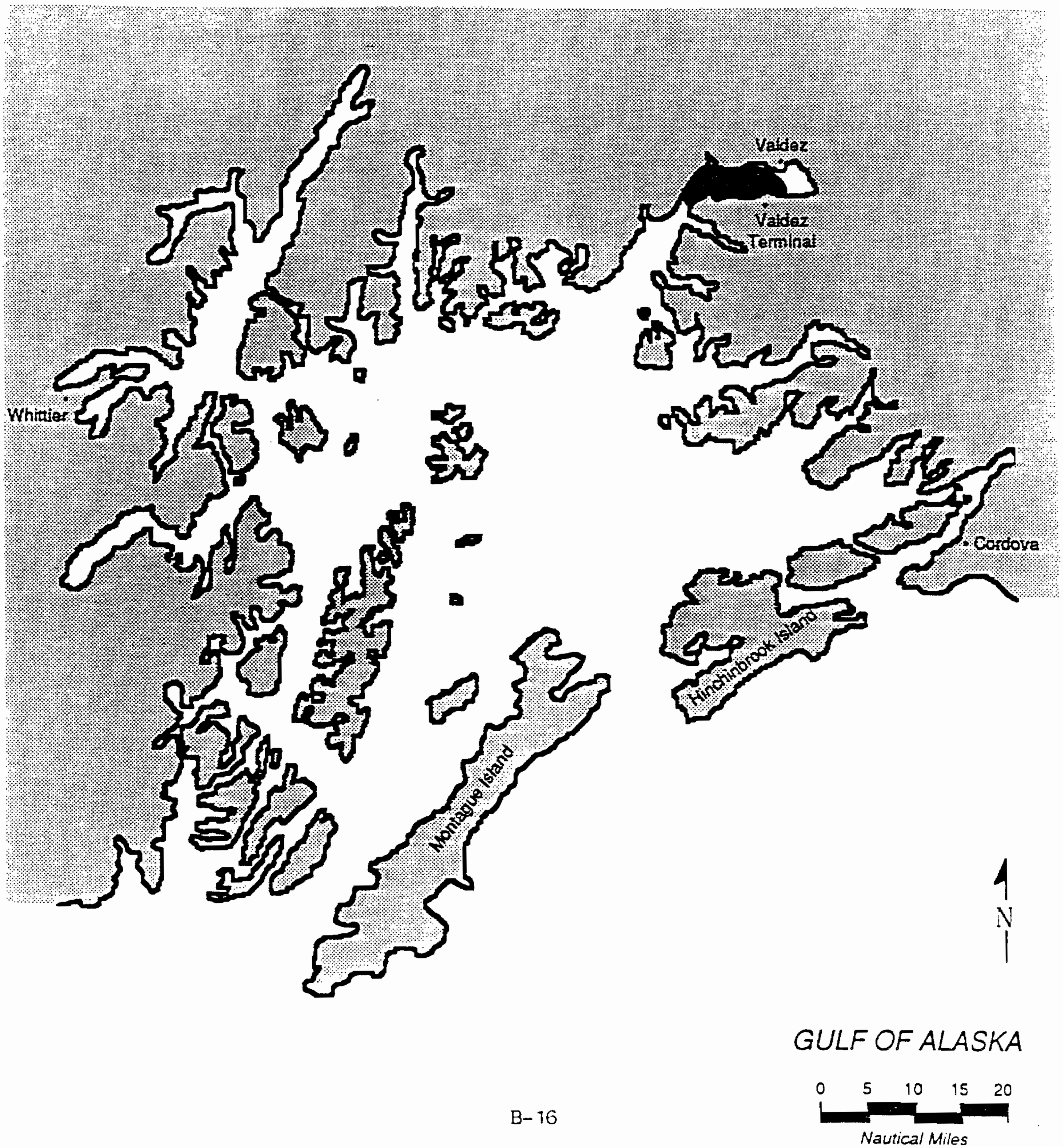
Port Valdez - 168 Hours After Spill
Spill Size = 11,000,000 Gallons
Typical Winter Wind And Current Conditions



Port Valdez - 672 Hours After Spill
Spill Size = 11,000,000 Gallons
Typical Winter Wind And Current Conditions

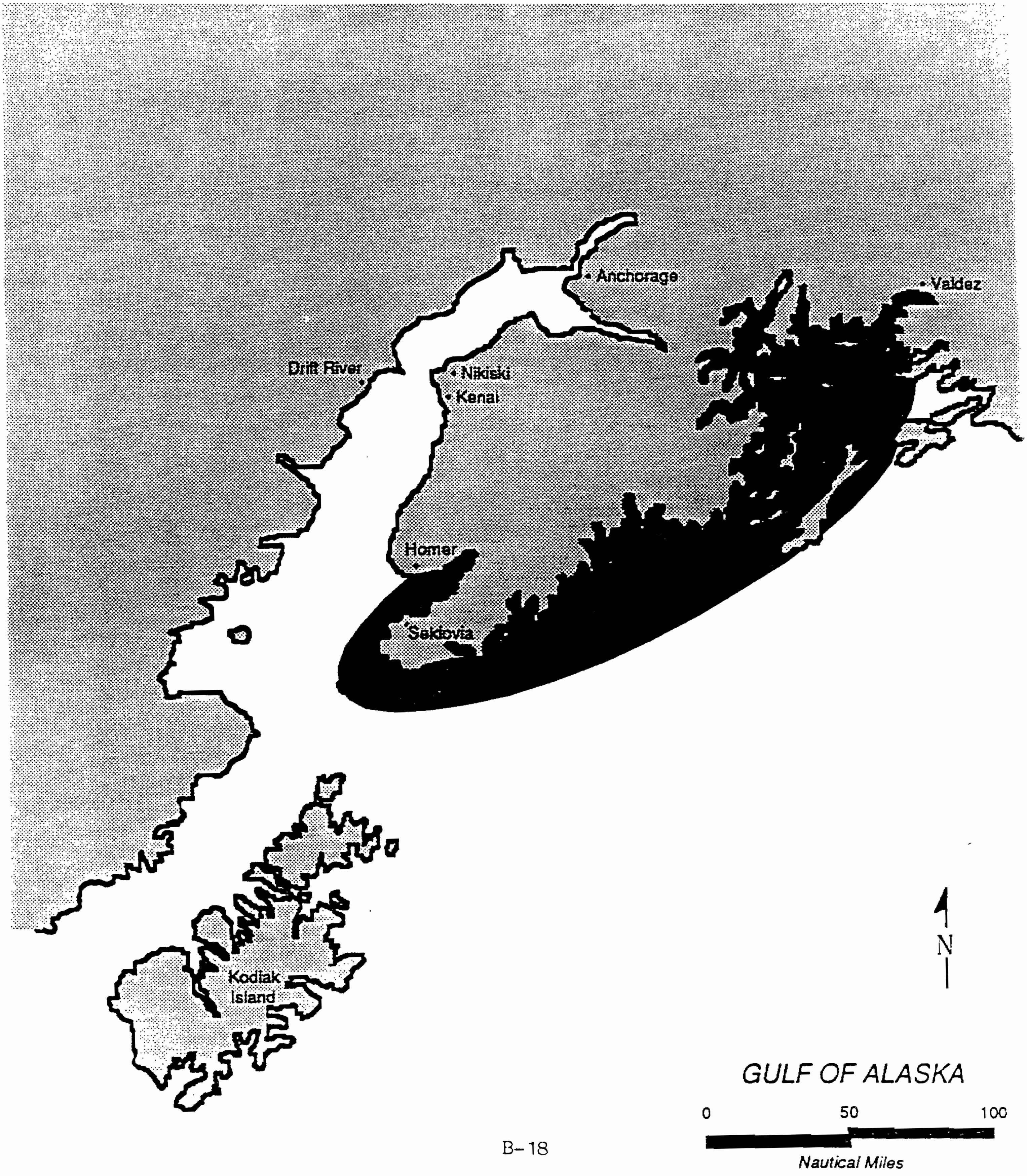


Port Valdez - 24 Hours After Spill
Spill Size = 75,000,000 Gallons
Typical Winter Wind And Current Conditions

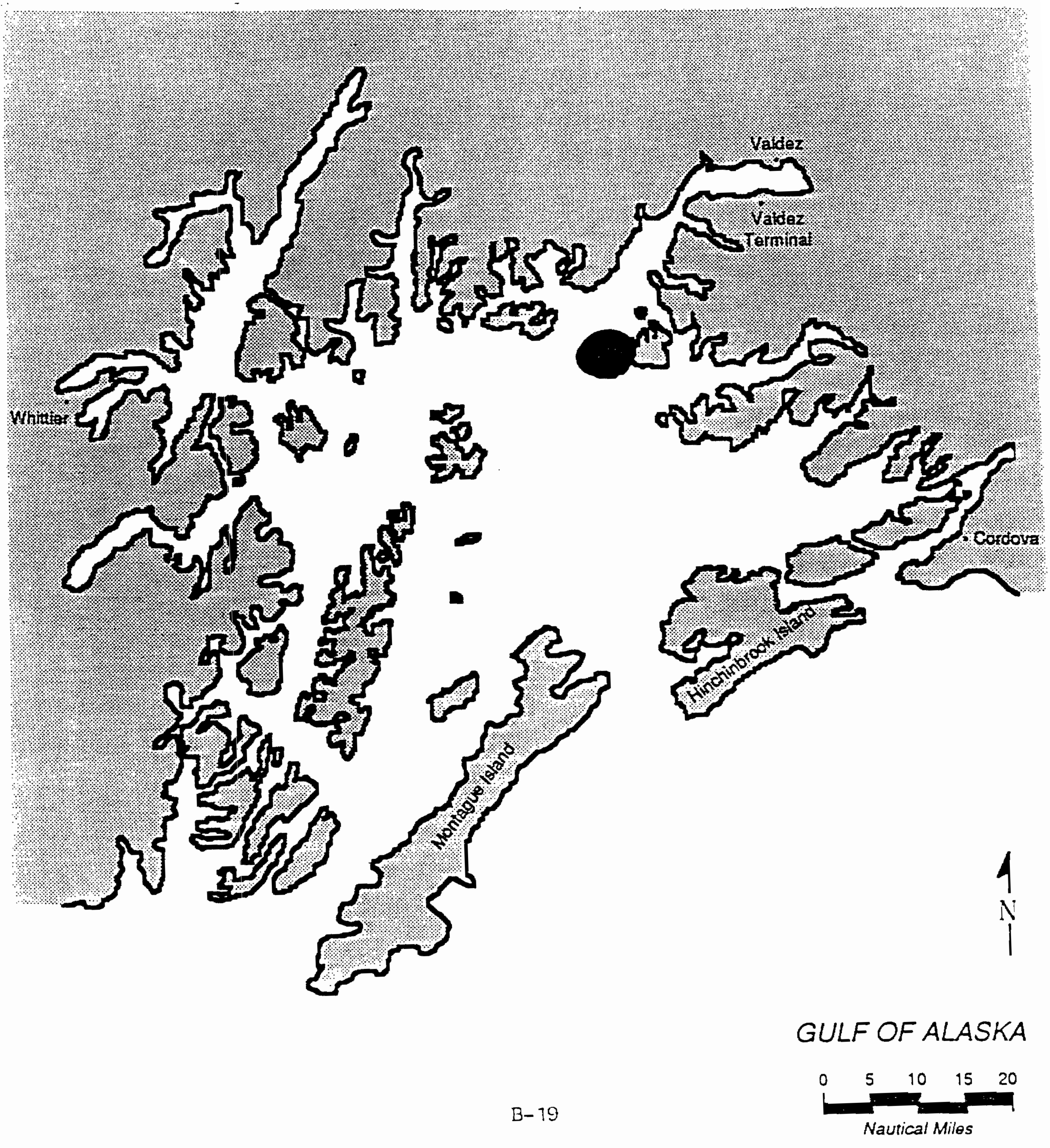


Port Valdez - 168 Hours After Spill
Spill Size = 75,000,000 Gallons
Typical Winter Wind And Current Conditions

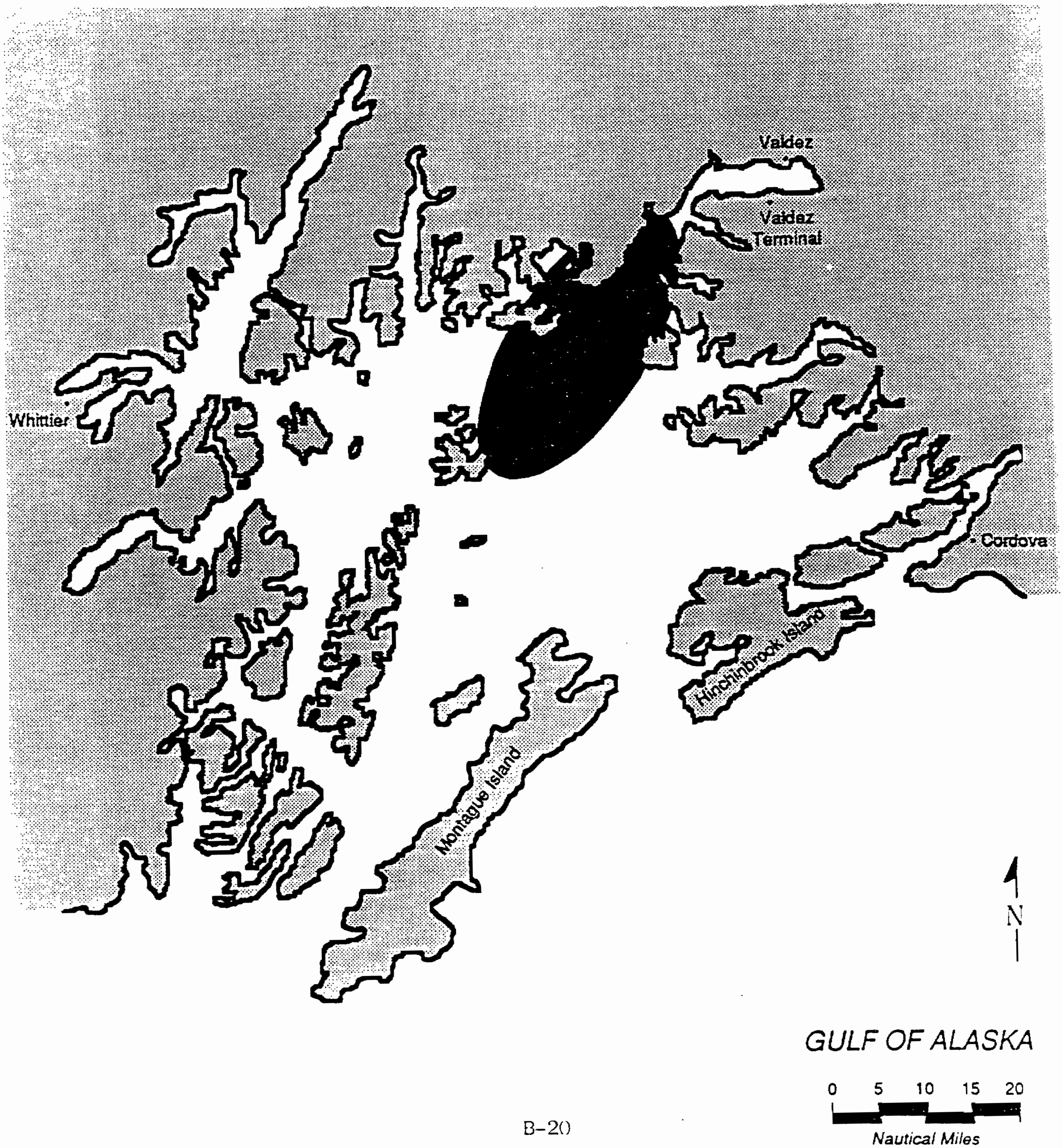
Port Valdez - 672 Hours After Spill
Spill Size = 75,000,000 Gallons
Typical Winter Wind And Current Conditions



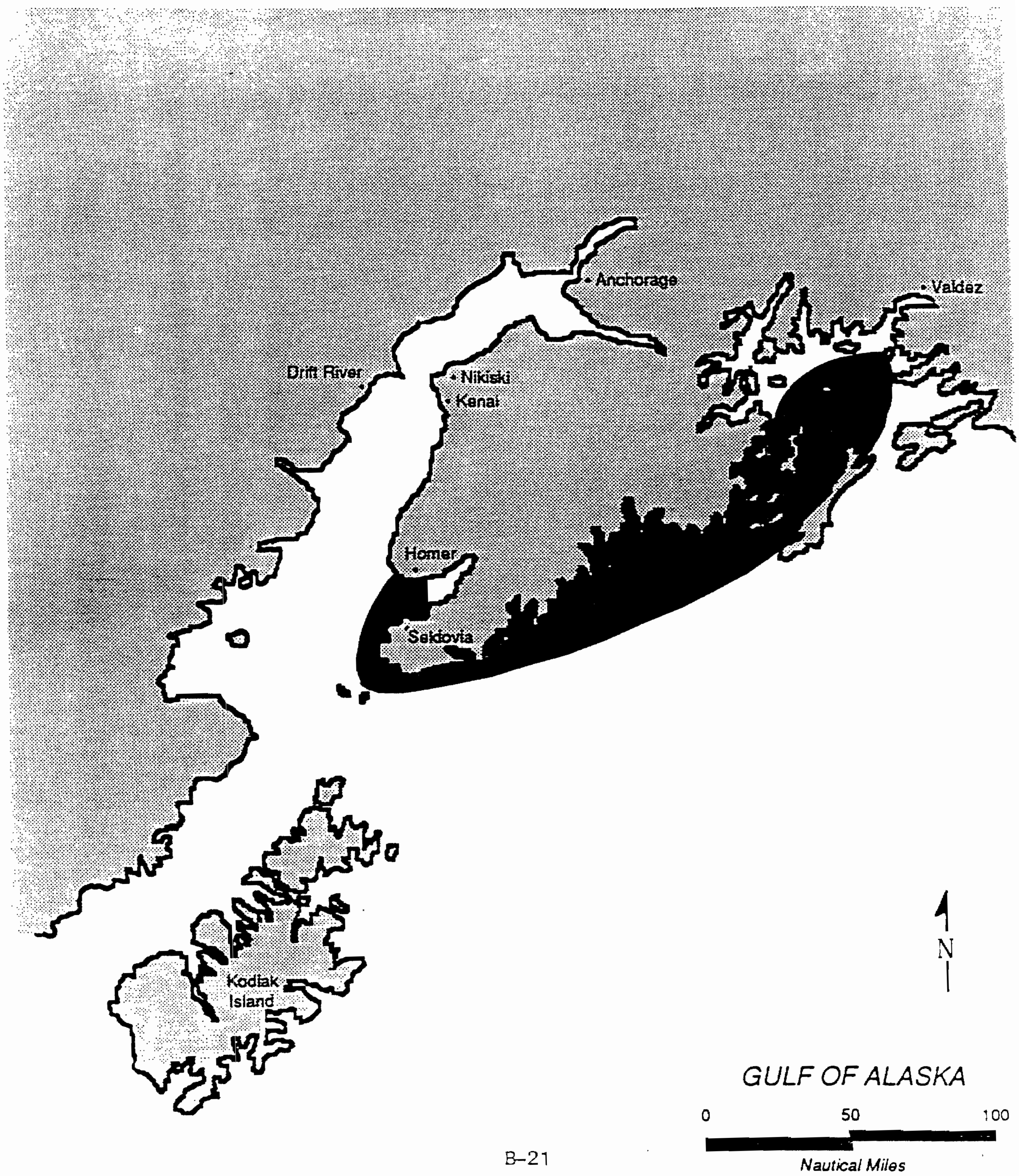
Bligh Reef - 24 Hours After Spill
Spill Size = 3,000,000 Gallons
Typical Summer Wind And Current Conditions



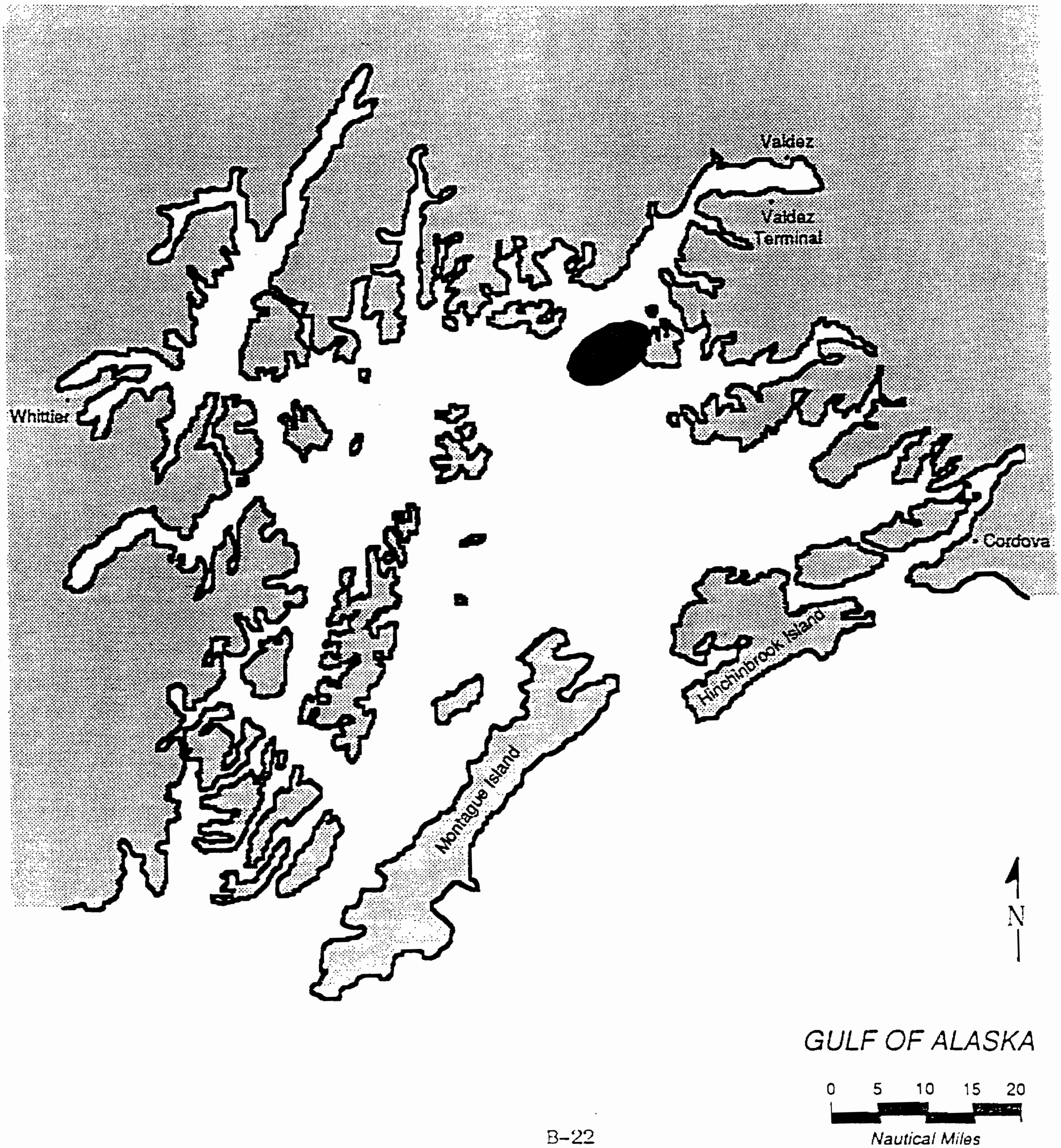
Bligh Reef - 168 Hours After Spill
Spill Size = 3,000,000 Gallons
Typical Summer Wind And Current Conditions



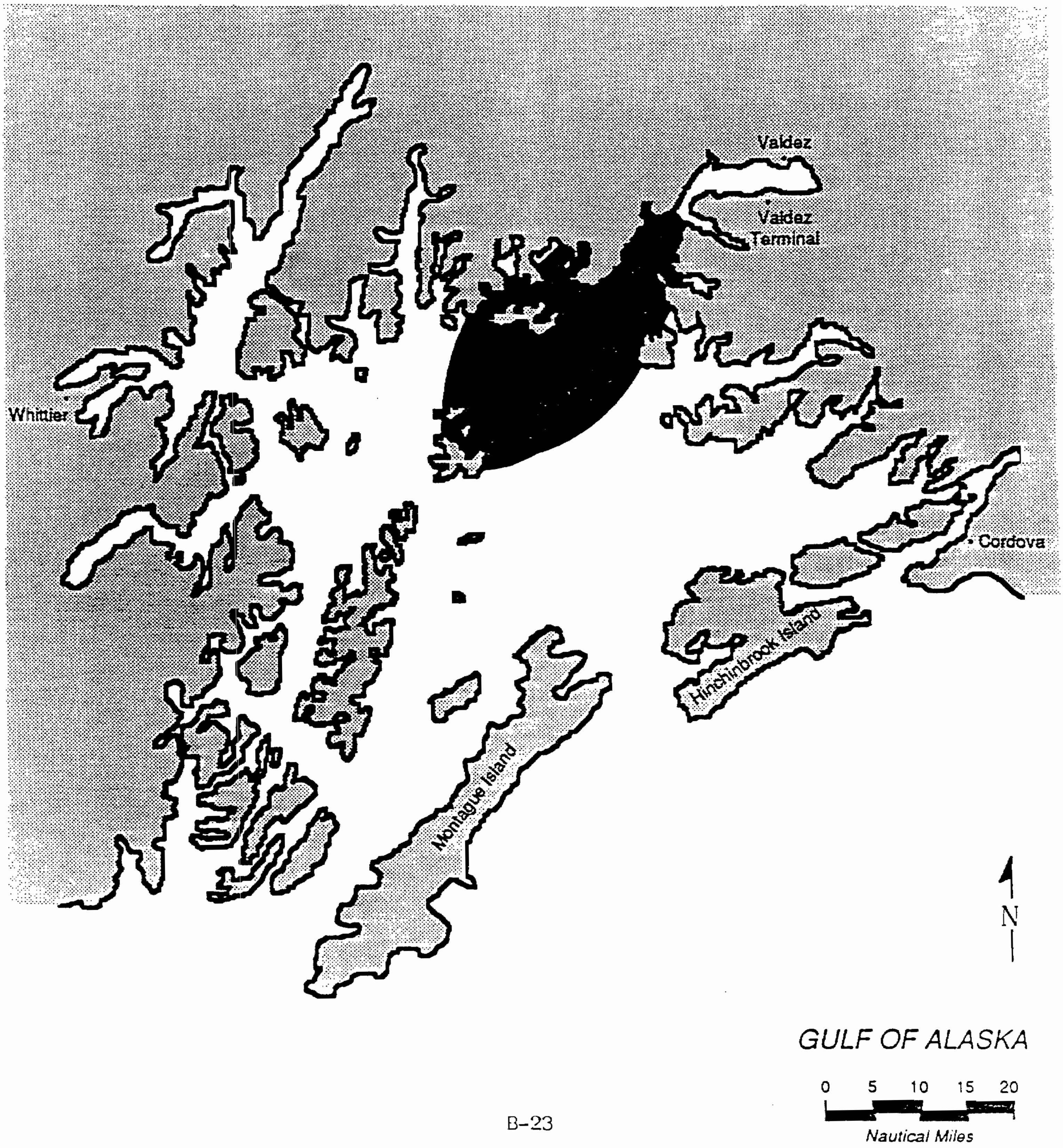
Bligh Reef - 672 Hours After Spill
Spill Size = 3,000,000 Gallons
Typical Summer Wind And Current Conditions



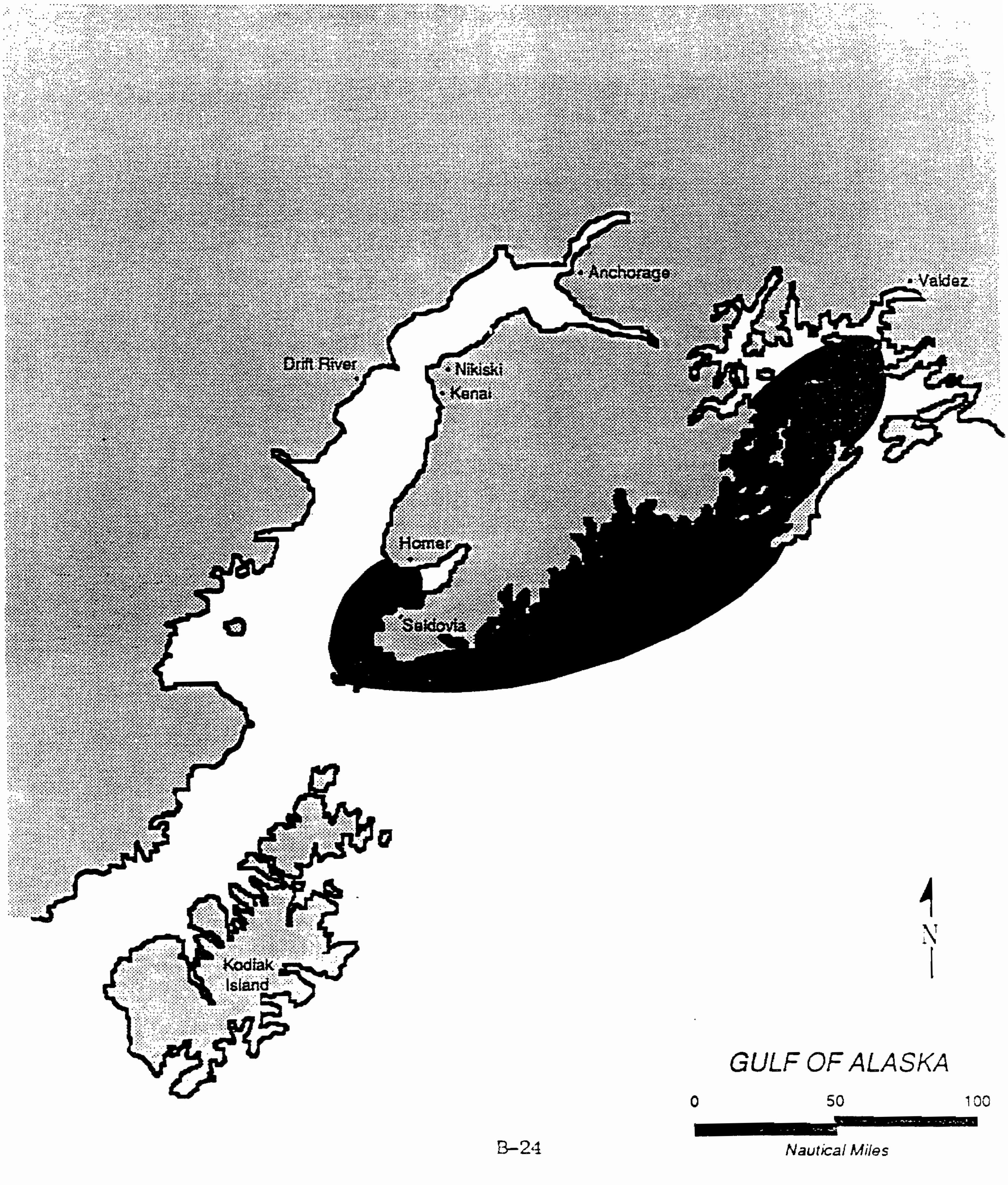
Bligh Reef - 24 Hours After Spill
Spill Size = 11,000,000 Gallons
Typical Summer Wind And Current Conditions



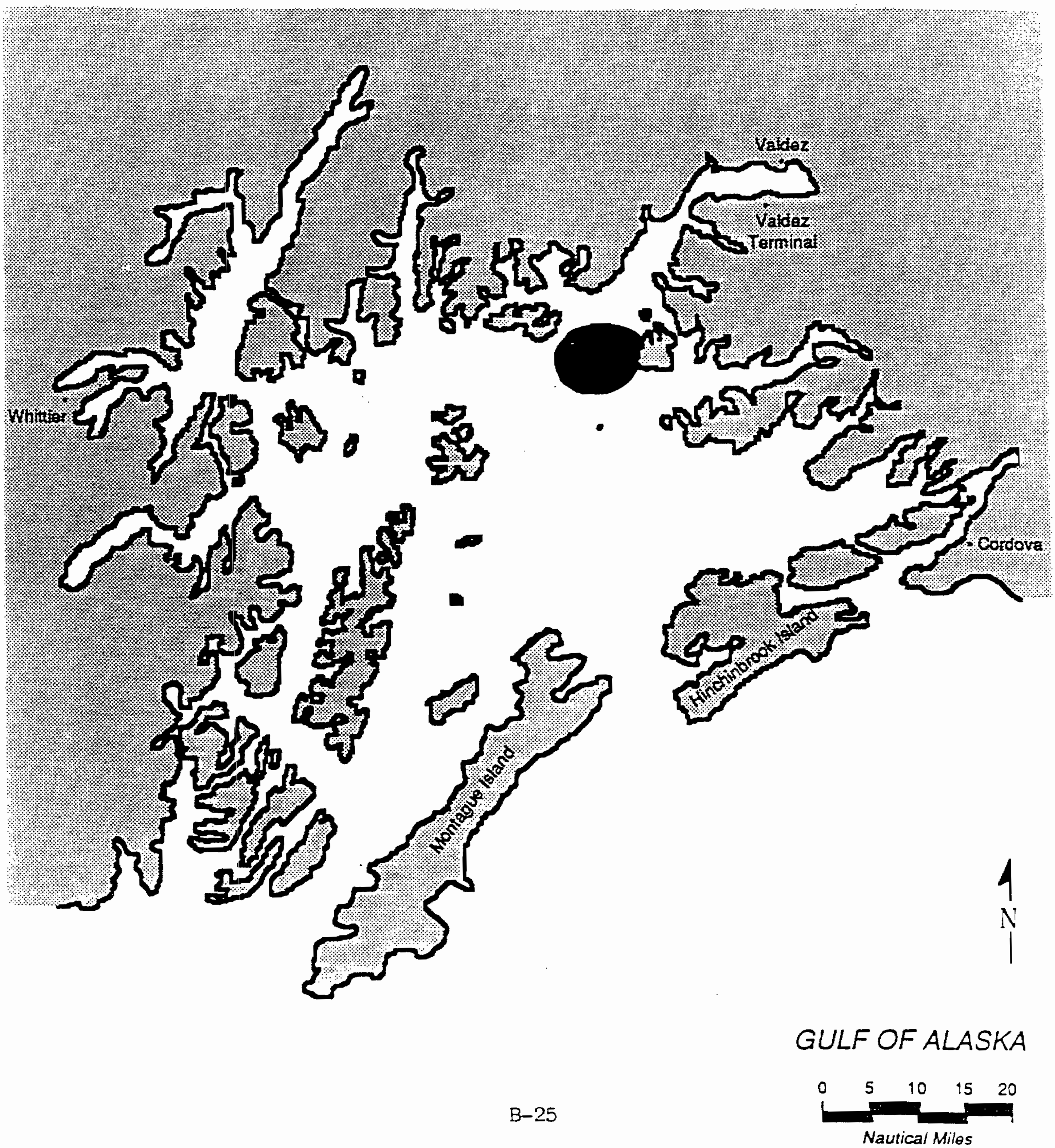
Bligh Reef - 168 Hours After Spill
Spill Size = 11,000,000 Gallons
Typical Summer Wind And Current Conditions



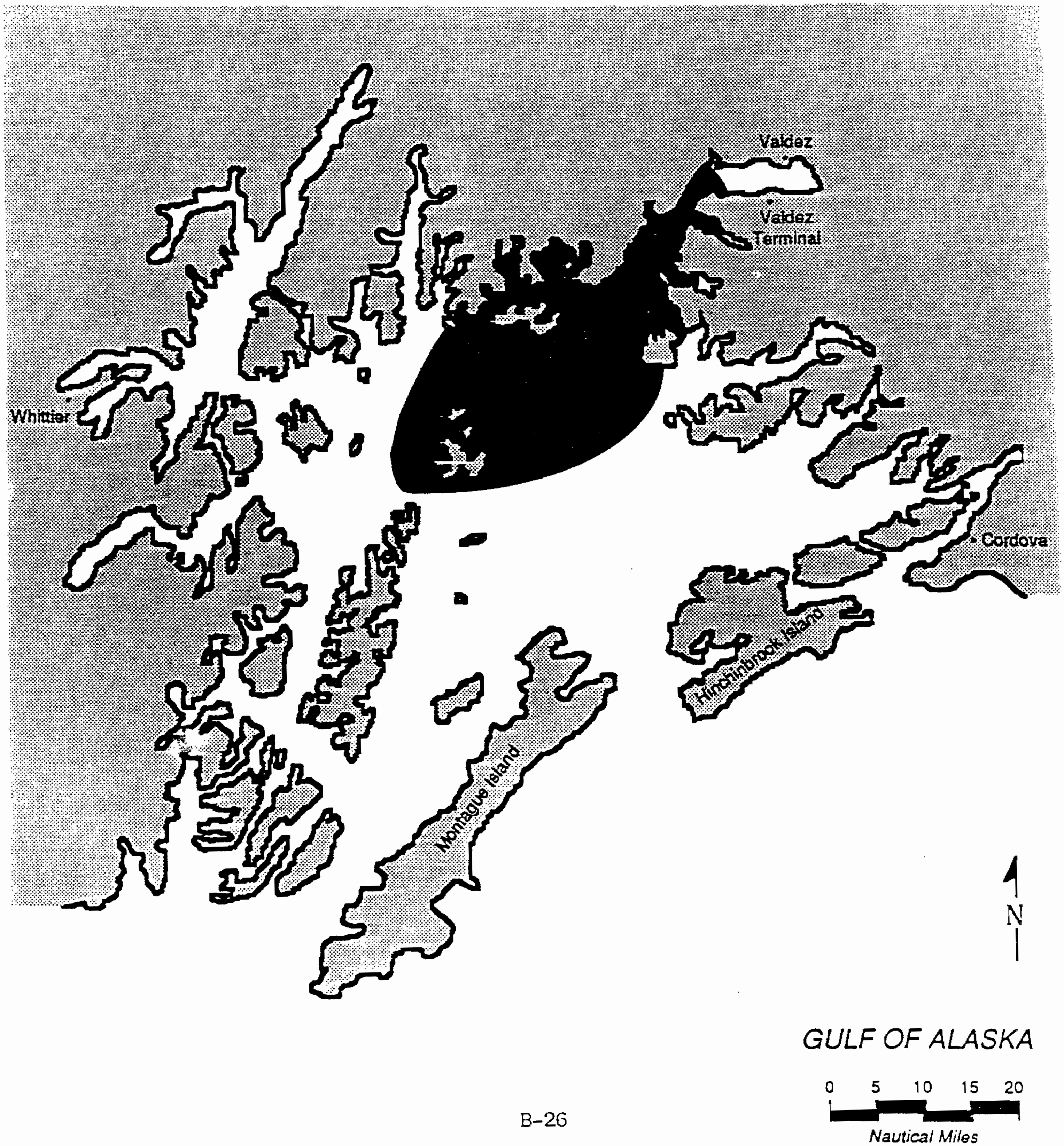
Bligh Reef - 672 Hours After Spill
Spill Size = 11,000,000 Gallons
Typical Summer Wind And Current Conditions



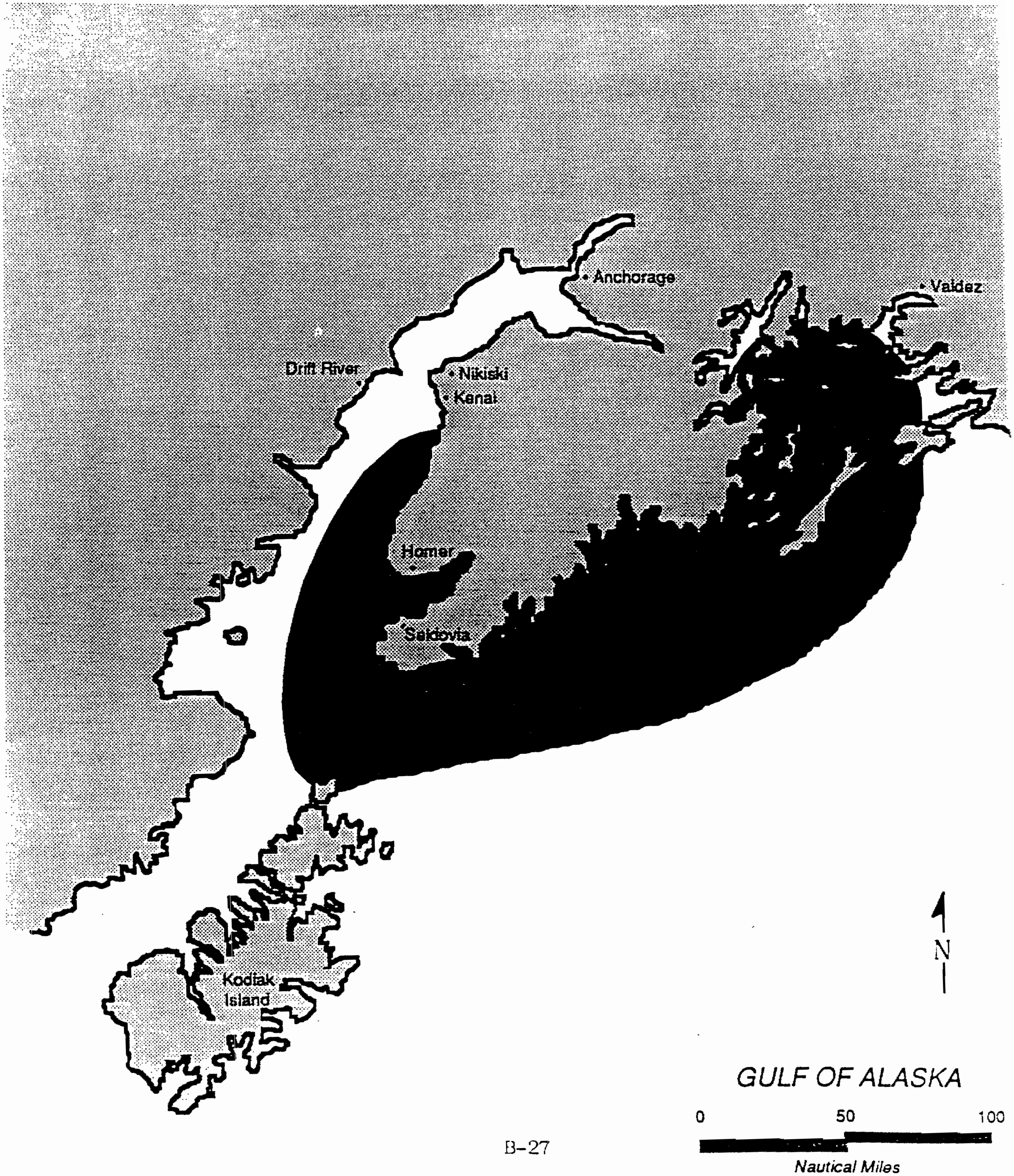
Bligh Reef - 24 Hours After Spill
Spill Size = 75,000,000 Gallons
Typical Summer Wind And Current Conditions



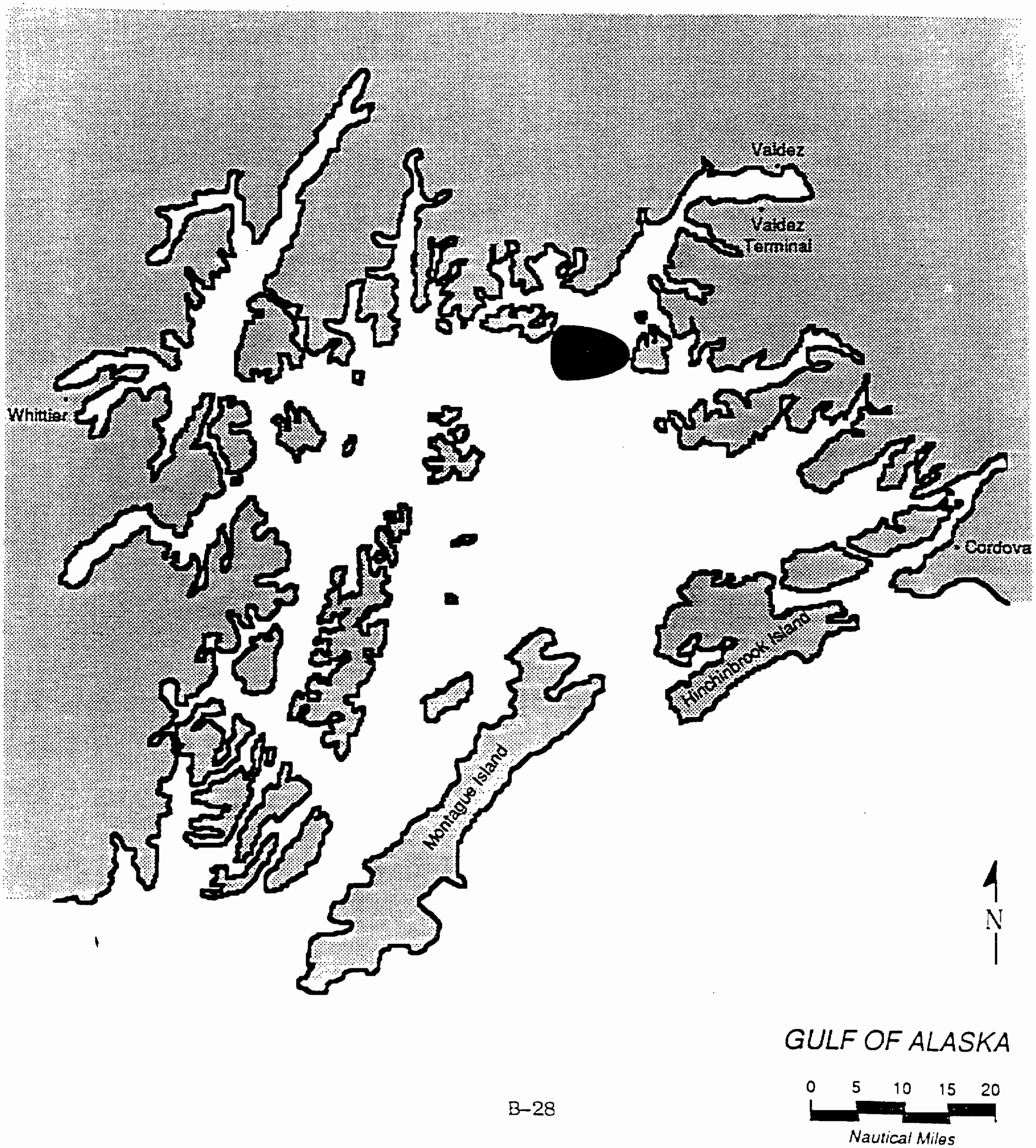
Bligh Reef - 168 Hours After Spill
Spill Size = 75,000,000 Gallons
Typical Summer Wind And Current Conditions



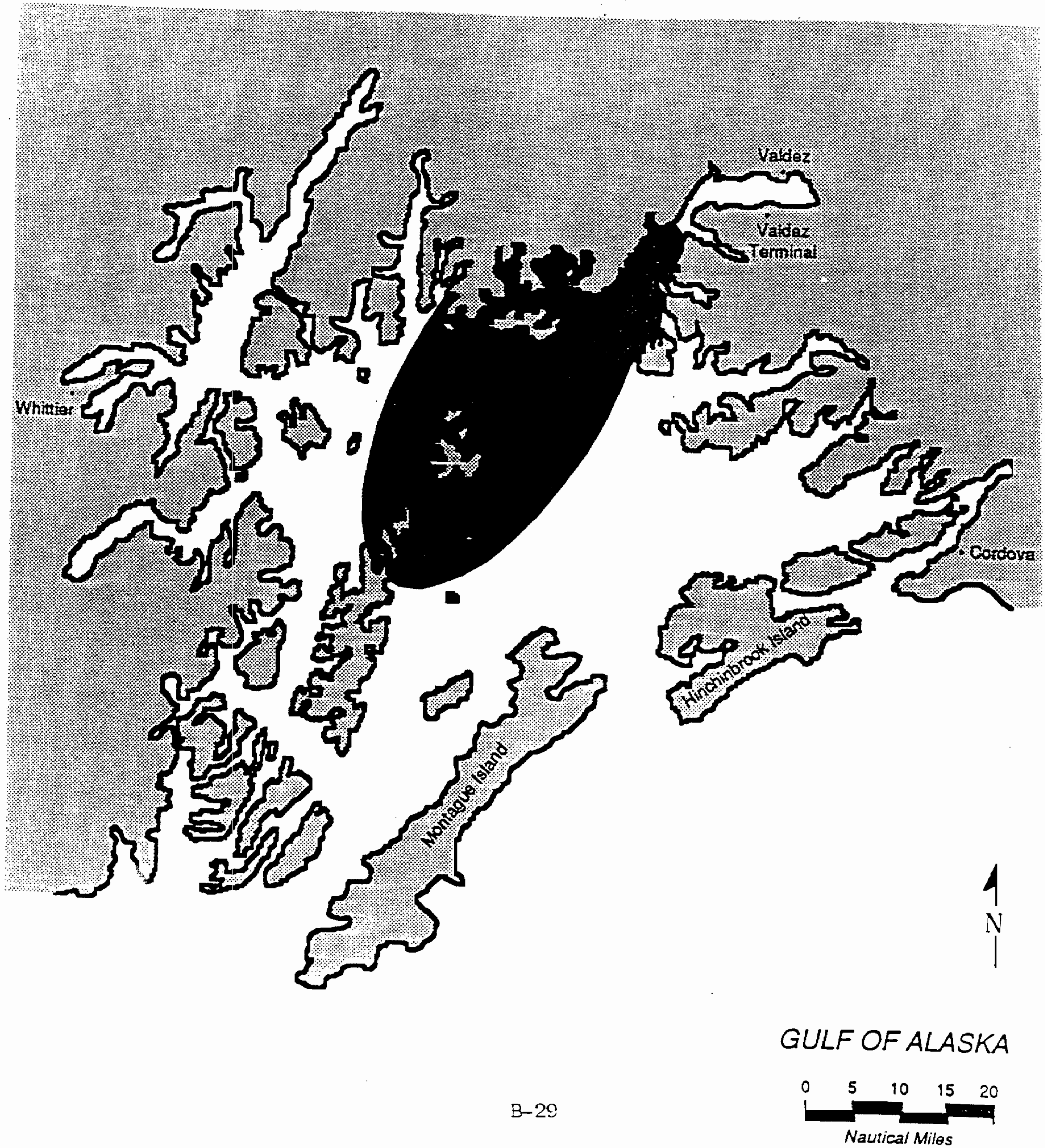
Bligh Reef - 672 Hours After Spill
Spill Size = 75,000,000 Gallons
Typical Summer Wind And Current Conditions



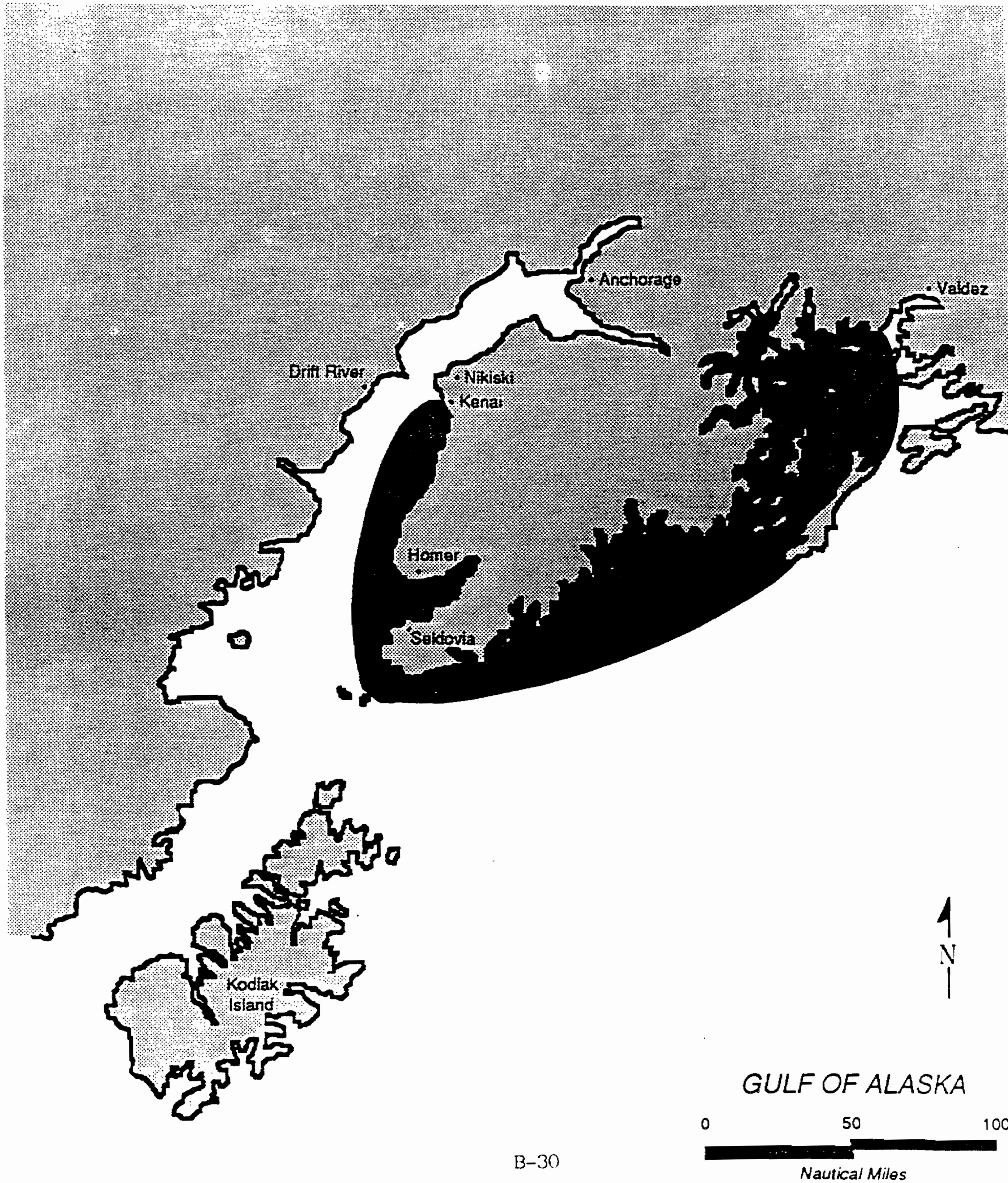
Bligh Reef - 24 Hours After Spill
Spill Size = 3,000,000 Gallons
Typical Winter Wind And Current Conditions



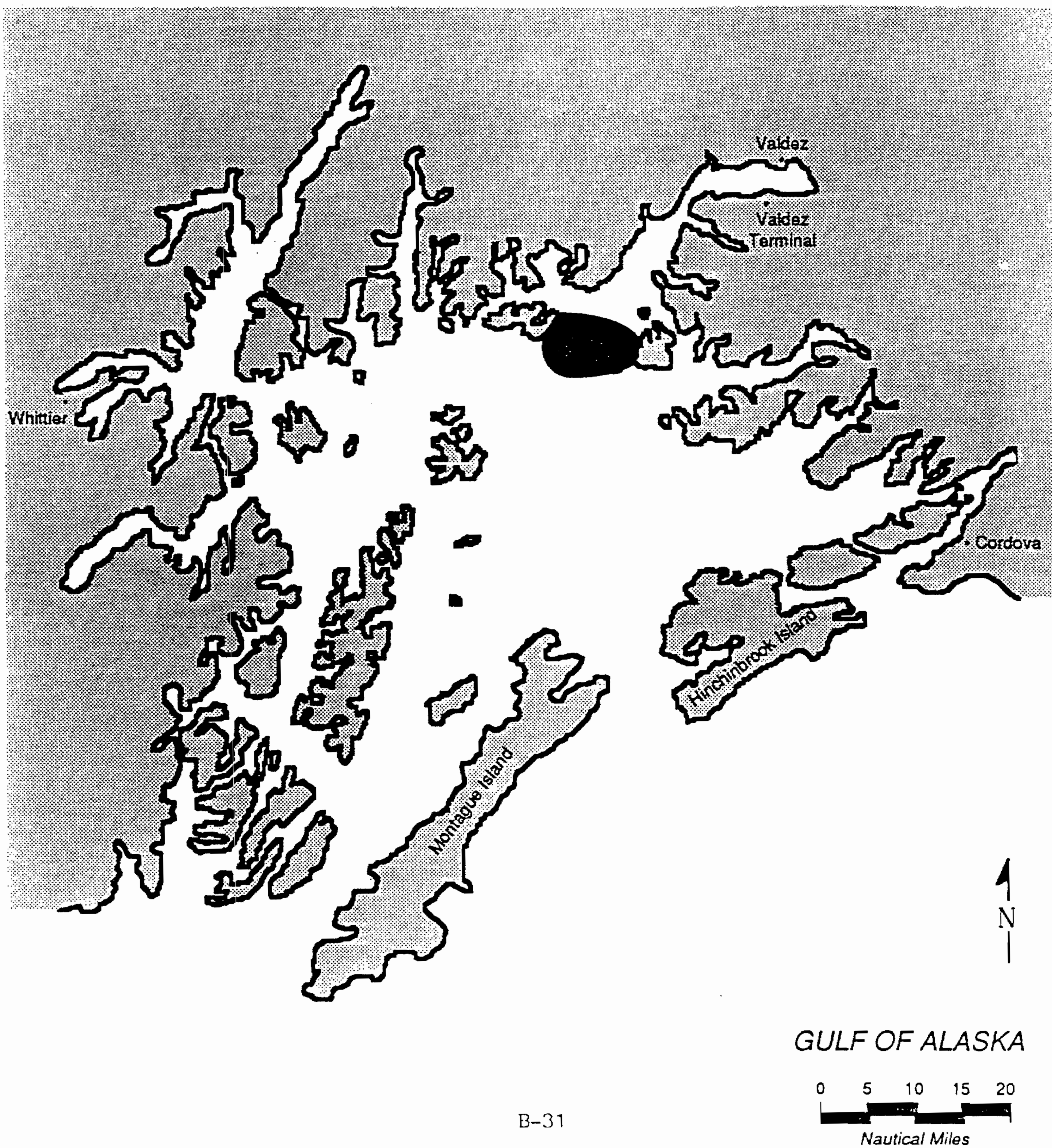
Bligh Reef - 168 Hours After Spill
Spill Size = 3,000,000 Gallons
Typical Winter Wind And Current Conditions



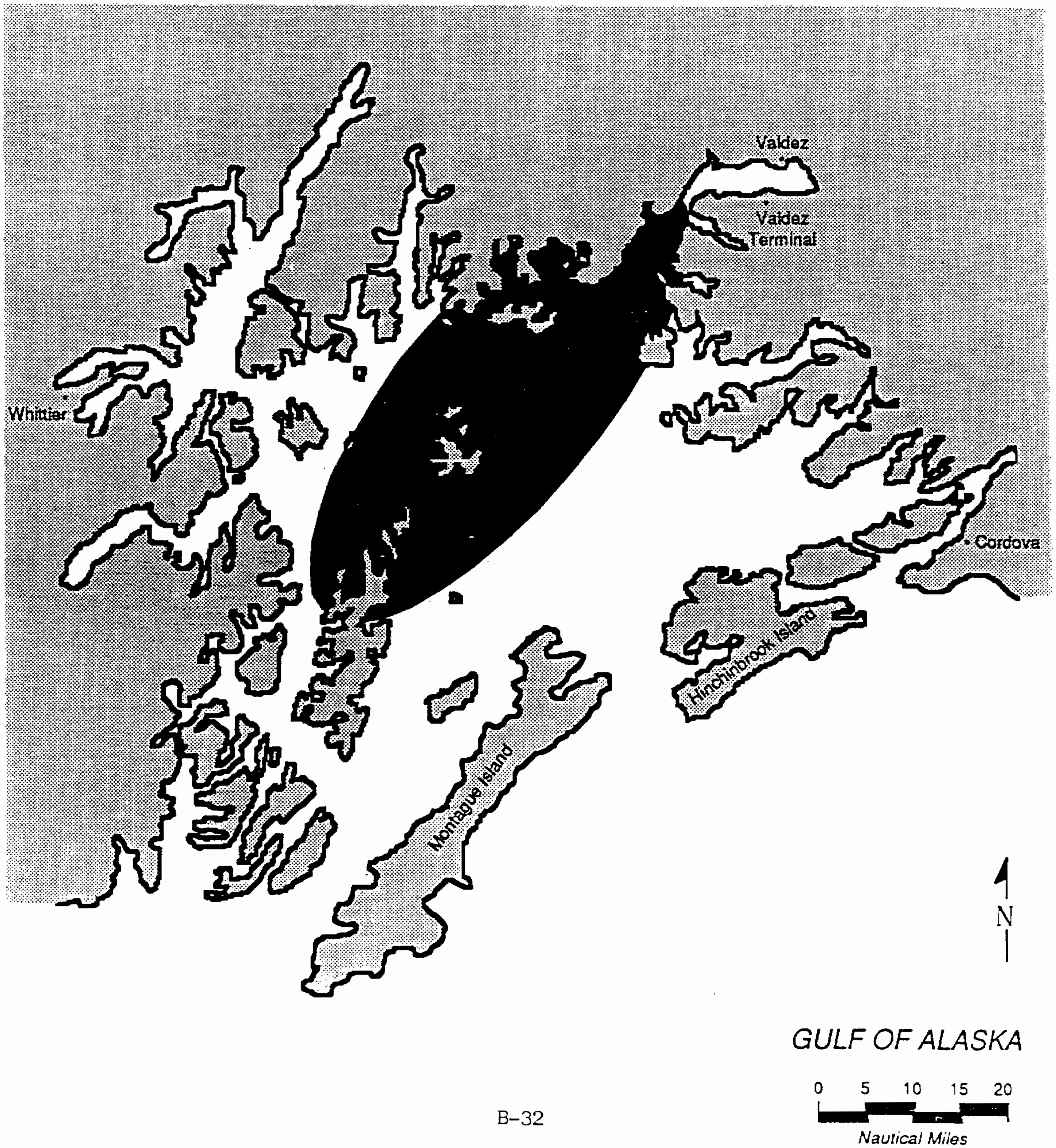
Bligh Reef - 672 Hours After Spill
Spill Size = 3,000,000 Gallons
Typical Winter Wind And Current Conditions



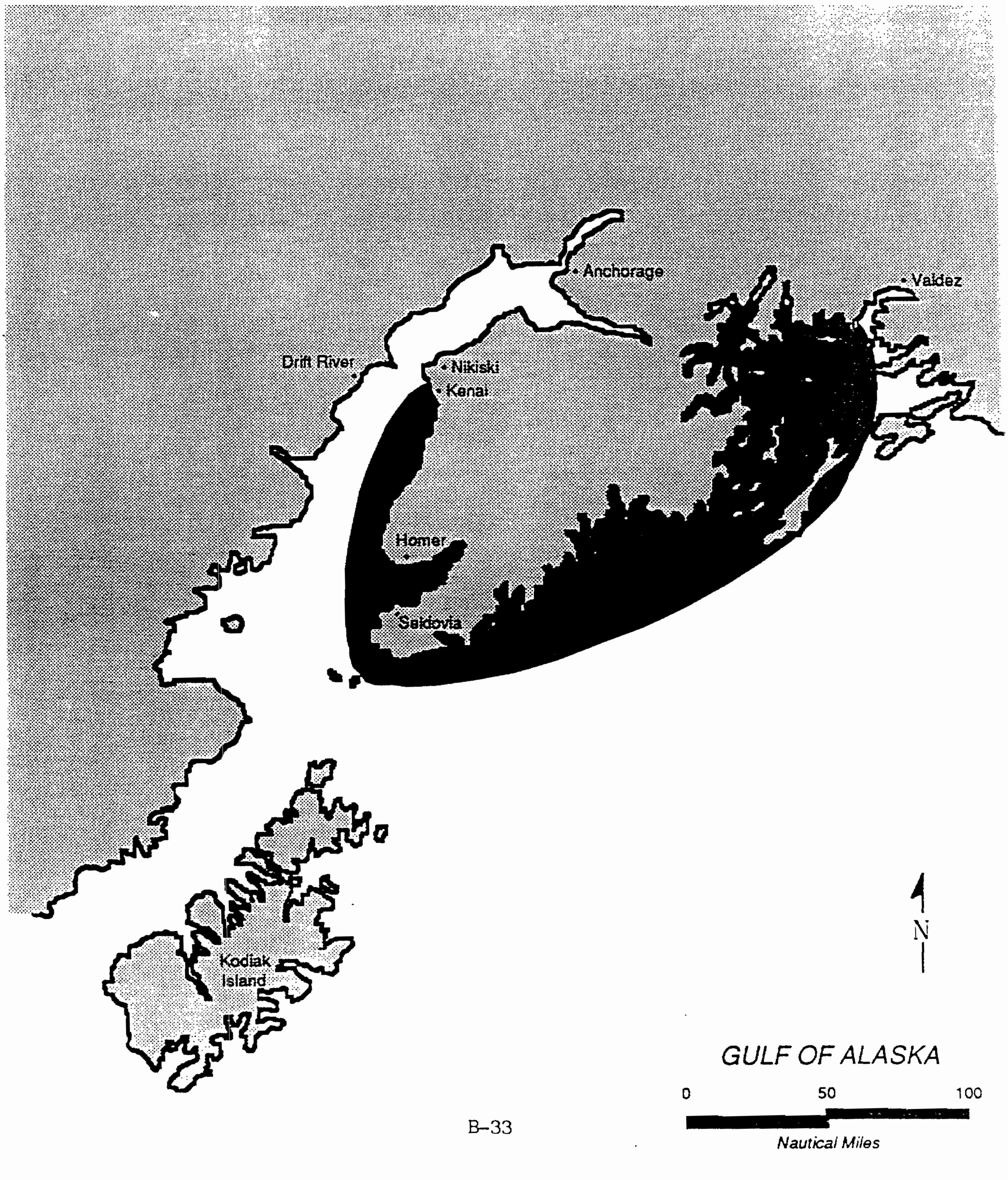
Bligh Reef - 24 Hours After Spill
Spill Size = 11,000,000 Gallons
Typical Winter Wind And Current Conditions



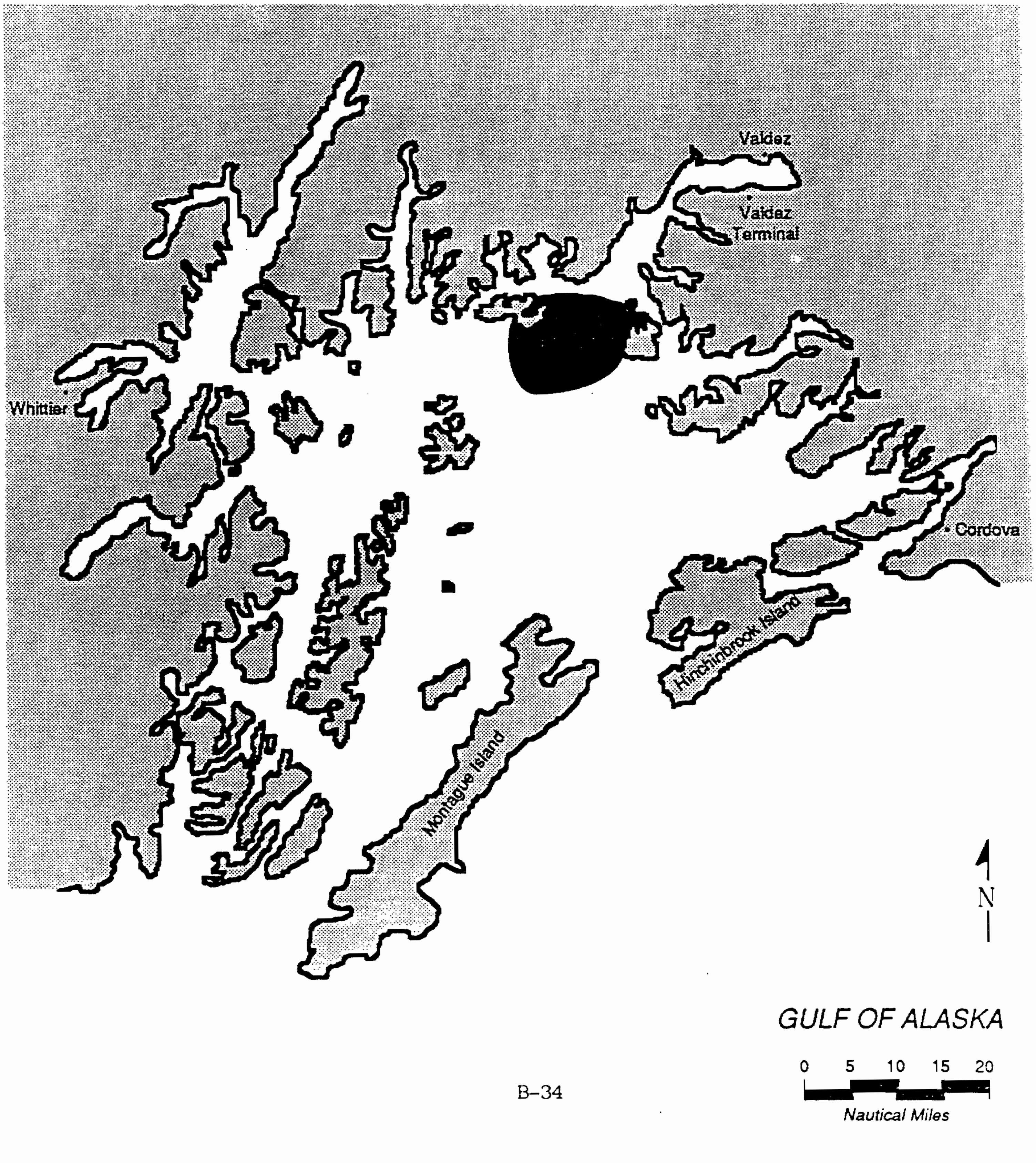
Bligh Reef - 168 Hours After Spill
Spill Size = 11,000,000 Gallons
Typical Winter Wind And Current Conditions



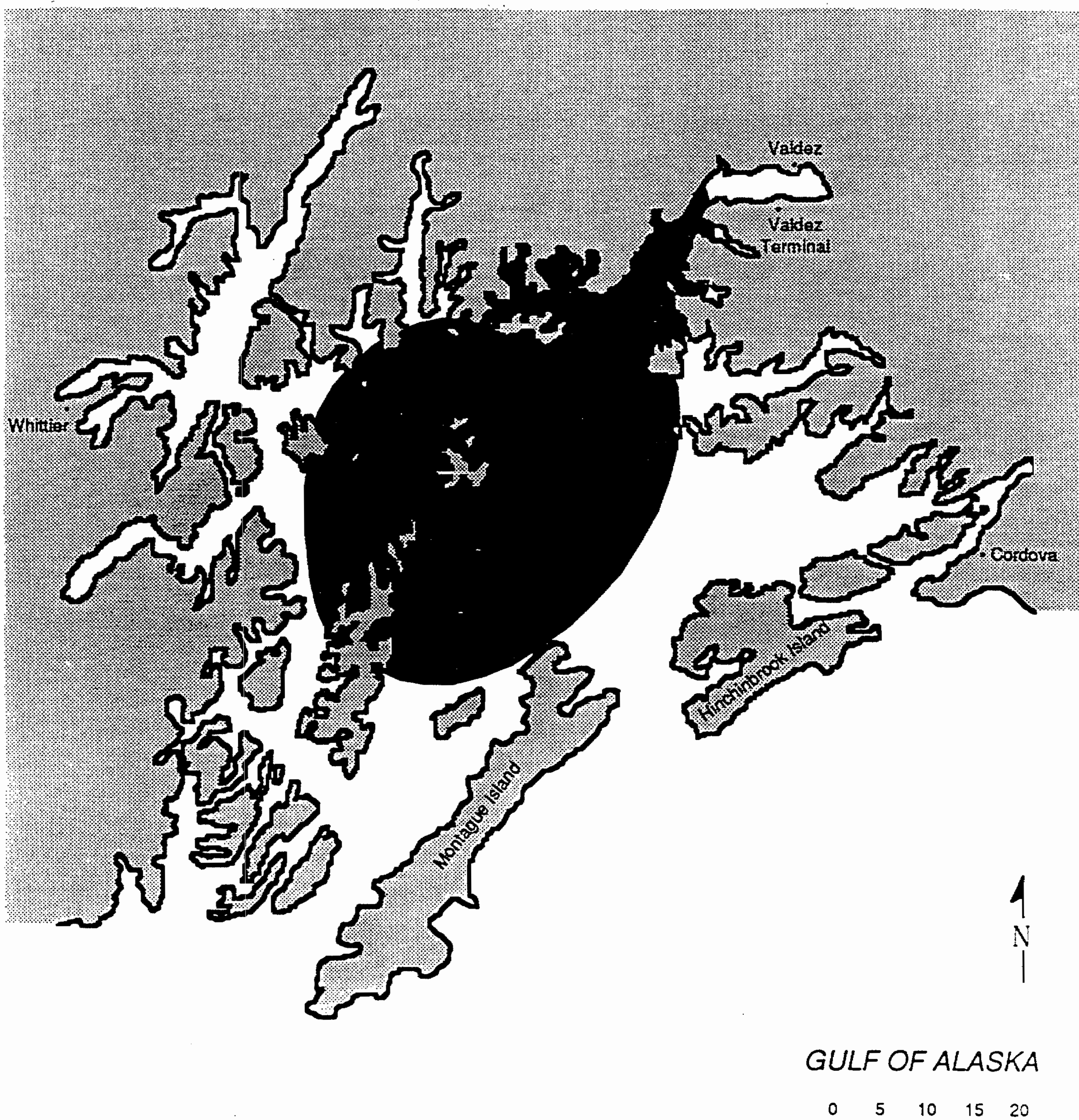
Bligh Reef - 672 Hours After Spill
Spill Size = 11,000,000 Gallons
Typical Winter Wind And Current Conditions



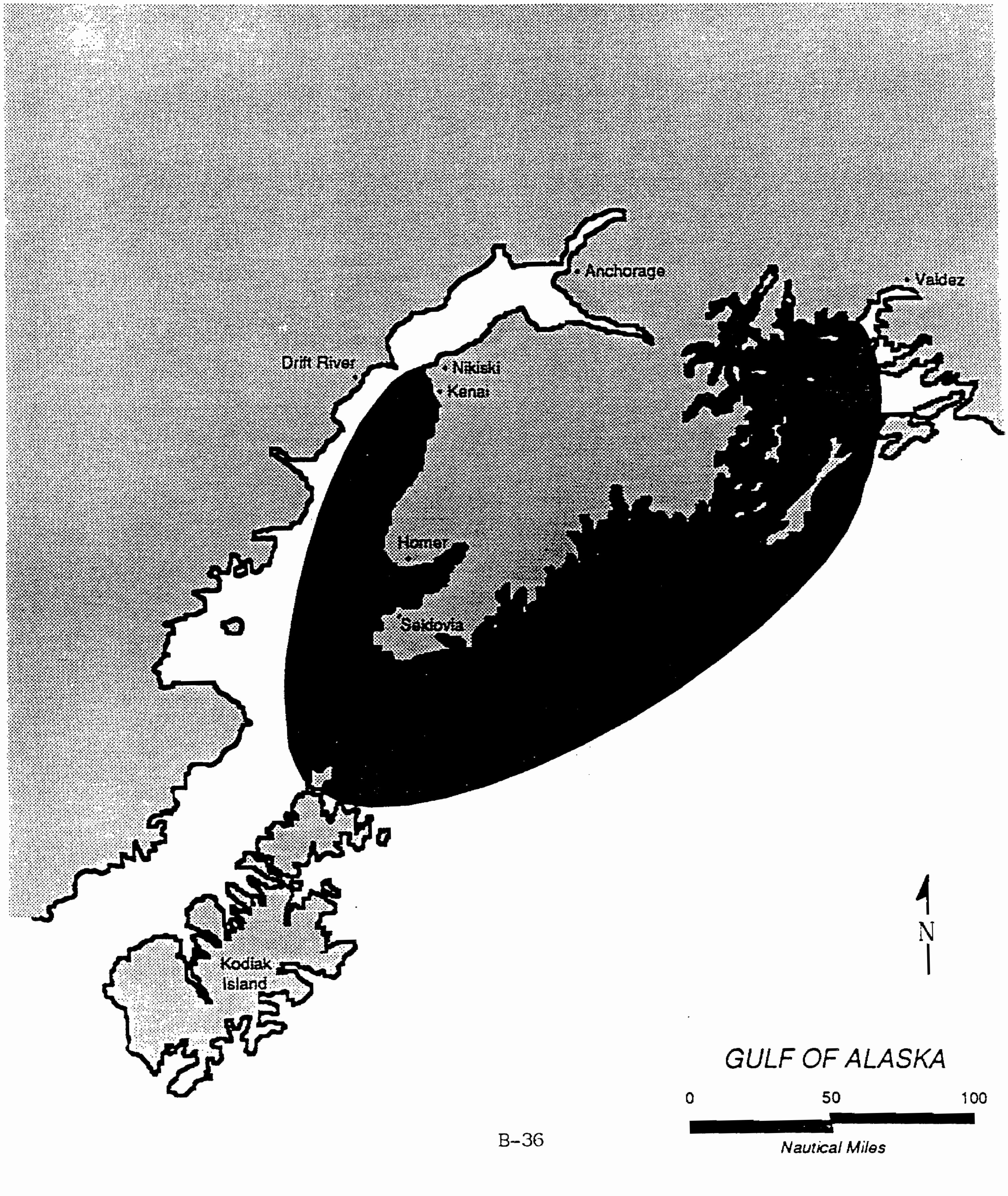
Bligh Reef - 24 Hours After Spill
Spill Size = 75,000,000 Gallons
Typical Winter Wind And Current Conditions



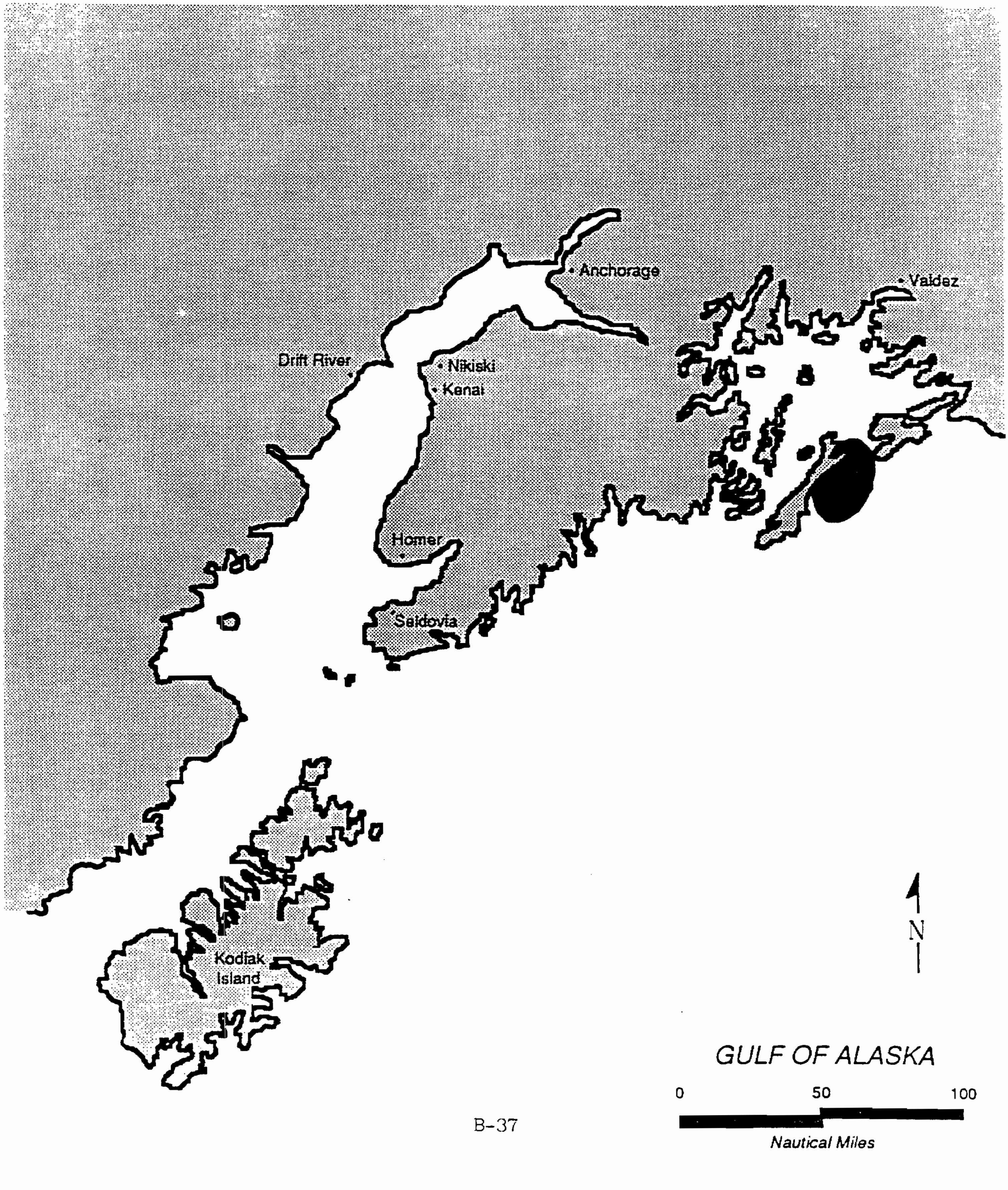
Bligh Reef - 168 Hours After Spill
Spill Size = 75,000,000 Gallons
Typical Winter Wind And Current Conditions



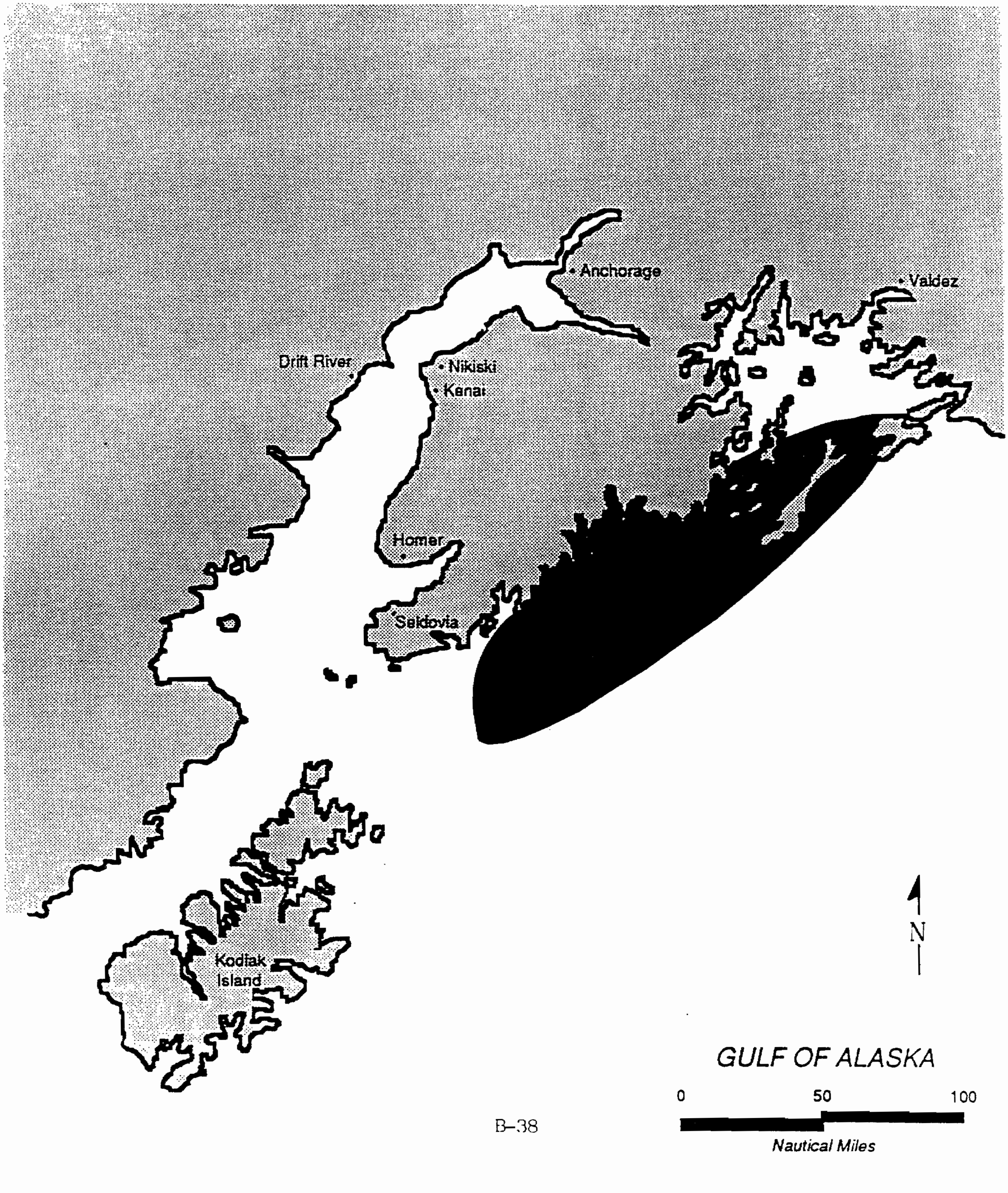
Bligh Reef - 672 Hours After Spill
Spill Size = 75,000,000 Gallons
Typical Winter Wind And Current Conditions



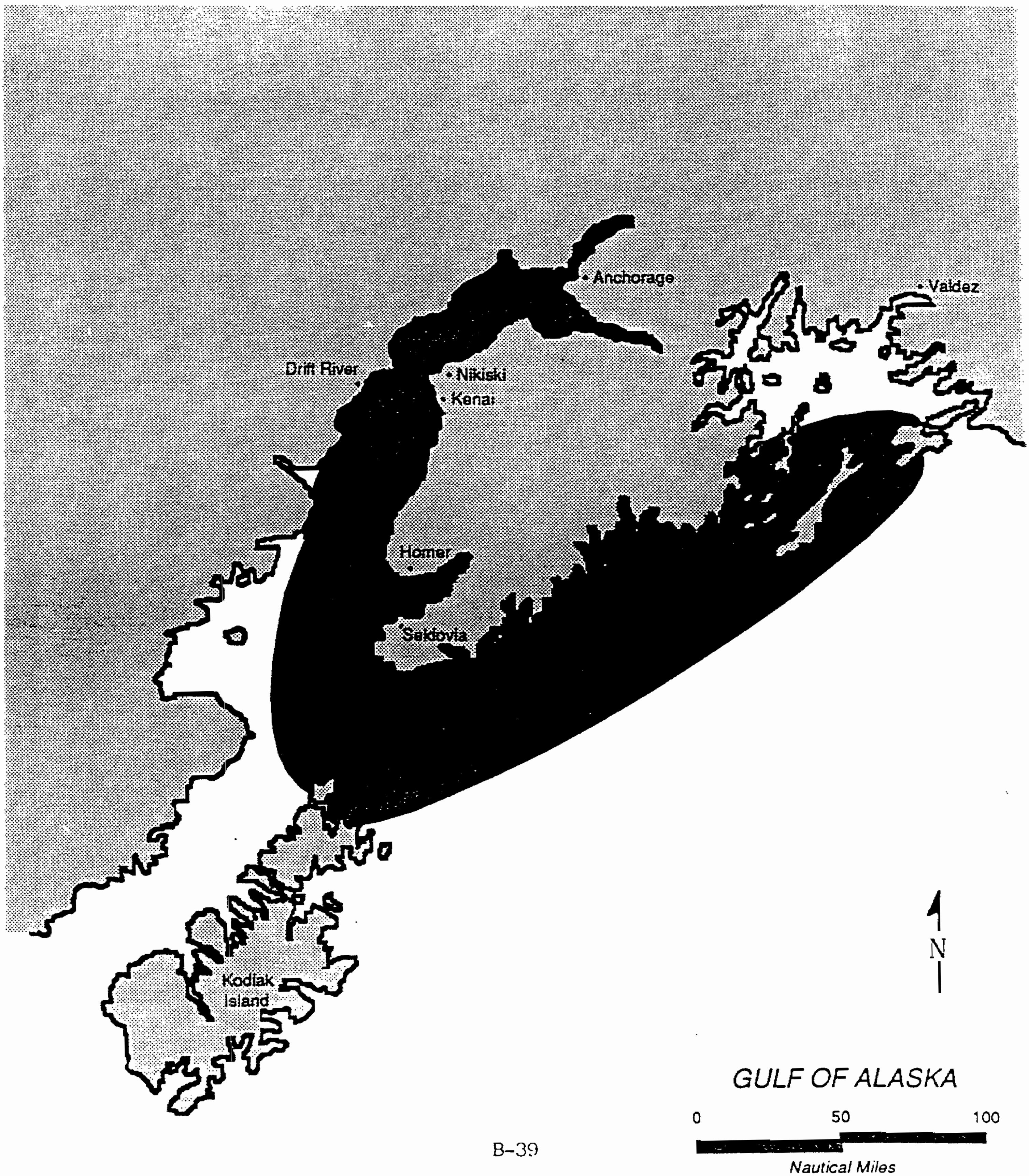
Hinchinbrook Entrance - 24 Hours After Spill
Spill Size = 3,000,000 Gallons
Typical Summer Wind And Current Conditions



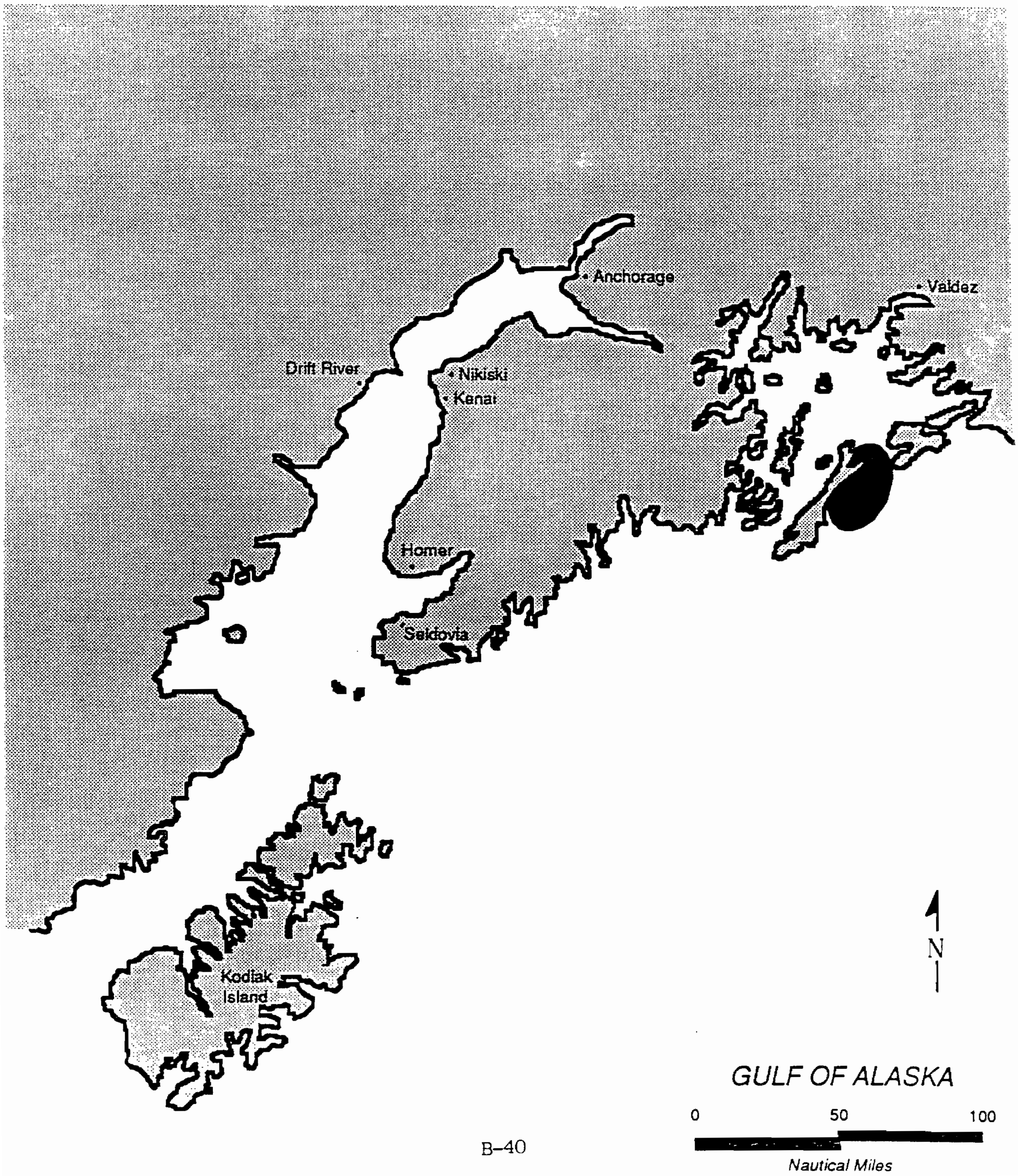
Hinchinbrook Entrance - 168 Hours After Spill
Spill Size = 3,000,000 Gallons
Typical Summer Wind And Current Conditions



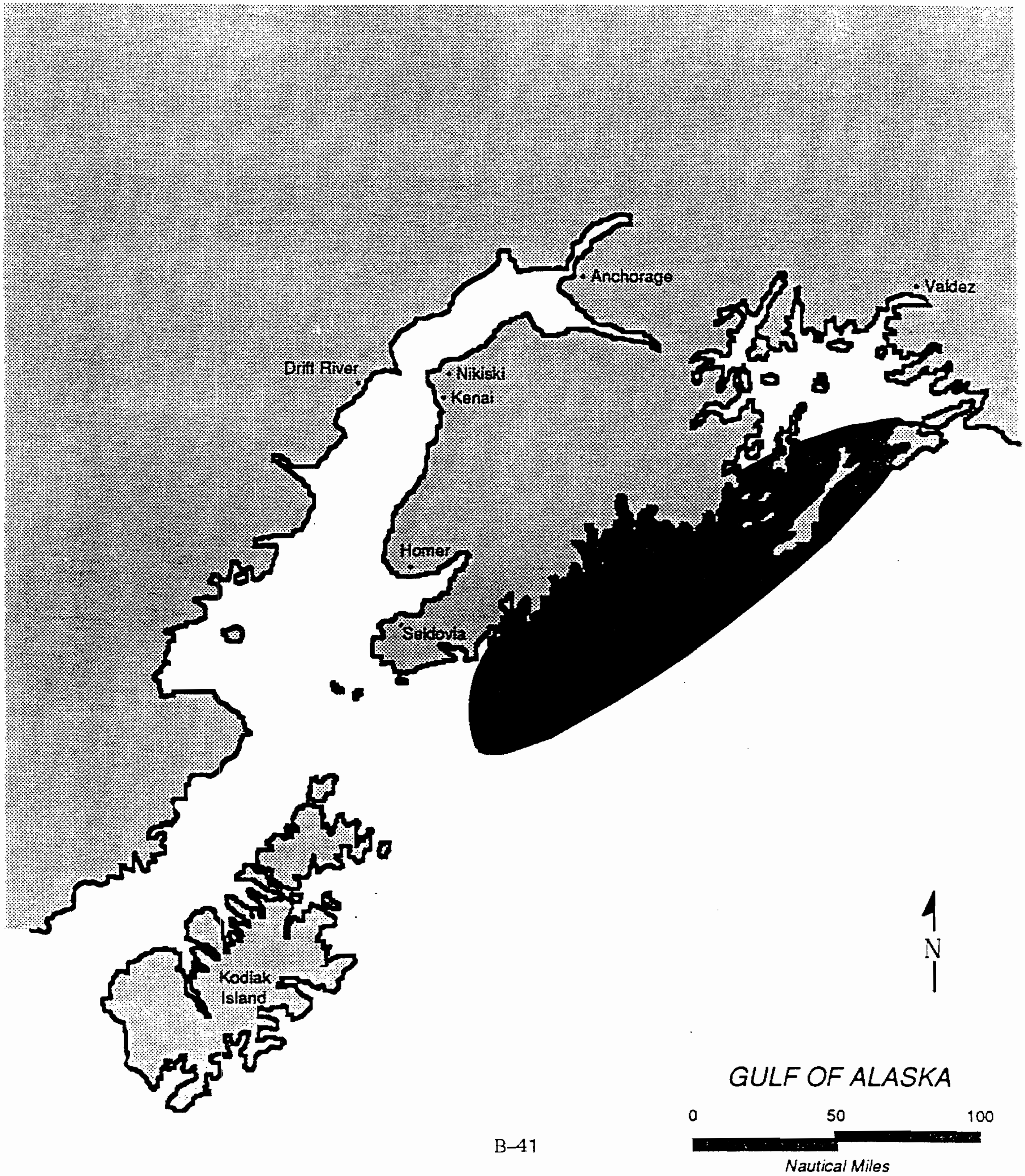
Hinchinbrook Entrance - 672 Hours After Spill
Spill Size = 3,000,000 Gallons
Typical Summer Wind And Current Conditions



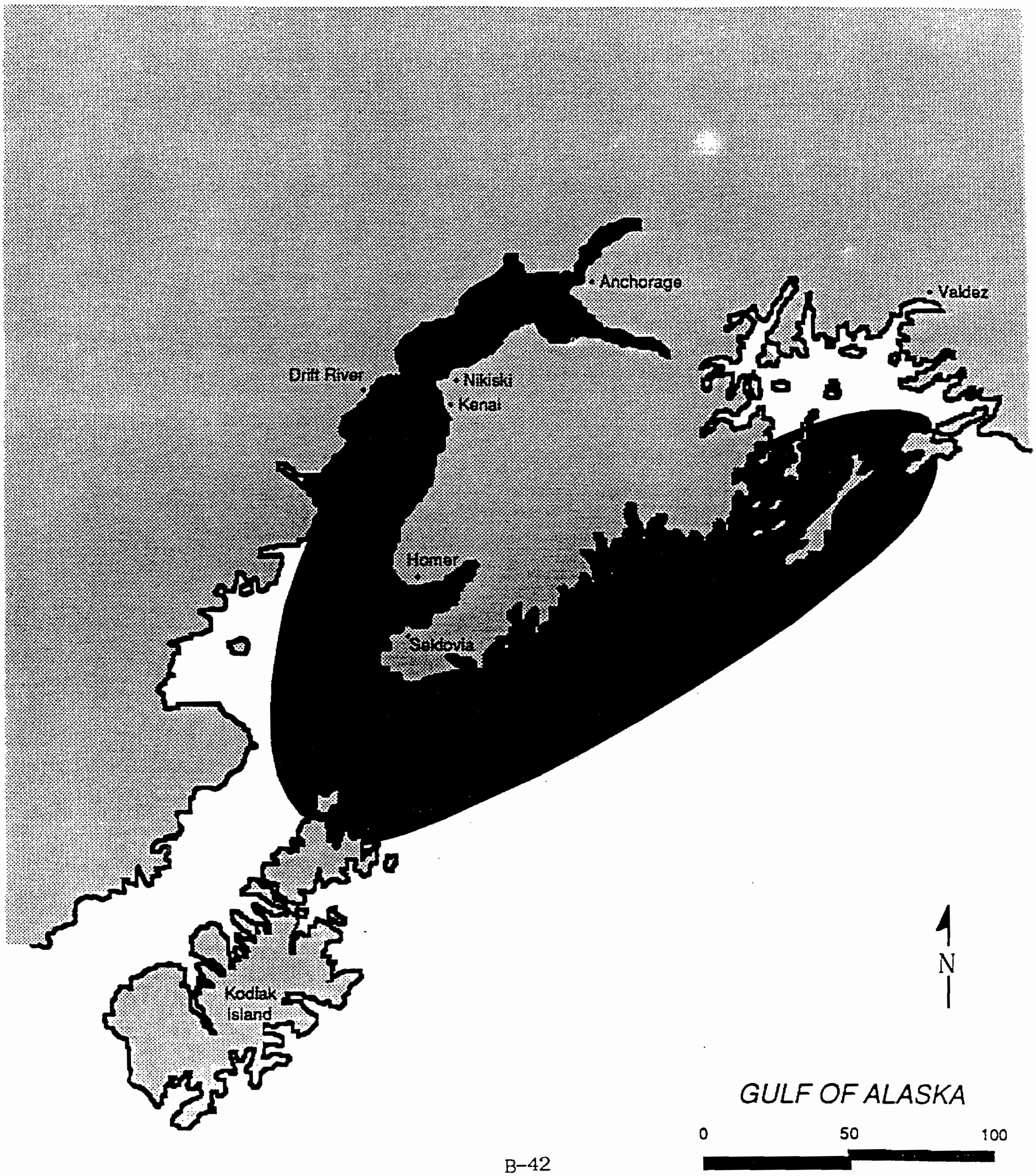
Hinchinbrook Entrance - 24 Hours After Spill
Spill Size = 11,000,000 Gallons
Typical Summer Wind And Current Conditions



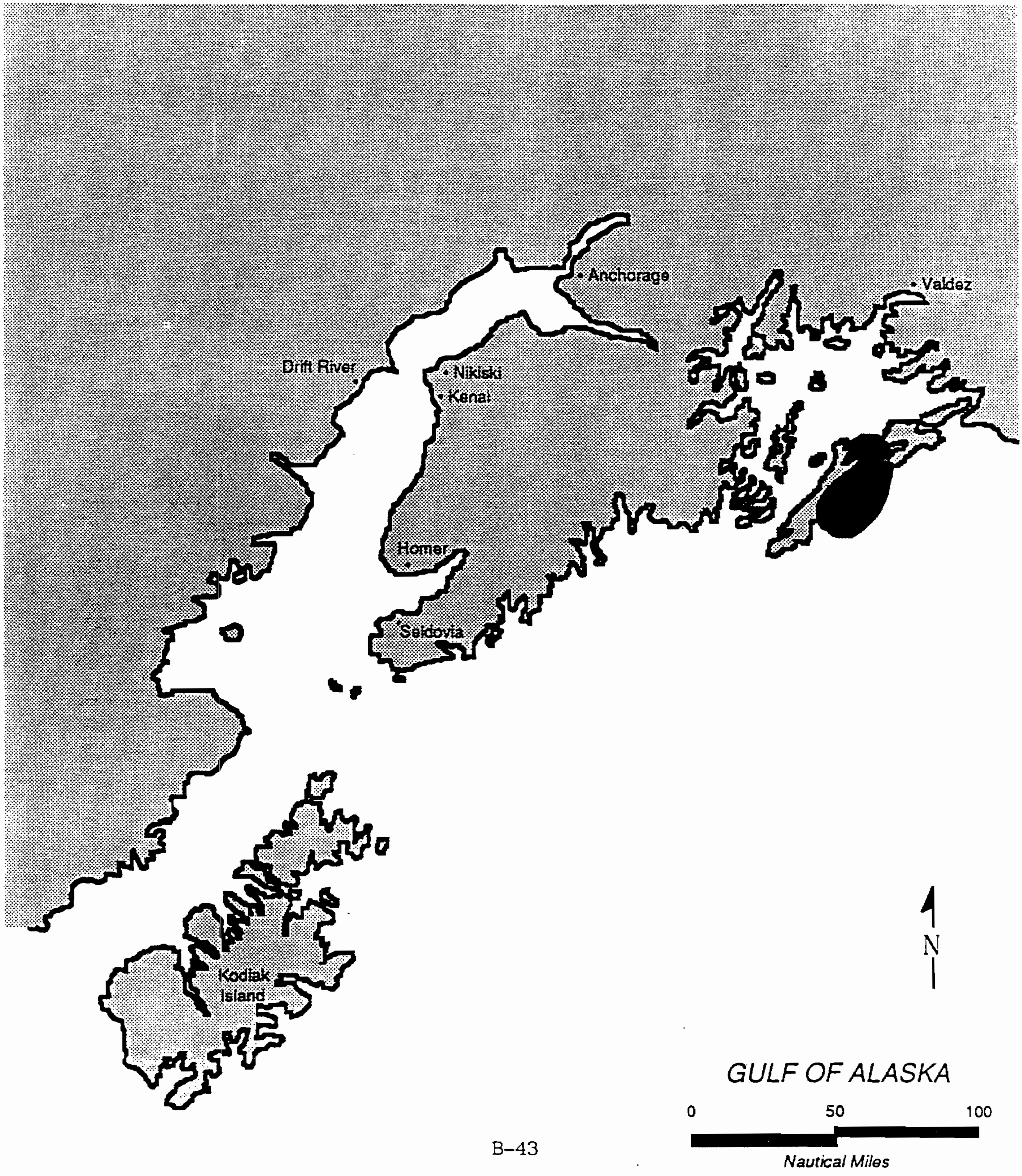
Hinchinbrook Entrance - 168 Hours After Spill
Spill Size = 11,000,000 Gallons
Typical Summer Wind And Current Conditions



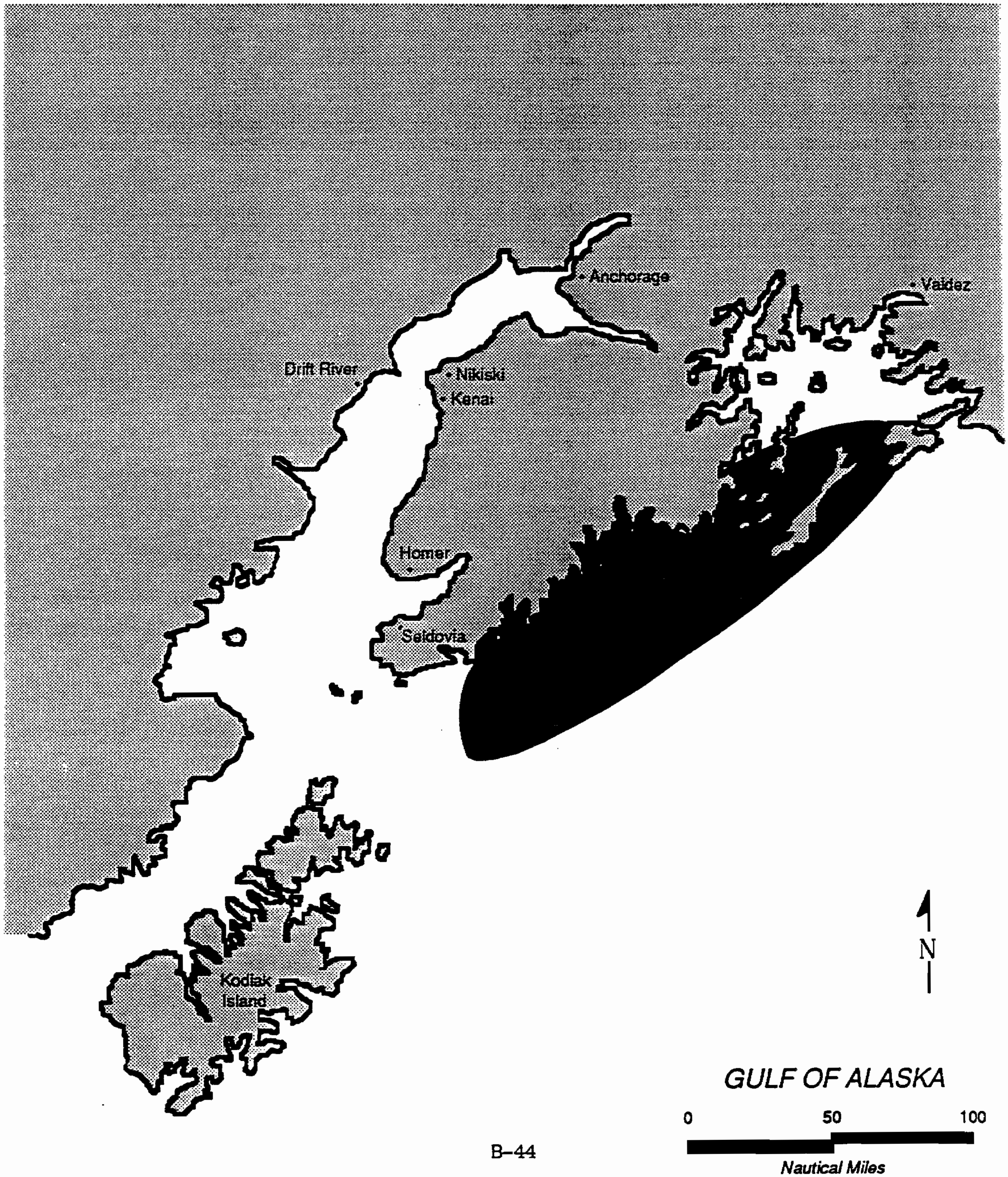
Hinchinbrook Entrance - 672 Hours After Spill
Spill Size = 11,000,000 Gallons
Typical Summer Wind And Current Conditions



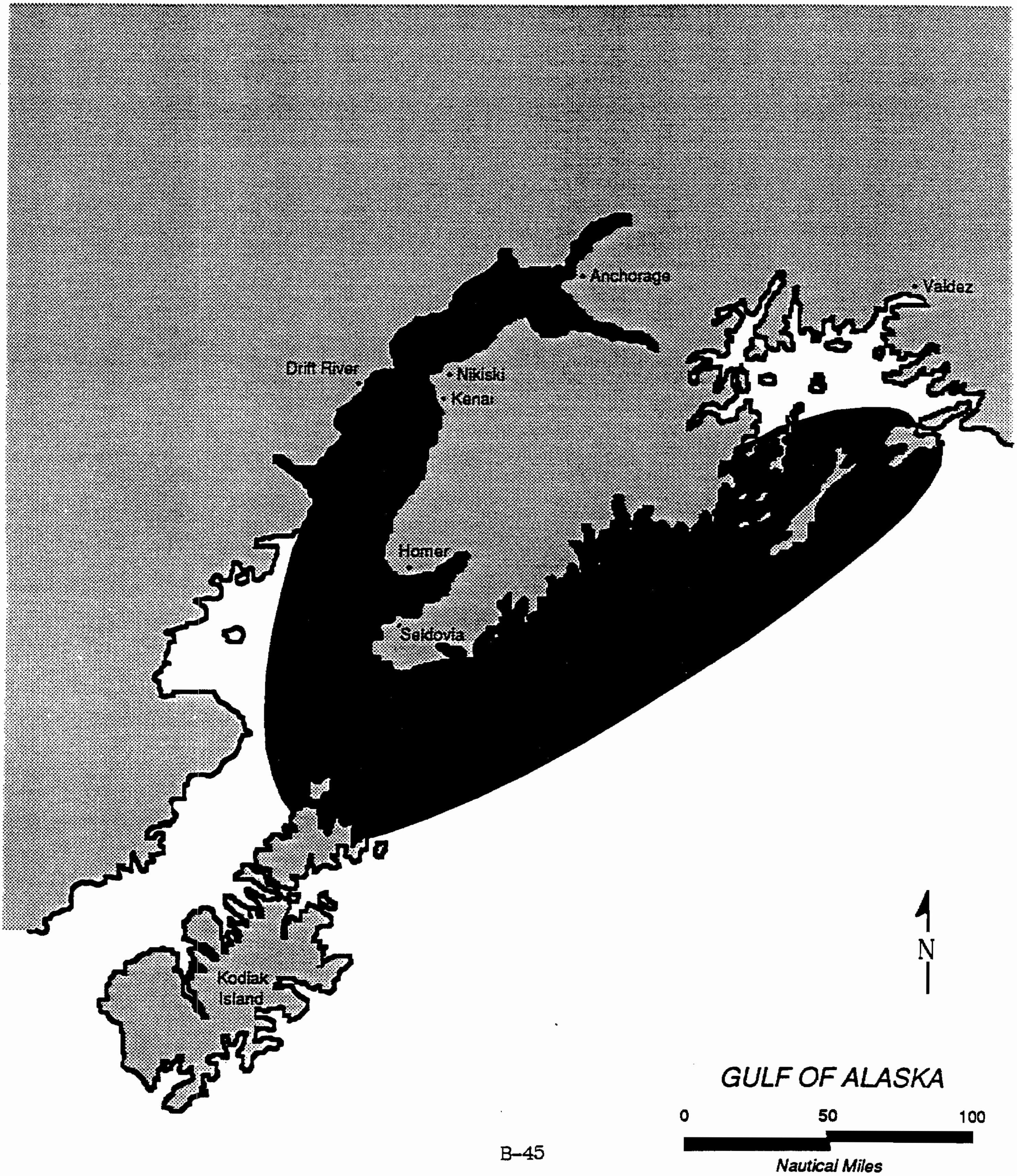
Hinchinbrook Entrance - 24 Hours After Spill
Spill Size = 75,000,000 Gallons
Typical Summer Wind And Current Conditions



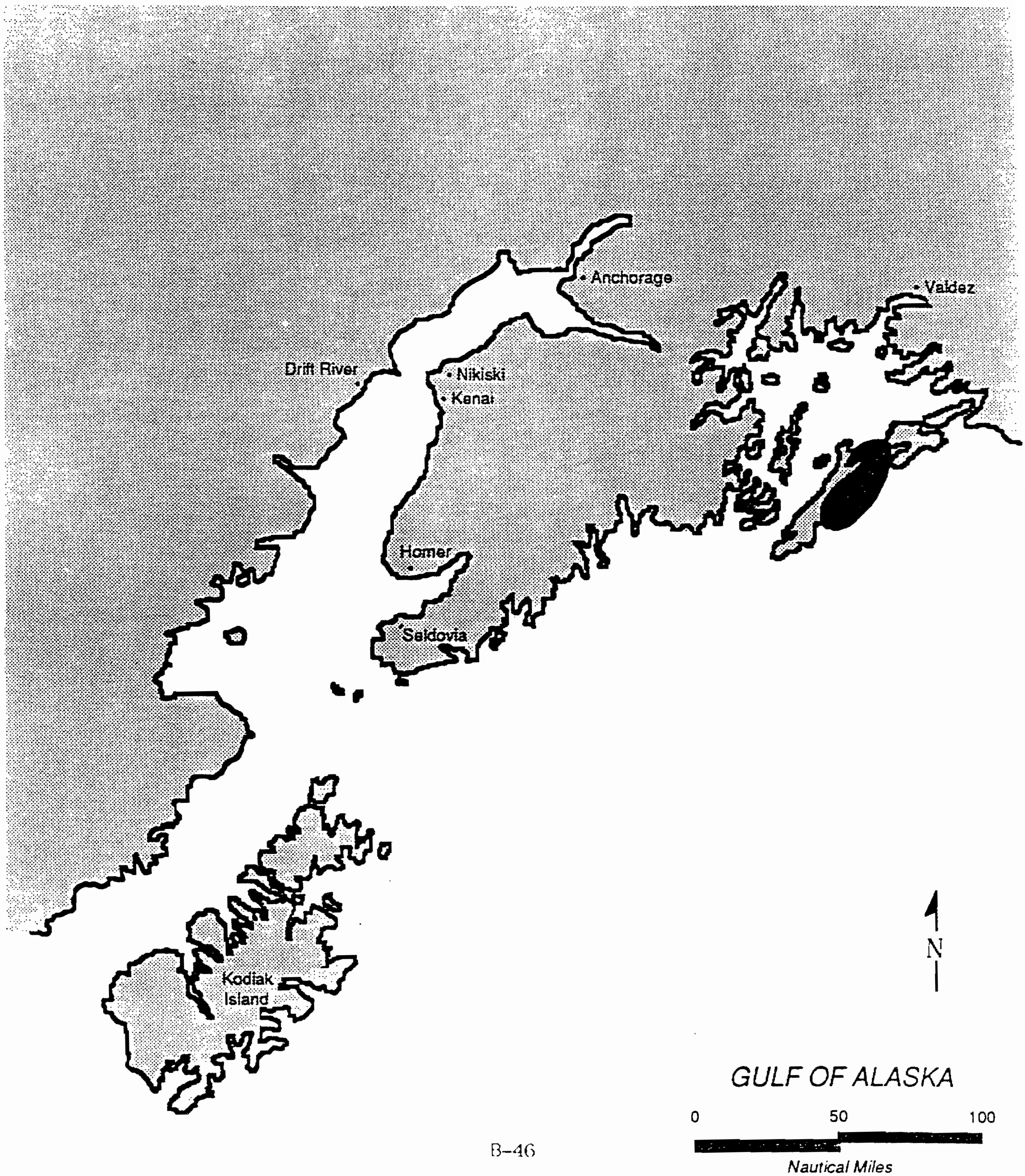
Hinchinbrook Entrance - 168 Hours After Spill
Spill Size = 75,000,000 Gallons
Typical Summer Wind And Current Conditions



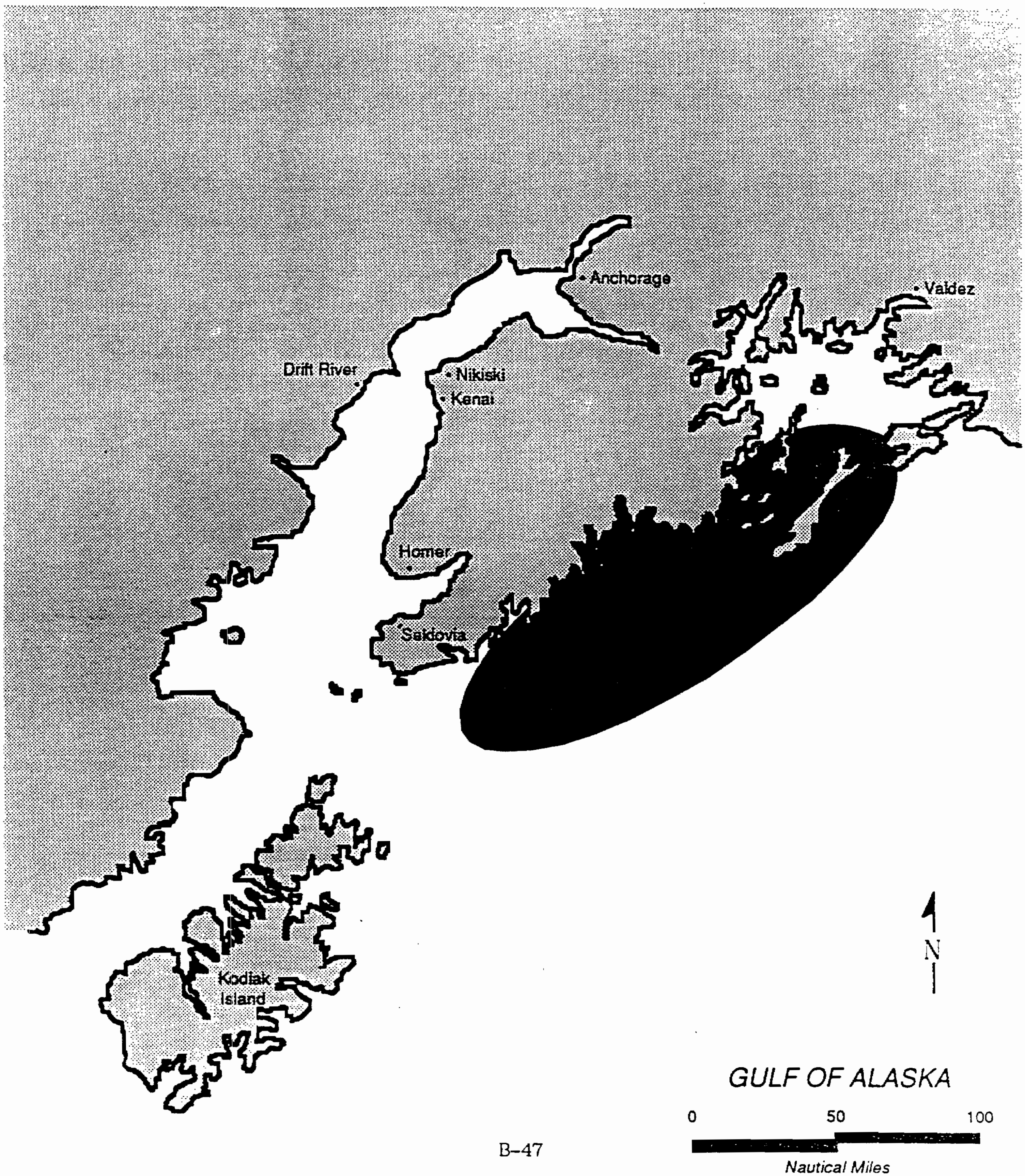
Hinchinbrook Entrance - 672 Hours After Spill
Spill Size = 75,000,000 Gallons
Typical Summer Wind And Current Conditions



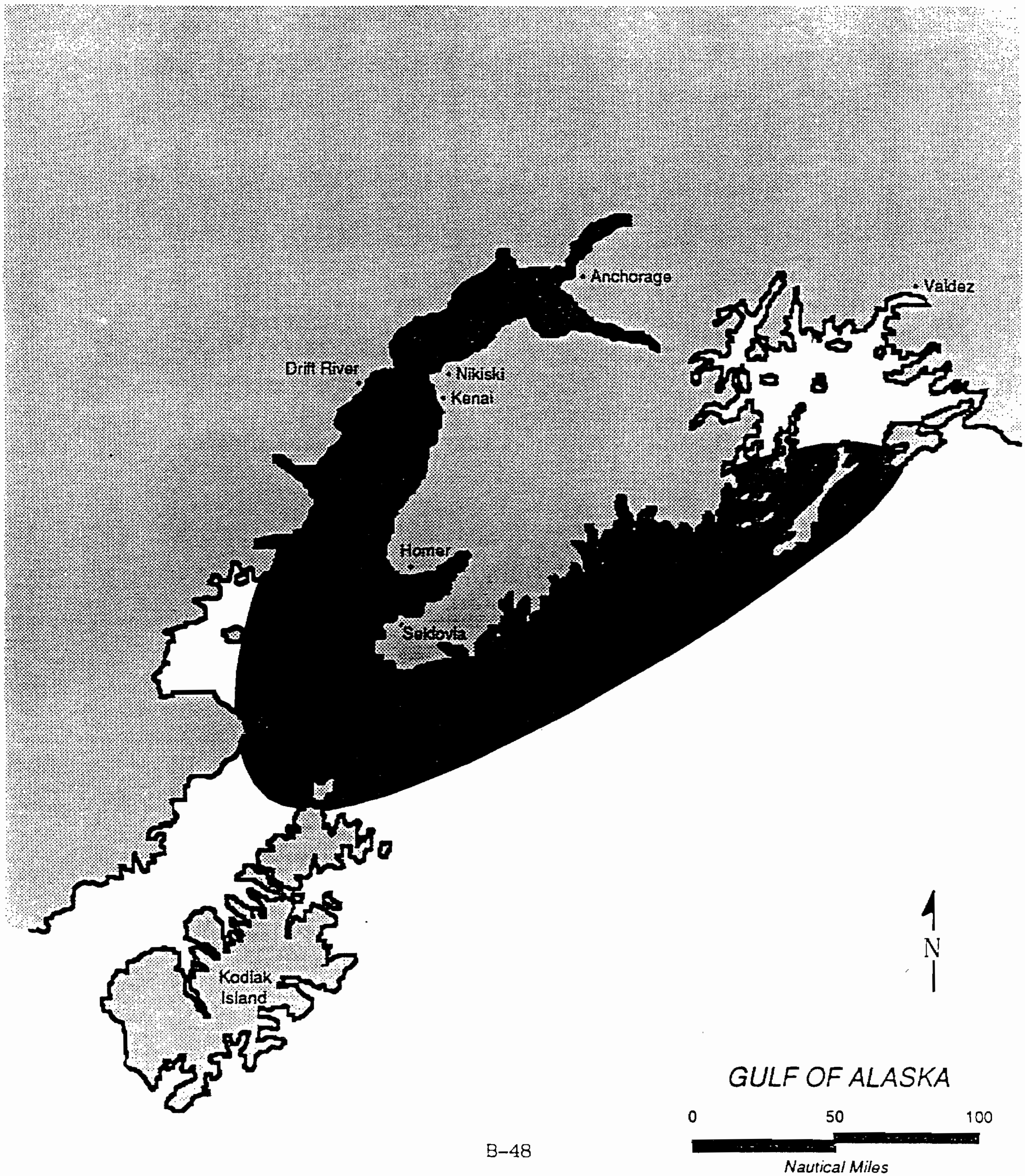
Hinchinbrook Entrance - 24 Hours After Spill
Spill Size = 3,000,000 Gallons
Typical Winter Wind And Current Conditions



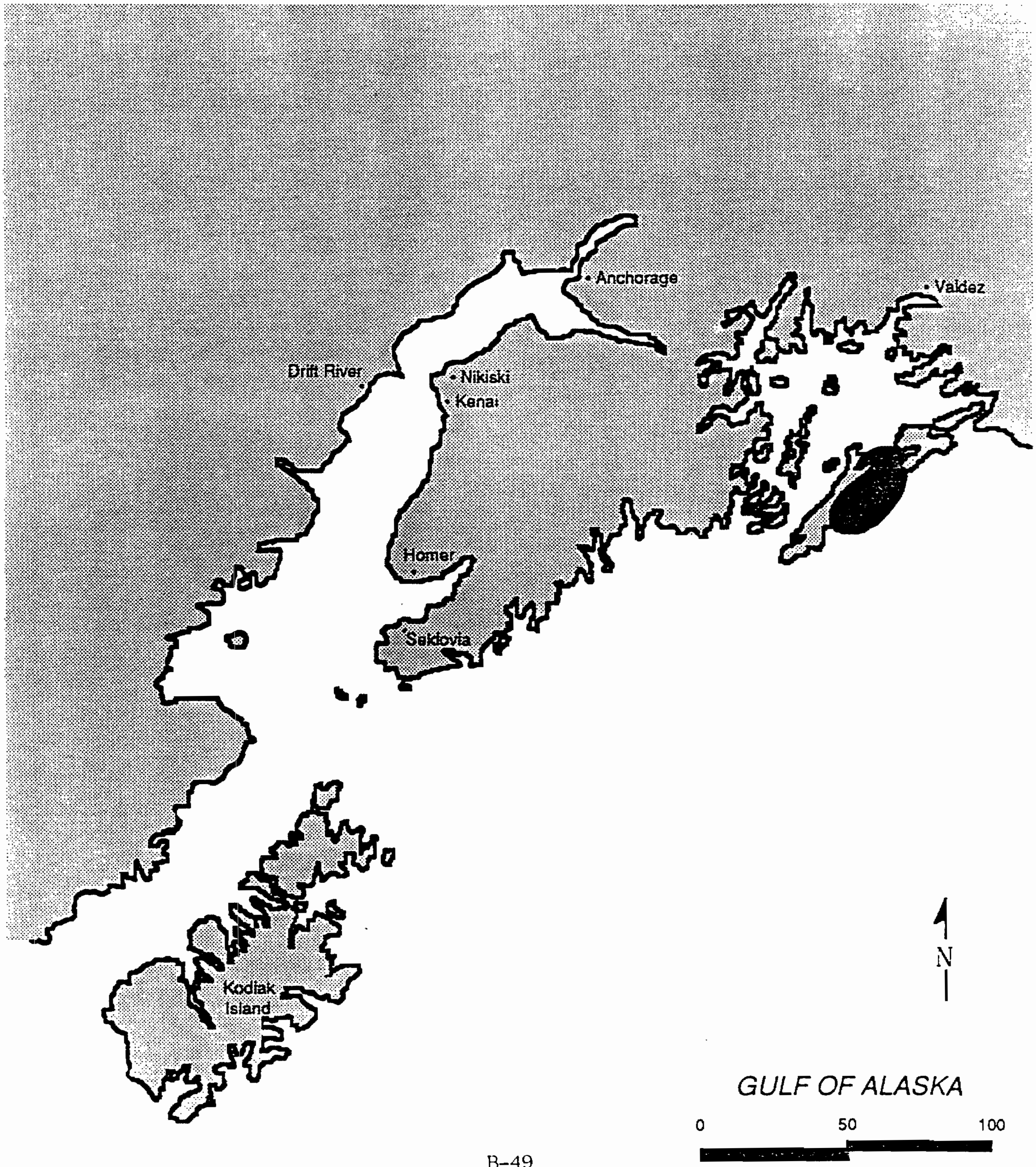
Hinchinbrook Entrance - 168 Hours After Spill
Spill Size = 3,000,000 Gallons
Typical Winter Wind And Current Conditions



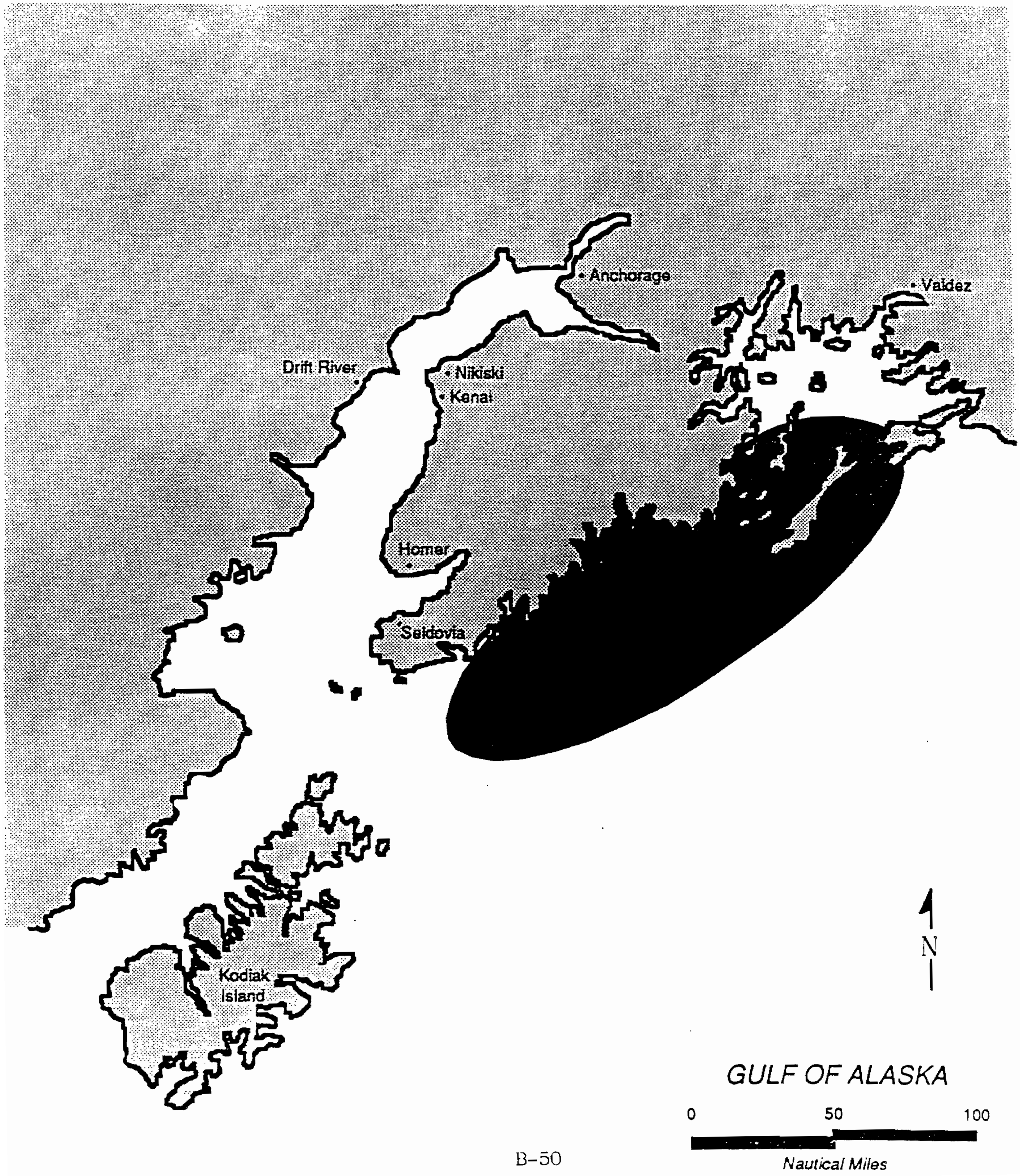
Hinchinbrook Entrance - 672 Hours After Spill
Spill Size = 3,000,000 Gallons
Typical Winter Wind And Current Conditions



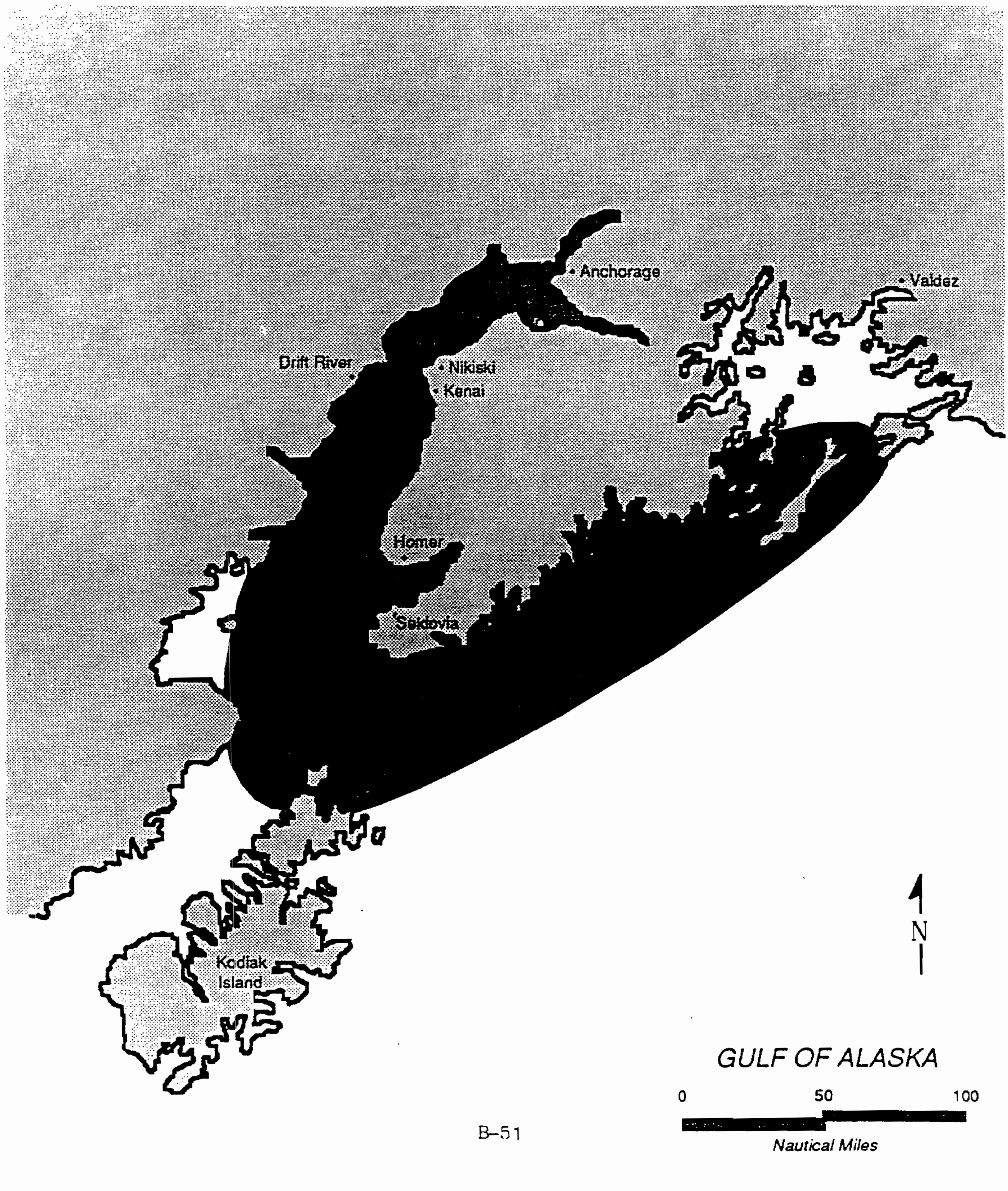
Hinchinbrook Entrance - 24 Hours After Spill
Spill Size = 11,000,000 Gallons
Typical Winter Wind And Current Conditions



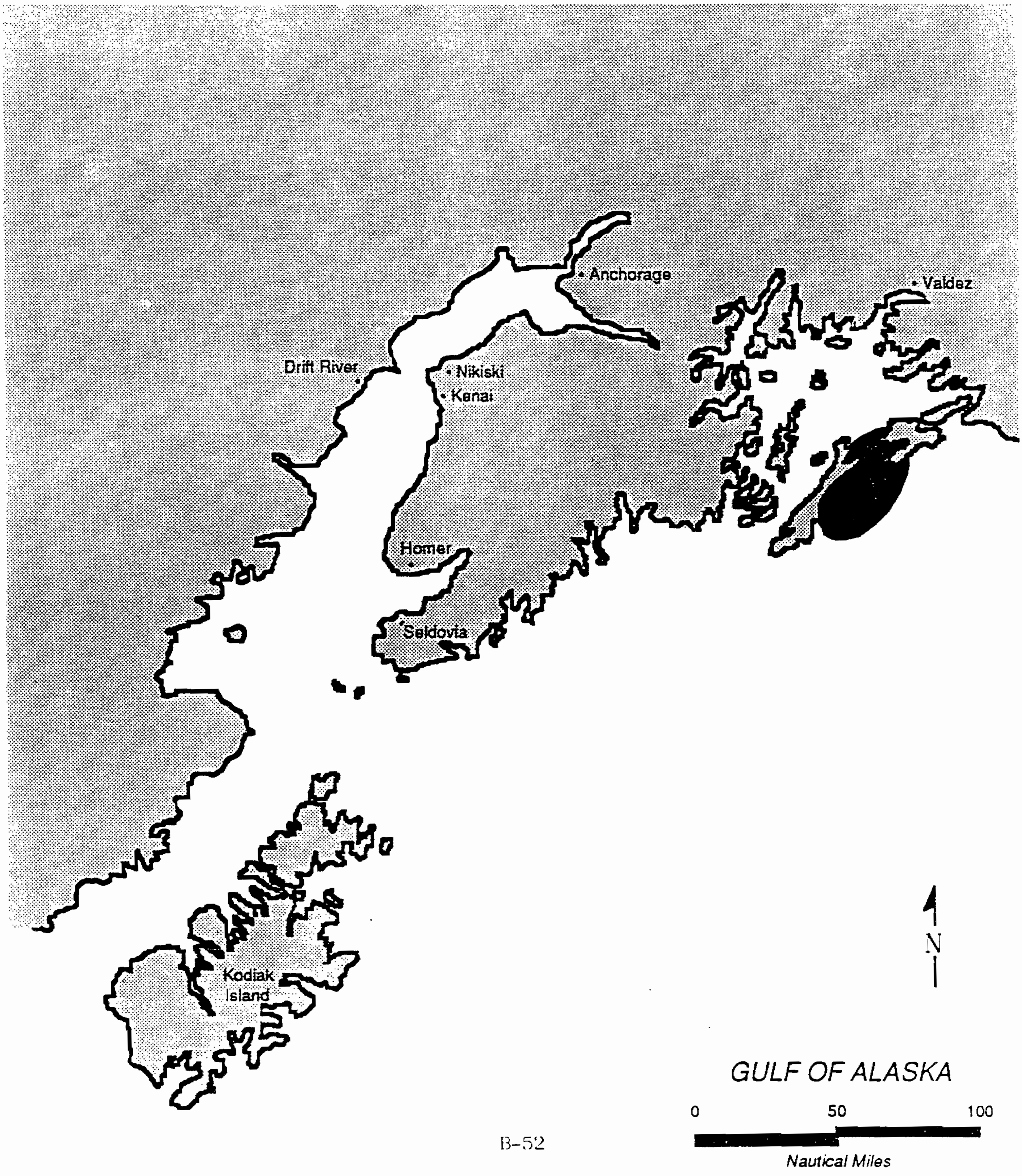
Hinchinbrook Entrance - 168 Hours After Spill
Spill Size = 11,000,000 Gallons
Typical Winter Wind And Current Conditions



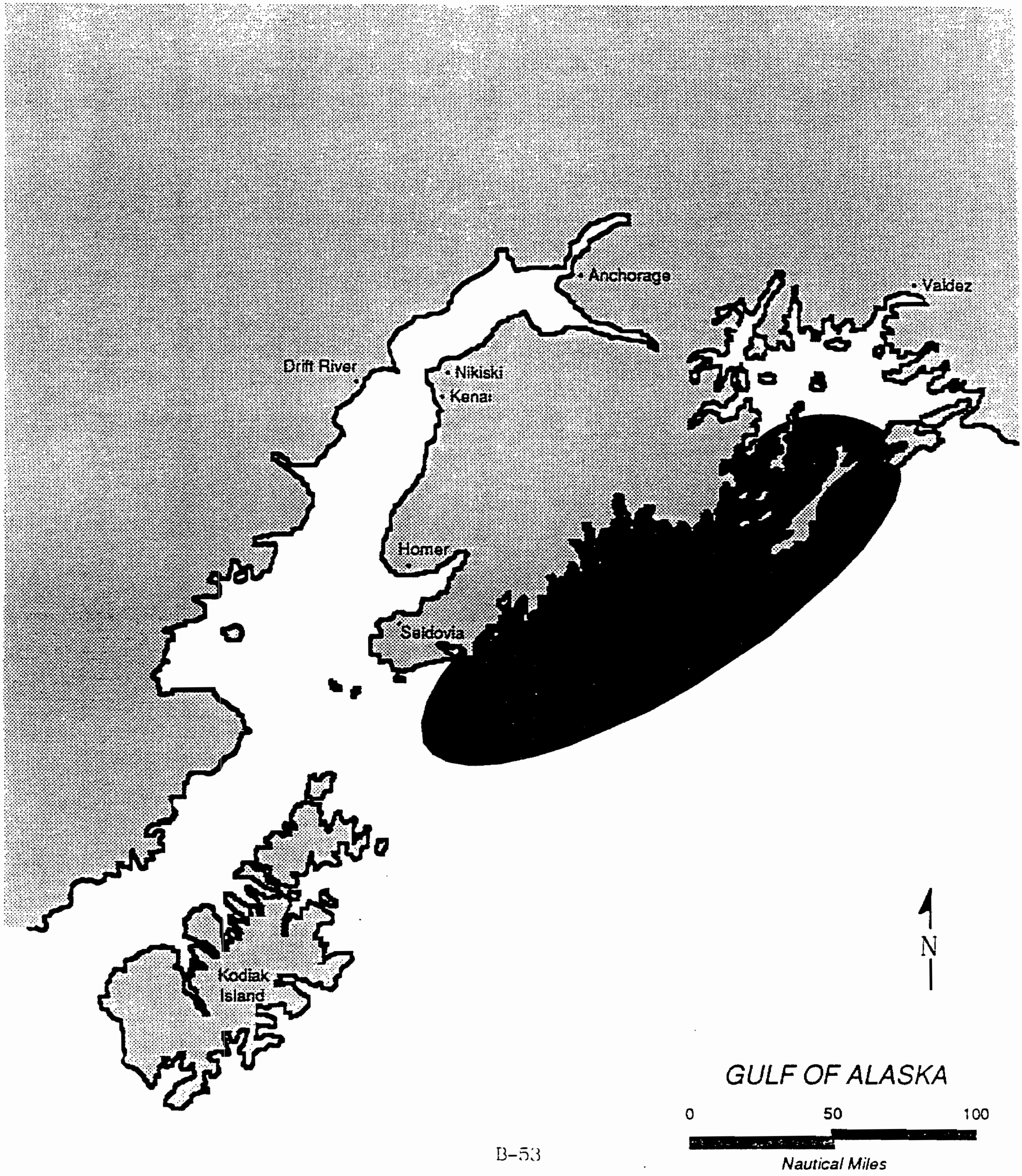
Hinchinbrook Entrance - 672 Hours After Spill
Spill Size = 11,000,000 Gallons
Typical Winter Wind And Current Conditions



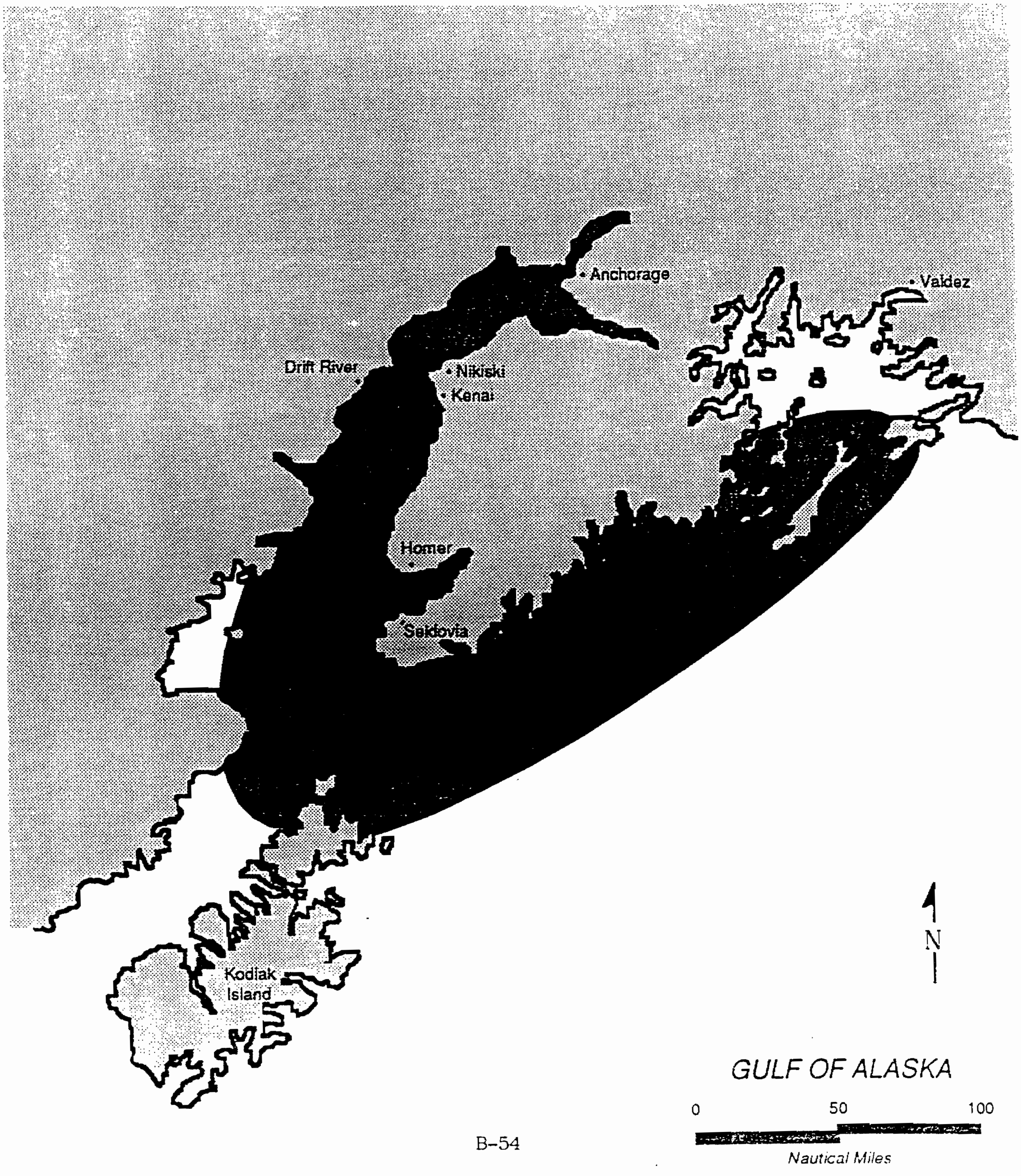
Hinchinbrook Entrance - 24 Hours After Spill
Spill Size = 75,000,000 Gallons
Typical Winter Wind And Current Conditions



Hinchinbrook Entrance - 168 Hours After Spill
Spill Size = 75,000,000 Gallons
Typical Winter Wind And Current Conditions



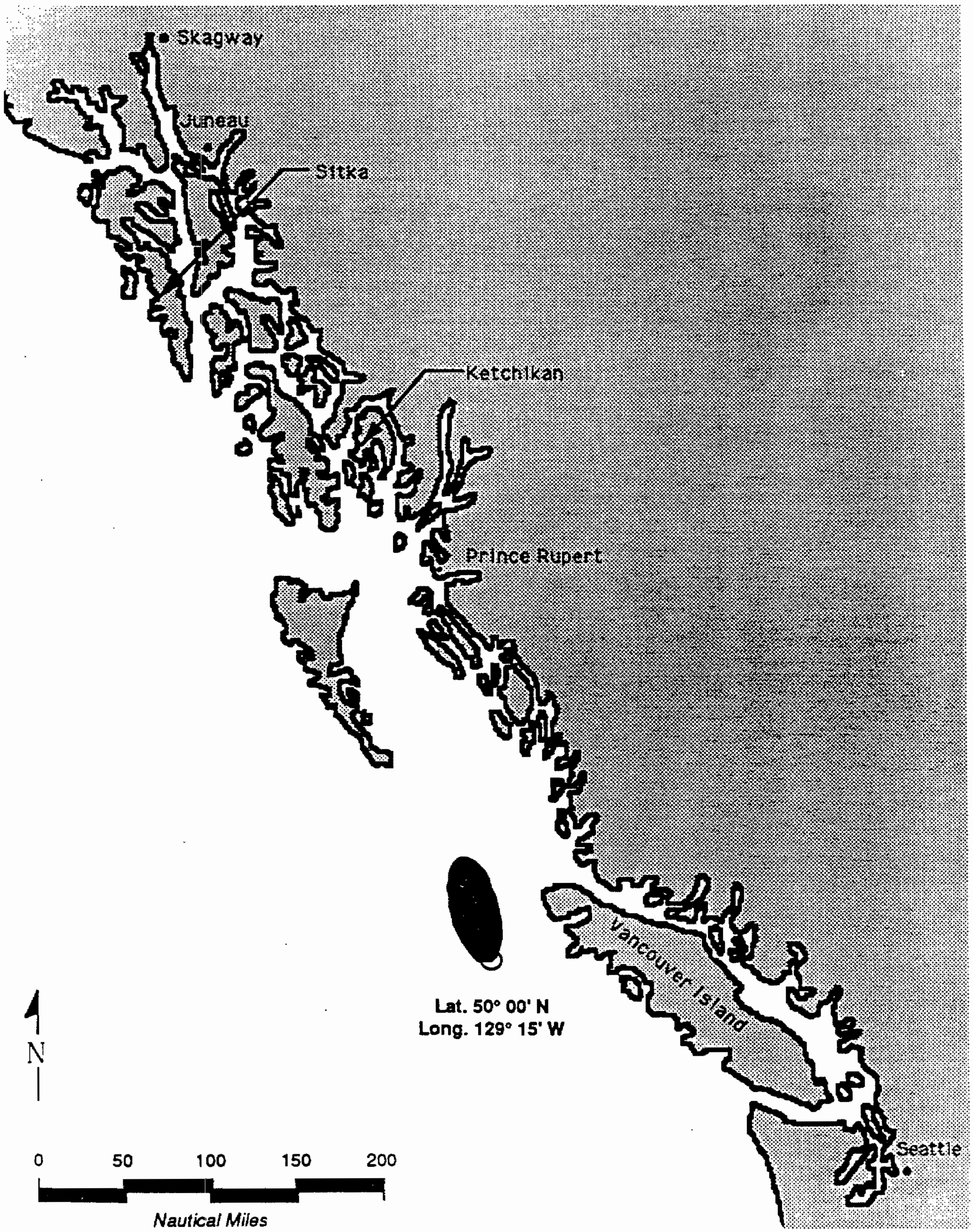
Hinchinbrook Entrance - 672 Hours After Spill
Spill Size = 75,000,000 Gallons
Typical Winter Wind And Current Conditions



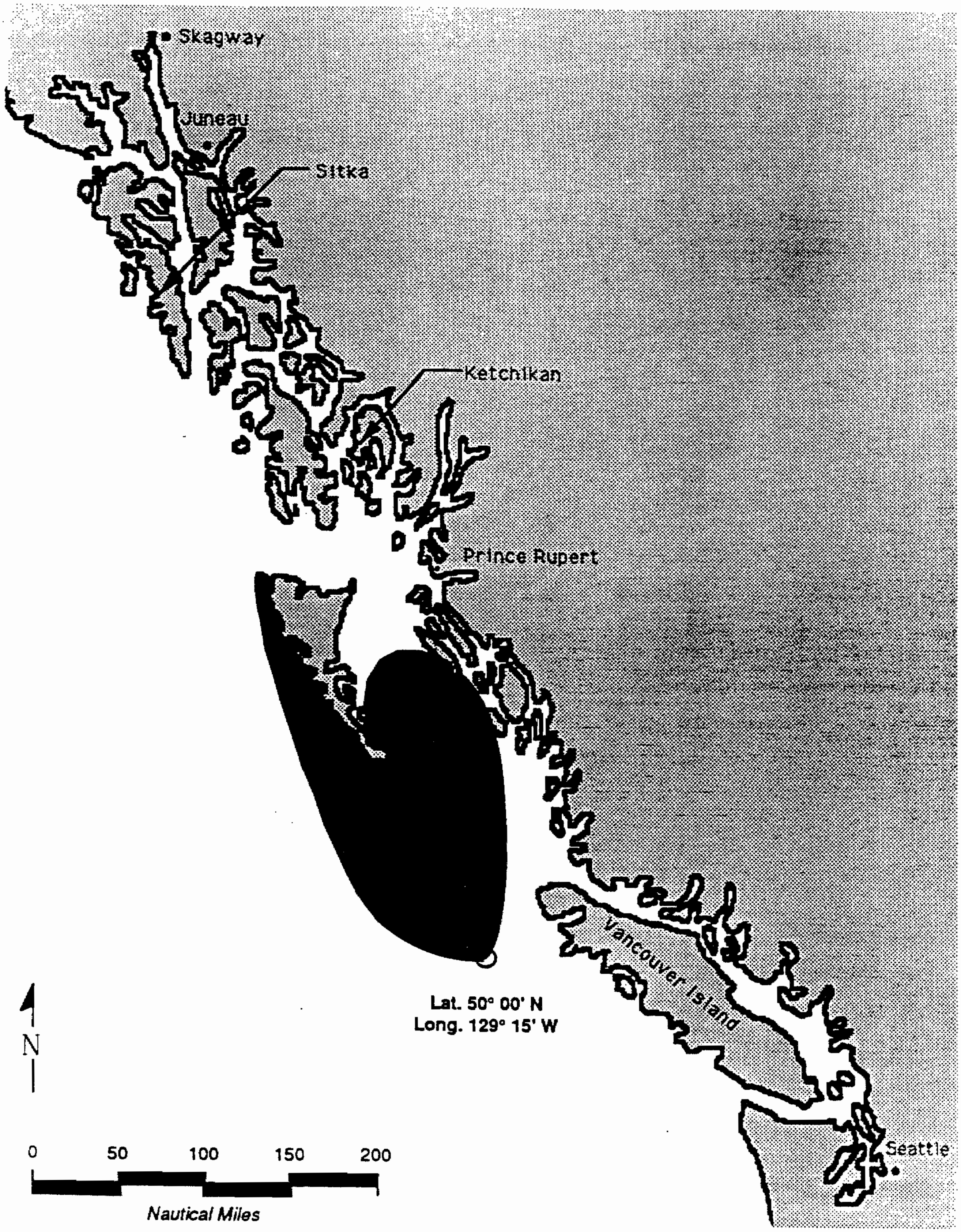
APPENDIX C

OFFSHORE SPILL PROJECTIONS

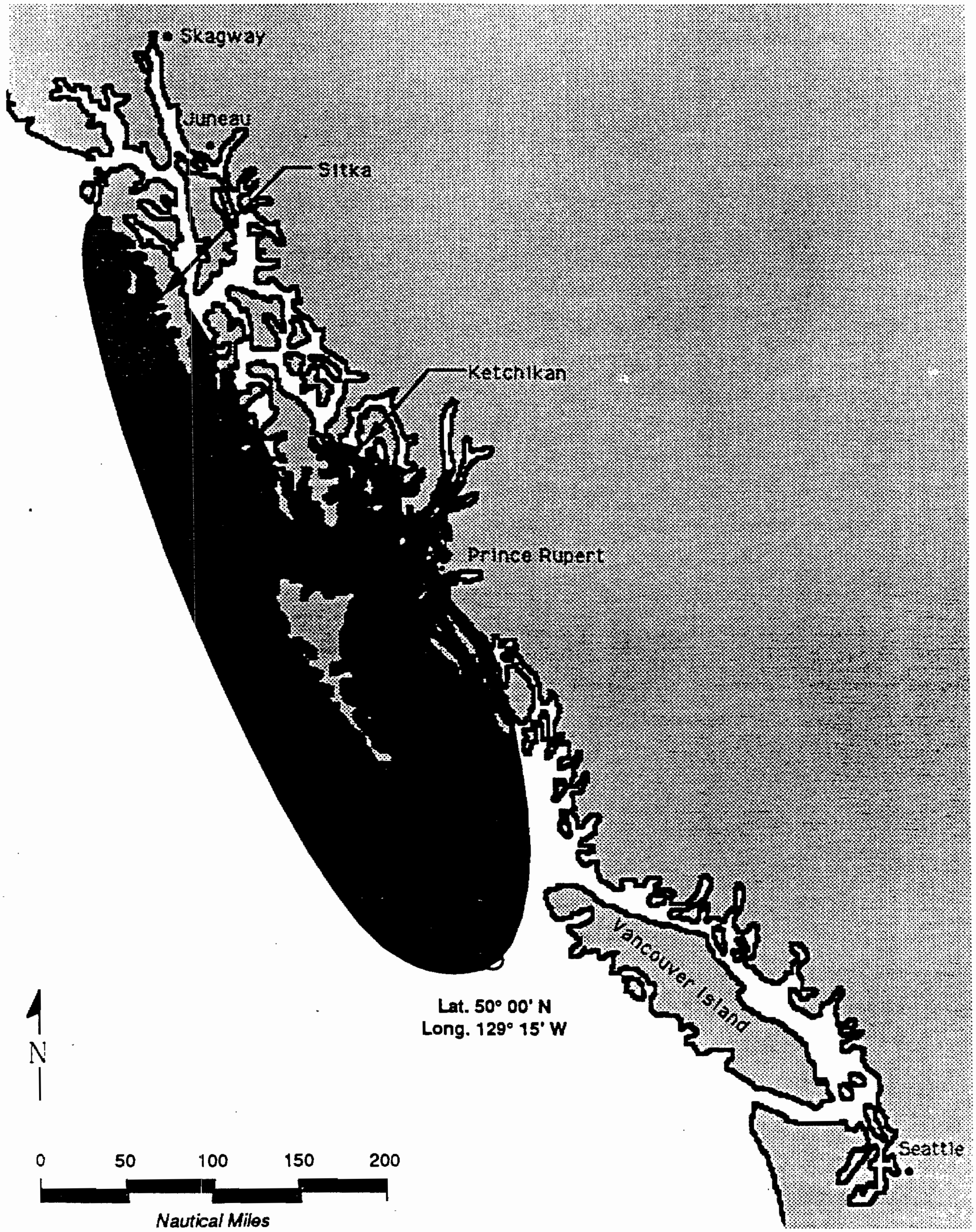
Offshore Spill Site 1 - 24 Hours After Spill
Spill Size = 75,000,000 Gallons
Typical Winter Wind And Current Conditions



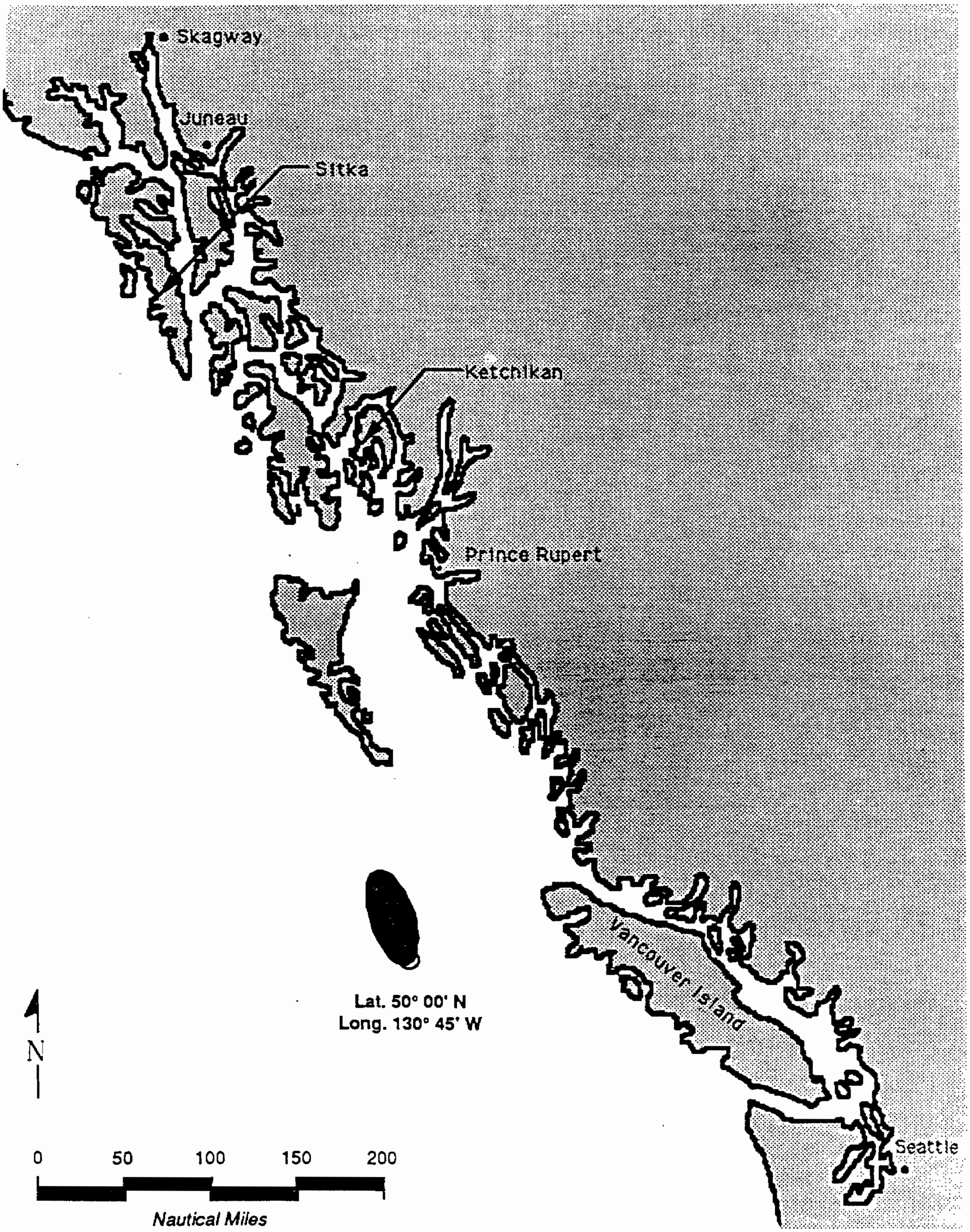
Offshore Spill Site 1 - 168 Hours After Spill
Spill Size = 75,000,000 Gallons
Typical Winter Wind And Current Conditions



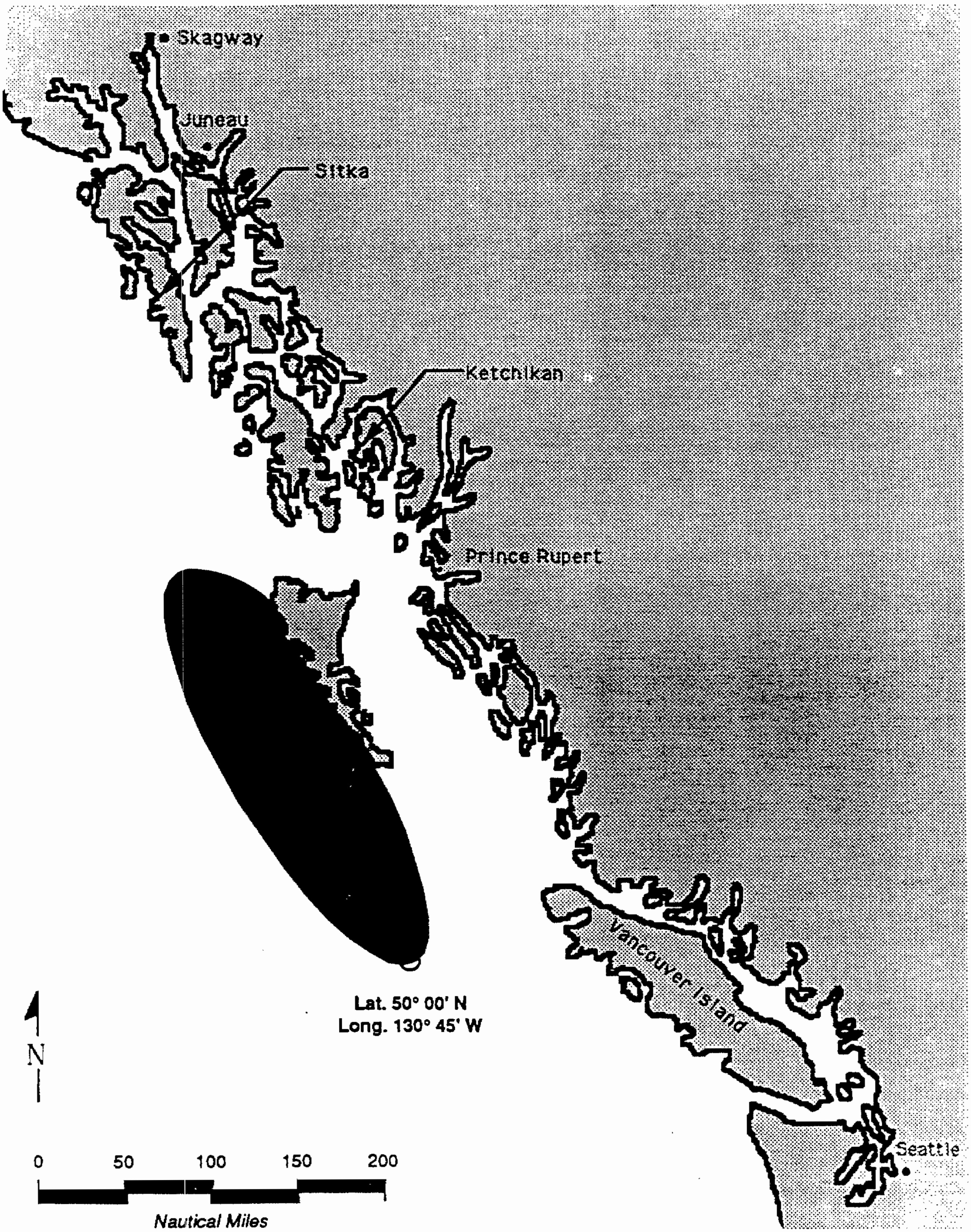
Offshore Spill Site 1 - 336 Hours After Spill
Spill Size = 75,000,000 Gallons
Typical Winter Wind And Current Conditions



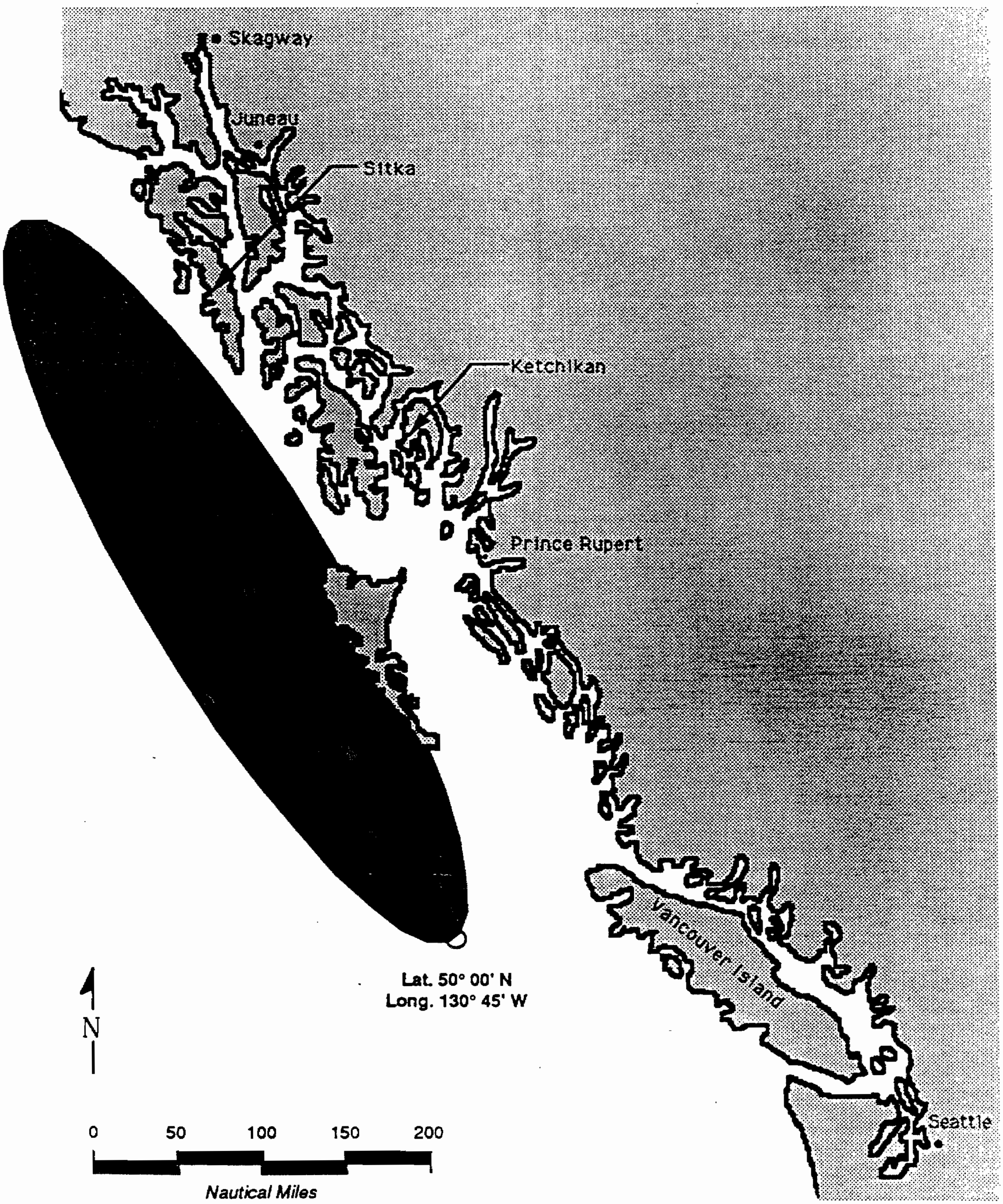
Offshore Spill Site 2 - 24 Hours After Spill
Spill Size = 75,000,000 Gallons
Typical Winter Wind And Current Conditions



Offshore Spill Site 2 - 168 Hours After Spill
Spill Size = 75,000,000 Gallons
Typical Winter Wind And Current Conditions



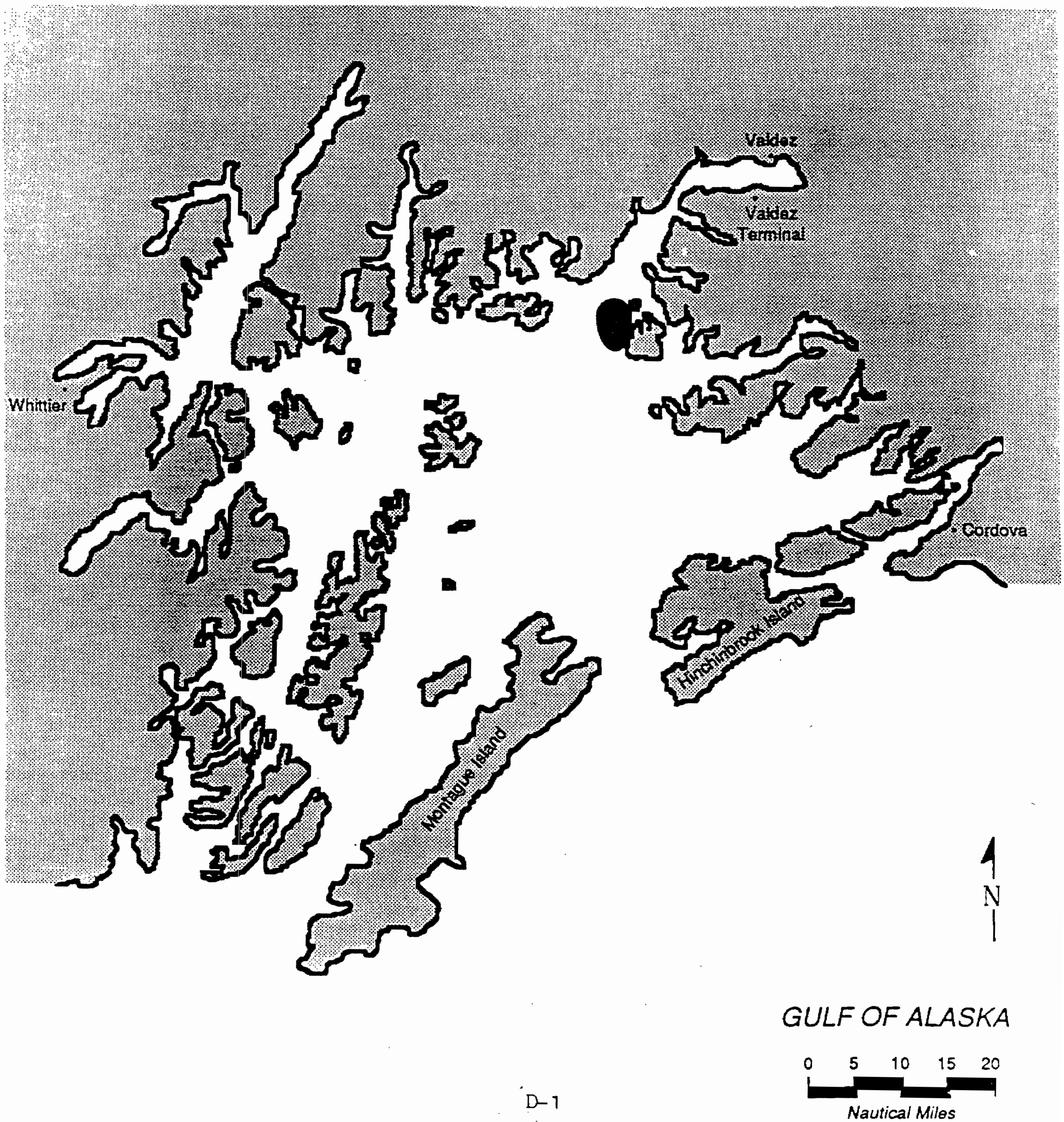
Offshore Spill Site 2 - 336 Hours After Spill
Spill Size = 75,000,000 Gallons
Typical Winter Wind And Current Conditions



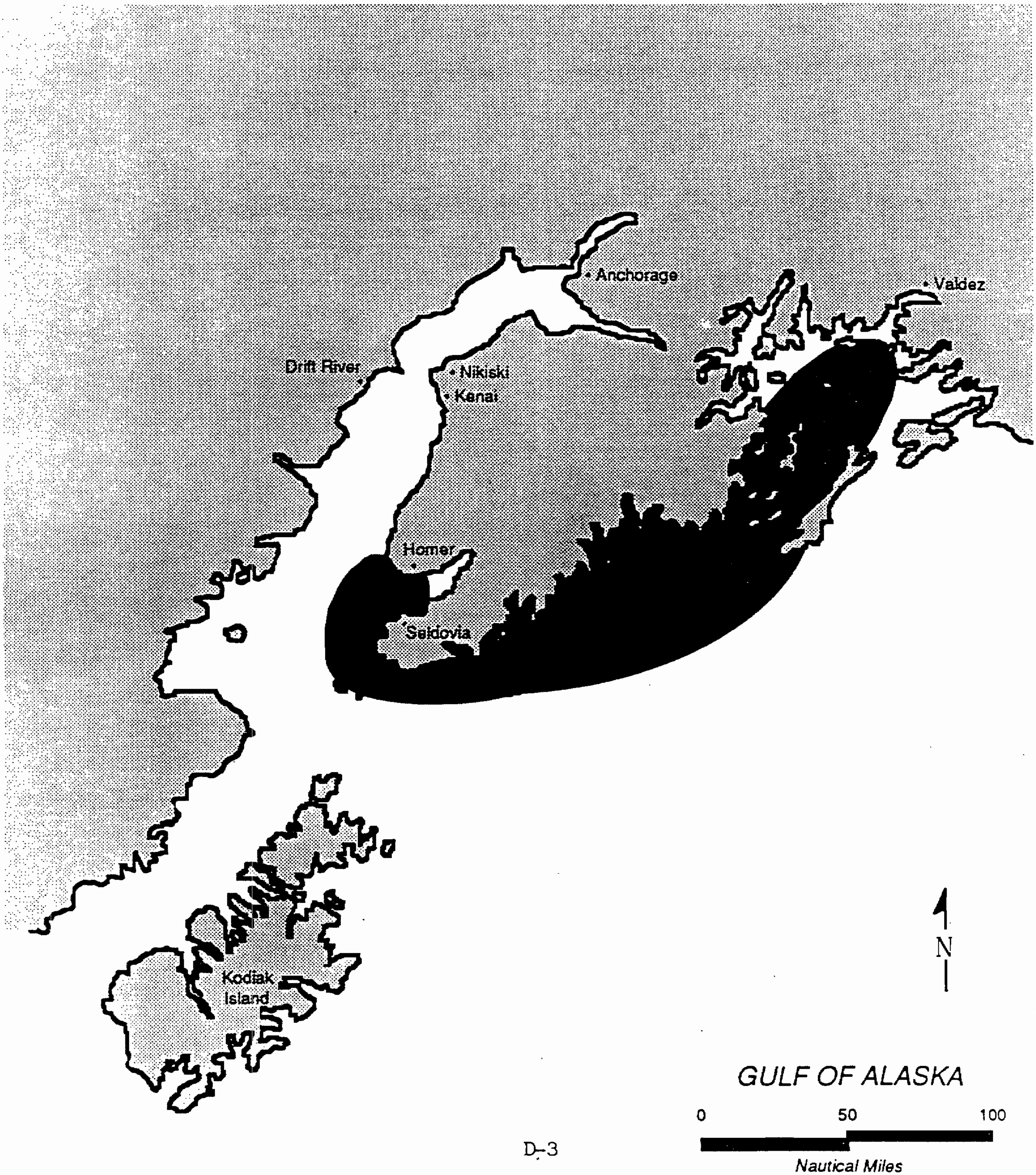
APPENDIX D

OIL SPILL MODEL VALIDATION

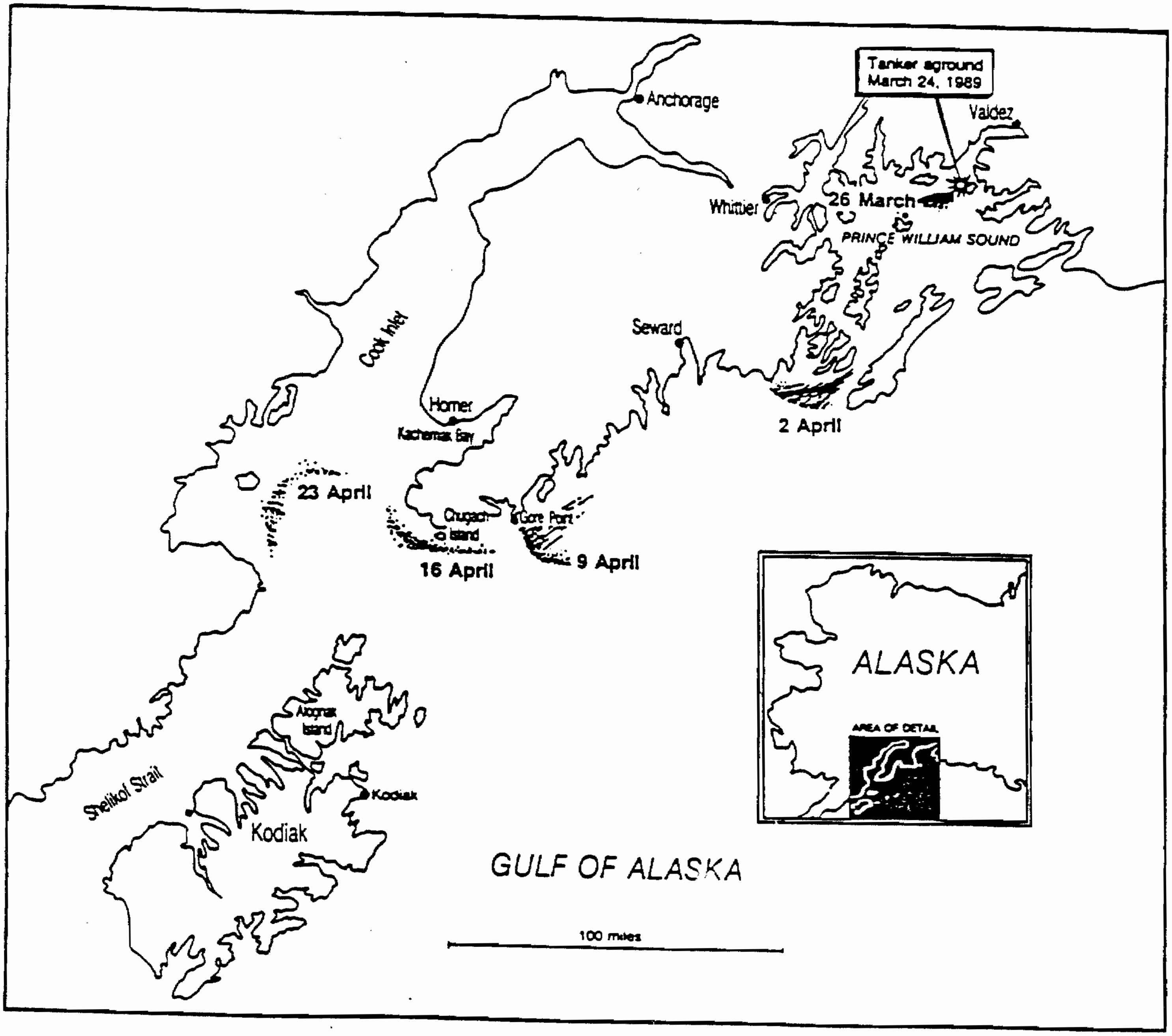
EXXON VALDEZ - 24 Hours After Spill
Spill Size = 10,500,000 Gallons



EXXON VALDEZ - 672 Hours After Spill
Spill Size = 10,500,000 Gallons



Leading Edge Of Oil Spill (through April 23)



Reference: Skinner, Samuel K., and Reilly, William K., "The EXXON VALDEZ Oil Spill, A Report to the President," page 26, May 1989.

APPENDIX E

OIL SPILL SKIMMERS

NOTES

(1) This appendix is not a complete review of all skimmers available. Rather, it only considers those that are readily available, that is, those manufactured in the U.S. or made by foreign firms that have a U.S. distributor. Small or low capacity skimmers are not considered and, in fact, only those that have potential for effective use in Alaska.

(2) Skimming speed with a deployed containment boom is assumed to be 0.7 knots in every case. At this speed, the sweep rate is 0.02 square nautical miles per hour (Sweep width 167 feet) with 500 feet of boom in a "U" configuration and 0.012 square nautical miles per hour (sweep width of 100 feet) with 500 feet of boom in a "J" configuration.

OIL SPILL SKIMMERS

Manufacturer/ Model	Size (ft) HxWxL	Weight (lbs)	Recovery Rate BBL/Hr (GPM) Tested (T) Published (P)	Skimming Speed Unassisted, Kts	Sweep Rate Unassisted (NM2/HR)	Approximate Cost	Performance Assessment
SUCTION SKIMMERS							
HYDE-VAC							
2415	3.1x6.6x7.6	995	146 (102) (P)	-	-	$36,200	Most suction skimmers are independent and do not have any skimming speed except when used with a towed containment boom. Sweep rate is for 500 Feet of boom with a sweep width of about 167 feet is 0.02 NM 2/HR.
3325	7.2x7.8x10.8	3240	801 (561) (P)	-	-	$69,600	
3515	4.2x8.3x9.9	1921	587 (411) (P)	-	-	$95,800	
3525	6.8x8.3x12.8	3361	1174 (822) (P)	-	-	$98,800	
4715	4.8x8.9x12	3656	1361 (953) (P)	-	-	$91,900	Any suction skimmer that can be transported to the spill can be used, but highly viscous oil will require a large inlet hose opening and high power. All suction skimmers will recover a large percent water so these systems must be used with an oil/water separator or an oil/water separation process
4725	8.9x9.0x16.0	6157	2721 (1905) (P)	-	-	$155,000	
SLICKBAR							
Model 60	2.5x2.7x2.0	204	57 (40) (P)	-	-	$3,000	
Model160	5.5x3.6x3.2	645	171 (120) (P)	-	-	$13,000	
Model 500D	12x7x7	7000	714 (500) (P)	-	-	$54,400	
WEIR SKIMMERS							
DESMITHSKE	WxL						
DS-150	5.9x4.9	265	94 (66) (P)	-	-		The Desmithske and PHAROS Marine weir skimmers are basically the same, both use an oil recovery hopper instead of a conventional weir with an archimedean screw pump below the weir to draw off the oil. These skimmers can be used in almost any viscosity oil as long as the oil can be directed into the hopper. In a test, the PS-210 pumped 88 gpm with 76% oil. All weir skimmers must be used in a thick concentration of oil or they will recover a large % water. Oil/water separation should be expected in every case.
DS-210	8.2x5.6	441	314 (220) (P)	-	-	$100,000	
			94 (66) (T)	-	-		
DS-310	9.8x7.2	992	880 (616) (P)	-	-		
DS-250	7.4x6.7	375	471 (330) (P)	-	-		
PHAROS MARINE							
GT-185	7.5x6.2	330	286 (200) (P)	-	-		
GT-260	10.2x6.9	778	629 (440) (P)	-	-		
VIKOMA							
FASFLOW	11.8x7.2x3.0	484	440 (308) (P)	5KTS	0.0135		The FASFLOW uses an expanding venturi to reduce flow velocity in the skimmer. Although this system can be used independently up to 5 kts, when used with a containment boom sweep speed is restricted to <1 Kt because of boom failure.
DISC SKIMMERS							
FRANK MOHN							
FRANO ACW 402	33x6.6x5	17800	611 (428) (T)	-	-	$600,000	The ACW 402 is a large deck-mounted skimmer with a hydraulic arm that controls the skimmer head. It is a weir/disc skimmer that achieves a high rate of recovery using the weir part of the skimmer. The discs are effective in light to medium viscosity oil but are not effective in highly viscous oil.
			97 (68) (T)	-	-		

OIL SPILL SKIMMERS

Manufacturer/ Model	Size (ft) HxWxL	Weight (lbs)	Recovery Rate BBL/Hr (GPM) Tested (T) Published (P)	Skimming Speed Unassisted, Kts	Sweep Rate Unassisted (NM2/HR)	Approximate Cost	Performance Assessment
DISC SKIMMERS (Cont'd)							
LOCKHEED							
Clean Sweep 3001	27' vessel	-	536 (375) (P) 143 (100) (T)	2 kt -	0.0025 -	Out of Production	The 3001 is an independent skimming vessel suitable for use in harbors. It is a disc skimmer with vanes across the edges of the discs to direct the oil into the skimming heads. This system is likely to become clogged quickly in highly viscous oil. (Lockheed has discontinued manufacturing skimmers.)
Hoyle Marine							
T18	4.2x3.8	298	116 (81) (P)	-	-		Hoyle Marine "T" disc skimmers have a capacity that is 3 to 6 times greater than conventional flat plate skimmers and because the discs are more widely spaced, they are more effective in highly viscous oil.
T20	5.8x1.9	165	126 (88) (P)	-	-		
T30	5.3x3.3	220	189 (132) (P)	-	-		
T54	8.2 diameter	1433	340 (238) (P)	-	-		
VIKOMA							These conventional disc skimmers have been used extensively world wide. They recover a very high % light to medium viscosity oil but are less effective in medium viscosity.
KOMARA 9K	5.2x2.6x2.6	132	57 (40) (P) 5 (3.4) (T)	<1 kt	(Fits in	$16,000	
KOMARA 12K	4' diameter	136	76 (53) (P)	<1 kt	boom)	$22,000	
KOMARA 30K	4.5 diameter	220	189 (132) (P)	<1 kt		$44,000	The KOMARA 50K is an offshore skimmer.
KOMARA 50K	7.4x7.4x4.6	1540	314 (220) (P)	<1 kt			
WEIR/VORTEX SKIMMERS							
Mattsson Producter							
WALOSEP	3.3 diameter	111	63 (44) (P)	-	-	$45,000	The Walosep is a weir skimmer that uses a rotating vane to improve the flow of oil into the system. These skimmers are less affected by debris and viscous oil than normal weir skimmers, and were effective in the Valdez spill for a much longer period of time than simple weir skimmers and disc skimmers. *Tests in "L" low viscosity oil and "H" high viscosity oil.
W1	4.6x4.3x2.9	189	251 (176) (P)	-	-		
W3	8.9x7.5x3.5	889	189-377 (132-264) (T)L* 180-610 (126-427) (T)H*	- -	- -		
ROPE MOP SKIMMERS							
ABASCO							Rope Mop Skimmers can be deployed along side a barge or large work boat from a jib or simply along the side of the ship. The RS 29 and RS212 have their own jib/boom to deploy the mop. Rope mops are effective in a wide range of oil viscosities up to and including any oil that will flow. They work well in water that contains debris and even ice. Rope mops have excellent wave following characteristics.
A14	1.2x1.8	160	10 (7) (P)	-	-	$8,000	
W26	6x3	1250	30 (21) (P)	-	-	$22,000	
W29	7.6x3.8	2200	100 (70) (P)	-	-	$32,000	
RS29	11x5x7	5000	100 (70) (P)	-	-	$35,000	
RS212	12x5x8	6000	150-200 (105-140) (P)	-	-	$92,000	
ARCAT	65' Vessel	50000	180 (126) (P)	1-3Kts	0.003	$600,000	"ARCAT" is the skimming vessel used by Alaska Clean Seas based at Prudhoe Bay. With four 9 inch rope mops, it has the potential for recovering up to 168 gpm. A highly maneuverable vessel, it can operate in 75 to 88% light ice cover and recover oil in 25 to 50% ice cover.

Manufacturer/ Model	Size (ft) HxWxL	Weight (lbs)	Recovery Rate BBL/Hr (GPM) Tested (T) Published (P)	Skimming Speed Unassisted, Kts	Sweep Rate Unassisted (NM2/HR)	Approximate Cost	Performance Assessment
ROPE MOP SKIMMERS (Cont'd)							
Containment Systems							
MW41	2x1	165	10 (7) (P)	-	-	$8,000	
MW62	5x3.5x4	900	30 (21) (P)	-	-	$13,000	
MW92	7.5x3.5x5	2000	100 (70) (P)	-	-	$27,000	
Oil Mop							
Mark I	3.4x1.6x1.7	191	6 (4.2) (T)	-	-		
			10 (7) (P)	-	-		
Mark II-4	3.8x2.1x2.7	450	30 (21) (P)	-	-		
Mark II-9			100 (70) (P)	-	-		
			19 (13) (T)	-	-		
O.P.E.C.							
Force 7	16x8x7.5	8.2 tons	441 (308) (T)*	2Kts	0.016	$200,000	* Tested in 6mm of oil. This device can be installed on the stern of a large work boat or tug. Ten rope mops are winched out, spread with a paravane, and retrieved. The mops recover a wide range of viscosity oils and the system has excellent wave following characteristics. The system will operate effectively in some debris and light ice up to the point that floating materials interfere with the paravane. The paravane spreads the mops so that the system has a good sweep width without using a boom. Force 7 is hard to maneuver in restricted waters.
LIFTING BELT SKIMMERS							
MARCO							
Class I	28' Vessel	6500	16-30 (11-21) (T)	0-2 Kts	0.0033	$200,000	These skimmers carry recovered oil up a ramp and deposit it into a hopper. Good in medium to high viscosity oils and will even recover any chunks of oil it can carry up the ramp. Highly successful with Valdez spill but had problems in unloading. System needs a positive displacement pump that can move the most viscous products.
			214 (150) (P)				
Class ID	38' Vessel	14500	214 (150) (P)	0-2 Kts	0.0046	$300,000	
Class V	36' Vessel	18500	60-94 (42-66) (T)	0-2 Kts	0.0059	$400,000	
			357 (250) (P)				
Class VII	50' Vessel	34000	714 (500) (P)	0-2 Kts	0.0118	$900,000	
MAC LORI							
Lori Type A	33 to 57' vessel	20000		0-4 Kts	0.0032-0.054		Lori uses a set of moving brushes to lift recovered oil up a ramp. Very effective in medium to heavy viscosity oils and very durable even when operating in severe environments. Since the vessels are primarily boom sweeps and can skim at 4 Kts, they are more effective operating independently than they would be in a boom configuration.
Lori Bow Collector	20' Vessel*	176	95 (67) (P)	0-2 Kts	0.0066		
	33' Vessel*	287	139 (97) (P)	0-2 Kts	0.0099		
	49' Vessel*	397	190 (133) (P)	0-2 Kts	0.013		
							* The LORI Bow collector is to be installed on vessels of opportunity of the sizes indicated. These units could work well on the LCM vessels stationed at Homer, Alaska.

Manufacturer/ Model	Size (ft) HxWxL	Weight (lbs)	Recovery Rate BBL/Hr (GPM) Tested (T) Published (P)	Skimming Speed Unassisted, Kts	Sweep Rate Unassisted (NM2/HR)	Approximate Cost	Performance Assessment
SUBMERGING BELT/RAMP SKIMMERS							
JBF Scientific							
DIP-3001	27' Vessel	14100	143 (100) (P)	0-3 Kts	0.0074	$450,000	The JBF DIP skimmers use a "dynamic inclined plane" that has a moving belt that forces the oil/water mixture down and the oil comes to the surface in a hopper aft of the plane. These skimmers are best in lighter oils because of the slow rise time of the more viscous products.
DIP-3003	38' Vessel	26000	571 (400) (P)	0-3 Kts	0.0089	$900,000	
DIP-5001	73' Vessel	190000	714 (500) (P)	0-3 Kts	0.0089	$2,500,000	
DIP-6001	110' Vessel	840000	1571 (1100) (P)	0-3 Kts	0.0098	-	
DIP-7001	160' Vessel	1120000	1571 (1100) (P)	0-3 Kts	0.0123	-	
Wartsila/LORI							
Ice Cleaner	24'x40'	22 tons	6 (4.2) (T)*	0-3 Kts	0.00119	About $1.5M	*Three tons of oil were recovered in 3 hours in an actual spill situation in ice. The Wartsila/LORI "Ice Cleaner" is an independent ice breaker bow/barge that is pushed by a large work boat or tug. The LORI brushes recover pooled oil and clean oiled ice. The system capacity may be very large but in ice encounter rate may be very low. On the other hand, since the oil is contained by ice in winter, time is available to recover oil slowly. This device shows great potential for spill recovery in broken ice and is well suited to winter operations in Cook Inlet. It is also likely to be effective in open water and in oiled debris.
SUBMERSION PLANE SKIMMERS							
LPI	35' Vessel	12000	1570 (1100) (P)	2-4 Kts.	0.0033	$280,000	This device showed great potential for success in tests, but has probably not been produced after the prototype model. Since the unit has an on-board o/w separator, recovery efficiently was near 100%. It is likely to be most effective in light and medium viscosity oils, but probably has not been tested in high viscosity oils. The separator may have a problem with viscous oils, but this could probably be adjusted or separation could probably be performed by pumping off the bottom of a storage tank.
LPI		-	80-279 (56-195) (T)		0.0066		
LPI	66' Vessel	-	4900 (3430) (P)	3 Kts	0.0119	$920,000	
LPI	110' Vessel	-	12343 (8640) (P)	4 Kts	0.0283	$1,470,000	
	220' Vessel		6629 (24640) (P)	6 Kts	0.0839	$3,780,000	
BOOM (WEIR-BOOM SKIMMERS)							
Vikoma							
10Weir	370'	-	3286 (2300) (T)*	3 Kts	0.0609	$490,000	* Performance reported in the 1XTOC (Gulf of Mexico) blowout. Weir-boom skimmers often have very high capacity but tend to become clogged in highly viscous oil.
			1286 (900) (T)				
5Weir	265'	-	1964 (1375) (P)	3 Kts	0.0436		
3Weir	232'	-	1179 (825) (P)	3 Kts	0.0382		Skimmer deployed with an additional 1640 feet of boom, sweeping at a speed of 0.7 Kts. This boom is available at Valdez, but not in Cook Inlet.

Manufacturer/ Model	Size (ft) HxWxL	Weight (lbs)	Recovery Rate BBL/Hr (GPM) Tested (T) Published (P)	Skimming Speed Unassisted, Kts	Sweep Rate Unassisted (NM2/HR)	Approximate Cost	Performance Assessment
BOOM (WEIR-BOOM SKIMMERS) (Cont'd)							
OFFSHORE DEVICES High Seas Skimming Barrier	612'	17500	757 (530) (T) 1071 (750) (P)	1-2 Kts	0.067	-	The High Seas Skimming Barrier was developed for the Coast Guard and is stocked by the Coast Guard, but Offshore Devices has gone out of business and the device is no longer available. The Barrier was used successfully in the Valdez spill for one week until the oil became so viscous that it couldn't go through the weirs, then it was just used as a containment boom.
VOSS	65'	4650	757 (530) (T) 1071 (750) (P)	1-2 Kts	0.013	-	
SCOOP	68'	7000	357 (250) (P) 151 (106) (T)	1-2 Kts	0.0148	-	
Tracor Marine SOCK	51'	7000	57-214 (40-150) (T) 370 (259) (T)*	2 Kts	-	$400,000	SOCK is a vessel of opportunity skimmer that was tested offshore successfully and is reported to recover oil at a rate of up to 259 gpm* in the IXTOC spill. Tracor is the licensed manufacturer, but the system is probably out of production.
HALLIBURTON Fast Response Unit (FRU)	30'	-	293-660 (205-462) (T)	1 Kt	0.005		Fast Response Unit includes a jib to carry a containment boom along side a large vessel of opportunity, probably a large supply boat. A weir skimmer recovers oil in the pocket of the boom and sends it to an oil/water separator.
Skimming Barrier	670'	-	293-660 (205-462) (T)	1 Kt			The Skimming Barrier is similar to the Fast Response Unit except that it can be used with a large towed containment boom. The encounter rate depends on the size of the containment boom.
IHC Slick Trail (also known as COSMOS HYDROVAC, & MARFLEX)	373' Vessel	-	6290 (4403) (P)	2-3.5 Kts	0.089		The Dutch dredge ship "COSMOS" was constructed with a collateral mission of spill response. It was designed to handle a spill of 30,000 m3 (188,700 BBL). The ship has a storage capacity of 31,450 BBL. It is equipped with two steel booms that extend at a 60° angle from both sides of the ship. The collected oil goes through a weir at the apex of the skimmer, then to open hoppers, where water is pumped off the bottom to an O/W separator. The skimming booms are portable and can be rigged to any vessel of this type. The "MARFLEX" skimming arm is similar and is currently assigned to a barge in Valdez. *Capacity assumes one arm on each side of the barge; sweep width includes both arms and beam of barge.
MARFLEX Sweeping Arm Type 8	52.8'	9700	2100 (1470) (P)	1-3 Kts	0.086*		

Manufacturer/ Model	Size (ft) HxWxL	Weight (lbs)	Recovery Rate BBL/Hr (GPM) Tested (T) Published (P)	Skimming Speed Unassisted, Kts	Sweep Rate Unassisted (NM2/HR)	Approximate Cost	Performance Assessment
BOOM (WEIR-BOOM SKIMMERS) (Cont'd)							
JASTRAM							
ORAS II	75'	72 tons	314 (220 (P)	1.5 Kts	0.013		ORAS II is a dedicated skimming vessel using HYDROVAC type system. The entire recovered oil/water mixture goes through a separator which results in a very low percent water in recovered oil and clean water returned to the sea.
ORAS Floater	40'	10 tons	314 (220) (P)	1.2 Kts	0.0304		ORAS Floater is a self contained skimming arm that can be attached to a vessel of opportunity. Skimming rate is for 2 units attached to a barge with an 84 ft beam.
OTHER V.O.S.S. SKIMMERS							SARAWAK provides a jib to deploy a containment boom from a vessel of opportunity. The containment boom is drawn up into a pocket where a floating skimmer removes the recovered oil. In this case a DESMI-250 is assumed, but other skimmers could also be used.
Hyde Products							
SARAWAK	50'	353	536 (375) (P)	1 Kt	0.008	-	
(double)	100'	706	1071 (750) (P)	1 Kt	0.0165	-	
SARAWAK (small ship)	18'	93	536 (375) (P)	1 Kt	0.003	-	The second entry (double) assumes that two of those units are deployed along side of a barge with a beam of 40 ft.
FISH NET SKIMMERS							Swedtrawl consists of a towable offshore boom that collects oil into 10 funnels. As the funnels become filled with oil, they can be closed and removed by a support vessel. Funnels can be emptied and re-used. Freeboard is a membrane with segmented foam floats for buoyancy; draft is a netting. Good only for highly viscous oil.
SVENSK OLJET RAL							
Swedtrawl	61'	778	Variable	1 Kt	0.0076	-	The Swedtrawl is a skimmer; more conventional seine netting of viscous oil is also possible. Oil is surrounded by a net/boom and oil thickness is increased by hauling in the net. Oil trapped in the net is recovered using an air conveyor or large vacuum unit.

APPENDIX K

THE EXXON VALDEZ OIL SPILL: A REASSESSMENT OF OIL SPILL CLEANUP TECHNOLOGIES

THE EXXON VALDEZ OIL SPILL: A REASSESSMENT OF OIL SPILL CLEANUP TECHNOLOGIES

PREPARED FOR:
ALASKA OIL SPILL COMMISSION
707 "A" STREET, SUITE 202
ANCHORAGE, ALASKA 99501

PREPARED BY:

ENGINEERING COMPUTER OPTECNOMICS, INC. (ECO)
1036 CAPE ST. CLAIRE CENTER
ANNAPOLIS, MD 21401

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ANALYSIS OF OIL SPILL RESPONSE TECHNOLOGIES

The recent EXXON VALDEZ massive oil spill incident in Prince William Sound, Alaska, has led to a need for the analysis of the capabilities of government and private organizations to respond to a major oil spill incident. The consequences of the EXXON VALDEZ spill has brought into question the usefulness of existing technology, the adequacy of planning efforts, and the ability of those who were responsible for maintaining a response capability.

This study will focus on two aspects of the technologies and capabilities that are available to respond to a major oil spill. A major spill in this context is defined as a spill in excess of 100,000 barrels, in an offshore, remote, or sensitive area, under potentially difficult physical and environmental operating conditions. The first section of this report will provide a general description of the technologies and capabilities available in the United States and the world to respond to the major spill. The second section will provide a discussion of the availability of the resources capable of being utilized in a major spill, their location, ownership, and logistical impediments to their use.

OVERVIEW OF OIL SPILL RESPONSE CAPABILITIES

The response to oil spilled in an open water environment is always a difficult effort due to the physical and environmental conditions in which it is undertaken. The key conditions that the spill response effort faces are discussed below.

Spreading of the oil. Oil spilled on the water starts to spread rapidly through gravity and surface tension forces. This spreading is dependent on the type of oil, its volume, and the amount of weathering that takes place. The spreading is commonly described by a three phase process. The initial phase is dominated by gravity forces collapsing the spill into a thin pool, countered by the inertia forces. The second phase is retarded by the drag of the oil slick over a viscous surface-water layer. The third phase is driven by differential surface tension forces between the water-air interface and the water-oil/water-air interfaces. Figure 1 shows this process for calm water conditions and uniform slick thickness, not necessarily real world conditions. The extent of the areal dispersion is affected by the wave action and by the current forces acting on the spill lens. The extensive area encompassed by a spill of significant volume substantially increases the amount of resources necessary to respond to the spill.

Composition of the oil. The viscosity of the oil can be a critical factor in the response effort. High viscosity oils are more difficult to recover mechanically and disperse than low viscosity oils. In addition, weathering processes such as evaporation and water takeup (emulsification) will increase the viscosity of the spilled oil over time. Figures 2 and 3 show the effect of evaporation and water takeup, respectively, on the density of the oil. Pumping capabilities typically show that liquid viscosities in excess of 2000 centistokes become very difficult to pump in commonly available pumps on skimmers and other response equipment. Figure 4 from the "Field Guide to Arctic Oil Spill Behavior" shows that Prudhoe Bay crude quickly exceeds 3000 centistokes at

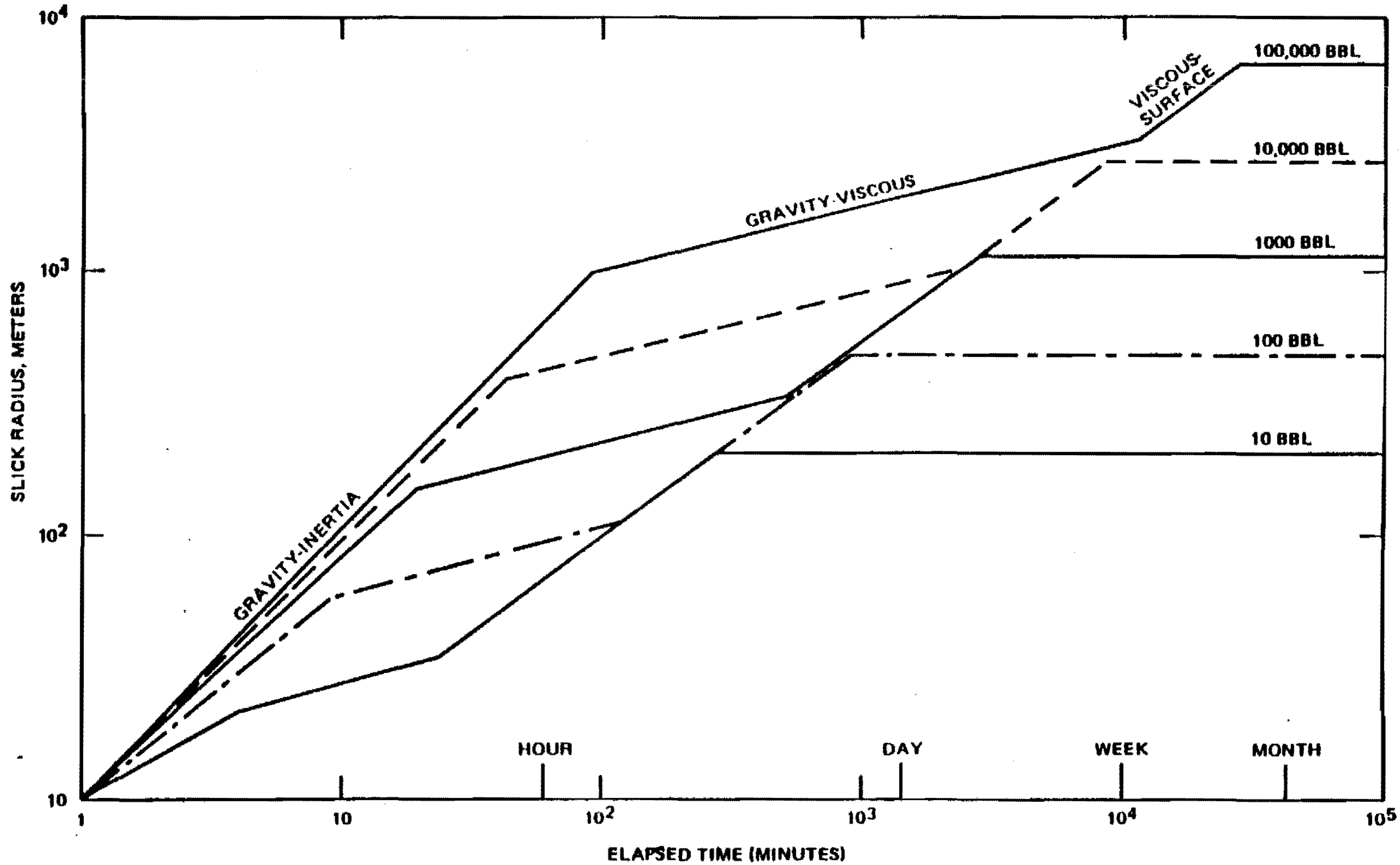


Figure 1. Slick radius versus time for 30° API gravity oil spills of various volumes ($10\text{-}10^5$ BBL), according to Fay (1971) three phase spreading

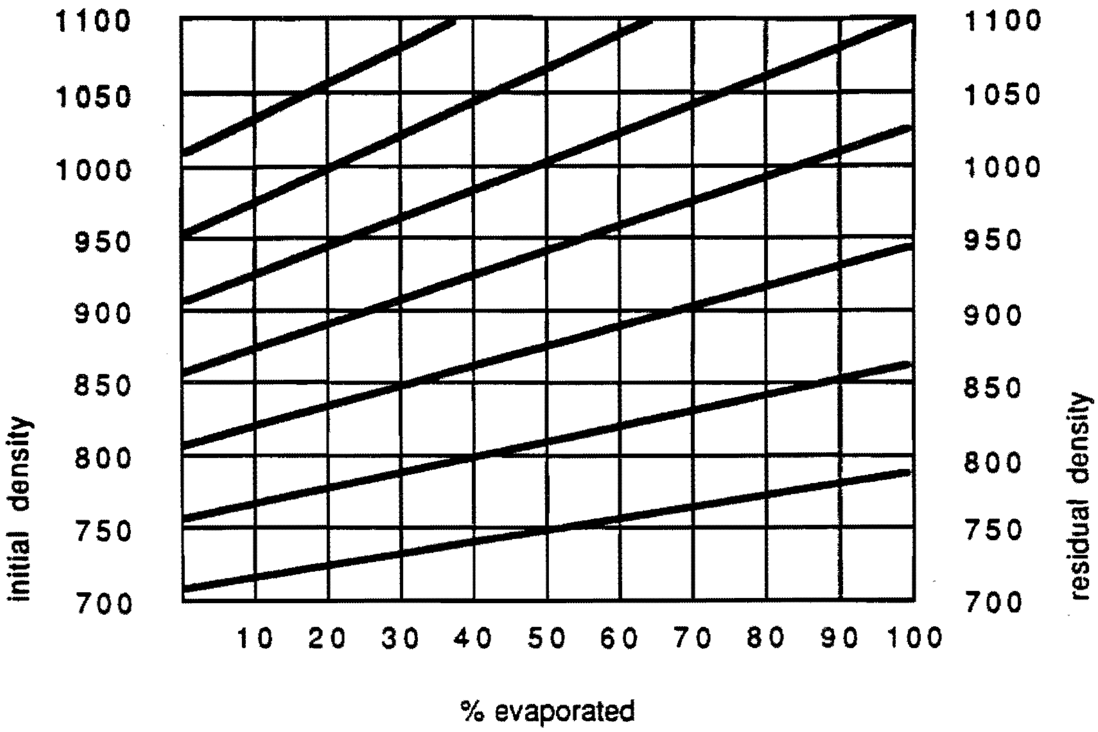


Figure 2. Change in density of oil as a function of evaporation

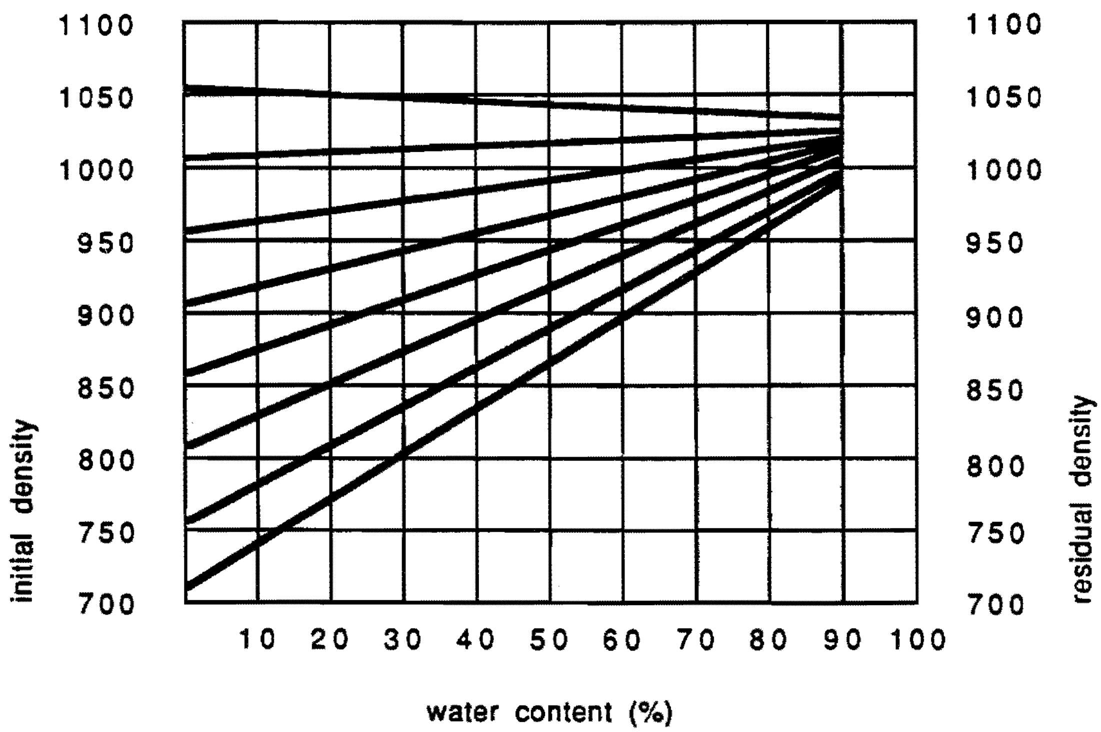


Figure 3. Change in density of oil as a function of water uptake

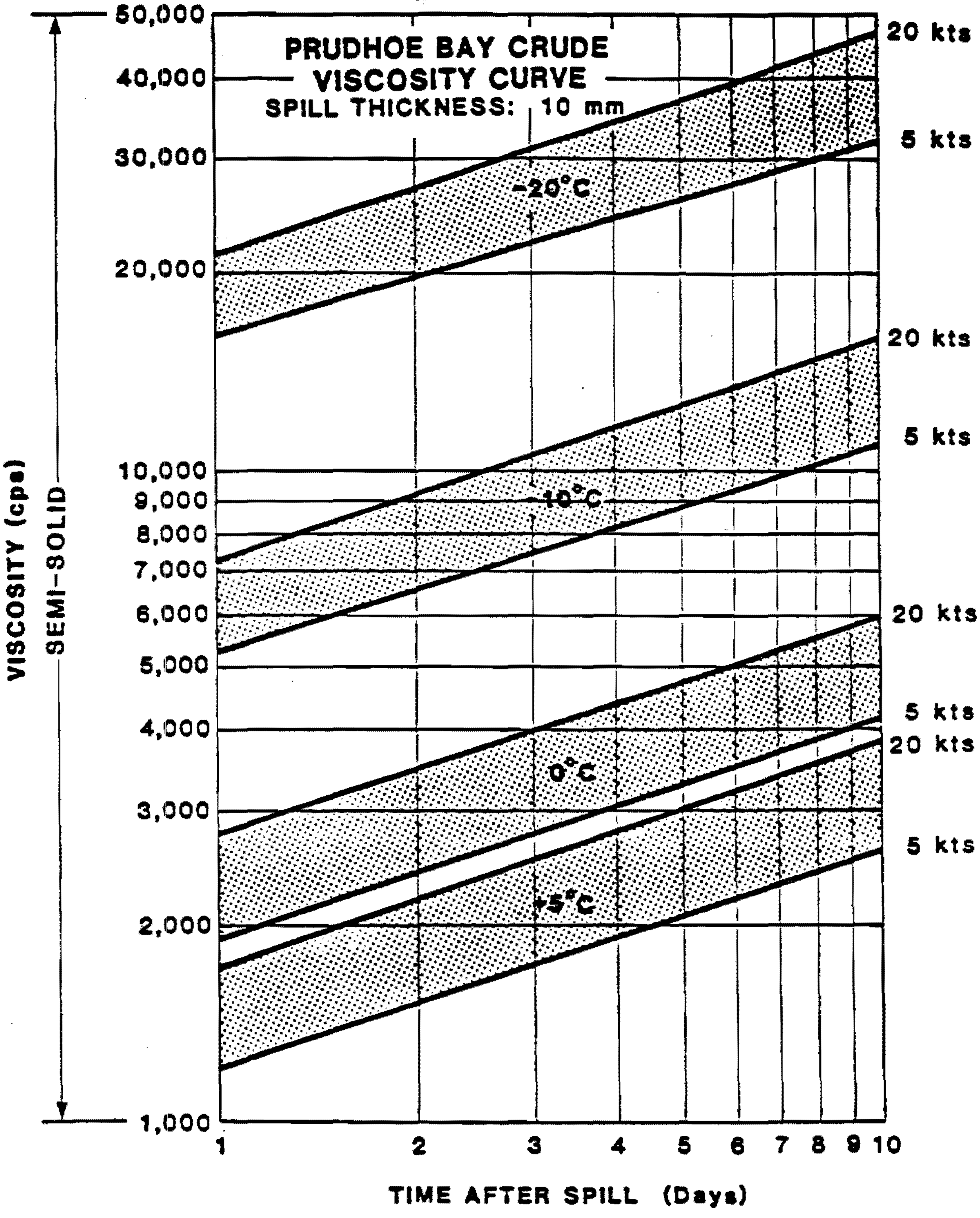


Figure 4. Viscosity of Prudhoe Bay Crude - 10 mm slick, days 1 through 10

0°-5° C, overpowering all but the very largest systems such as dredges with over 12 inch suction hoses. The effectiveness of burning and dispersants also decreases as the viscosity of the oil increases.

Sea conditions. Seas in excess of 2 meters will render most response equipment inoperable or ineffective along with the small boats that may be used to deploy the equipment. Containment with booms becomes virtually impossible with current velocities perpendicular to the boom in excess of 1 knot. As skimmers become ineffective without containment, current velocities over 1 knot also shut down most recovery efforts. Current velocities of 1 knot or more can be developed by natural current patterns, wind, and wave action from 2 meter waves.

Location. The location of the spill in terms of logistic support and in terms of the nearness of environmental resources will affect the response effort in critical ways. The remoteness of Valdez and limited transport facilities limited the amount of resources that could be brought to bear on the spill event.

MECHANICAL RESPONSE TO MAJOR OIL SPILLS

This section of the report will discuss the relative capabilities of categories of oil spill response equipment. The discussion will focus on each category but it is necessary to keep in mind that each category is not independent of the other categories. The mechanical containment and recovery of oil spilled on the water is made up of a number of components which are used normally in a serial manner. The components are:

- containment
- recovery
- deployment
- transfer
- storage
- disposal

The absence of, and/or deficiency in, any of the components will reduce the effectiveness of any oil spill response effort and may cause its failure. In the ALVENUS spill of the mid-80s, the refusal of a barge owner to authorize discharge of the recovered oil into his barge delayed the response efforts past the time of effective cleanup, even though the United States Coast Guard (USCG) was ready to start response efforts with deployed containment and recovery equipment. Each of the components is also a system unto itself and requires additional equipment and personnel to be deployed effectively.

The ability of mechanical response equipment is affected by the environmental and physical conditions under which it must operate. The major factors are:

- current velocity
- wind velocity
- wave height
- ice/debris presence
- visibility
- volume of oil spilled
- type of oil

The discussion below focuses on the capabilities of the containment and recovery components of the mechanical recovery process, and on the factors which affect their performance.

RECOVERY SYSTEMS

This section describes oil spill recovery skimmers and classifies them according to type. Next, it describes how these skimmers can be expected to operate in various types of oils and marine environments Finally, it provides an overall assessment of each skimmer type with specific information on:

- operation and expected performance
- availability
- testing
- recent experience

Skimmer Types

Oil recovery skimmers are generally arranged in categories according to the way they pick up oil. That is, skimmers with similar principles of operation are generally grouped together. The "World Catalog of Oil Spill Response Products" defines thirteen different kinds of skimmers. These definitions include just about every kind of skimmer that is available.

Skimmer types can be defined as follows:

- Suction - Any simple suction head used on a hose from a vacuum truck or portable pump.
- Weir - A device with a slightly submerged lip, that is designed to drain oil off the surface of the water. In spill recovery, the weir is generally a floating skimming head that is used with a pump.
- Boom Skimmer - A recovery system with one or more skimmers mounted in the face of a spill containment boom. The skimming device is generally a weir.
- Brush Skimmer - A horizontal, cylindrical brush rotates through oil, which is then scraped off into a sump.
- Disc - A series of vertical discs that are rotated through the oil surface. Oil that adheres to the disc surface is scraped away into a sump.
- Vortex - A skimmer that separates oil and water by centrifugal force. This principle is sometimes combined with a weir so that the oil is drawn into the skimmer and separated in the weir.
- Belt - Belt skimmers are identified according to the way they operate:
  - Paddle Belt: Paddles are attached to the belt to lift oil out of the water.
  - Sorbent Belt: A sorbent belt moves horizontally over the water absorbing oil.
  - Sorbent Lifting Belt: A sorbent belt that lifts the oil out of the water. Recovered oil is scraped from the surface and wrung out of the sorbent belt.
  - Brush Lifting Belt: A chain of brushes lifts oil from the water. Cleaning devices remove oil from the brushes.

- Submersion Belt: A solid belt moves along a plane and forces the oil under water. The oil then surfaces in a collection sump.
- Sorbent Submersion Belt: A submersion belt that also acts as a sorbent.

• Submersion Plane - A solid plane that forces the oil under water. The oil then surfaces in a collection sump.

These categories describe nearly every type of skimmer currently in use. In some cases devices use a combination of methods to recover oil, such as the submersion belt/weir skimmer, and the weir vortex skimmer.

Skimmer Performance as a Function of Oil Viscosity and the Marine Environment

Skimmer performance varies widely depending on the viscosity of the oil being recovered. Some skimmers recover light fuels such as diesel oil very well, but are quickly clogged by highly weathered crudes or heavy fuel oils. On the other hand, some skimmers are designed to recover thick accumulations of viscous oils, but would not be effective in thin layers of light fuels.

In some spill situations the viscosity of oil changes dramatically as it weathers and is emulsified by rough seas. When the oil is first spilled, it may have a low to moderate viscosity and be suitable for skimming by a great many devices. As it weathers, it often becomes highly viscous, emulsified by the rough seas, and mixed with debris. Only a limited number of skimmers can deal with oil in this condition.

In large spills the spill response effort may continue for months. During this time the character of the spilled oil may change substantially. As a result, skimmers that were effective when the oil was first spilled are not effective a month or more later. In these cases a great variety of spill response equipment must be available so that the response effort will be effective in every phase of operations.

Waves effect skimmer performance because rough seas move the skimmer collection mechanism away from the oil floating on the water surface. Simple skimmers, such as weirs, often perform poorly in rough seas because the weir lip is alternately above or below the oil/water interface causing the skimmer to alternately draw in air or water.

Skimmers with a large inertial mass generally have problems following the oil-water interface. To solve this problem, some skimmers are designed so that the mass of the skimmer in the water is quite low and heavy equipment, such as pumps and tanks, are stored on the host ship.

Lifting belt and submersion belt skimmers are only able to operate in waves that are not higher than the vertical dimension of their belts. Similarly, submersion plane skimmers can only operate in waves that are not higher than the vertical dimension of their submersion planes.

Currents affect the performance of skimmers because high currents generally cause oil to escape under collection booms. Also, high currents may swamp skimmer intakes or cause the surface to move past the skimmer collection element so fast that it is not effectively recovered. Skimmers that are effective in high currents often have a collection element that moves with the current. These skimmers are generally called "zero relative velocity" skimmers. In some cases these skimmers can recover oil in currents up to 6 knots.

Measures of Skimmer Performance

Skimmers are generally rated according to recovery efficiency, which is the percent oil in the recovered mixture. They are also rated according to oil recovery rate, which is the rate at which pure oil is being recovered, generally expressed in gallons per minute.

These two skimmer performance parameters, recovery efficiency and recovery rate, should be considered together. A high skimmer recovery rate and a high recovery efficiency (percent oil) do not generally occur together. Typically, recovery efficiency goes up as recovery rate goes down, and vice versa. This means that as you try to recover oil faster, you generally have higher water content in the recovered product.

The best method of operation depends on the spill situation. If an oil/water separator is available, a high recovery rate with a low recovery efficiency can probably be tolerated because the excess water can be removed in the separator. If however, a separator is not available and the recovered product has to be removed in a tank truck, or if storage space is limited, than recovery efficiency (percent oil) may be very important. In this situation recovery rate should probably be sacrificed for carrying away a more concentrated product.

In most spill emergencies, oil must be recovered as quickly as possible in order to mitigate the damage to the environment and to protect public health. In these cases oil must be recovered as fast as possible with the hope that adequate storage space will be available. Sometimes if oil/water separators are not available, an elementary separation can be performed by decanting water from the bottom of a storage tank. In some spills, however, this is not possible because the oil is viscous and the temperature is so low that the oil becomes congealed in the collection tank and the separated water freezes. In addition, the specific gravity of the oil may be so close to that of water that the two elements do not separate easily and the collection tank may have layers of oil and water alternately from top to bottom. In this case oil/water separation or even decanting of the tank is not possible. This condition occurred in the spill in Valdez.

Overall Recovery System Assessment According to Type

Suction Skimmers

Operation and expected performance. Suction skimmers may use a simple open hose or they may have some sort of a simple skimming head that serves to float the attached hose and direct the suction to the oil/water interface.

Suction skimmers are simple to operate and can be used almost anywhere. Although they can be used in a gentle swell, they are not effective in choppy waves.

Suction skimmers have the disadvantage of being easily clogged with trash or even highly viscous oil. These problems can be reduced by using larger suction devices with very large diameter hoses.

Suction skimmers are likely to have a high pumping rate but they typically recover a low percentage of oil in a thin slick. The pumping rate is only limited by pump capacity, but in practice, pumping rate must be reduced in order to obtain a higher percent oil.

Availability. Suction skimmers are the most common oil recovery devices used today for every application and they are available virtually everywhere. Vacuum trucks are, in fact, suction skimmers and these are used by oil spill contractors in nearly all spill situations.

Testing. Most testing has been directed to the use of special skimming heads on suction skimmers. Suction skimmers can have problems passing highly viscous oil and debris, and in some cases, even ice. The problem is generally the size (diameter) of the suction lines. Lubrication may also be required in the lines for viscous oil and debris. This could be an area in which additional testing is needed. (Also see comments in the following paragraphs.)

Recent experience. Suction skimmers have been used extensively in the recent spill near Valdez. Sometimes these skimmers were highly successful and sometimes there were problems. Large vacuum units were successful when used with 8 inch diameter suction hose; 4 inch hose was too small and in some cases a 6 inch hose was too small to transfer the recovered product. In an extreme case the problem of small hose diameter was solved using an Army Corps of Engineers hopper dredge. The dredge has a suction head with a diameter of about 24 inches. This suction head was led under a boom that contained a heavy accumulation of oil. When inside the boom, the suction head was pointed vertically upward so that it operated like a weir. This system evacuated collected oil in minutes that could not be moved by other means in days.

Even vacuum trucks were used on barges in Valdez. The trucks were moved around by means of barges to accumulations of oil, and they recovered oil with 8 inch diameter hoses. In some cases the oil was so viscous, it could be recovered with an 8 inch hose but it could not be emptied out of the truck with a 6 inch hose. In this case a special large funnel was constructed so that the entire end of the truck tank could be opened and the recovered oil emptied into a barge hatch.

Weirs

Operation and expected performance. Weir skimmers use gravity to drain oil off the water surface. These skimmers work best if the edge of the weir is right at the oil/water interface, but in practice, this adjustment is difficult to achieve. Some weir skimmers have flotation elements that can be mechanically adjusted so that the weir lip is positioned at the oil/water interface. (Of course the position of the interface changes as the oil layer becomes thinner.) Some "automatic" weir skimmers can adjust the "bite" of the weir by varying the pumping rate. As the oil layer becomes thinner, the pumping rate must be reduced to get a higher percent oil. This technique requires a fair amount of operator attention, and as the recovery effort continues, recovery rate may become very low. In thick accumulations of oil, weir skimmers may recover up to 50 percent oil; however, in thin slicks, the recovery efficiency is likely to drop to about 10 percent.

Most small weir skimmers are the first to be clogged by debris and highly viscous oil during a spill emergency. These skimmers are likely to be the first to drop in effectiveness as the oil weathers in a long term response effort.

Some special kinds of weir skimmers are more effective in large accumulations of oil, or even in debris and highly viscous oils. One of these is basically a combination weir and vortex skimmer in that it has rotating paddles that draw the oil into the weir. Large skimmers of this type extend the effectiveness of weir skimmers over a much wider range of oil viscosities.

Another kind of weir skimmer has an oil recovery hopper for an intake instead of a conventional weir, with an archimedean screw pump to draw off the highly viscous oil. This type of skimmer can be used in almost any viscosity oil as long as the oil can be directed into the hopper. This skimmer is quite effective in large spills where thick layers of oil are available for recovery or where thick layers of oil have been accumulated by containment boom. The characteristics of this type of skimmer could probably be improved for highly viscous oils by increasing the size of the skimming hopper.

An innovative system developed in Europe incorporates an adjustable weir in a system that contains an oil/water separator. Since these units are always used together as a system, the results are far different from a standard weir skimmer. This system must therefore be considered separately.

The adjustable weir system is generally employed from a specially fitted vessel. This vessel has "guiding walls" like containment boom that can be extended at an angle of about 60° from the side of the vessel. The oil that accumulates in this area passes over a "pre-weir" to smooth the flow then moves to a "slide gate," which is an operator-controlled weir. The slide gate can remain closed until oil accumulates in the system, then can be lowered hydraulically by an operator. The operator controls the flow of the oil/water mixture that enters the vessel by adjusting the level of the hydraulically controlled weir. Since the entire mixture goes through an oil/water separator, some water flow with the oil is desired. The output of the separator is oil that contains less than 5 percent water and water that is less than 100 ppm oil.

These systems are sometimes installed on very large vessels and have a tremendous capacity to process oil/water mixture. Smaller units can handle about 220 gallons per minute while larger units are rated up to 2,800 gallons per minute at the stern, that opens to form the inlet section with its hulls. Smaller, floating systems, are completely self contained and can be fitted on to a vessel of opportunity.

Availability. Nearly all of the simple weir skimmers are manufactured in the United States and are generally available. The two newest, and most effective weir skimmers, the weir/vortex skimmer and the weir/hopper skimmer, as previously described, are only manufactured in Europe. These skimmers are available through distributors in the U.S. and are used by many of the large spill coops; however, they are not in general use among oil spill contractors. The adjustable weir systems have been produced in some quantity and are currently in use in Europe and Mexico.

Testing. Many of the simple weir skimmers produced in the U.S. have been tested. Most models of the advancing weir/vortex skimmer have not been tested, but these skimmer types show great potential for success in large spills. The large, adjustable weir systems cannot be tank tested because of their size; however, these systems show great potential for application in large spills and their performance should be investigated.

Recent experience. A great many weir skimmers were used in the recent spill in Valdez. The simple weir skimmers worked well early in the spill when the oil was still fresh. As the oil weathered and became more viscous, emulsified, and mixed with debris, the simple weir skimmers quickly clogged and were no longer useful. The simple weir skimmers were the first to become ineffective as recovery became difficult. The weir/vortex skimmers were effective for a much longer period of time, especially some of the larger models.

The recovery hopper weir skimmers were effective for a longer period of time, but were finally stopped by very viscous oil mixed with pot weed and kelp. In some cases these skimmers could be used if the oil could be moved into the hopper. These skimmers could possibly be more effective if they had large hoppers.

Boom Skimmers

Operation and expected performance. Boom skimmers are designed for recovering large, high rate spills at sea. In tests these skimmers have recovered 400 to 1500 gallons of oil per minute with a recovery efficiency of 50 percent to 60 percent in thick accumulations of oil. Systems presently available use several weir traps in the collection pocket of large offshore containment booms. These weirs skim the surface oil and a pump transports the collected oil to a storage area. Where the oil accumulation is thick enough, recovery may occur with a very low percent water. If booms can follow the wave surface reasonably well, the weir skimmers are able to maintain a relatively high level of recovery effectiveness. The weirs can be screened from some types of debris, but they cannot generally recover highly viscous or emulsified oils.

Availability. Boom skimmers are manufactured in Europe and the U.S. Because they are large, expensive systems, they are not easily available everywhere. In the U.S., the Coast Guard ODI boom skimmer is the only known model. It is available to the Coast Guard Strike Teams and was used in the Valdez spill.

Testing. The Coast Guard Boom skimmer has been tested extensively by EPA in the OHMSETT facility. Additional testing is probably not required.

Recent experience. The Coast Guard boom skimmer system was put into service six days after the Valdez spill occurred and it worked well for a period of a week. After that the oil became too viscous to go through the weirs. The system continued to be used as a sweeping net. The oil was accumulated in the boom, which was drawn together as a net (purse) and the oil was pumped out. In some cases a large sorbent lifting belt skimmer was used inside the boom.

Brush Skimmers

Operation and expected performance. This skimmer has a horizontal, cylindrical brush that rotates through oil, which is then scraped off into a sump. This is an experimental skimmer that is being developed for skimming highly viscous oil and oil on ice.

Availability. Only prototype models are available.

Testing. The skimmer has been tested briefly by the oil industry. Additional testing and development is required for this system to become operational.

Recent experience. No experience other than prototype tests.

Rope Mop Skimmers

Operation and expected performance. Rope mops employ a long, continuous loop of absorbent oleophilic material that floats on the surface of the water and is then led through a wringer that removes the oil. The rope is generally guided over the oiled water by a pulley that has been secured at some convenient location. The rope can be deployed in a single loop with one pulley or over a larger area by using two pulleys. The important advantages of rope mop skimmers are that they can skim over a large area and they are relatively unaffected by debris. They can even be used in a broken ice field.

Rope mop devices are also used in catamaran hull vessels. A series of separate ropes are arranged between the hulls of the catamaran. They are allowed to hang loosely on the water surface and are rotated aft at a velocity that is close to the forward speed of the vessel.

One offshore rope mop skimmer deploys five large rope mops over the stern of a large supply ship. They are cast out 410 feet astern and separated by a spreader to increase swath width. The mops are then recovered, wrung out, and redeployed. These skimmers have the ability to recover large amounts of viscous oils in rough seas.

Rope mop skimmer have a recovery efficiency 50 percent to 80 percent in light to medium viscosity oils and may have an efficiency of more than 90 percent in thick layers of crudes.

Availability. Rope mop skimmers are readily available in the U.S. and they are even used extensively for industrial waste oil recovery operations.

Testing. Although more recent models of rope mop skimmers have not been tested, the skimming principle was tested on earlier models.

Recent experience. Rope mop skimmers were not used in the general response effort in Valdez but they are being used to recover oil draining off the shoreline. Large rope mop skimming systems designed for use in recovering viscous oils are manufactured but apparently were not available for use at Valdez.

Disc Skimmers

Operation and expected performance. Disc skimmers rely on the adhesion of oil to the surface of aluminum or plastic discs. As the disc is rotated through the oil/water interface, the oil adheres to the surface and is then removed with a scraper. Scraper blades are installed on each disc and the oil is collected in a sump and pumped away.

Disc skimmers come in many sizes and shapes. There are floating disc skimmers that range in size from small devices that can easily be handled by one man, to large devices that have a draft of two meters and have to be lifted over the side of a ship with a large crane. Some of these large devices have the capacity of recovering up to 100 tons of oil per hour.

Disc skimmers are most effective in medium viscosity oils, but their effectiveness can sometimes be extended into higher viscosities if the discs are operated very slowly. Some skimmers use a combination disc/weir mechanisms. This extends the range of operation considerably; however, in highly viscous oils, only the weir system is operating.

In ideal conditions, disc skimmers have a very high recovery efficiency, often as high as 97 percent. On earlier skimmers, this high efficiency was accepted as a trade-off for a fairly low recovery rate; however, recently a "T" disc skimmer has been developed that has both a very high recovery efficiency and a high recovery rate.

Availability. Disc skimmers are only manufactured in Europe and Canada, but they are generally available in the U.S. from distributors.

Testing. Early models of the disc skimmers were tested extensively, but more recent developments, such as the "T" disc skimmer, have not been tested. This should be done.

Recent experience. At Valdez, disc skimmers were effective early in the spill before the oil had become viscous, emulsified, and mixed with debris. The disc/weir skimmer was used for a longer period of time because, as the oil became viscous, the rather large weir could be used alone. Some observers believe that disc skimmers could have been used for a longer period of time if the skimmer operators were more familiar with their use.

Vortex skimmers

Operation and expected performance. Vortex skimmers are essentially centrifugal separators that create a vortex in the center of a collection chamber where the oil gathers and can be pumped away. Powered vortex skimmers are troubled by a high power requirement and a low through-put. A natural vortex skimmer used the forward velocity of the platform vessel to develop a cyclone where the oil collected and was pumped away. These devices have a small sweep width and do not perform well in waves. Vortex skimmers can achieve a reasonable recovery rate in medium to heavy oils, but the recovery efficiency is generally not more than about 25 percent.

Availability. Vortex skimmers are made in Europe and available in the U.S. through distributors.

Testing. Skimmers have been tested in the U.S. and Canada.

Recent experience. Vortex skimmers were not used in Valdez.

Paddle Belt Skimmers

Operation and expected performance. A typical paddle belt skimmer pulls oil up a ramp using four or more paddles. In one of these skimmers the paddles draw a wedge of oil/water over a ramp. The water settles down through the holes in the ramp leaving an oil-rich fluid wedge in a sump where it is pumped off. In tests and in spills these skimmers have had a high recovery rate and a recovery efficiency of 60 percent to 88 percent. They operate best in medium to high viscosity oils.

Availability. Paddle belt skimmers are manufactured in the U.S. and are easily available.

Testing. They have been tested at the EPA tank at OHMSETT. Additional testing in highly viscous oils would be in order.

Recent Experience. The device was used briefly in Valdez but did not work well. The paddles on this skimmer move up a ramp with small holes. For highly viscous oils, the skimmer should have a ramp with large holes. This may not have been available. This skimmer has the potential for use in highly viscous oil and merits additional development and attention. A special paddle belt skimmer that moves down through the oil and scoops it up into a sump was used in Valdez and it worked quite well.

Sorbent Belt Skimmer

The sorbent belt skimmer is one that has a continuous, flat belt that moves horizontally over the water in the well of a collection vessel. Although there is only one known example of this skimmer, it represents a significant example of spill recovery technology.

The sorbent belt skimmer was developed by the Shell Oil Company and the USCG. This zero relative velocity skimmer consists of two continuous sorbent belts that are pulled between the catamaran hulls of the support vessel at the forward velocity of the vessel. The oleophilic belts collect oil from the water surface and are scraped and squeezed in a series of rollers.

In tests, the skimmer achieved high recovery rates with a high recovery efficiency in light and medium viscosity oils. The skimmer is not much affected by debris and it can perform effectively at very high speeds for a skimmer (up to 6 knots) or in very high currents.

Availability. Only a single prototype was built.

Testing. The prototype was tested extensively at OHMSETT.

Recent experience. There are no known cases of the system being used operationally. This is a concept that should be investigated further.

Sorbent Lifting Belt

Operation and expected performance. Sorbent lifting belts are made of porous oleophilic material that allows the water to pass through. The belt is rotated at an angle to the water and passed through a set of rollers where the oil is removed by scraping and squeezing. Highly viscous oils ride near the surface of the belt and are removed by scraping. The skimmers operate best in medium to heavy oils up to and including cold Bunker C or nearly solid products. High viscosity products can be transported up on the filter belt and removed by a scraper. These devices are usually not adversely affected by debris, unless the pieces are very large. Sorbent lifting belt skimmers are generally mounted on fairly large vessels and are intended for use in harbors and offshore. Sorbent lifting belt skimmers can be expected to have a high recovery rate and recovery efficiency. Recovery efficiency can be expected to run from 70 percent to 95 percent.

Availability. These skimmers are manufactured in the U.S. and are available in many oil spill coops. A great many of these skimmers are available from the U.S. Navy.

Testing. Sorbent lifting belt skimmers have been tested extensively at OHMSETT.

Recent experience. Sorbent lifting belt skimmers have been the main stay in the spill at Valdez. Since the spilled oil became so viscous and emulsified, the sorbent part of the belt was not generally used. The sorbent surface was removed and only the conveyor belt type material was used to transport the viscous oil up the ramp. One of the big problems with these skimmers was pumping the recovered oil out of the sumps.

Brush Lifting Belt Skimmers

Operation and expected performance. These skimmers have a chain of brushes that lift oil from the water. Cleaning devices remove oil from the brushes at the top of a ramp. This is a new concept that has not yet been used extensively, however the concept shows potential for success, particularly in large spills of highly viscous oil.

Availability. These skimmers are manufactured in Europe and are available in the U.S. through distributors.

Testing. There are no known government tests. Testing is required.

Recent experience. These skimmers were not used in Valdez.

Submersion Belt Skimmers

Operation and expected performance. There are two types of submersion belt skimmers; specifically, a solid belt and a sorbent belt. The operating principle of submersion belt skimmers is the opposite of lifting belt skimmers. Instead of carrying the oil up out of the water, the submersion belt skimmers force the oil below the surface of the water where it rises through natural buoyancy to the surface in a collection sump. The sorbent belt absorbs low viscosity oil as well as forcing the oil below the surface of the water.

The solid submersion belt skimmers work best in low viscosity oils and thin slicks, which is in contrast to most other skimmers that require thick accumulations of oil. The sorbent submersion belt skimmer is effective in light to heavy oils. Both of these skimmers have a relatively low recovery rate and a high recovery efficiency.

Availability. Solid submersion belt skimmers are manufactured in the U.S. and are available in coops and in the U.S. Navy. The Navy has purchased a great many of these skimmers and generally at least one of these skimmers is available at every Navy base. On the other hand, the sorbent submersion belt skimmers are made in Canada and not generally used in the U.S.

Testing. These skimmers have been tested extensively at OHMSETT.

Submersion Plane Skimmer

The submersion plane skimmer is similar to the submersion belt skimmer except that it does not have any moving parts. The fixed plane is advanced through the oil, submerging it and directing it into a collection area aft. The skimmer can be expected to have excellent performance in light and medium viscosity oils. Since the skimmer uses an onboard separator, it collects virtually water-free product. In tests at OHMSETT, the skimmer recovered oil at a rate of nearly 200 gallons per minute with a recovery efficiency of 93 percent to 100 percent. This is excellent performance. Some efficiency may be lost when skimming at high speeds, however the best performance range is from 2 to 3 knots. (This is a relatively high skimming speed. Most skimmers operate at about 1 knot.)

Availability. This skimmer was developed and produced in the U.S., but as of this writing there are no known examples except the tested prototype. It appears that this is a very good skimmer that has never been produced because of the lack of demand for large harbor and offshore skimmers.

Testing. The submersion plane skimmer was tested at OHMSETT. Results were very promising.

Recent experience. There is no known operational experience using this skimmer. This is a good concept that needs attention.

CONTAINMENT BOOM

This section briefly tells the reader what containment booms are and how they operate. It describes boom requirements in general terms, summarizes test results, and discusses containment boom requirements based on the reports of experience in the Valdez spill.

Boom Components

Oil spill containment booms generally have five operating components.

- Float - the buoyancy element that keeps the boom riding on the surface of the water. Heavier booms and booms used in rough seas need more buoyancy and therefore have a larger volume of float materials.
- Freeboard - the vertical height of the boom above the water line. the freeboard prevents oil from washing over the top of the boom, but if it is too high it may cause the boom to be pushed over in high winds.
- Skirt - the continuous portion of the boom below the floats. The skirt helps to contain the oil.
- Tension Member - any component that carries horizontal tension loads on the boom. The tension members may be cables, chains, or may be the boom fabric itself.
- Ballast - weight applied to the skirt to improve boom performance. Ballast is generally a chain (which is also a tension member) or lead weights attached to the bottom of the skirt of the boom.

How Booms Operate

Three physical processes determine how booms operate.

- buoyancy
- roll response
- heave response

Buoyancy is important to keeping the boom afloat and maintaining adequate freeboard. A boom should be designed with adequate buoyancy, however, the flotation elements providing the buoyancy may be damaged with use. For example, some kinds of foam flotation can be crushed and the result is a loss of buoyancy. Some booms have inflated chambers as buoyancy members. If these chambers are torn, the boom may sink.

Roll response is the rotation of the boom from rest caused by wave, wind, or current forces. Oil may be lost under a boom if the skirt is deflected excessively or has "rolled" from the vertical position.

Heave response describes the vertical movement of a boom. A boom with good heave response is one that can closely follow the water surface as a wave passes by the boom. If a boom does not have good heave response, it may sink below the surface as a wave passes. This, of course, can result in oil being lost over the top of the boom.

Types of Boom Available

There are basically two types of booms in general use today:

Fence booms have a rigid or semirigid material as a vertical screen against oil floating on the water. The fence boom mechanically couples the skirt and freeboard together causing them to roll and heave as a single unit. If current and wind roll a fence boom away from the vertical, there is also a loss of freeboard and draft. Further, if the fence boom is too rigid to conform to the surface of a passing wave (poor heave response), there is also a loss of freeboard and draft.

Curtain booms have a flexible skirt that is held down by ballasting weights or a separate tension line. A flexible curtain boom has a skirt that is free to move independently of the flotation and freeboard; therefore, movement of the skirt away from the vertical does not necessarily result in a loss of freeboard. Conversely, depression of the freeboard by the wind does not necessarily result in the loss of skirt depth.

Fireproof booms include both fence booms and curtain booms that have been designed to withstand the heat and stress of in situ burning. These booms vary from stainless steel fence booms that can withstand fire with repeated use to curtain booms that are constructed of fire resistant material (or covered with fire resistant material) and are generally intended for one use.

Ice booms are designed to be used for spills in broken ice conditions.

Sorbent booms are booms made of cylinders of sorbent materials enclosed in nylon netting. These devices are not "booms" in the sense that they have a flotation element or a skirt, but they are simply a device used to absorb small amounts of oil on the surface of the water.

Boom Failure Mechanisms

In order to understand how booms should operate, it is also necessary to understand how they fail and the causes of this failure. There are five types of boom failure, which are described below.

Entrainment failure occurs when strong currents cause a headwave to build up upstream of the boom. Oil collects in the headwave, where turbulence causes oil droplets to break away from the headwave, and oil passes under the boom.

Drainage failure occurs when oil collected at the boom face increases in depth until it finally flows down the face of the boom and escapes to the other side. Drainage failure occurs because the water at the boom face is diverted downward and accelerates to keep up with the water flowing directly under the boom skirt. Since increasing skirt depth increases the distance the water must travel to go under the boom, it causes a greater acceleration of the water and may cause drainage failure to occur at a lower velocity. Drainage failure is a problem that is aggravated by having a deeper skirt.

Spill response supervisors in the Valdez spill reported some cases of massive drainage failure. In these cases a very thick (or deep) layer of oil contained inside a boom suddenly drained and passed under and out of the boom enclosure. This is not something that anyone there had witnessed before. A recent article in the 1989 Oil Spill Conference Proceedings discussed a similar phenomenon called curtailment which causes failure through immediate drainage rather than entrainment for very viscous oils contained within a boom as the radius containment boom decreases to a given limit.

Splashover failure occurs in choppy seas when oil splashes over the boom's freeboard.

Submergence failure occurs when the water (and oil) is carried over the top of the boom. Submergence may occur either when a boom is anchored in rapidly moving water or is towed at a high velocity.

Planing failure may occur when a boom lays flat on the water as a result of a strong current and a high wind moving in opposite directions.

Structural failure occurs when the boom parts because of excessive tensile loads.

Classification of Booms According to Use

Containment booms have been classified according to intended use to help spill response personnel to determine the kinds of equipment they need in different situations (Ref: World Catalog). Booms are classified according to their physical characteristics, which includes freeboard, draft, reserve buoyancy to weight ratio, total tensile strength, skirt fabric tensile strength, and skirt fabric tear strength.

Although all of these characteristics are important to the user, only the freeboard and draft will be mentioned here to give the reader an idea of the overall size of booms that are used for various applications.

BOOM CLASSIFICATION ACCORDING TO FREEBOARD AND DRAFT

SERVICE	FREEBOARD Inches	DRAFT Inches
Calm Water	4-10	6-12
Harbor	10-18	12-24
Offshore	>18	>24

This table shows that boom recommended for harbors and offshore is quite large. That is, boom recommended for harbor uses would have a vertical dimension (freeboard plus draft) of 22 to 42 inches and boom recommended for offshore use would have a vertical dimension of more than 42 inches.

Reports from spill response supervisors at the spill at Valdez indicate that some very large boom was used, but also that boom of nearly every vertical dimension down to 18 inches was used successfully. This provides new information on the kinds of boom that users feel is necessary in offshore operations.

One supervisor reports that there was boom used in Valdez that had a vertical dimension of 60 inches and even 80 inches. He further reported that they did not need this large boom to contain the oil, rather the large boats that were used to tow it could not slow down enough to tow it slowly, therefore they used big boom for drag to slow them down. (Most work boats and fishing boats do not operate well at very low speeds. This is a problem with using vessels of opportunity for spill response.) He further reported that boom with an overall vertical height of 36 to 48 inches would have been adequate if they had had the right kinds of boats to tow it.

Other spill response supervisors reported similar experience with booms. One reported that 32 to 36 inch boom is adequate and there is an application for boom in the 18 to 24 inch range, even offshore. A senior official reported that there was a shortage of boom in the 36 to 42 inch range.

These reports are both interesting and helpful, because they indicate that for successful spill containment offshore, boom does not have to be as large as was previously assumed. Clearly other characteristics are also very important, such as heave response. In offshore operations, ability to follow the wave patterns may be one of the most important characteristics.

Tests of Containment Booms

A number of tests of oil spill booms have been performed over the years. Although the results of these tests are helpful in understanding how some types of booms perform, they are not very useful in selecting a boom for a particular application. There are several reasons for this.

First, most of the tests were performed many years ago. Since then many of the booms tested have been improved or changed substantially. In fact, the results of the tests themselves provided the information needed for the changes. Second, only a small number of products were tested as compared to the number of booms that are currently available. In fact, most of the booms tested are no longer on the market, at least not in the configuration tested. Some offshore boom tests have also been performed. In many cases, these were only sea-keeping tests. That is, the booms were deployed in severe weather conditions to see how well they would ride the waves and also to see how well they would survive. These tests provide useful information, but they do not tell the user how well the booms will perform their primary mission, to contain oil.

In most cases, offshore boom tests were conducted without oil present because of the problems of getting necessary permits to release oil at sea. In one set of tests, however, oil was released, even in rather severe weather conditions off the coast of Newfoundland. In these test the best of booms were able to retain oil for periods of about 45 minutes. These results may be viewed as either adequate or unsatisfactory depending on your point of view. As a practical matter, this performance could be considered to be quite good. If a skimmer were employed inside the boom, most of that oil could probably have been recovered in 45 minutes. This also emphasizes that offshore boom can contain oil for recovery, provided skimmers are available at the spill site, ready to go, and are able to recover oil in existing wave conditions.

Tests of Fireproof Booms

Recently more time and money has gone into developing and testing fireproof booms than any other R&D development activity for spill response. In limited, controlled conditions, these tests have been quite successful. Typically a slick of 2 to 3 mm has been burned away in about 2 hours with a burn efficiency of something like 98 pecent. Although this seems to be encouraging, it does not provide conclusive evidence that this technique will be effective in real spill situation. To burn effectively, the slick must be a few millimeters thick, it must have adequate volatility, it must be continuous, and it cannot be emulsified. All of this means that the burn must be conducted in very special conditions, generally early in the spill when the product is still fresh. Additional work is probably needed in developing methods for effective in situ burning.

DEPLOYMENT ASSETS

Recovery and containment systems cannot be deployed at the site without the provision of significant support resources. These support resources include material handling equipment such as forklifts and cranes, boom and skimmer handling vessels, storage vessels, and trained personnel. Table 1 shows the deployment assets required at a minimum for various response components.

TABLE 1: REQUIRED DEPLOYMENT ASSETS

SYSTEM	STAGING AREA	TO SITE	ONSITE	PERSONNEL (per system)
CONTAINMENT	Space Forklift-4 ton Crane-4 ton Maintenance facilities Spares	Vessel with minimum of 8' by 20' clear deck space for each 2000' of boom	A-frame/davit/handling equipment with minimum one ton capability Boats capable of tending boom 3-5 foot waves per 2000' of boom •one if boom anchor used •two if no boom anchor used	2 2 per boat
RECOVERY				
Skimming Barrier	Space Forklift-10 ton Crane-10 ton Maintenance facilities Spares	Vessel with minimum of 8' by 35' clear deck space per system	A-frame/davit/handling equipment with minimum one ton capability Two boats for maintaining barrier opening and shape and capable of operating at low speeds-1-2 knot Barge for receipt of recovered oil Tug to tend barge or to shuttle barge to onshore storage location Platform for prime mover(may be barge)	4-6
Self-propelled/Self-propelled skimmer	Space Forklift-10 ton Crane-10 ton Maintenance facilities Spares	Vessel with minimum of 12' by 35' clear deck space per system	A-frame/davit/handling equipment minimum one ton capability Two boats for maintaining barrier opening and shape Barge for receipt of recovered oil Tug to tend barge or to shuttle barge to onshore storage location Boat with 10-ton crane at 35' reach deploy and recover	7-8
Vessel of opportunity skimmer	Space Forklift-10 ton Crane-10 ton Maintenance facilities Spares	Vessel with minimum of 8' by 24' clear deck space per system	A-frame/davit handling equipment minimum one ton capability for deployment and recovery Barge for receipt of recovered oil Tug to tend barge or to shuttle barge to onshore storage location	3 to deploy 2 to operate

TABLE 1: REQUIRED DEPLOYMENT ASSETS (CON'D)

SYSTEM	STAGING AREA	TO SITE	ONSITE	PERSONNEL
DISPERSANT APPLICATION				
Air deliverable	Pumps to transfer from barrels to tank truck Tank truck Ground personnel	See onsite requirements	Surveillance aircraft for spotting Aircraft equipped to spray dispersant	2
Vessel deliverable	Space Forklift-8 ton Crane-8 ton Maintenance facilities Spares	Vessel with 8' by 24' clear deck space	Surveillance aircraft for spotting Vessel capable of accepting vessel system	2-3 to deploy 2 to operate
TRANSFER PUMPS	Space Forklift-2 ton Maintenance Facilities Spares	Vessel with approx. 8' by 24' clear deck space Helicopter with one-ton lift capacity	Barge for receipt of offloaded oil Tug to tend barge or to shuttle barge to onshore storage location Hoses and couplings Fenders	–

INTEGRATED SYSTEMS

The difficulties encountered in spill response incidents, with respect to obtaining deployment resources such as boom and skimmer handling vessels and storage vessels, have led to the development of integrated systems which are equipped to perform all the functions of the mechanical recovery process. These systems fall into three basic categories: vessel-of-opportunity systems; single purpose specially designed oil spill response vessels; and multiple purpose vessels of which one of the purposes is oil spill recovery. These systems all use conventional skimmer techniques to recover the oil and are subject to the efficiencies and shortcomings of those systems. However, they also have the advantage of being independent of other supporting equipment in their recovery process, until their storage capacity is exceeded.

Vessel-of-Opportunity Systems (VOSS)

VOSS are systems designed to be deployed from any suitable vessel. They are arranged fixed to the side of the vessel, and they recover oil while the vessel progresses through the oil slick. Figure 5 shows a typical layout of this type of system. The VOSS was initially designed to be utilized with offshore supply vessels and in response to offshore drilling platform spill events. Several cooperatives on the east and west coast utilize the system and have additionally installed dispersant spray equipment on the vessels so that the vessel can now perform all functions of the spill response process.

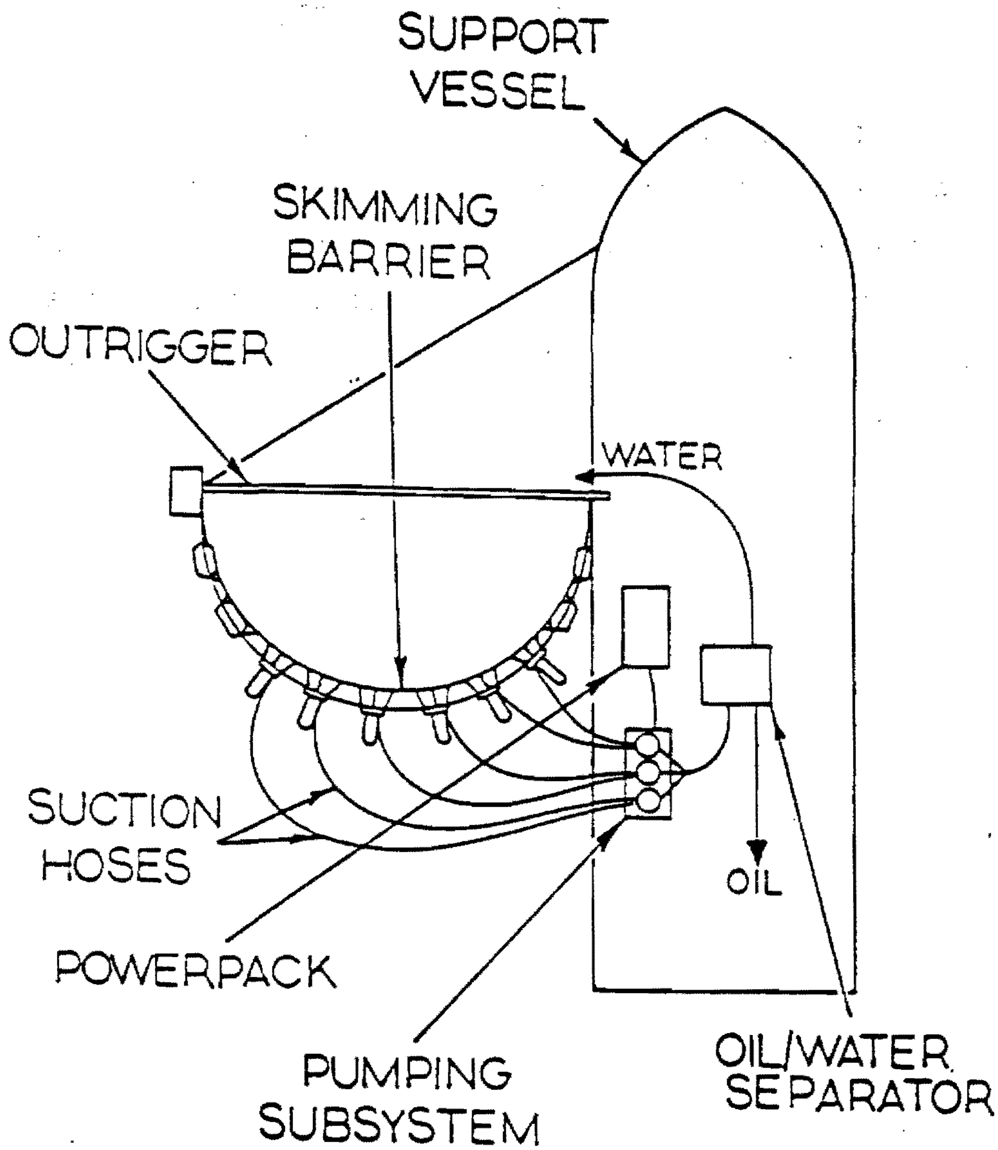


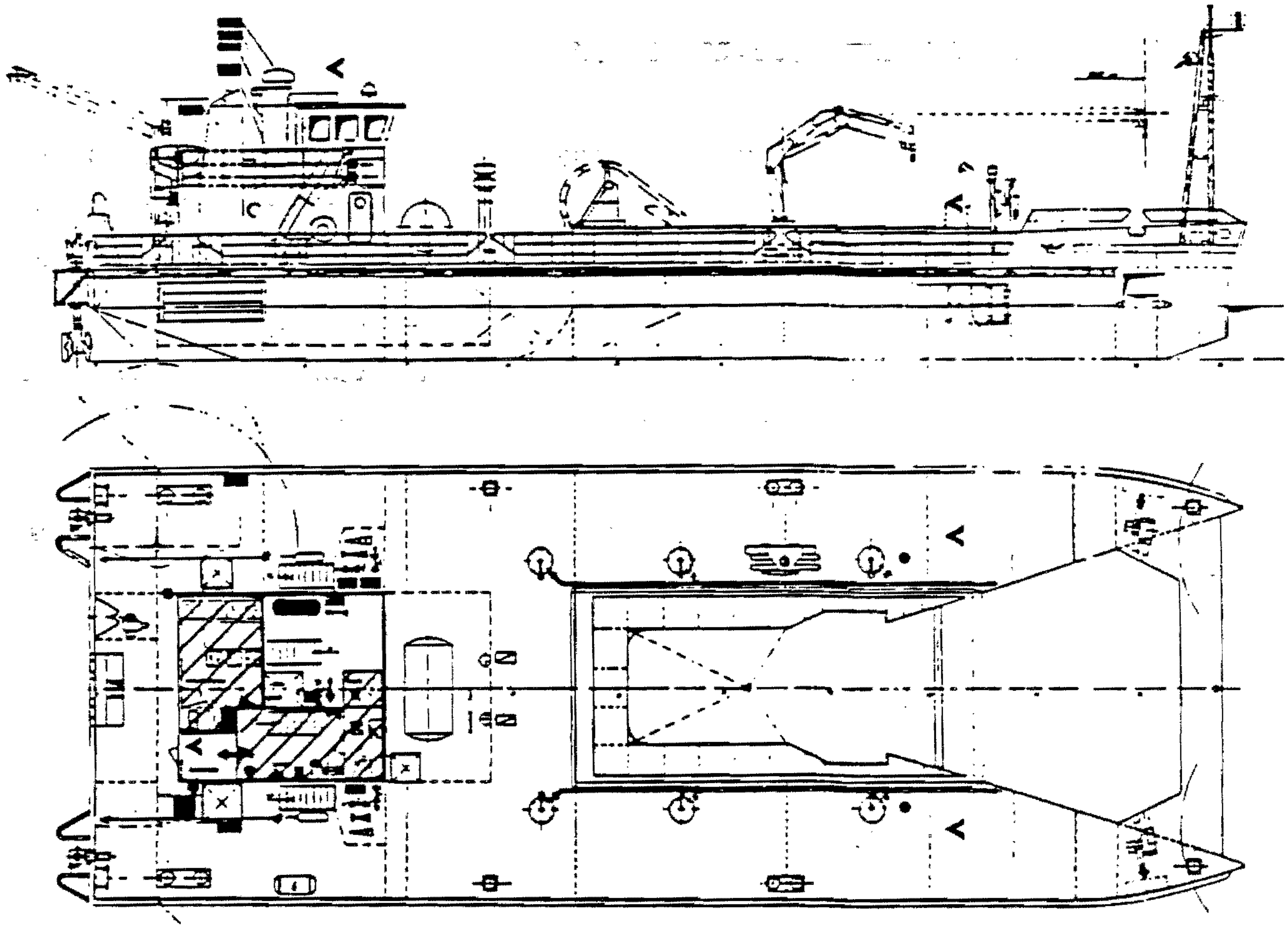
Figure 5. Vessel-of-opportunity skimming system

Specially Designed Oil Spill Response Vessels

Various entities, mainly the Germans and the Dutch, have developed designs for unique oil spill response vessels that are capable of operation in open water situations. These vessels are large units, operating either under their own power or with tug assistance. Figures 6, 7, and 8 are examples of those designs. The most innovative of them, shown in Figure 8, is a tank vessel that is hinged at the stern and operates in a V-configuration, using its split hulls to form a boom-like collecting system. Two of these vessels are in use and a third has been reported ordered by Mexico. These systems are very expensive and are location limited. They do have the advantage of being complete systems with significant onboard oil/water separation capability and storage capacity.

Multiple Purpose Vessels

The publicity surrounding the use of the Russian dredge in the VALDEZ spill has focused attention on the use of dredges and other vessels as platforms for oil spill response systems. The Russian dredge was designed from the beginning as a trailing hopper dredge with oil recovery capability. The first report of using a dredge as a platform was in 1977 with the design of the COSMOS shown in Figure 9. The great capacity of these vessels for storage of viscous materials, and their pumping systems (including suction hose up to 24 inches in diameter), make them ideal for recovering very viscous weathered oil. U.S. Army Corps of Engineers dredges were also used in the VALDEZ spill without specific modification. The dredge concept should receive further investigation to improve its application in oil spill response activities.



Technical Data
Pontoon

Lenght	appr. 33 m
Width	appr. 12 m
Height	2.65 m
Draught	0.75 - 1.8 m
Oil collection tanks	300 m^3
Carrying capacity	250 - 330 tdw
Jobbing crane	max. 7.5 t

Diesel-generator set with hydraulic/electric equipment
Classification according to customer requirements

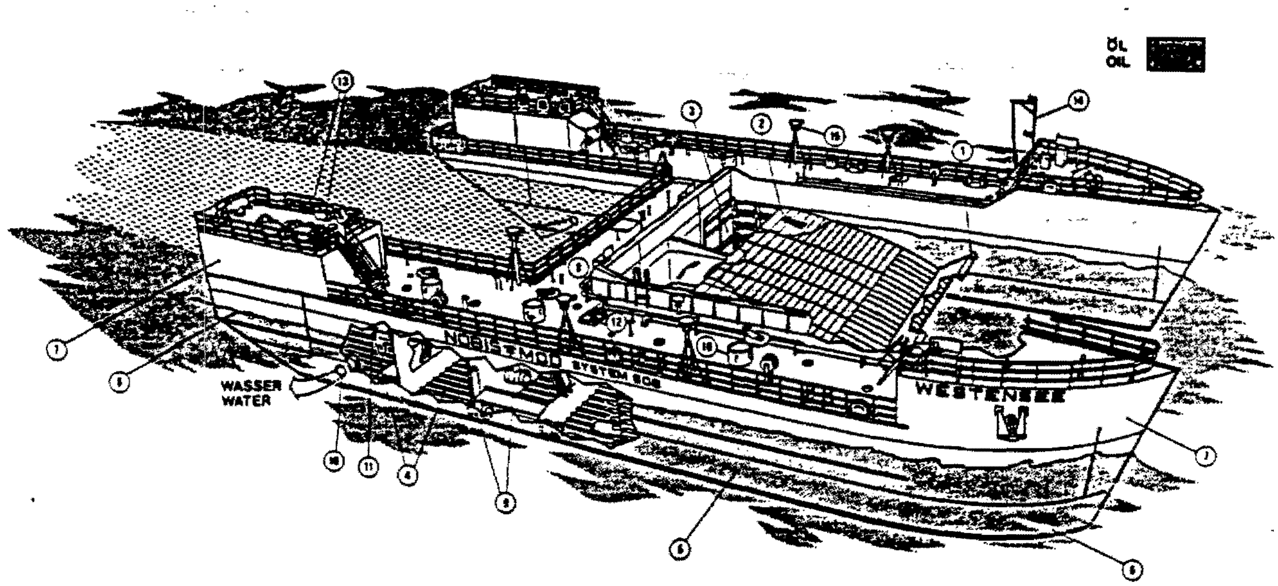
Technical Data
Oil Skimmer

Length	appr. 10 m
Width	appr. 5.1 m
Height	appr. 2.1 m
Draught	0.9 m
Oil pumps	2 x 300 m^3/h
Weight	appr. 17.4 t

Oil pick-up rate at a skimming width of 12 m:

Calm water (2 knots)	appr. 180 m^3/h
Rough water (2 knots)	appr. 100 m^3/h

Figure 6. Multi-purpose oil skimmer system (MPOSS)



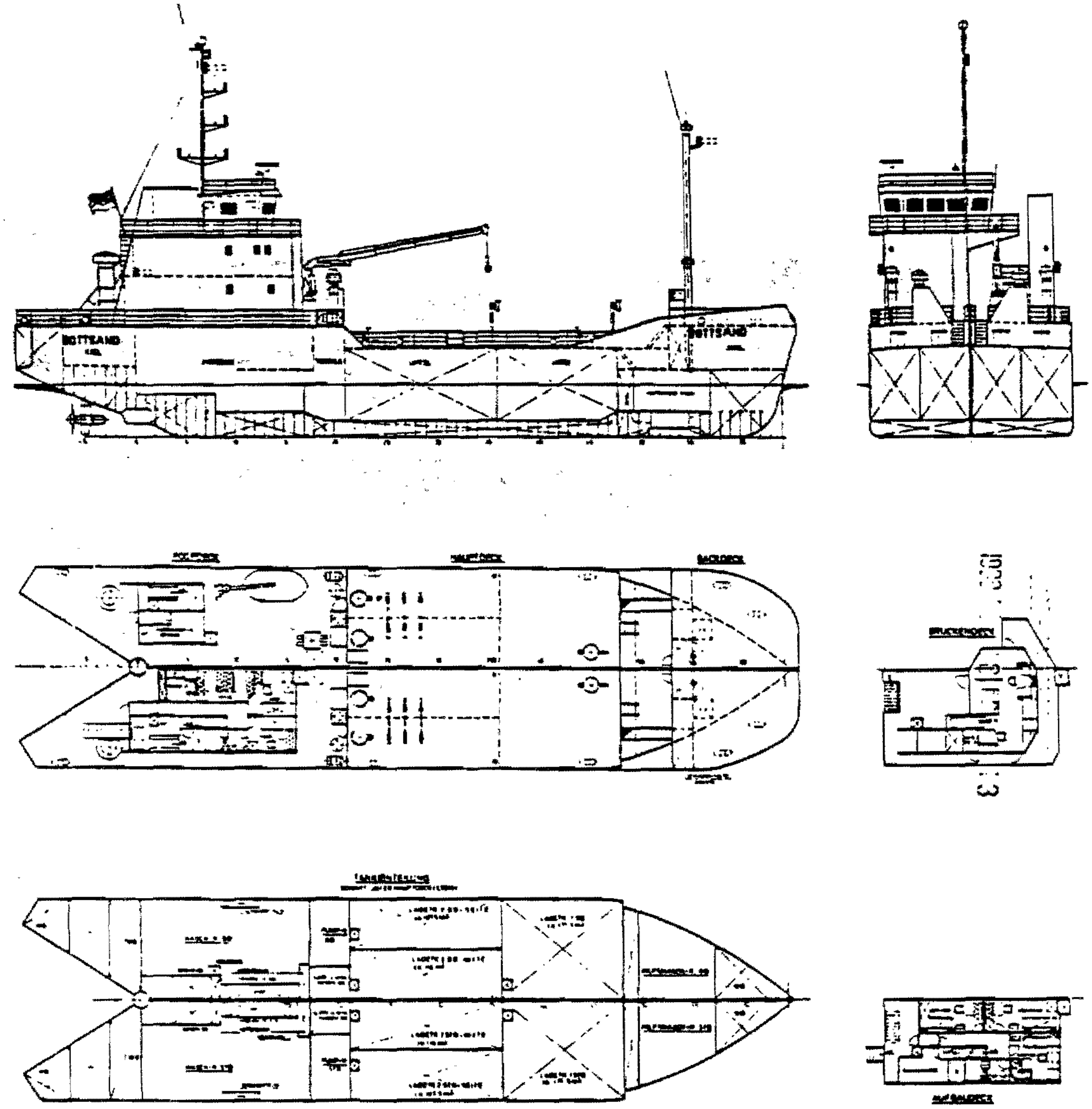
1 Wehr
2 Rampe
3 Querkanal
4 Ölabsetztanks
5 Ölsammel-Tank
6 Auftrieb-Tank
7 Ballast-Trimm-Tank
8 Kastenträger mit Pumpenraum

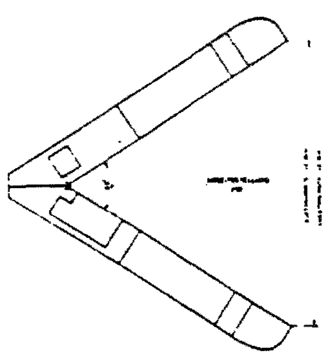
9 Überlaufrohre
10 Austrittsventil
11 Schwimmende Sauger
12 Ölübergabestation
13 Verholeinrichtung
14 Signalmast
15 Tanklüftung
16 Tankluke

1 weir
2 ramp
3 collective trough
4 setting tanks
5 oil collecting tank
6 buoyancy tank
7 ballast-trim tank
8 box transverse girder with pumproom

9 overflow pipes
10 draining valve
11 floating sucker
12 oil transfer station
13 mooring equipment
14 signal mast
15 tank ventilation
16 tank hatch

Figure 7. Oil-skimming catamaran





Technical data

Total length	appr. 46.30 m
Breadth	12.00 m
Depth	5.20 m
Draught	appr. 3.10 m
Deadweight	appr. 650 tdw
Cargotank Capacity	appr. 790 m^3
Tonnage	less than 500 GRT
Main Propulsion	2 × 600 kW
Ancillary Propulsion	2 × 150 kW
Speed	10 kn
At Oil-Spill Recovery	
Sweeping width	appr. 42 m
Speed	appr. 1 kn
Recovery	
at 2 mm oilslick-thickness	appr. 140 m^3/h

Figure 8. Twin-hull oil recovery vessel

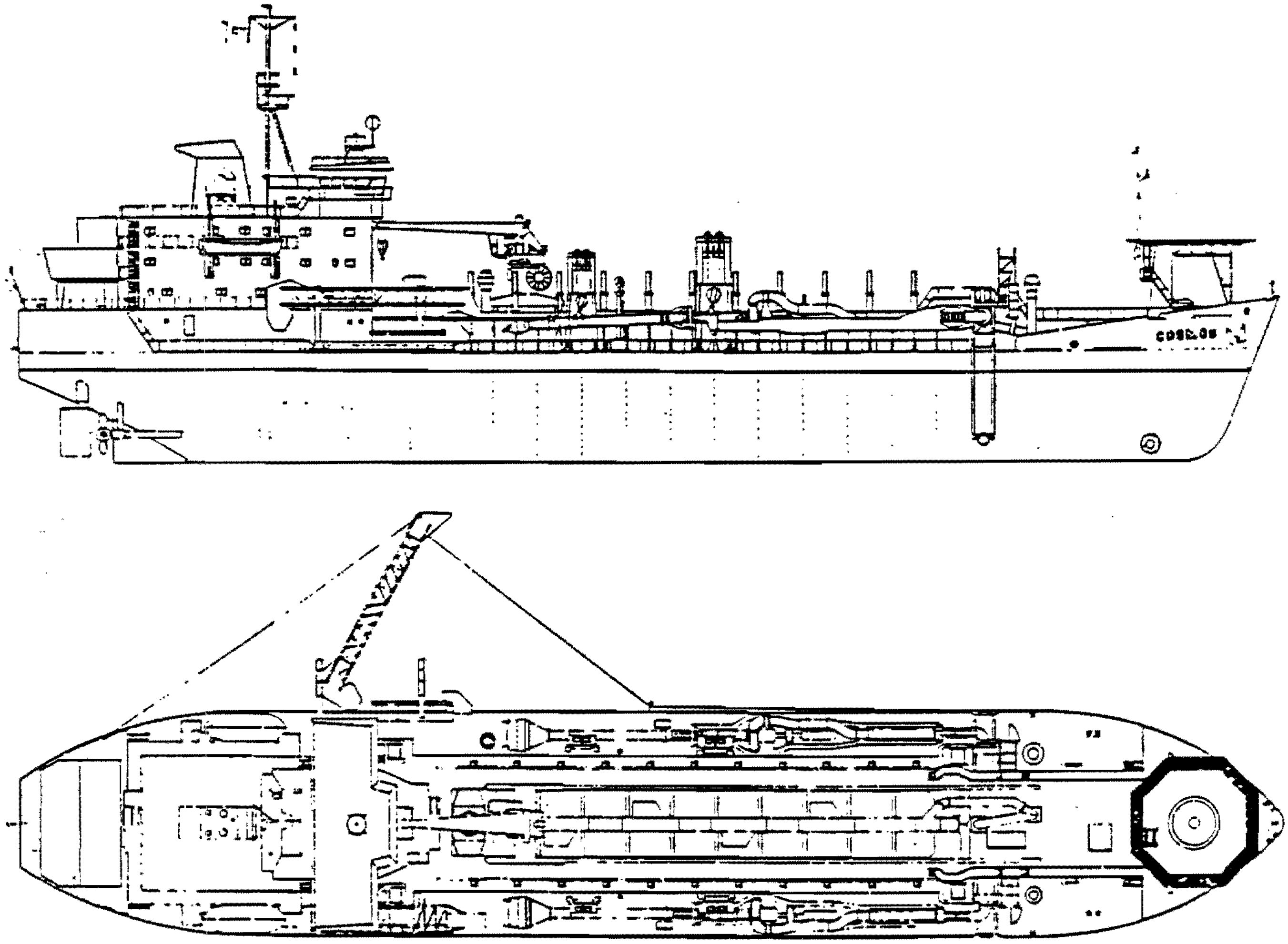


Figure 9. General arrangement of the Cosmos

SITE RESPONSE TO OIL SPILLS

With the general inability of mechanical removal systems to cope with large oil spills in the open ocean, processes that do not involve the physical removal of the oil from the water are presented as alternatives. The main processes that are involved include the dispersal of the oil by chemical means, the burning of the oil on site, and bioremediation.

CHEMICAL DISPERSANTS

The use of chemical means to disperse the oil into the water is probably the most controversial issue in the field of response to oil spilled on water. The National Academy of Science has recently completed an exhaustive study of the use of dispersants. Of particular interest to this study was the reiteration that dispersants must be applied at the early stages of the spill since oil becomes less dispersible as its viscosity increases. The NAS study concludes that "Dispersants are most effective for oil viscosities less than about 2,000 centistokes, and almost no dispersion occurs over 10,000 centistokes.

In general, a dispersant sprayed onto an oil slick is intended to reduce the cohesiveness of the slick so that the oil is broken into small droplets by wave action and water current. The resulting oil droplets are then dispersed into the water column and diluted to low concentrations. The operational advantages of using a dispersant include:

- their simplicity in use as opposed to booms and skimmers and the obviation for handling recovered oil or emulsions
- their utility and effectiveness in all sea states

- their faster response time and their ability to treat more oil per unit of time than mechanical means, particularly if aerial application is utilized.

The basic condition for dispersant use is that it must result in the least overall environmental damage of the options available. In essence, this involves trading the probable environmental effects of a treated slick with an untreated one.

Dispersant Application Systems

Dispersants can be applied by either fixed wing aircraft, helicopters, or systems installed on a vessel. The major consideration that is involved in applying the dispersant is to achieve a relatively uniform application on the oil without undue wind drift losses.

Fixed wing aircraft. Large aircraft have been equipped with spray boom and interior storage and are most useful for large spills because of their range, capacity, speed, and potential for areal coverage. However, due to the controversy regarding dispersant use, the fixed wing assets are not readily available, although Conair out of Canada does have a fleet of six planes. The Airborne Dispersant Delivery System is a unit developed for deployment on a C-130 commercial aircraft and is the only system that does not require a permanent installation as it can be used with almost any available C-130 aircraft. Logistics are not trivial for aircraft deployment, as civilian aircraft, normally in competitive trade, must be relied on.

Boat systems. The application of dispersants from vessel platforms has some distinct advantages such as selective spraying on the leading edge of the slick to mitigate further spreading. The major disadvantage, as with Helicopter systems, is the low volume of dispersant they can carry and their relatively short range.

BURNING

In-situ burning is defined as the process of burning an oil spill on land or water. Since the early 1970's many tests have been conducted in Alaska and Canada to evaluate the effectiveness of this technique as an oil spill countermeasure .

In order for oil on water to burn, the slick must be relatively fresh and at least 3mm thick. Since the volatile components in the oil begin to evaporate as soon as the spill occurs, the potential for in-situ burning decreases with time. Fresh oil slicks on any surface which have sufficient thickness can be ignited by matches, burning rags, air deployable igniters, and lasers. The field tests suggest that up to 90 percent of an oil spill can be removed from the water surface by in-situ burning. However, depending on wind speed and temperature, as much as 50 percent of an oil slick can evaporate in 24 hours or less. Once this occurs, it may be impossible to ignite the oil remaining on the water surface. In-situ burning produces a tarry residue which could be difficult to clean up. Under optimum burn conditions, about 10 percent of the oil will remain on the water as burn residue. In addition, the burning creates black smoke which could violate air quality control regulations and present a health hazard for nearby communities.

Burning may not be prudent near populated areas because it produces a variety of toxic chemicals which may adversely affect human health and welfare. For example, soot and polynuclear aromatic hydrocarbons created by in-situ burning can cause cancer and mutations in living tissue. Along with these items, the smoke from burning oil may also contain zinc, vanadium, lead, nickel, or other metals which were in the oil. It is important to recognize that the combustion products from in-situ burning can travel great distances before falling to earth.

The fallout resulting from in-situ burning can affect the environment in the following ways:

- Carcinogenic compounds and heavy metals in the fallout could enter both the aquatic and terrestrial food web.
- Fallout can contaminate fresh water lakes which provide drinking water.
- Excessive fallout can coat plants and block the sunlight needed for photosynthesis.
- Fallout can increase the absorption of solar radiation by ice and snow.
- The sulfer content of the oil can produce sulfur dioxide as the oil burns and can exacerbate the acid rain problem.

BIOREMEDIATION

Bioremediation is the use of microbes to biodegrade spilled hydrocarbon molecules in place. The microbes could be naturally occuring in the spill area or they could be non-indigenous naturally occurring or engineered microbes, and nutrients could be added to enhance their activity. Bioremediation is potentially the least damaging and least costly cleanup option. However, cleanup times are very long and significant scientific and practical application issues must be addressed. The effect on local habitat of increased microbe creation, both indigenous and non-indigenous, must be studied in depth to ensure the cure is not worse than the disease. This is a new but burgeoning area that should be carefully monitored for its great potential.

AVAILABILITY OF OIL SPILL RESPONSE TECHNOLOGIES

Prior to the discussion of the worldwide availability of major spill response equipment, it should be emphasized that this equipment is large and expensive, and normally has been purchased to serve a particular need in a defined area such as the Caribbean or a defined activity such as offshore drilling, or to provide unique capability such as those resources of the U.S. Coast Guard Strike Team. The owners of these resources are normally either government or industry cooperatives who have come together to purchase and operate these expensive resources in order to be able to economically share the expense. Even the cooperative arrangement does not allow for the acquisition of large stocks of these resources in terms of their response capability. The API Task Force Report on Oil Spills states that "The only cooperative world wide which has a capacity greater than 20,000 tons (144,000 barrels) is Oil Spill Response Ltd. (OSRL) in Southampton, England." That same report indicates that the equipment required to respond to a 30,000 ton spill - approximately the size of the EXXON VALDEZ - would have an acquisition cost of approximately fifteen million dollars and would include the following:

- four lightering pumps and associated equipment
- 30,000 feet of offshore boom
- 30,000 feet of medium boom
- four skimming barriers and twelve other skimmers with a combined capacity of 7400 barrels per hour
- two ADDS Pack dispersant systems and four helicopter dispersant systems along with 22,000 gallons of dispersant
- associated logistics equipment.

This volume of equipment would be the largest stockpile in the world, with the possible exception of Alyeska's planned increase in resource availability.

SOURCES WITHIN THE UNITED STATES

The following four tables provide information on the availability of major oil spill response components within the U.S. Where possible, information on the performance characteristics of the component is given in terms of:

- gallons affected
- sea state performance
- composition of the oil encountered.

In addition, a sense of the ready availability of the resources is provided as not all assets can be utilized in a direct manner. The regime for availability is as follows:

TABLE 2: MAJOR SOURCES OF SKIMMERS IN THE US

REGION	LOCATION	SERVICE TYPE	NO.	TYPE (a)	POWER[b]	STORAGE CAPACITY[c] (gallons)	RECOVERY (gpm)	PERFORMANCE[d] SEA STATE 1	2	3	VISCOSITY	DEBRIS	EXPECT AVAIL
EAST COAST	DAVISVILLE, RI	WEIR	2	B	N	0	1000	G	G-F	F	G	F	B
	WILLIAMSBURG, VA	SORBENT LIFTING BELT	8	SC	Y	1700	200	G	F	F-P	F	G	A
	DAVISVILLE, RI	WEIR	4	VOO	N	0	120	G	F	P	G	F	B/C
	DAVISVILLE, RI	WEIR	2	VOO	N	0	120	G	F	P	G	F	B/C
GULF COAST	MOBILE, AL	WEIR	8	B	N	0	1000	G	G-F	F	G	F	A
	VENICE, LA	WEIR	1	VOO	N	0	120	G	F	P	G	F	B/C
	VENICE, LA	WEIR	1	VOO	N	0	120	G	F	P	G	F	B/C
	INTERCOASTAL, LA	WEIR	1	VOO	N	0	120	G	F	P	G	F	B/C
	CAMERON, LA	WEIR	1	VOO	N	0	120	G	F	P	G	F	B/C
	CAMERON, LA	WEIR	1	VOO	N	0	120	G	F	P	G	F	B/C
	HOUMA, LA	WEIR	2	VOO	N	0	120	G	F	P	G	F	B/C
	GRAND ISLE, LA	WEIR	1	VOO	N	0	120	G	F	P	G	F	B/C
	GRAND ISLE, LA	WEIR	1	SC	Y	0		G	F	P	G	F	C
	ROCKPORT, TX	WEIR	1	VOO	N	0	120	G	F	P	G	F	B/C
	GALVESTON, TX	WEIR	1	VOO	N	0	120	G	F	P	G	F	B/C
WEST COAST	STOCKTON, CA	SORBENT LIFTING BELT	8	SC	Y	1700	200	G	F	F-P	F	G	A
	PORT SAN LUIS, CA	WEIR	1	VOO	N	0	120	G	G	F	F	F	C
	PORT SAN LUIS, CA	WEIR	2	SC	Y	0	250	G	G-F	F	G	F	C
	SANTA BARBARA, CA	WEIR	2	SC	Y	0	250	G	G-F	F	G	F	C
	SANTA BARBARA, CA	WEIR	1	VOO	N	0	120	G	G	F	F	F	C
	HAMILTON AFB, CA	WEIR	19	B	N	0	1000	G	G-F	F	G	F	A
	CONCORD, CA	WEIR	1	VOO	N	0	120	G	P	P	F	F	C
	SAN PEDRO, CA	WEIR	1	VOO	N	0	120	G	P	P	F	F	C
	SAN PEDRO, CA	WEIR	1	VOO	N	0	120	G	G	F	F	F	C
	SAN PEDRO, CA	WEIR	1	VOO	N	0	200	F	P		G	G	C
	SEATTLE, WA	SUBMERSION BELT	1	SC	Y	10000	500	G	G	F	G	F	C
ALASKA	VALDEZ,AK	WEIR	1	SC	Y	1700	200	G	F	F-P	F	G	C
	VALDEZ, AK	WEIR	1	SC	Y	3400	400	G	F	F-P	F	G	C
	DUTCH HARBOR,AK	WEIR	1	VOO	N	0	300	G	F	P	F	F	B
	DUTCH HARBOR,AK	WEIR	1	VOO	N	0	120	G	G	F	F	F	B
	DEADHORSE, AK	WEIR	1	SC	Y	0		G	F	F/P	G	G	C
	DUTCH HARBOR, AK	WEIR	2	VOO	N	0	120	G	F	P	G	F	B/C

[a] B - Barrier skimmer
SC - Self-propelled/self-contained skimmer
VOO - Skimmer system operated from a "Vessel of Opportunity"
[b] Y - Self-propelled
N - Requires external source of power
[d] Source: COMDTINST M16466.2"Oil Pollution Response Planning Guide for Extreme Weather"
Rating indicates estimated performance of the system as a whole, including barriers, support, etc.

TABLE 3: MAJOR SOURCES OF CONTAINMENT BOOM IN US

REGION	LOCATION	TOTAL LENGTH	FREE BOARD	DRAFT	UNIT WEIGHT (per 100')	TENSILE STRENGTH (lbs)	SEA STATE PERFORMANCE[a] 1	2	3	MAX	EXPECT AVAIL
EAST COAST	DAVISVILLE, RI	1000'	24"	36"	1280	18000	G/G	F/G	P/G	4	B
	DAVISVILLE, RI	1476'	14"	16"	880	69000	G/G	F/G	P/F	5	B/C
	DAVISVILLE, RI	2000'	24"	36"	1200	120000	G/G	G/G	F/G	5	B
	WILLIAMSBURG, VA	12000'	12"	24"	1280	18000	G/G	F/G	P/G	4	A
GULF COAST	MOBILE, AL	2448'	21"	27"	1600	50000	G/F	G/G	F/G	5	A
	MOBILE, AL	2448'	21"	27"	1600	50000	G/F	G/G	F/G	5	A
	GRAND ISLE,LA	1040'	12"	24"	300	20000	G/P	G/G	G/F	5	B
	VENICE,LA	1000'	12"	24"	300	20000	G/P	G/G	G/F	5	B
	VENICE,LA	1000'	12"	24"	475	16500	G/G	F/G	P/G	4	B
	INTRACOASTAL, TX	1000'	12"	24"	1400	40000	G/G	F/G	P/G	4	B
	GALVESTON, TX	1000'	12"	24"	1400	40000	G/G	F/G	P/G	4	B
	ROCKPORT, TX	1000'	12"	24"	1400	40000	G/G	F/G	P/G	4	B
WEST COAST	CONCORD, CA	8000'	17"	27"	152	55000	G/G	G/G	G/G	5	C
	CONCORD, CA	4000'	14'	17'	156	5700	G/G	F/G	P/G	3	B/C
	SAN PEDRO, CA	5000'	20"	30"	1800	104000	G/G	F/G	P/G	5	B/C
	SAN PEDRO, CA	5000'	14"	16"	880	69000	G/G	F/G	P/F	5	B/C
	SAN PEDRO, CA	4100'	16"	23"	360	95000	G/G	G/G	F/G	5	B/C
	SAN PEDRO, CA	3100'	12"	24"	1280	18000	G/G	F/G	P/G	4	B/C
	SAN PEDRO, CA	16500'	14"	17"	156	5700	G/G	F/G	P/G	3	B/C
	SAN PEDRO, CA	4000'	20"	23"	353	16500	G/G	G/G	F/G	4	B/C
	SAN PEDRO, CA	6400'	17"	27"	152	55000	G/G	G/G	G/G	5	C
	SANTA BARBARA, CA	2000'	20"	23"	353	16500	G/G	G/G	F/G	4	B/C
	SANTA BARBARA, CA	10900'	14"	17"	156	5700	G/G	F/G	P/G	3	B/C
	SANTA BARBARA, CA	3200'	17"	27"	152	55000	G/G	G/G	G/G	5	C
	SANTA BARBARA, CA	2696'	12"	24"	1280	18000	G/G	F/G	P/G	4	B/C
	SANTA BARBARA, CA	2035'	14"	24"	1280	18000	G/G	F/G	P/G	4	B/C
	STOCKTON, CA	11000'	12"	24"	1280	18000	G/G	F/G	P/G	4	A
	HAMILTON AFB, CA	12852'	21"	27"	1600	50000	G/F	G/G	F/G	5	A
	SEATTLE, WA	6000'	14"	16"	880	69000	G/G	F/G	P/F	5	B/C
	SEATTLE, WA	14000'	--	--	475	25000	G/G	G/G	F/G	4	B/C
ALASKA	VALDEZ, AK	11000'	14"	16"	880	69000	G/G	F/G	P/F	5	B/C
	VALDEZ, AK	11000'	12"	24"	290	30000	G/G	F/G	P/G	4	C
	VALDEZ, AK	8000'	17"	27"	152	55000	G/G	G/G	G/G	5	C
	DEADHORSE, AK	5400'	--	--							B/C
	DEADHORSE,AK	4000'	14'	16'	880	69000	G/G	F/G	P/F	5	B/C
	DEADHORSE, AK	2035'	14'	24'	1280	18000	G/G	F/G	P/G	4	B/C
	DUTCH HARBOR,AK	4500'	14'	17'	156	5700	G/G	F/G	P/G	3	B/C
	ANCHORAGE, AK	4500'	12"	24"	1280	18000	G/G	F/G	P/G	4	A

[d] Source: COMDTINST M16466.2"Oil Pollution Response Planning Guide for Extreme Weather"
Rating indicates estimated performance of the system as a whole, including barriers, support, etc.

TABLE 4: MAJOR SOURCES OF DISPERSANT DELIVERY SYSTEMS IN US

	LOCATION	PLATFORM	OIL TREATMENT[a] RATE COMPARISON (gpm)	STORAGE CAPACITY (gallons)	EXPECTED AVAILABILITY
EAST COAST	DAVISVILLE, RI	BOAT	500	500	B
GULF COAST	GRAND ISLE, LA	BOAT	500	500	B
	HOUMA, LA	BOAT	500	500	B
	ROCKPORT, TX	BOAT	500	500	B
	GALVESTON, TX	BOAT	500	500	B
	CHANDLER, AR	DC-4	<8000	2500	B
	CHANDLER, AR	ADDS/C-130	<8000	5000	A
	MESA, AR	DC-4	<8000	2500	B
WEST COAST	SAN PEDRO, CA	BOAT	48	DRUMS	B
	SAN PEDRO, CA	BOAT[b]	48	DRUMS	C
	SANTA BARBARA, CA	BOAT[b]	48	DRUMS	C
	SANTA BARBARA, CA	BOAT[b]	48	DRUMS	C
	SANTA BARBARA, CA	BOAT	48	DRUMS	B
ALASKA	ANCHORAGE, AK	BOAT	500	DRUMS	B
	ANCHORAGE, AK	HELICOPTER	1600	DRUMS	B

TABLE 5: MAJOR SOURCES OF OFFLOADING PUMPS IN US

REGION	TYPE	CITY	UNITS	CAPACITY (gpm)	PERFORMANCE CHARACTERISTICS Viscosity Light	Viscosity Heavy	Debris Tolerance Silt	Debris Tolerance Gravel	Debris Tolerance Seaweed	Emulsify liquids	EXPECTED AVAILABILITY
EAST COAST	DESTROIL	WILLIAMSBURG, VA	2	310	G	P	G	G	F	G	A
	THUNE-EUREKA	WILLIAMSBURG, VA	10	2000	F	G	G	G	P	P	A
	VISCOUS OIL	ELIZABETH CITY, NC	1	2000	F	G	G	G	P	P	A
GULF COAST	ADAPTS	MOBILE , AL	12	1000	P	G	G	G	P	P	A
	VISCOUS OIL	MOBILE, AL	1	2000	F	G	G	G	P	P	A
WEST COAST	ADAPTS	HAMILTON AFB, CA	12	1000	P	G	G	G	P	P	A
	VISCOUS OIL[a]	HAMILTON AFB, CA	2	2000	F	G	G	G	P	P	A
	THUNE-EUREKA	STOCKTON, CA	11	2000	F	G	G	G	P	P	A
	DESTROIL	STOCKTON, CA	2	310	G	P	G	G	F	G	A
	ADAPTS	CONCORD, CA	1	1000	P	G	G	G	P	P	B
	ADAPTS	SAN PEDRO, CA	1	1000	P	G	G	G	P	P	B
ALASKA	DESTROIL	ANCHORAGE, AK	1	310	G	P	G	G	F	G	B
	STOPS	VALDEZ, AK	2	1000	G	G	G	G	P	P	B
OTHER	THUNE-EUREKA	DETROIT, MICH	5	2000	F	G	G	G	P	P	A
	ADAPTS	DETROIT, MI	2	1000	P	G	G	G	P	P	A

- A - Readily available in most cases. This equipment is mainly Government resources of the USCG and the U.S. Navy.
- B - Equipment which may be available depending on specific equipment needs and circumstances existing at the time of need. These assets are mainly held by cooperatives for the convenience of its membership within a defined area either as a matter of operating or economic necessity. In the case of the former (such as offshore lease requirements), waivers from Governmental entities may have to be obtained, or agreement may be required among the members to cease operations, continuing or planned.
- C - Resources that may be made available but only within a specified area. Equipment that is permanently installed on a vessel would, for instance, only be available within that vessel's areal limitation.

Only containment, recovery, dispersant application, and pump availability will be considered, as storage and disposal components are subject to local availability and local jurisdiction.

SOURCES OUTSIDE THE UNITED STATES

Almost every country in the world with a significant coastal area has developed at least some oil spill response capability. The extent of that development is dependent upon the level of oil transport and development that impacts upon the country, the assumption of risk of spill that will occur, and the perceived responsibility of the oil industry in making contingency plans within the country's sphere of influence. Germany, for instance, has developed a significant offshore capability for the Baltic Sea with dedicated oil spill response vessels unique in their construction and operation. For the majority, the response assets are barely sufficient for their particular needs and reflect a risk assumption limiting the major spill event to a maximum of 10,000 tons.

Cooperatives have been developed in many parts of the world where several oil companies operating in close proximity to each other have made arrangements for a pooling of resources in the setting up of a centralized cooperative. A listing of major cooperatives are given below along with their area of influence.

Clean Caribbean	Caribbean area
Clean Nigeria	Nigeria
Tiered Area Response	Malacca and Singapore Straits
GAOCMAO	Persian Gulf
Oil Spill Response Ltd.	Worldwide
English Channel	English Channel
North Sea	North Sea

The use of these assets outside the particular area of influence is marginal. The Clean Caribbean cooperative was asked by EXXON to provide an ADDS dispersant system and had to advise that the equipment was not allowed to be used outside its area of intention. The Tiered Area Response Capability equipment may be used outside its area but must be returned or replaced within 24 hours on demand in case of need. The only stockpile that is available on a world wide basis is that of Oil Spill Response Ltd. which has sufficient resources to respond to two 10,000 ton spills.

ALYESKA ACQUISITIONS

Alyeska has, since the EXXON VALDEZ spill incident, substantially increased the amount of response equipment that it will have on hand to respond to any future spills. The equipment obtained, or on order, is listed below along with its source if available.

Vikoma Weir Boom	Vikoma, England
Framo Transrec	Under construction-Frank Mohn, Norway
Marflex Sweep Arm	Purchased from emergency stockpile of Holland
(to be fitted to integrated tug barge of 140,000 bbl capacity)	
Vikoma Skimmer 50	Vikoma, England
Vikoma Boom Deck Reel	Vikoma, England
Expandi 4300 Boom	Swedish Coast Guard
Scot Boom	Macclellan Rubber, Scotland
RoBoom Ocean 2000	German and Dutch government reserves
Vikoma HI 950 Boom	Vikoma, England
Containment System (Arctic Harbor Boom)	Containment Systems, Inc. USA
Response Vessels	Los Angeles (under modification)
	Los Angeles (under modification)
	Panama Canal (under modification)
	Singapore
Skimming/Lightering	Florida
Storage Barges	Seattle

The equipment was selected on three criteria:

- suitability for the requirements of present oil spill response strategy
- available by May 15, 1989, as required by the of State of Alaska
- suitable for incorporating into long term plan and alternative spill scenarios.

It is apparent that the equipment required to respond to an open water spill is not normally an off the shelf item and in most cases is required to be manufactured to order. In this instance, the availability of excess equipment from Sweden, Germany and Holland was probably a provident occurrence. It is interesting to note that Alyeska was not able to obtain equipment within the U.S. with the exception of the harbor boom.

LOGISTICAL AND LEGAL CONSTRAINTS

As has been seen from the above discussions, major oil spill response equipment is widely dispersed and the amount at any one location is insufficient to respond to a major oil spill incident. The ability to orchestrate the transportation of massive amounts of equipment in terms of size and numbers can be decisive to the response effort. In the EXXON VALDEZ spill, equipment was obtained from the east and west coast of the U.S., England, and Canada utilizing commercial and military aircraft. Two incidents are typical of the time and logistics required. In the first incident, EXXON ordered a Boeing 707 to Southampton to pick up skimmers and boom at 0600 on 24 March; that plane arrived in Anchorage on 26 March at 0518. In the second case, the ADDS dispersant system was ordered also at 0600 on 24 March; the C-130 and the ADDS system departed from

Phoenix at 2155 on 24 March. The point of these two incidents is that the acquisition of transportation assets, which are normally involved in other commercial activities, is or can be, an extended process.

Legal constraints on obtaining resources take two basic forms. The first has been addressed in the discussion of availability of resources from operational mandated stockpiles of cooperatives. Flexibility in terms of both current and future (short term) operations may be required to fully address the availability of these assets for a major spill incident. The second legal issue has to do with the acquisition of resources from countries outside the U.S. In the Prince William Sound spill, resources from Canada, the UK, and Russia were subject to customs requirements that may have inhibited their timely use. In particular, there was much concern about the arrival of the Russian dredge/skim ship.

SUMMARY

The above discussions have described the capability and the availability of the components of oil spill response equipment for responding to a major oil spill of the size and complexity of the EXXON VALDEZ oil spill incident in March of this year. Details providing an indication of the resources currently available for major response activitives have been provided including the limitations of such resources in terms of environmental and physical operating conditions that may be encountered. In addition, the effectiveness of the resources in the EXXON VALDEZ spill have been discussed. It should be emphasized that the conditions of that spill may not be typical of every major spill, and that performance characteristics of the response equipment will vary according to those physical and environmental factors that are encountered.

It must be concluded that the success of mechanical recovery of oil spilled at sea was not reinforced by the performance of resources deployed at the scene of the Alaskan spill and that significant improvements - an order of magnitude or more - must be made if mechanical recovery is to be an effective front-line tool in oil spill response.

APPENDIX L

AN OVERVIEW OF SPILL RESPONSE IN THE ALASKAN ARTIC
BERING STRAIT TO THE CANADIAN BORDER

AN OVERVIEW OF SPILL RESPONSE IN THE ALASKAN ARCTIC - BERING STRAIT TO THE CANADIAN BORDER

PREPARED FOR:

ALASKA OIL SPILL COMMISSION
707 "A" STREET, SUITE 202
ANCHORAGE, ALASKA 99501

PREPARED BY:

ENGINEERING COMPUTER OPTECNOMICS, (ECO) INC.
1036 CAPE ST. CLAIRE CENTER
ANNAPOLIS, MARYLAND 21401

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The area discussed by this paper, which includes the Chukchi Sea and the Beaufort Sea, is vast and diverse, particularly when considering the differences caused by ice cover. This discussion, therefore, must be divided into units according to ice seasons, spill behavior, and logistics problems caused by spills in remote areas. The principal division is according to ice season, and the discussion within that division describes expected spill behavior and likely response effort. The ice seasons used here are:

- Summer
- Fall
- Shorefast ice
- Break-up

Even using these divisions is a simplification of the diversity of ice forms and possible problems with ice; however, it will give the reader a good basis for understanding the types of problems that can occur.

The format for this survey, therefore, includes a brief discussion of ice conditions in each season, a description of spill behavior in that environment, a brief description of the kind of spill that may occur, and finally, a very general assessment of the type of spill response effort that could be mounted in the various areas under consideration.

SUMMER ICE SEASON

The summer ice season begins after the shorefast ice has broken up and disappeared. This usually happens during late July or early August. Typically the summer ice season lasts about 60 days along the Beaufort Sea coast of Alaska. Any fragments of the shear zone, or multi-year floes, nearshore decay as the polar pack ice edge retreats north, usually through the middle of September. Open water conditions (less than about 10 percent ice cover) prevail from the coastline to about 16 to 35 nautical miles from shore.

Periodic movement of the pack ice means that the summer ice season is not always "open water." During exceptional years the edge of the polar pack ice may retreat to more than 50 miles from shore, or it may advance to the coastline eliminating open water areas. During the summer of 1975 the polar pack ice edge moved in to the shoreline causing shipping along the North Slope to be virtually halted. That summer the polar pack ice covered 30 to 60% of the normally open water area. In other years the edge of the pack ice may advance shoreward into open water areas on a smaller scale.

The point here is that even in arctic summer the actual open water time for spill response is very short, from the end of July when some floating ice persists until the end of September when new ice starts to form. In unusual conditions, the polar pack may move in during the normal open water season and close things down. We are specifically calling this period of time the "summer ice season" rather than the "open water season" because it is a time when open water conditions may not prevail.

Spill Behavior in Open Water

Spill behavior in the Arctic is mainly concerned with ice conditions; however, even though a spill may occur in ice, the spill may move the open water at break-up. As a result, spill movement on open water is still an important consideration for all arctic spills.

As an example of Prudhoe Bay crude spreading on water, some computations for the instantaneous release of 50,000 barrels of oil have been done. Based on a mathematical model, the central portion of the spill would be 2.8 cm thick. The central, thick part of the slick would only go out to a radius of about 300 yards - this gives a slick diameter of about 0.3 nautical miles, but the thin, outside part of the slick moves more quickly from a radius of about 800 yards to a radius of a little more than 5 miles in a period of two days. The reason the central part of the slick is so thick is that the spilled oil is quickly chilled to its pour point by low air and water temperatures. The air and water, even during the open water season, will remain close to 0°C (or 32°F). (Even in August, the average air temperature is only about 4°C, or 39°F.) This cools the oil very quickly to a temperature that is near its pour point. Based on this information, there is evidence to conclude that a spill on open water may have a thickness that ranges for 5 mm to several centimeters depending on how rapidly it cools. If the spill is continuous, a 50,000 barrel release 3 cm thick would have a radius of about 300 yards, or a radius of about 700 yards if it spreads to a terminal thickness of 5 mm. That is to say, the range of the radius of a continuous slick is likely to be 300 to 700 yards.

Based on reports of large spills, however, the slick is not likely to remain continuous for a long period of time, even in a low energy wave environment. Instead, the spill is likely to stretch out in windrows and break into pancakes 10 to 30 cm in diameter and 5 mm to several centimeters thick. It is very likely that the heavier parts of the spill would bleed off into a sheen a few microns thick. As time goes on, the larger formations are likely to break-up into globs a few centimeters in diameter down to particles that are a few millimeters in diameter. These spill components would move with currents, winds, and waves to be deposited on shorelines, ice, or move out to sea, depending on the local situation. At this point spill behavior becomes a process of transport rather than spreading.

Spill Response in the Summer Ice Season

Spill response in our defined area depends on where the spill occurs. If the spill occurs offshore at Prudhoe Bay, a sizable response effort can be mounted. If the spill occurs in the Chukchi Sea, the response effort would be limited. These two areas represent the extremes and they will be discussed in order.

Spill Response at Prudhoe Bay

In the area offshore Prudhoe Bay, the ARCAT response vessel would be the principal recovery vehicle. It would probably be used with 500 to 1500 feet of containment boom to increase the sweep width. Mathematical models show that a small spill of crude oil is likely to be concentrated in a relatively small area, so if response is rapid, the ARCAT skimming system may be able to contain and skim a significant amount of the spilled oil. If the cold water causes the oil to chill quickly to a temperature near its pour point, recovery with the ARCAT rope mop skimmers could be more difficult. Although rope mop skimmers are known to be successful in skimming everything up to and including industrial grease, skimming a highly viscous product is slow because the wringers do not remove the viscous product from the mop very well.

Alaska Clean Seas also has about a dozen smaller, portable rope mop skimmers. These units can be mounted on barges so the mops will be able to skim abeam the barges. These units could skim oil that has accumulated in booms and they probably could also be used in a sweeping mode. All of these skimming systems could have problems skimming in areas close to the shore line because most areas are so shallow. The ARCAT draws about four feet of water, but the tugs and supply vessels are likely to have a much deeper draft and therefore a much more limited area of safe operation.

The central, thick part of the spill would be handled by oil skimmers, while the micron-thick sheen that bleeds off the edges could be treated with dispersants. Dispersants could be expected to be quite effective on the sheen but they would not be at all effective on the central, viscous accumulation of oil.

Some of the spilled oil could probably be isolated in fire resistant containment boom and burned. Burning could be an important part of the response effort. A recent response equipment list shows that Alaska Clean Seas has 2,500 feet of fire containment boom. Much more fire resistant boom needed if contained burning is to be an important part of the response effort.

Storage of the recovered product should not be such a great problem as it is in other areas of Alaska because there are generally 30 to 32 barges available in the area. As in other areas, there could be problems in off-loading the barges because of the viscosity of the oil. If the oil could be removed from the barges, it could be re-injected into the oil wells. It probably could also be burned in open pit burners or in the high capacity open flame burner maintained by Alaska Clean Seas.

Sensitive shoreline areas could be boomed off and protected from the migrating spill. Oil collected ahead of these booms could be recovered with portable rope mop units.

The spill response effort should be effective for small to moderate size spills. For large spills, there probably would not be enough equipment to contain and recover the oil so large quantities of spilled oil would escape into the environment.

It is never possible to anticipate exactly how much recovery equipment will be necessary for spill response, but experience has shown that there is never enough. Even though models show that Prudhoe Bay crude will not spread rapidly on cold water, spill recovery is likely to be slow, so there will be ample opportunity for oil to be transported out of the area. This means that more recovery platforms will be required.

When considering the types of equipment that should be procured, thought should be given to obtaining equipment with some diversity in recovery mechanisms. Recent experience in Prince William Sound emphasizes the fact that no single recovery mechanism is effective across the entire range of spill conditions as oil weathers. After the oil had been in the water a considerable period of time, the lifting belt skimmers were just about the only devices, other than Corps of Engineers suction dredges, that were recovering oil at all. There are even reports that the product became so viscous that the lifting belt skimmers were recovering chunks of oil that had to be broken apart with a shovel so that they would fit up the conveyer belt ramp.

At Prudhoe Bay, emphasis has been put on using rope mop skimmers because of their ability to operate in a variety of environmental conditions, even in light ice. There are even actual spill situations in which rope mop devices have been effective in recovering oil mixed with ice and even oil under ice; however, in most of these spill situations, the rope mops were recovering No. 2 fuel oil and diesel. This is vastly different than recovering Prudhoe Bay crude that has chilled in near-freezing water. There were some laboratory experiments performed with rope mop skimmers recovering Prudhoe Bay type oil in ice, but these tests cannot be considered to be conclusive proof that the rope mops will do the job in all stages of weathered oil.

Bearing this in mind, equipment procurement programs should place special emphasis on consideration of recovery devices that have been successful in recovering oil that has weathered to the point that it is floating (and sometimes only barely floating) in chunks. Right now the skimmers that meet these requirements are the MARCO Class V and VII and the LORI Type A lifting belt skimmers. This is not to say that the rope mop concept should be abandoned or that additional rope mop units should not be procured. Rope mop skimmers are likely to have a very important role in spill recovery at Prudhoe Bay. The point is that response equipment should represent a diversity of skimming techniques so that there will be some devices available that can deal with oil in all stages of weathering.

Finally, there should be some testing of recovery equipment in the actual spill environment. Contingency planning at Prudhoe Bay relies very heavily on response with the ARCAT skimmer, but to date all tests of this device have only been to determine its maneuvering capability and sea-keeping characteristics in light ice conditions. So far there have been no tests to see how well it recovers oil, and specifically, how well it recovers highly weathered Prudhoe Bay crude.

Spill Response in Remote Areas

As far as spill response is concerned, any area that is distant from Prudhoe Bay is a remote area. An effective response effort could probably be launched from Barrow, but not promptly. Nearly all of the equipment would have to be flown in, so it is likely that a large part of the spilled oil would escape before the response effort began. The Chukchi Sea must be considered as a very remote area and an effective response effort could only be launched long after the fact. As examples of spill response in a remote area, consider the cases of a spill from a drill ship and a spill from a tanker.

If a drill ship in a remote area had a blow out, the first consideration would probably be evacuation of the crew. The blow out might light spontaneously, or it may be ignited intentionally, after evacuation, as a response measure. Except for the part of the spill that could be consumed by burning, most of the spilled oil would be lost to the environment. A recovery effort could be made after the blowout had been stopped, but only a small percent of the oil would be recovered. For a relatively small spill, a fairly effective response effort could probably be launched from a drill ship, providing they had the plans and equipment to deal with it. Drill ships could maintain recovery equipment on board that could take care of small to moderate size spills that occur along side the vessel. These vessels could also probably launch small boats with containment boom to recover spilled oil providing weather conditions are not severe. There is likely to be a storage problem for the recovered oil if barges are not available; however, some of the recovered oil could probably be eliminated with special open flame burners.

A tanker accident in a remote area would present a considerably more complex problem for spill response. If the tanker is leaking as a result of running up on a grounded piece of ice or a large ice floe, the first concern is for the safety of the ship and the crew. Saving the ship is the first order of business, and evacuation of the crew, is the next order, if that becomes necessary. The ship could carry some containment boom and skimmers, but skimming oil back onto a leaking or sinking ship is not a viable option. First the ship must have a lightering tanker or barge. Once the flow of oil out of the ship has been stopped and the safety of the ship has been secured, then some response effort could be mounted. This would, of course, happen a long time after the accident occurred both because of the problems of saving the ship and also the problems of getting response equipment to the spill area. An effective response effort for a tanker spill that is very far from either Prudhoe Bay or Barrow would be extremely difficult.

FALL ICE SEASON

The fall ice season occurs from freeze-up to the time that the shorefast ice becomes stable. Typically, freeze-up occurs during late September in sheltered waters along the Beaufort Sea coast. Calm, cold air accelerates freeze-up. The initial freeze may be followed by a warmer or windy period during which some or all the new ice is either melted or deformed. By the first or second week of October, the freeze-up process is usually well underway and substantial areas of new ice cover the coastline and stretch out into the protected waters of bays and inside the barrier islands. At this time, the polar pack ice moves toward the shore and large areas of new and young first-year ice occur along its advancing edge. Eventually the ice growing seaward and the ice moving toward shore meet and the first shear zone of the year is created.

Fall season weather is important in determining the new ice growth and deformation. This season begins with subfreezing nighttime temperatures, and the first ice forms during the typical subfreezing cold spell in September. By October the average daytime maximum temperatures are normally about -6°C (21°F) and readings of -20°C (-4°F) at night are not uncommon. Sea ice forms quickly on the ocean under these conditions if the wind is calm.

The surface features of the new ice sheet depend upon the type of deformation processes that occurred as it was forming. Cold calm air provides ideal ice growing conditions, and results in a featureless expanse of ice. This flat ice may extend for many miles. The only surface features are snow drifts that form later in the winter.

A discussion of the fall ice season is not complete without reference to the extreme ice motion events that have been recorded. There is evidence that the barrier islands have been at least partially covered by moving sea ice sheets up to three feet thick more than once during the last 20 years. Ice-ride up onto beaches is fairly common with ice pileups nearly 36 feet high, reaching up to 20 yards inland. The barrier island events usually occur in the fall, while shoreline pileup events can occur during the fall and spring, when the first-year ice is free to move.

Spill Behavior in Fall Ice

Laboratory experiments found that Prudhoe Bay crude oil, introduced in a field of grease ice and pancake ice, occupies the spaces between the pancakes and is pumped onto the surface of the pancakes as they move in a wind generated wave pattern. Oil in the areas of grease ice is also confined and spreads very little. Although it is not possible to calculate the area covered by a spill in these ice conditions, it is sufficient to say that the spill does remain confined to a relatively small area.

Spill Response at Prudhoe Bay

Spill response options in a growing ice field are fairly limited. Since rope mop skimmers have some effectiveness in growing ice, the ARCAT would probably be fairly effective early in the fall ice season. Ice pieces could not be so large that they would have problems going between the twin hulls of the catamaran, and in low temperatures there could be some problems with ice on the rope mops and ice in the oil collection sumps. The ARCAT would probably be used independently without containment boom to increase sweep width.

Portable rope mop skimmers could be used over the side of barges. These skimmers could be expected to have a fair level of effectiveness in recovering the oil on ice and between the pancake ice, but their response effort would be quite slow. The weir skimmers, such as the SOCK and Halliburton units, would not be effective because they would be quickly jammed with ice. In situ burning may be possible in some of the thicker accumulations of oil. Dispersants are not likely to be effective.

Currently there are no oil skimmers at Prudhoe Bay that were designed for use in a growing ice field or during break-up. At this writing, the only known device that has been designed for this environment is the Wartsila Marine/LORI "Ice Cleaner." This device is a self-contained skimmer unit that is pushed by a supply ship or tug. It has been used to recover oil from a tanker spill in ice near Finland. A video tape and literature describing this system was presented at the "Alaska Arctic Offshore Oil Spill Response Technology" conference that was held in Anchorage in December of 1988. Based on the requirement for a response vehicle which could be used in growing and broken ice conditions, this concept should continue to receive attention in contingency planning.

The spill response effort in the growing ice field would only be marginally effective; however, there would be no immediate impact on the environment because the oil would be frozen into the ice. Although this alternative seems to be more favorable than the spreading and transport of spilled oil that occurs in summer, there could be significant problems in the long run. The oiled ice could be rafted up on the barrier islands and along the shoreline. When spring comes, there would be a new spill wherever this ice happened to land. The ice could be transported to a wide variety of locations, and, in a highly dynamic break-up environment, spilled oil would be rapidly released in areas that were a considerable distance from the original spill. Spill response at this time would be very difficult, and the small number of skimmers available would be hard pressed to recover a significant amount of oil in the widely spaced areas where the oil was being released.

Spill Response in Remote Areas

As in the summer ice season, a blowout at a drill ship is an emergency in which all the effort would be directed to saving the crew and the ship. The growing ice would retard the transport of spilled oil. As a result, there is a possibility that some response effort could be launched during the shore fast ice season. This could be done by transporting men and equipment onto the ice for response. If this is not possible, or if it appears that the oil frozen into the ice would be inaccessible to the response teams, there would be a second opportunity for response at break-up in the spring. At break-up, there are likely to be large amounts of oil released from the ice that could be disposed of by in situ burning. It would not be necessary to put a crew down for this response effort; rather pooled oil could be ignited from aircraft. If this action is taken promptly as the oil comes out of the ice, it could be effective providing the oil had not weathered to the extent it could not be ignited.

There are virtually no effective response measures that could be taken for a tanker accident in a remote area in the fall ice season. As in the case of the drillship spill, in situ burning would probably be possible in spring when the oil is released from the ice.

SHOREFAST ICE SEASON

Stable, shorefast ice characterizes this season. Shorefast ice is defined as first-year ice that is attached to the shore. In shallow water the ice is frozen to the sea floor. Often multi-year floes may be incorporated into the shorefast ice if the floes are relatively near shore during freezeup. The shorefast ice varies in extent during the season but it always retains the property of being virtually immobile. The shorefast ice season usually begins around late November, but there is considerable yearly variation. For example, in some years the nearshore new ice becomes stable in late October, but in other years significant ice motions can still occur in December. The shorefast ice season generally ends in late May as the break-up process begins.

Shorefast ice grows in a fairly regular pattern. Sheltered areas are always the first to develop shorefast ice and the ice grows seaward as it thickens. The ice thickens at a rate of about 10 mm per day through February. Later growth proceeds more slowly so that ice reaches an average maximum thickness of 6 to 7 feet in early May.

The seaward growth is not as regular. Forces generated by the wind and currents can break away large pieces of shorefast ice, and interactions with the pack ice can change the boundary of the stable ice by deforming the seaward edge. These deformations reduce the extent of the shorefast ice by creating shear ridges and rubble.

Shorefast ice grows seaward during the winter and reaches its maximum extent in April of most years. Typically, the outer edge of shorefast ice is bounded by shear ridges in about 60 feet of water. During years of intense pack ice pressure, the shorefast ice may be limited to a narrower offshore area. This is especially true near headlands and points where the stable ice may only reach to the 20 or 40 foot isobath. In other years, the shorefast ice may reach to the 66 foot isobath and beyond, if the pack ice does not impact the seaward edge. This extreme seaward growth of landfast ice occurs seaward of the shear zone. When the pack ice reapplies shearing forces, or when a storm surge changes sea level, the floating fast ice seaward of the grounded ridges is likely to move.

Surface features of the shorefast ice sheet do not have much vertical development, generally less than 1 foot. Most, if not all, of the surface features are caused by early season deformation. Thin ice is easily moved and deformed by the wind, causing ridges only a few inches to a foot high to be formed. Rafting is common as one ice sheet overrides another and leaves a "micro ridge" only a few inches high on the surface.

Sometimes the new ice does not remain in a flat sheet. Wind or wave action breaks thin ice into many pieces. As the pieces bump and rub together they form small round floes called pancake ice. Pancake ice can be identified by the tiny, round ridges on the perimeter of each floe that are preserved as the season progresses.

Taller features are also found in the shorefast ice and are commonly associated with an old shear zone or with multi-year ice pieces. Multiple sets of shear ridges are often formed over the course of a winter. The shorefast ice grows seaward until it interacts with the pack ice. This interaction forms shear ridges that protect the remaining shorefast ice from deformation because they are grounded. The next time the pack retreats from the edge of the shorefast ice, new ice becomes attached to the shear ridges. This new ice can then become part of the shorefast ice sheet and have a new, active set of shear ridges at its seaward boundary. This process continues until the pack ice prevents the further expansion of the shorefast ice. Generally the shear ridges that form later in the winter have more vertical development because the ice is thicker and the deforming forces are greater with increasing distance offshore.

Snow accumulates on all ice surfaces except for very smooth refrozen melt ponds and the upwind side of pressure ridges. The snow accumulates in drifts parallel to the wind leaving spaces between drifts covered by very little snow. Thicker snow acts as an insulator and inhibits ice growth. Thus, the shorefast ice develops a bottom topography of undulating troughs and ridges that correspond to the surface snow drifts.

In summary, new ice forms in the fall and becomes stable in late November. Nearshore ice becomes bottom fast during the winter as the ice becomes 6 to 7 feet thick. Floating shorefast ice is generally undeformed and has snow drifts aligned with the wind. Shear ridges formed in the early winter may be encountered shoreward of the final active set of shear ridges usually grounded in about 60 feet of water. During the winter, the shorefast ice is virtually immobile.

Spill Response at Prudhoe Bay

Spill response in the shorefast ice season is totally different from that practiced in the other seasons. During the shorefast ice season spill response becomes an effort of moving heavy equipment and personnel out on the ice where pooled oil and oiled snow is recovered with scrapers and front end loaders. The oiled snow and ice may be separated by heating in portable open tanks; then the oil can be burned in portable open pit burners or transported in a tank to the shoreline. Oil that has accumulated under the ice can often be recovered by drilling and pumping the oil out of the ice or permitting it to naturally rise to the surface. In some cases the ice can be trenched to collect accumulations of oil that are recovered with rope mop skimmers.

Spill recovery on shorefast ice is not easy, but generally there is a positive trade-off in that there is more time to recover the oil. During the shorefast ice season, spilled oil will accumulate on the ice, in the ice, and under the ice, but it is unlikely to rapidly move out of the area as it may in the summer.

Spill Response in Remote Areas

Spill response at a drill ship during the shorefast ice season would be the same as spill response near Prudhoe Bay except that it would be much more difficult to get the necessary people and heavy equipment on the ice to do the job. Barring safety problems, the crew of the drill ship could probably go out on the ice and perform some response. (This is in the case of a normal spill, not a blowout.) Depending on the ice conditions and the distance from the distressed ship from land bases, some response equipment could probably be flown to the spill site. This equipment could be brought in by helicopter, or if smooth, flat stretches of ice are available, fixed wing aircraft may even be able to land on the ice to bring in equipment.

In spite of these alternatives, spill response in a remote area on the ice is likely to be minimal. If the spill site is within helicopter range of land bases, a fairly extensive program of in situ burning could occur when the spilled oil surfaces in the spring.

BREAK-UP ICE SEASON

The break-up ice season usually begins during the last two weeks of May when the major rivers of the north slope region flood over the fast ice. Water absorbs much more shortwave solar radiation than ice, accelerating the melting of the ice under the flooded areas. Since the ice surface is above sea level, any openings through the ice act as drains. Seal breathing holes or naturally occurring thin spots develop into major drainage points for water that has accumulated on the ice surface. Large whirlpools, called strudel zones, often develop as the water drains. These areas are dangerous to approach.

In early June the ice surface begins to melt, and melt pools form because of the long daylight hours and rising temperatures. On undisturbed, flat shorefast ice, a shallow layer of water may develop stretching several miles in all directions. Water does not accumulate on ridged ice, and therefore ridges remain relatively dry and reflective. After about three weeks, (at the end of June), the shorefast ice is usually decayed to the point that cracks develop and the previously stable ice begins to move. Floes many miles across have been observed during this time. The presence of open water greatly enhances the ocean's ability to absorb energy. This causes the cracks to quickly expand, and the remaining ice is then free to move with the wind. Floe size generally decreases as the break-up season progresses because the ice deforms and decays. By the end of July or beginning of August the shorefast ice is usually gone.

During the early stages of break-up the shear zone remains intact, especially if grounded features are present. The ridges resist decay since they are more reflective than the water covered ice. The shear zone breaks up as the ridges melt away and the surrounding ice becomes mobile. Some of the more massive ridge fragments survive the break-up and summer seasons and become multi-year ice fragments. Usually the shear zone deteriorates rapidly in mid to late July as the ridges collapse and capsize.

Spill Behavior in Broken Ice

Oil moving in broken ice can be expected to enter the cracks and leads between the various floes and chunks of ice. The oil will then spread to some equilibrium thickness governed by ice concentration and the physical properties of the oil. At first the ice will restrict the flow of the oil so that the area covered by the spill will be less than for open water. As break-up progresses, or as the oil enters an open area, the floes and pieces of ice will move freely with winds and currents. At this point the effect of the ice becomes uncertain. Instead of restraining the movement of the oil, the ice may now transport the oil great distances from the original spill and contaminate a wider area than if the ice had not been there at all.

During break-up there are several forces operating on spilled oil. The oil on ice or the oil being released from the ice will follow the path of the melting water: it will tend to cover the surface of melting ice; it will move from pool to pool with the water; it will follow the vortex flow of the water down through the ice; it will follow the water spilling off the ice into leads; and, it may even be blown by the wind over the water pooled on the ice. In short, oil moving on melting ice at break-up time becomes a major problem for the spill response personnel. Whereas the winter ice provides a barrier to oil movement, summer ice provides many paths for it to flow, and the melting ice may even accelerate its flow into new, previously inaccessible areas. Break-up can turn the slow routine of winter cleanup on ice into a real disaster. The prospect of uncontrolled spill movement at break-up emphasizes the importance of a maximum response effort while the ice is still secure.

Spill Response at Prudhoe Bay

Spill response at break-up will begin slowly. As break-up begins, there will be some pooling of oil on ice and in some locations oil will accumulate between pieces of ice. If the oil has not weathered extensively, in situ burning may be possible. At this point it will no longer be safe to have personnel working on the ice and the accumulations of oil will also be inaccessible to any mechanical recovery equipment. There could be a period of from one to several weeks in which response crews could observe the dynamic break-up of the ice and equally dynamic movement of spilled oil and have no effective means of recovering oil.

As areas of open water appear, some mechanical recovery may be possible. In a summer field test performed in 1983, the ARCAT skimmer was able to successfully maneuver in water containing 88% broken ice. Whether or not the skimmer can effectively recover oil in this environment is another question. The ability of ARCAT to operate in broken ice will depend on the size and movement of the ice pieces, and skimming effectiveness will depend on the average size of the ice pieces. The skimmer will not be able to operate when large pieces of ice become wedged between the catamaran hulls. The skimmer is also not likely to be able to operate with containment boom designed to increase sweep width. Barges with rope mop skimmers deployed over the side are also likely to operate. These systems will be able to skim accessible pools of oil.

If a Wartsila/LORI ice cleaner is procured, it would probably be effective in recovering pooled oil and oil mixed with low formations of ice that are deteriorating. This system may be the most effective mechanical recovery option available at break-up. Skimming rate is likely to be slow, but some progress could be made.

Spill Response in Remote Areas

During break-up remote areas will be even more inaccessible than they were during the shorefast ice season. During break-up crews will not be able to work on the ice and aircraft will not be able to land on the ice. Further, because the decaying ice remains thick and marked with deep pressure ridges, it remains an obstacle to nearly all shipping other than ocean class ice breakers, and even these vessels would move very slowly. Remote areas, therefore, would remain inaccessible to both air and surface craft, so in situ burning using air dropped igniters is about the only response option available. Of course oil released from ice at this time would be transported by the ice and currents so there would be extensive transport of the oil that remained.

Conclusions and Recommendations

Summer Ice Season

PRUDHOE BAY

Conclusions: The spill response effort should be quite effective for small spills. For large spills, there is insufficient equipment to contain and recover the oil, so that large quantities of spilled oil would escape into the environment.

Recommendations: Additional response equipment should be procured with special attention given to providing a diversity of response methods. Particular attention should be given to the problems of recovering highly viscous oil.

Conclusions: Contingency planning at Prudhoe Bay relies very heavily on response with the ARCAT skimmer, but so far there have been no tests to see how well it recovers oil, and specifically, how well it recovers highly weathered Prudhoe Bay crude.

Recommendations: Offshore tests of the ARCAT skimmer should be conducted during cold weather and under severe ice conditions.

REMOTE AREAS

Conclusions: An effective response effort for a large spill from a drill ship or for a tanker accident that is very far from Prudhoe Bay or Barrow is extremely difficult.

Recommendations: A plan should be devised for dealing with or mitigating the impact of large oil spills in remote areas. Prevention should be the first line of defense.

Fall Ice Season

PRUDHOE BAY

Conclusions: The spill response effort in a growing ice field using currently available equipment would only be marginally effective.

Recommendations: Steps should be taken to investigate response alternatives for use in growing ice and during break-up.

REMOTE AREAS

Conclusions: There are virtually no effective response measures that could be taken for a large oil spill in a remote area in the fall ice season.

Recommendations: A plan should be devised for dealing with or mitigating the impact of large oil spills in remote areas. Again, prevention should be the first line of defense.

Shorefast Ice Season

PRUDHOE BAY

Conclusions: Spill recovery on shore fast ice is not easy, but generally there is a positive trade-off in that there is more time to recover oil.

Recommendations: Steps should be taken to insure there is enough equipment available to respond to a large spill on ice. Special attention should be given to stocking portable open pit burners, graders, tanks, pumps capable of moving highly viscous oil, and down hole drills to remove oil under ice and oil encapsulated in ice.

REMOTE AREAS

Conclusions: Spill response at a drill ship during the shorefast ice season would be the same as spill response near Prudhoe Bay except that it would be much more difficult to get the necessary people and heavy equipment on the ice to do the job.

Recommendations: A contingency plan should be developed for transporting equipment and personnel to remote locations for spill response during the shorefast ice season.

Break-Up Ice Season

PRUDHOE BAY

Conclusions: There could be a period of from one to several weeks during break-up in which response crews could observe the dynamic break-up of the ice and equally dynamic movement of spilled oil and have no effective means of recovering oil.

Recommendations: Steps should be taken to investigate response alternatives available for use during break-up.

REMOTE AREAS

Conclusions: Remote areas would remain inaccessible to both air and surface craft, so *in situ* burning using air dropped igniters is one of the few available response options.

Recommendations: Steps should be taken to investigate response alternatives available for use in remote areas during break-up.