Final Report

M/V Selendang Ayu Spill of December 2004: Modeling of Physical Fates

by

Deborah French McCay and Jill Rowe

Applied Science Associates
70 Dean Knauss Drive
Narragansett, RI 02882
Voc: 401-789-6224
Fax: 401-789-1932
dfrench@appsci.com

Prepared for:

Breck Tostevin, Senior Assistant Attorney General
Alaska Department of Law (DOL)
Anchorage, AK
and
Leslie A. Pearson, Program Manager
Alaska Department of Environmental Conservation (ADEC)
Division of Spill Prevention & Response
Prevention & Emergency Response Program
Anchorage, Alaska

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SUMMARY

Oil spill modeling was performed for the *M/V Selendang Ayu* oil spill of December 2004 off the northern coast of Unalaska Island, Alaska. The objectives were to provide an assessment of the trajectory and fate of the oil, and thus estimate exposure to the water surface, shorelines, water column, and sediments. Observations and data collected during and after the spill were used as much as possible as input to and to calibrate the model. Where data from the event were not available, historical information was used to make the assessment as site-specific as possible.

The model uses wind data, current data, and transport and weathering algorithms to calculate mass balance in various environmental compartments (water surface, shoreline, water column, atmosphere, sediments, etc.), surface oil distribution over time (trajectory), and concentrations of the oil components in water and sediments. Geographical data (shoreline/habitat type mapping and shoreline location) were obtained from existing Geographical Information System (GIS) databases based on Environmental Sensitivity Indices (ESI). Water depths were available from National Oceanic and Atmospheric Administration (NOAA) National Ocean Service (NOS) soundings databases. Hourly wind speed and direction data during and after the spill were obtained from two nearby meteorological stations. Background (non-tidal) currents were estimated based on observations in published literature and NOAA drifters and “sketched in” using ASA’s graphical user interface. Thus, the current patterns are approximate and do not include details of flow that likely prevailed at the time of the spill.

Specifications for the scenario (date, timing, amount, duration of release, etc.) were based on information obtained and distributed during the response by NOAA HAZMAT, the US Coast Guard, the State of Alaska, and the Responsible Party’s representative. The spill involved a total release of 339,538 gal (= 8,084 bbl = 1,271MT) of IFO 380 and 14,680 gal (= 349 bbl = 46.1 MT) of marine diesel oil, beginning on 8 December 2004 at 7:14 PM (Folley et al., 2006; Barry, 2005). The majority of the oil was released on the water surface immediately as the ship grounded, while the remainder was released in the days to week following the wreck (Folley et al., 2006; Barry, 2005). Given the stormy conditions and the highly volatile and dispersable (low viscosity) properties of diesel fuel, it is assumed that all of the diesel volatilized or was dispersed at sea; however, a diesel case based on the timing and inputs of the best IFO scenario was also modeled.

Modeling of the trajectory and fate of the oil was performed using SIMAP, varying uncertain parameters to calibrate the model and evaluate sensitivity to those assumptions. The fates model results of surface oil were visually compared to observed surface oil locations (e.g., from over-flights), SCAT reports, and other field data, as available. The surface (IFO) oil trajectory for the simulation best fitting the observations generally agreed with observations from overflights, mapping of shoreline oil (from SCAT surveys and other observations), and other field records. The model replicates well the overall movement and timing of the IFO away from the spill site and the primary areas where shoreline oiling occurred.

Ultimately, 7.2% of the IFO and 22.6% of the diesel evaporated. For the best simulation, initially 50% of the oil is submerged in the water column; and this oil dispersed, slowly degraded and settled to the sediments incorporated with suspended sediments. After a week, less than 2% of the IFO and none of the diesel was floating. By 8 weeks (28 days), 14.2% of the IFO and 3.4% of the diesel had come ashore. The diesel primarily either entrained in the water, evaporated, or came ashore near the spill site within hours of release. Much of the IFO was carried farther from the spill site before coming ashore. Oil that came ashore eroded over time, with its ultimate fate being the sediments and degradation. After 28 days of simulation, 7.8% evaporated, 13.7% remained ashore and 78.5% was dispersed at sea (ultimately residing in the water and subtidal sediments or decayed) of the total oil (354,218 gal of IFO plus diesel) released.

1. INTRODUCTION

Oil spill modeling was performed for the *M/V Selendang Ayu* oil spill of December 2004 off the northern coast of Unalaska Island, Alaska. This report describes the data inputs for and results of the modeling. Inputs include shoreline/habitat type and depth mapping, winds, currents, other environmental conditions, chemical composition and properties of the source oil, specifications of the release (amount, timing, etc.). Some inputs have significant influence on the modeling results. Sensitivity analysis was performed by varying critical input data.

Model results of the case that is closest to the oil observations during the spill are displayed by a Windows movie file (*.avi) that animates the trajectory of the spill over time. The figures included here (in the appendices) are selected snapshots taken from that simulation's output, as well as from the matrix of runs that were performed as part of the sensitivity analysis. Appendix A.1 shows the spill location and nearby areas. Place names on the map are used in this report to describe observations and model results. Appendices A.2 and A.3 show the shoreline and habitat types, and water depths in the model domain.

At 7:14 PM on 8 December 2004, the *M/V Selendang Ayu* grounded during a storm and broke in half between Skan Bay and Spray Cape on the northern shore of Unalaska Island. The boat had been adrift without power for nearly two days when it grounded. The contents of one of the vessel's double bottom fuel tank were released immediately, and the remaining oil from the two other double bottom fuel tanks was released into the water as storms and waves continued to pound the wreck. In total, it is estimated that 339,538 gal (= 8,084 bbl = 1,271MT) of IFO 380 and 14,680 gal (= 349 bbl = 46.1 MT) of marine diesel oil were released into the water over the course of the spill (Folley et al., 2006; Barry, 2005).

Figures in Appendix B show observations of oil movements and the extent of oil contamination. As of 8AM on 10 December, the spilled oil had washed up on the beaches behind the wreck and into Skan Bay, according to situation reports from the Unified Command (vessel owners, US Coast Guard, and the State of Alaska). By 2PM on 10 December, tar balls and sheening were spotted in Makushin Bay, north of Skan

Bay. By the morning of 11 December, weather conditions worsened, therefore stopping all field operations. On the morning of 12 December, an overflight showed streamers of black oil and mouse (2-5m wide) in Skan Bay and just inshore of the wreck, with light sheening coming off the beaches. Some black oil and sheening oil was also visible in Makushin Bay (Figure B.1-1). During an overflight from 11:18AM to 2:30PM on 13 December, sheening was observed in Portage Bay and Cannery Bay, and along the shoreline out and around Cathedral Point into Humpback Bay (Figure B.1-2). There were no significant changes in the oil spill observations during an overflight on 14 December (Figure B.1-3). On 15 December, the US Fish and Wildlife Service performed an overflight, and observed a string of tarballs in Pumicestone Bay, to the south of the spill site (Figure B.1-4). By the morning of 19 December, a small area of oil sheen was observed in Kashega Bay, south of Pumicestone Bay.

SCAT surveys (summarized in maps by Polaris, May 2005; Figure 1) showed heavy oiling in Skan Bay and Makushin Bay, particularly in Humpback Bay, Portage Bay and in between Portage and Cannery Bay. Smaller sections of heavy oiling were also observed as far south as Pumicestone, Kashega, and Kismaliuk Bays (Figures 1 and B.2-1). Moderate oiling was observed as far north as Unalaska Bay, in Portage Bay, Cannergy Bay, Skan Bay, Pumicestone Bay, and as far south as Kismaliuk Bay. The farthest extent of oiling was as far south as Cape Aspid and Peso Point (Figure 1).

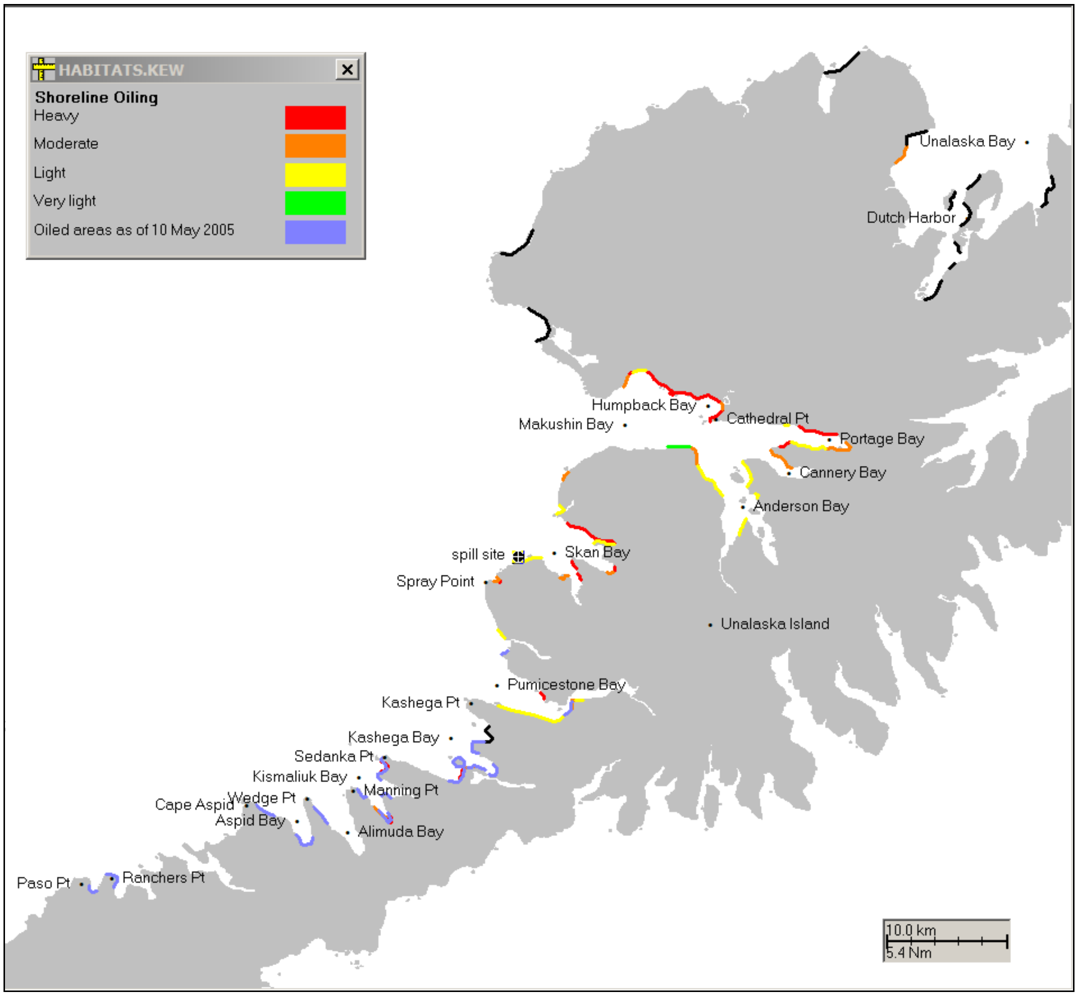

Figure 1. Shoreline oiling as observed from NOAA/Hazmat SCAT surveys.

There is evidence that a considerable percentage of the spilled oil was awash or in the water column. This could have resulted from the rough seas prevalent during the event and incorporation of sediment into the oil, making it slightly denser than sea water but suspended in the water column by the high turbulence prevailing during the winter in the area. The release was in heavy surf, so incorporation of sediment into the oil likely occurred. Tarballs and sheens were observed during the water quality sampling program in January-February of 2005 as far northeast as Unalaska Bay and as far southwest as the extent of the Bering Sea coast of Unalaska Island (southwest of Paso Point in Figure 1; Nuca Research and Planning Group, 2005).

Section 2 describes the physical fates model used for this analysis. Section 3 describes the model input data and assumptions. Results of the physical fates model are described in Section 4. Section 5 contains the conclusions. References cited are in Section 6. Appendices provide input data and model results, in tables, maps and other figures.

2. MODEL DESCRIPTION

The analysis was performed using the model system developed by Applied Science Associates (ASA) called SIMAP (Spill Impact Model Analysis Package). SIMAP contains physical fate and biological effects models, which estimate exposure and impact on each habitat and species (or species group) in the area of the spill. The physical fate model uses wind data, current data, and transport and weathering algorithms to calculate the mass of oil components in various environmental compartments (water surface, shoreline, water column, atmosphere, sediments, etc.), oil pathway over time (trajectory), surface oil distribution, and concentrations of the oil components in water and sediments. The biological effects model, which was not used in this analysis, simulates movements of organisms, their exposure to oil, acute toxic effects of that exposure, and population-level impacts of the lost individuals. Current data are used to transport oil components and organisms. A tactical response model, which was not used in this analysis, allows the user to simulate booming, mechanical cleanup, burning, and dispersant usage. Environmental, geographical, physical-chemical, and biological databases supply required information to the model for computation of fates and effects. SIMAP has been validated with more than 20 case histories, including the Exxon Valdez and other large spills (French McCay, 2003, 2004; French McCay and Rowe, 2004, 2006), as well as test spills designed to verify the model's transport algorithms (French et al., 1997).

SIMAP was derived from the physical fates and biological effects submodels in the Natural Resource Damage Assessment Model for Coastal and Marine Environments (NRDAM/CME), which were developed for the US Department of the Interior (USDOI) as the basis of Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) NRDA regulations for Type A assessments (French et al., 1996). The technical documentation for the model is in French McCay (2003, 2004). Below is a brief summary of the model algorithms and assumptions.

2.1 Physical Fates Model

The physical fate model estimates the distribution of oil (as mass and concentrations) on the water surface, on shorelines, in the water column and in the sediments. Processes simulated include slick spreading, evaporation of volatiles from surface oil, transport on the water surface and in the water column, randomized dispersion, emulsification, entrainment of oil as droplets into the water column, resurfacing of larger droplets, dissolution of soluble components, volatilization from the water column, partitioning, sedimentation, stranding on shorelines, and degradation. Oil mass is tracked separately for lower-molecular-weight aromatics (1 to 3-ring aromatics), which are soluble and cause toxicity to aquatic organisms (French McCay, 2002), other volatiles, and non-volatiles. The lower molecular weight aromatics dissolve from both from the surface oil slick and whole oil droplets in the water column, and they are partitioned in the water column and sediments according to equilibrium partitioning theory (French et al., 1996; French McCay, 2003, 2004).

“Whole” oil (containing non-volatiles and volatile components not yet volatilized or dissolved from the oil) is simulated as floating slicks, emulsions and/or tarballs, or as dispersed oil droplets of varying diameter (some of which may resurface). Sublots of the spilled oil are represented by Lagrangian elements (“spillets”), each characterized by mass of hydrocarbon components and water content, location, thickness, diameter, density, and viscosity. Spreading (gravitational and by transport processes), emulsification, weathering (volatilization and dissolution loss), entrainment, resurfacing, and transport processes determine the thickness, dimensions, and locations of floating oil over time. The output of the fate model includes the location, dimensions, and physical-chemical characteristics over time of each spillet representing the oil (French McCay, 2003, 2004).

3. MODEL INPUT DATA

3.1 Geographical and Model Grid

For geographical reference, SIMAP uses a rectilinear grid to designate the location of the shoreline, the water depth (bathymetry), and the shore or habitat type. The shore type defines habitat type for intertidal habitats; and subtidal habitats are specified using other types of mapped information. The grid is generated from a digital coastline using the ESRI Arc/Info compatible Spatial Analyst program. The cells are then coded for depth and habitat type. Note that the model identifies the shoreline using this grid. Thus, in model outputs, the coastline map is only used for visual reference; it is the habitat grid that defines the actual location of the shoreline in the model.

Ecological habitat types (Table 3-1) are broadly categorized into two zones: intertidal and subtidal. Intertidal habitats are those above spring low water tide level, with subtidal being all water areas below that level (indicated by W in Table 3-1). The fringing intertidal types (indicated by F in Table 3-1) are the shoreline in the model, and are assigned oiling band widths that may vary by shore type. Boundaries between land and water are fringing intertidal habitat types.

The digital shoreline and shore type identifications were obtained from the Environmental Sensitivity Index (ESI) Atlas database compiled for the area by Research Planning, Inc. (RPI). These data are distributed by NOAA Hazmat (Seattle, WA). The intertidal habitats were assigned based on the shore types in the digital ESI. Open water subtidal areas were defaulted to sand bottom, as open water bottom type has no influence on the model results. The gridded habitat type data are shown in Appendix A.2. The grid scale resolution is indicated in Table A.2-1 of Appendix A.2.

Depth data were obtained from Hydrographic Survey Data supplied on CD-ROM by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Geophysical Data Center. Hydrographic survey data consist of large numbers of individual depth soundings. The gridded depth data are shown in Appendix A.3.

Table 3-1. Classification of habitats. (Fringing types indicated by (F) are only as wide as the intertidal zone in that province. Others (W = water) are a full grid cell wide and must have a fringing type on the land side.)

Habitat Code	Zone	Ecological Habitat	F or W
1	Intertidal	Rocky Shore	F
2		Gravel Beach	F
3		Sand Beach	F
4		Fringing Mud Flat	F
5		Fringing Wetland (Saltmarsh)	F
6		Macrophyte Bed	F
7		Mollusk Reef	F
8		Coral Reef	F
9	Subtidal	Rock Bottom	W
10		Gravel Bottom	W
11		Sand Bottom	W
12		Silt-mud Bottom	W
13		Wetland (Subtidal of Saltmarsh)	W
14		Macroalgal (Kelp) Bed	W
15		Mollusk Reef	W
16		Coral Reef	W
17		Seagrass Bed	W
18	Intertidal	Man-made, Artificial	F
19		Ice Edge	F

3.2 Environmental Data

The model uses hourly wind speed and direction for the time of the spill and simulation. Standard meteorological data were acquired from the National Data Buoy Center Internet site for the two nearest NDBC buoys, number 46072, “Central Aleutians”, at 51.63° N, 172.16° W, and number 46071, “Western Aleutians”, at 51.16° N, 179.05° W. Data from Buoy 46072 were used until December 17th, at which time it went offline, and data from Buoy 46071 were used from that point until the end of February (NDBC, 2006). Wind speed and direction data are in Appendix C.

A mean temperature of 5^{o}C was assumed for both the water surface and the air immediately above the water based on data for the Aleutian Islands from the NRDAM/CME (French et al., 1996). Water temperature affects evaporation rate, and so surface oil volume, but not the trajectory of the spill. The effect of water temperature within the range of a few degrees Celsius is insignificant.

Salinity was assumed to be the mean value (32 ppt) for the location of the spill site, based on data compiled in French et al. (1996). The salinity value is used to calculate water density (along with temperature), which is used to calculate buoyancy of the oil. The IFO evaluated had a density less than that of the water, and so floated if sediments were not incorporated into the oil. However, the observations of tarballs suspended in the water column is evidence that some of the oil picked up sediment (likely in the surf zone as it was released) and, thus, the whole oil was somewhat denser than the water, but remained suspended due to the high turbulence in the Bering Sea in winter. This submerged oil in the water was modeled as if it were neutrally-buoyant, while the floating oil was modeled using the source oil density. (See further discussion below.)

In the deeper waters, suspended sediment is assumed 10 mg/l, a typical value for nearshore waters (Kullenberg, 1982). The oil model estimates the adsorption of oil droplets and dissolved components to suspended sediments (a different process than incorporation of sediment into whole oil, and tracked separately in SIMAP). The sedimentation rate for suspended sediments with adhered oil droplets is set at 1 m/day. These default values have no significant affect on the model trajectory. Sedimentation of oil and PAHs via adsorption becomes significant at about 100 mg/L suspended sediment concentration.

Sensitivity analysis was performed by varying the horizontal diffusion (randomized mixing) coefficient, which was assumed to range from 10-100 m^2/sec. The vertical diffusion (randomized mixing) coefficient in the surface mixed layer was calculated from wave height, a function of wind speed input to the model. In deep water, the vertical diffusion coefficient was assumed 0.0001 m^2/sec. These are reasonable values for coastal waters based on empirical data (Okubo and Ozmidov, 1970; Okubo, 1971) and modeling experience. The vertical diffusion coefficient used kept the upper water column well mixed, and so variation of this parameter had no significant impact on the results.

3.3 Currents

3.3.1 Background Currents

Currents have significant influence on the trajectory and oil fate, and are critical data inputs. Wind-driven and background currents are included in the modeling analysis. The local surface wind drift is calculated within the oil spill model (as described in the next section). The background (non-tidal) currents are input to the oil fates model from a current file that is prepared for this purpose.

Currents were estimated based on published literature and NOAA drifters. Stabeno et al. (1999) show a general flow to the northeast along the north side of Unalaska Island (and nearby Aleutian Islands) and a northwestward flow from the northeast end of Unalaska Island along the Bering Sea shelf break. Kowalik and Stabeno (1999) estimated that the currents along Unalaska Island averaged 20 cm/s (pers. comm. Kenwyn George, ADEC). Therefore, currents of 20 cm/s to the northeast were used along the northern coast of the island. Based on drogue plots analyzed by Phyllis Stabeno (NOAA;

http://www.pmel.noaa.gov/foci/globec/gl_drifters.shtml), currents near the shelf break (to the northwest of Unalaska Island) averaged 32 cm/s to the northwest (pers. comm. Kenwyn George, ADEC).

The model grid is shown in Appendix D (Figure D-1). Figure D-2 shows the current vector plot assumed for the simulations.

3.3.2 Wind-driven Surface Currents

Local wind-driven surface currents are calculated within the SIMAP fates model, based on local wind speed and direction. Surface wind drift of oil has been observed in the field to be 1-6% (average 3-4%) of wind speed in a direction 0-30 degrees to the right (in the northern hemisphere) of the down-wind direction (ASCE, 1996). In nearshore waters, the angle tends to be near zero, while in open waters the angle develops to be 20^o-30^o to the right of down wind. In the simulations, 3.5% of wind speed with zero angle was assumed.

3.4 Oil Properties

The modeled oil was IFO 380. Physical and chemical data on intermediate fuel oil were based on data in Environment Canada's catalogue of crude oil and oil product properties (described in Jokuty et al, 1996; http://www.etcentre.org/spills), except density and viscosity which were available from measurements on the source oil (Simecak-Beatty and Pichel, 2006). Minimum oil slick thickness was assumed 1mm, based on McAuliffe (1987). Properties and sources of the data are listed in Table E-2 of Appendix E.

The fuel density (0.989 g/cc) is lighter than seawater, and so the (pure) fuel would float. The viscosity (4,873.5 cSt = 4,873.5 cp) of IFO 380 is typically high, which slowed wave-driven entrainment and dispersion of pure oil into the water column to a very low rate. Variation of these two parameters within the typical range for heavy bunker fuels would have no significant effect on the results for the floating oil.

However, oil that had incorporated some sediment would have a higher density than seawater and tend to sink, if there were no turbulence. A portion of the spilled oil was assumed to be heavier than water but to remain suspended due to high turbulence during the spill period. The portion of oil assumed submerged versus floating was a model input assumption. A range was run in a sensitivity analysis, from 10% to 90% of the released oil.

3.5 Shoreline Oil Retention

Retention of oil on a shoreline depends on the shoreline type, width and angle of the shoreline, viscosity of the oil, the tidal amplitude, and the wave energy. The shore width (intertidal zone width where oiling would occur) was assumed 1 m based on typical beach widths for Gulf of Alaskan gravel beaches, the dominant shore type in the area affected (French et al., 1996).

3.6 Scenario

The spill site was offshore the northern coast of Unalaska Bay, at 53^o 38'4" N, 167^o 7'30" W, just outside Skan Bay. The oil releases occurred at the water surface beginning at 7:14PM on 8 December 2004. The releases were modeled as ending on 14 December at 11AM, 136 hours later. According to the ADEC situation reports, the tanks were still intact at this time, however, overflights from this time forward did not observe any more oil leaking from the ship. The total volume of IFO 380 released was estimated at 339,538 gal (= 8,084 bbl = 1,271MT); and the volume of marine diesel oil released was 14,680 gal (= 349 bbl = 46.1 MT) (Folley et al., 2006; Barry, 2005). The IFO release was assumed to be in two phases, based on observations of a major release occurring as the ship broke in half, with 42,442 gal (12.5%) of the IFO being released in the first 0.25 hours, and the remaining 297,096 gal (87.5%) of IFO being released over the next few days to week. The release of diesel fuel was assumed even over the 136 hours, as more detailed information is unavailable. The IFO and diesel releases were simulated in the model, however, sensitivity analysis was performed only for the IFO releases, as the diesel evaporated and dispersed quickly and did not warrant additional analyses. Appendix E contains a list of model inputs for the SIMAP physical fates model.

4. FATES MODEL RESULTS

Modeling of the trajectory and fate of the oil was performed using SIMAP, varying uncertain parameters to calibrate the model and evaluate sensitivity to those assumptions. The calculations were made with a time step of 0.25 hour. The model was run for 28 days, during which time all the oil evaporated, came ashore, or dispersed at sea.

As noted above, two model inputs were uncertain and a range of possible values was assumed for each in a matrix of model runs. The horizontal diffusion (randomized mixing) coefficient was varied from 10-100 m^2/sec. The percent of oil submerged (assumed by incorporation of sediment into the oil) was varied from 10% to 90%.

The fates model results of surface oil were visually compared to observed surface oil locations (e.g., from over-flights), SCAT reports, and other field data, as available. Surface oil distribution from over-flights and other observations are briefly summarized in Appendix B. Quantitative observations of the oil distribution in the field are not available. Thus, quantitative comparisons to the model simulations could not be made. The final values of the uncertain inputs were selected based on the best model fit to observed shoreline oiling (Figure 1). The results for that final "best-fit" run are summarized below and in Appendix F.

The SIMAP model quantifies, in space and over time:

- The spatial distribution of oil mass and volume on water surface over time
- Oil mass, volume and thickness on shorelines over time
- Subsurface oil droplet concentration, as total hydrocarbons, in three dimensions over time

- Dissolved aromatic concentration (which causes most aquatic toxicity) in three dimensions over time
- Total hydrocarbons and aromatics in the sediments over time

The fates model output at each time step includes:
- oil thickness (microns or g/m^2) on water surface,
- oil thickness (microns or g/m^2) on shorelines,
- subsurface oil droplet concentration (ppb), as total hydrocarbons,
- dissolved aromatic concentration in water (ppb),
- total hydrocarbon loading on sediments (g/m^2), and
- dissolved aromatics concentration in sediment pore water (ppb).

Model results are displayed by a Windows graphical user interface that animates the trajectory and concentrations over time. The figures included in the appendices are summaries of that output.

Appendix F.1 summarizes the sensitivity analysis results for IFO contamination on shorelines. The shoreline oiled by each simulation is plotted by red dots that do not all represent the same amount of oil. However, this easily-viewed output makes the distribution of oil on the shoreline clearly visable in a figure of the scale presented. Note that the shorelines shown in these model outputs are for visual reference only, whereas the habitat (and corresponding depth) grid (Appendix A.2) defines the actual shoreline to the model.

When the horizontal diffusion coefficient was assumed 10 m^2/sec, the oil did not disperse away from the spill site area and Skan Bay. This horizontal diffusion coefficient is typical of calmer seas, and so not realistic for this case, as borne out by the results. Thus, only the results for runs with the horizontal diffusion coefficient 25-100 m^2/sec are discussed further.

Shoreline oil distribution for runs assuming horizontal diffusion of 25, 50, 75, and 100 m^2/sec and 10, 25, 50, 75, and 90 percent of IFO submerged are shown in Figures F.1-1 to F.1-20. These oil distributions may be compared to the SCAT data results summarized in Figures 1 and B.2-1. The best match was obtained assuming a horizontal diffusion coefficient of 75 m^2/sec and 50% of the oil assumed submerged after release. If the horizontal diffusion coefficient is lower, a smaller percentage of the floating oil moves northeast into Makushin Bay on Dec 9-10. If the percent of submerged oil is less than 50%, there is too much shoreline oiling, particularly outside the Skan Bay to Makushin Bay area; while if the percent of submerged oil is greater than 50%, there is little or no shoreline oiling outside of the Skan Bay to Makushin Bay area. As the details of the currents are not known or modeled, and the winds were assumed constant across the horizontal domain whereas they are actually spacially variable, the details of the shoreline oiling do not match the observations exactly. However, the general distribution of oiling is comparable.

With the Windows movie file of the trajectory for the best simulation (SELENDANG-IFO-H75-E50-TRAJ.avi), one can view the model results for all times steps of the model simulation that best fits the oil observations. The points in the trajectory animation represent the center of mass for "spillets" used to simulate the spill. Each spillet is a sublot of the total mass spilled. The spillet is transported by currents and surface wind drift. The mass distribution around the spillet center spreads (for surface floating oil) and disperses over time according to the horizontal dispersion coefficient. The model trajectory replicates well the overall locations and timing of the oil movement from the spill site to the east into Makushin Bay, and then to the west along the north coast of Unalaska Island.

A second movie file (SELENDANG-IFO-H75-E50-THC.avi) shows total hydrocarbon concentrations in the water after the spill over time. Concentrations (mass per unit volume) in the water are calculated for a grid (50 X 50 cells horizontally, 5 layers vertically) sized to just cover the 3-dimentional plume at the time of the output. Concentrations exceeding 1 ppb total hydrocarbons occurred in the simulation along the entire northern coast of Unalaska Island, in (general) agreement with observations of tarballs in the water (Nuka Research and Planning Group, 2005).

Appendix F.2 contains figures for the best IFO simulation (horizontal diffusion coefficient of 75 m^2/sec and 50% of the oil assumed submerged after release). For this scenario, IFO was assumed released continuously over the first 136 hours, half entrained by high turbulence (not adhered to sediments) and half on the surface. Appendix F.2.1 shows the mass balance of IFO over time. The graph shows, as a function of time since the release start, percent of total mass spilled on the water surface, in the water column, on shorelines, in the sediment, in the atmosphere, and degraded. Ultimately, 7% of the IFO evaporated. Initially, 50% of the oil is submerged in the water column (as an initial condition), and this oil dispersed, slowly degraded and settled to the sediments incorporated with suspended sediments. After a week, less than 2% of the IFO was floating, and 60% of the floating oil (30% of IFO spilled) came ashore. Oil coming ashore eroded over time, with its ultimate fate being the sediments and degradation. Sediment contamination was widely dispersed, and so did not exceed 0.0001 g/m^2 as an average in any single model grid cell.

Quantitative measurements of mass cleaned up are not available. Thus, cleanup operations (including on shorelines) were not included in the model simulations. Thus, oil simply accumulates and remains on the shore. Inclusion of shoreline cleanup would have no effect on the amount of oil simulated coming ashore, dispersed at sea or evaporated.

Appendix F.2.2 shows the amount of oil accumulated on shorelines for the (best) IFO simulation, as mass of total hydrocarbons per unit area (g/m^2, averaged in each habitat grid cell). The heaviest oiling was in Skan Bay, Humpback Bay, Portage Bay, in accordance with observations. The simulation indicates spotty oiling to the west of the spill site by 4 weeks after the spill (January 5, 2005). In the field, tarballs were observed scattered over more shoreline to the west of the spill site and on the north side of

Unalaska Island, including in Dutch Harbor, in the months after the spill. Likely, that oil came ashore after January 5, which was the last day of the model simulation. Also, in the model, submerged oil was assumed not to come ashore, whereas some submerged tarballs could have done so. The simulations with 25% of the oil submerged show more widespread shoreline oiling (Appendix F.1, e.g., Figure F.1-17).

Tables F.3-1 to F.3-4 summarize the mass balance for the best and other model simulations of the IFO spill. The tables show that the amounts and percentages of the oil on shore are more sensitive to the assumed percent of oil that is submerged than to the horizontal diffusion coefficient used. For the best simulation and after 28 days of simulation, 7.2% evaporated, 14.2% remained ashore, and 78.7% was dispersed at sea (ultimately residing in the water and subtidal sediments or decayed) of the total IFO (339,538 gal of IFO) released. The amount ashore would continue to decline over time (due to decay and erosion into the sea) if the simulations were run for additional weeks.

The shoreline areas in the model grid oiled at various average thicknesses (after 28 days of simulation) are listed in Table 4-1 for the best IFO simulation. (The area >0.1 mm is included in the area >1mm, and so on.) Note that the shore length within a model grid cell is the diagaonal distance across a grid cell, and the area is that times 1m (so length in meters and area in square meters are equivalent). The actual shore length within the grid cell can be longer, depending on the degree of convolutions in the shoreline. Approximately 96 km of shore was oiled, ranging from 0.0001mm to > 1mm (0. 1 g/m^2 to >1kg/m^2).

Table 4-1. Shoreline areas (m^2) oiled with IFO at various average thicknesses (1 mm ~ 1 kg/m^2) for the best IFO simulation.

Shore Type	>1 mm	>0.1 mm	>0.01 mm	>0.001 mm	>0.0001 mm
Rocky shoreline	0	0	0	21,579	27,973
Gravel beach	32,968	63,338	64,937	65,336	65,336
Wetland	1,998	2,398	2,398	2,398	2,398
Total shoreline	34,966	65,736	67,334	89,313	95,707

Appendix F.4 contains figures for the diesel simulation (horizontal diffusion coefficient of 75 m^2/sec and 50% of the oil assumed submerged after release, same as the best simulation of IFO). Appendix F.4.1 shows the mass balance of diesel over time. The graph shows, as a function of time since the release start, percent of total mass spilled on the water surface, in the water column, on shorelines, in the sediment, in the atmosphere, and degraded. After a week, no diesel was floating. Diesel coming ashore (a maximum of 12% was ashore at any single time) eroded over time (to 3.4% remaining after 28 days), with its ultimate fate being the sediments and degradation. Ultimately, 22.6% of the diesel evaporated and 74% was dispersed at sea, degraded, or incorporated into subtidal sediments. The shoreline areas oiled at various average thicknesses (after 28 days of simulation) are listed in Table 4-2 for the diesel simulation. Approximately 33 km of shore was oiled, ranging from 0.0001mm to > 1mm (0. 1 g/m^2 to >1kg/m^2), but with most shoreline lightly oiled by sheen. Sediment contamination was widely dispersed, and so did not exceed 0.0001 g/m^2 as an average in any single model grid cell.

Table 4-2. Shoreline areas (m^2) oiled with diesel at various average thicknesses (1 mm ~ 1 kg/m^2) for the diesel simulation.

Shore Type	>1 mm	>0.1 mm	>0.01 mm	>0.001 mm	>0.0001 mm
Rocky shoreline	0	0	0	0	2,198
Gravel beach	0	2,997	9,191	16,384	25,575
Sand beach	0	0	0	999	2,997
Wetland	0	200	999	2,597	2,597
Total shoreline	0	3,197	10,190	19,981	33,368

5. CONCLUSIONS

Refinement of the Background Current Patterns

For the simulations provided herein, offshore background (non-tidal) currents were estimated based on observations in published literature and NOAA drifters and “sketched in” using ASA’s graphical user interface. Near-shore currents and tidal currents were not included. Thus, the current patterns are approximate and do not include details of flow that likely prevailed at the time of the spill. Refinement of the model simulation would require either refinement of the current patterns or modeling of the details of the current and wind fields. However, the general patterns of oil movement and shoreline oiling are predicted by assuming the simple current field and spatially-constant wind field (based on NOAA buoy wind measurements) used.

Some improvement in the details of the shoreline oiling could be accomplished by calibration of the current field, i.e., entering nearshore vectors that move the oil in accordance with observations. For example, the oil moved from Skan Bay to Makushin Bay without oiling the coastline between the two bays. This was not simulated using just the modeled wind drift in the nearshore zone. The wind drift predicts that oil would have come ashore between Skan Bay and Makushin Bay. An along-shore current along this coastline, which would be expected to occur, could be modeled and added to the current field to simulate this behavior. However, this would require considerable additional effort.

Hydrodynamic Modeling of Tidal Currents

Hydrodynamic modeling of tidal currents would likely improve the details of oil movements in and out of Makushin Bay. However, the overall patterns of oiling would likely not change dramatically. Again, the hydrodynamic modeling would require considerable effort.

Oil Distributions and Mass Balance

As noted, the specific locations of oil coming ashore are approximate and not a one-to-one match with observations. However, the general patterns match observations. Moreover, the mass balance of the oil is reasonably accurate, given the assumption of 50% of the oil initially entrained into the water column. The mass balance (Table 5-1) would not change significantly if other current patterns were input to the model.

Table 5-1. Mass Balance at the end of 28 days, combining the diesel simulation with the best IFO model run.

Compartment	% of Diesel	% of IFO	% of IFO + Diesel
Atmosphere	22.57	7.17	7.81
Shoreline	3.43	14.16	13.72
water column	56.93	42.19	42.80
sediment	4.00	20.13	19.46
decay	13.06	15.72	15.61

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APPENDIX A: GEOGRAPHICAL DATA AND MAPS

This appendix contains maps of the areas affected by the spill and the model habitat and depth grids used in the simulations.

A.1 Maps of the Vicinity of the Spill

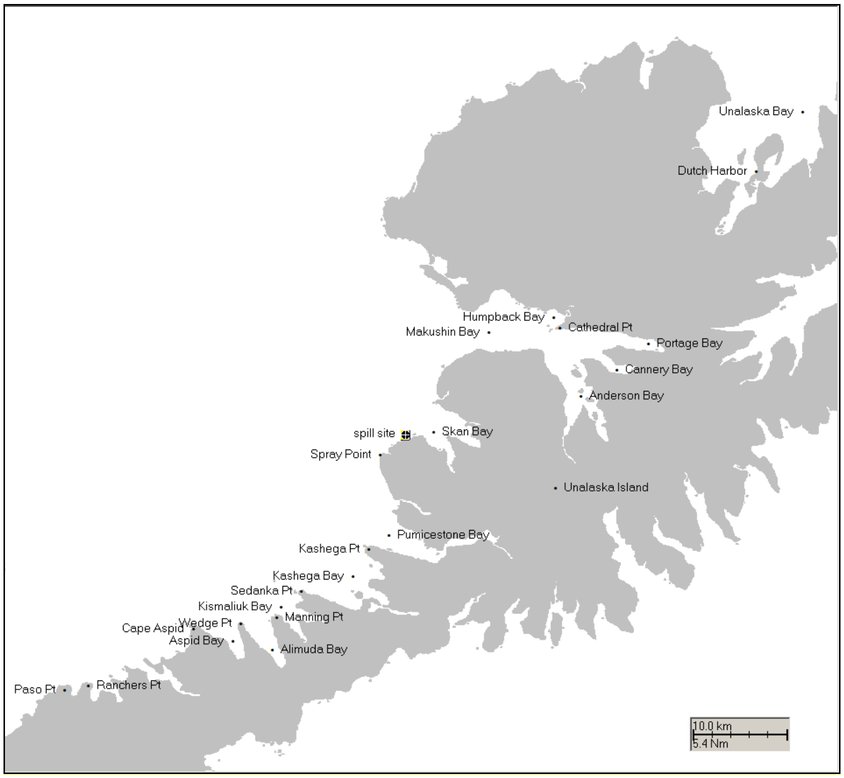

Figure A.1-1. Map of the vicinity of the spill.

A.2 Gridded Habitat Mapping

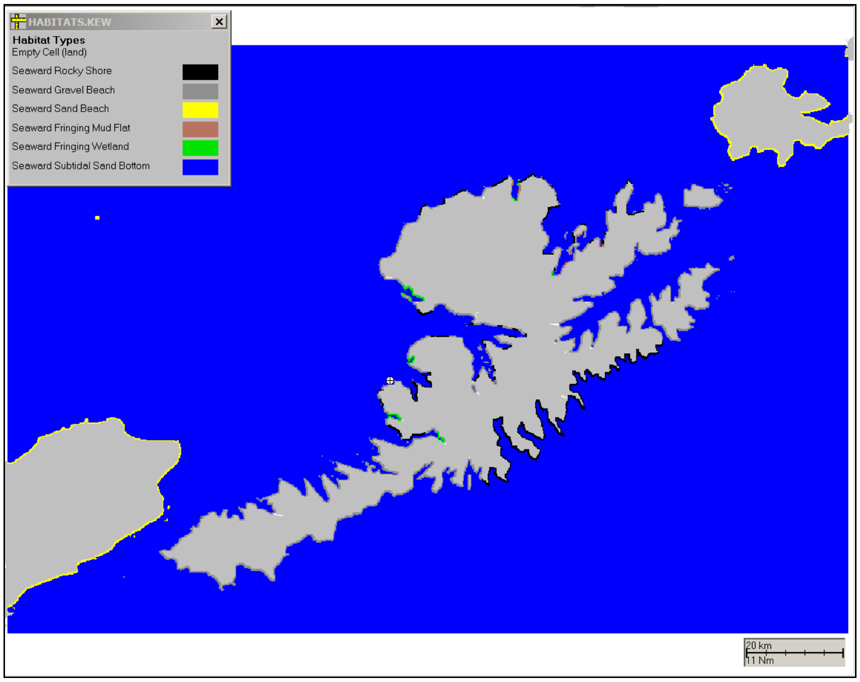

Figure A.2-1. Entire view of habitat grid used in modeling.

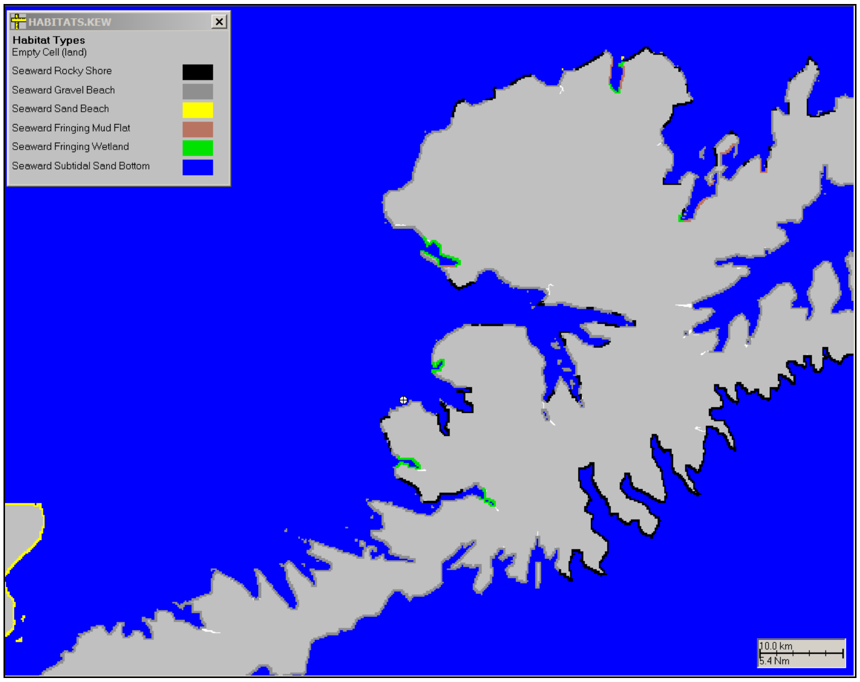

Figure A.2-2. Closer view of habitat grid used in modeling.

The location and dimensions of habitat grid are listed in Table A.2-1.

Table A.2-1. Location and dimensions of the habitat grid cells.

Characteristic	Value
Grid W edge (°longitude)	-168.335510
Grid S edge (°latitude)	53.157978
Cell size (°longitude)	0.002951
Cell size (°latitude)	0.001831
Cell size (m) west-east	196.41
Cell size (m) south-north	203.26
# cells west-east	900
# cells south-north	600
Water cell area (m^2)	39922.40
Shore cell length (m)	199.81
Shore cell width – exposed rocky (m)	1.0
Shore cell width – wave cut platform (m)	1.0
Shore cell width – fine sand (m)	1.0
Shore cell width – course sand (m)	1.0
Shore cell width – sand/gravel (m)	1.0
Shore cell width – gravel (m)	1.0
Shore cell width – exposed tidal (m)	1.0
Shore cell width – sheltered rocky (m)	1.0
Shore cell width – sheltered tidal (m)	1.0
Shore cell width – marsh (fringing) (m)	1.0
Shore cell width – glacier (m)	1.0

A.3 Gridded Water Depth Data

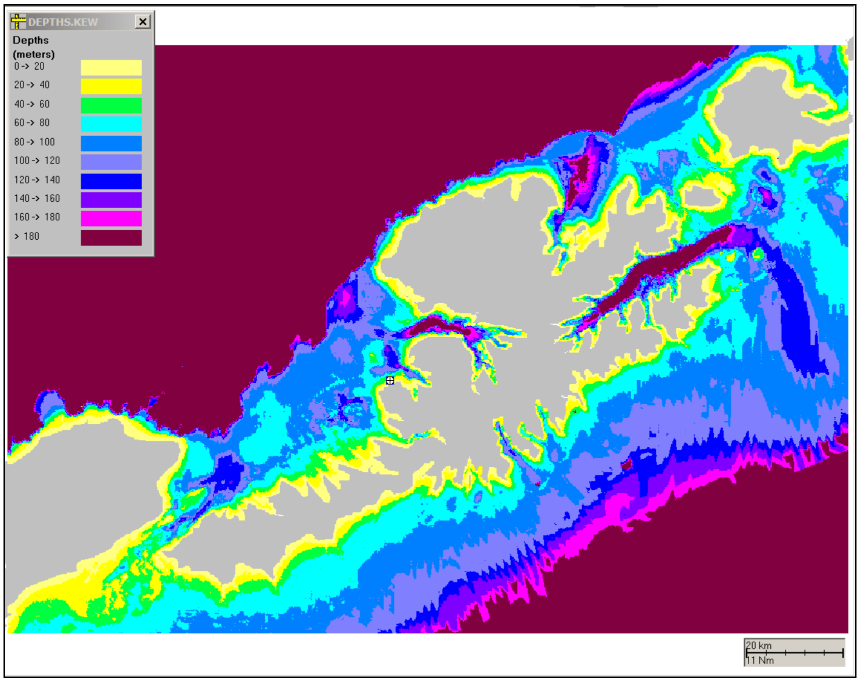

Figure A.3-1. Entire view of depth grid used in modeling.

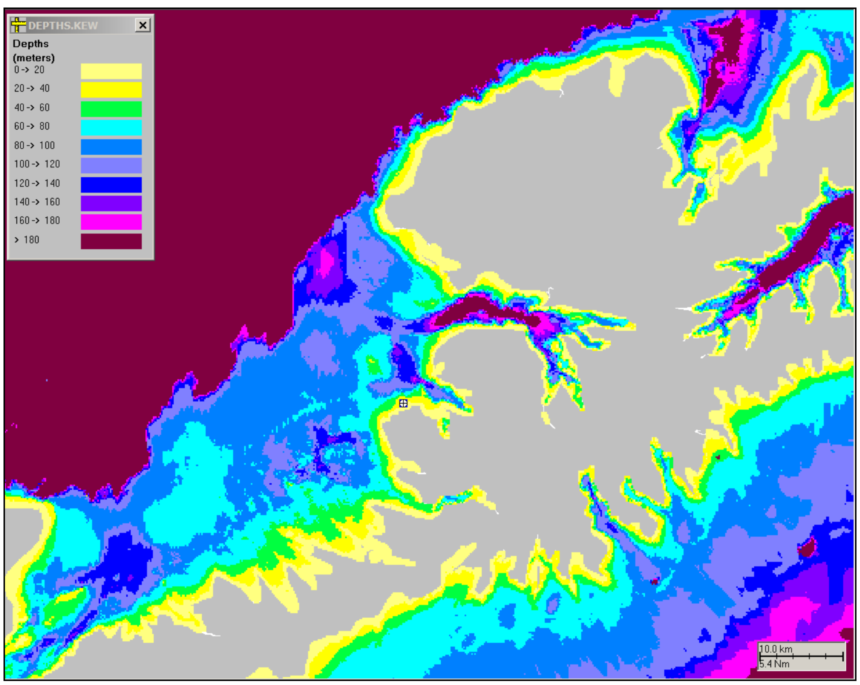

Figure A.3-2. Closer view of depth grid used in modeling.

APPENDIX B: OBSERVATIONS OF OIL CONTAMINATION AND RESPONSE ACTIVITIES

B.1 Observations of Oil Movements

The overflight observations conducted from 12 December to 15 December showed silver sheens, black oil/mousse, and tarballs dispersed between Skan Bay, Makushin Bay, Humpback Bay, Portage Bay, Cannery Bay and Anderson Bay.

The following maps are from NOAA HAZMAT and US Fish and Wildlife response over-flights on the dates indicated.

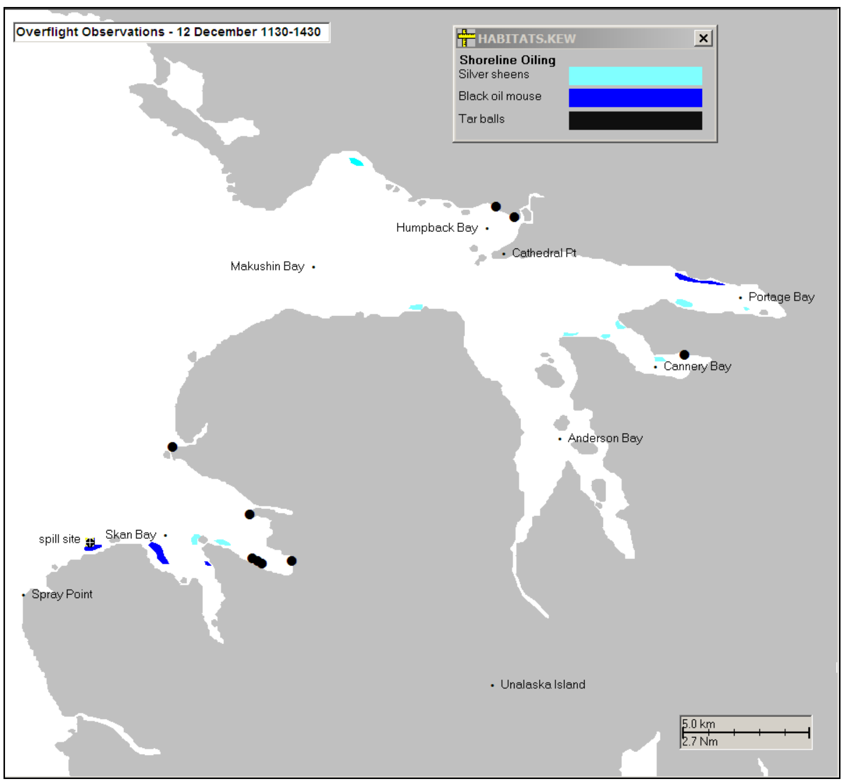

Figure B.1-1. Overflight observations from 12 December 2004 from 1130-1430.

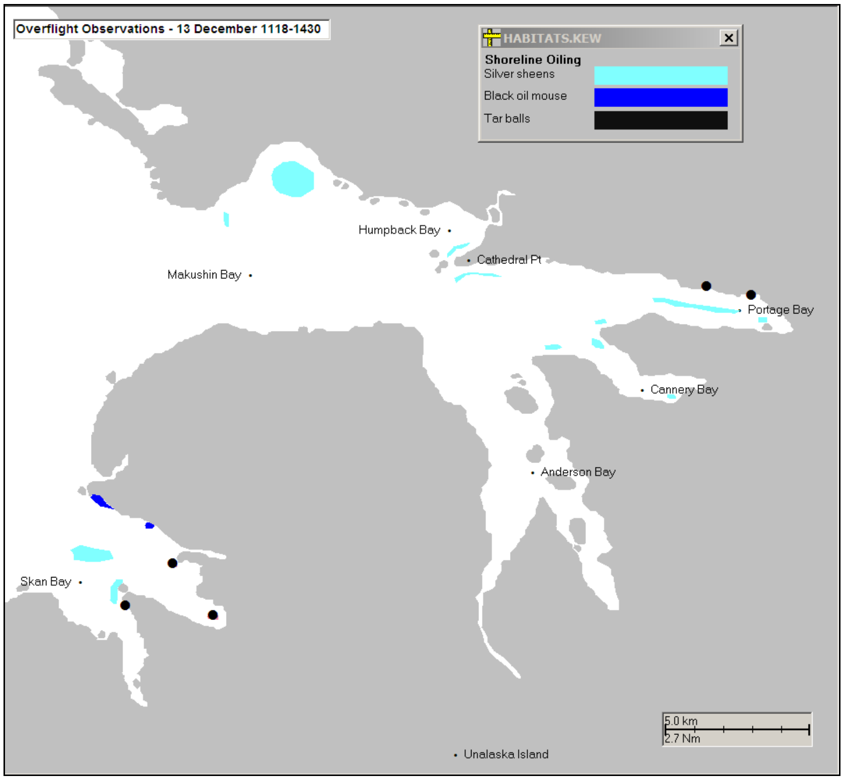

Figure B.1-2. Overflight observations from 13 December 2004 from 1118-1430.

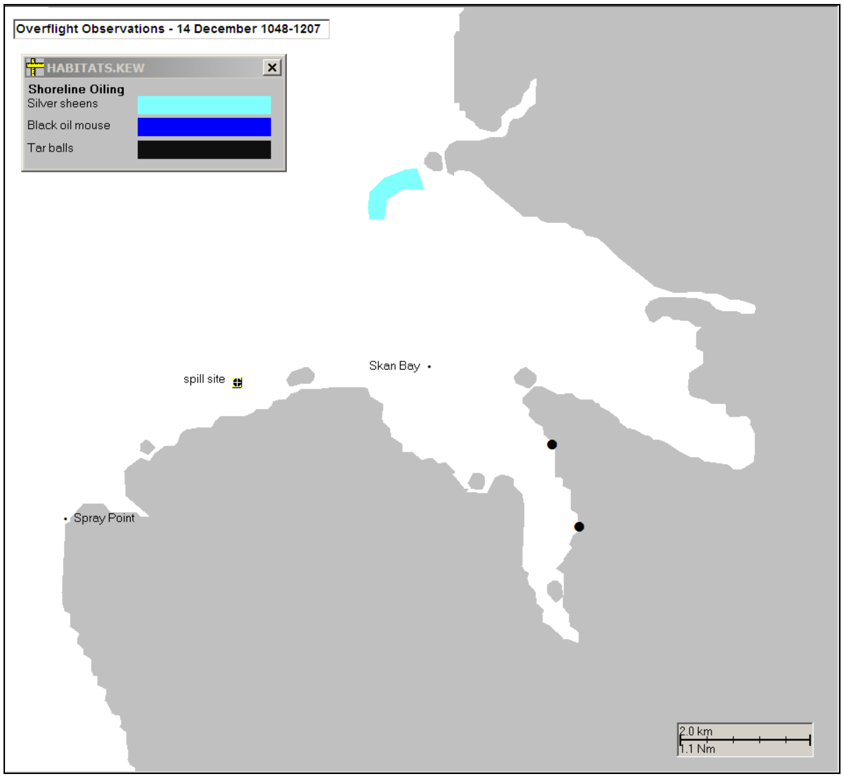

Figure B.1-3. Overflight observations from 14 December 2004 from 1048-1207.

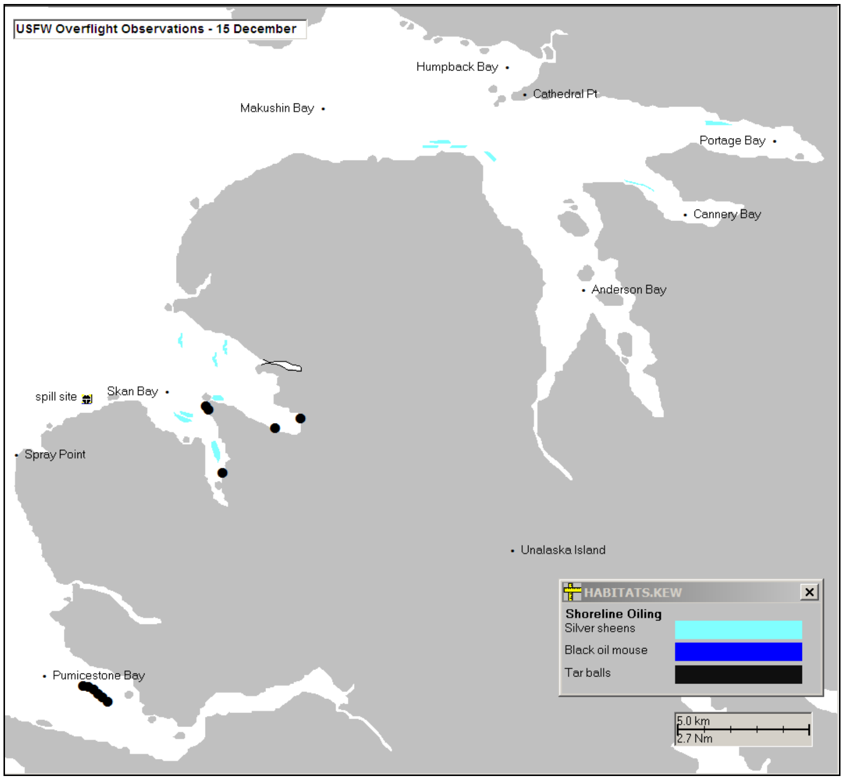

Figure B.1-4. Overflight observations from 15 December 2004 from US Fish and Wildlife Service (time not specified).

B.2 Shoreline Contamination

Figure B.2-1 is a composite of the SCAT oiling observations. The heavy, moderate, light, very light and tar ball observations were from surveys completed between 27 December and 5 February. The oiled areas (shown in blue) in the figure are areas that were observed oiled (map prepared by Polaris as of 10 May 2005).

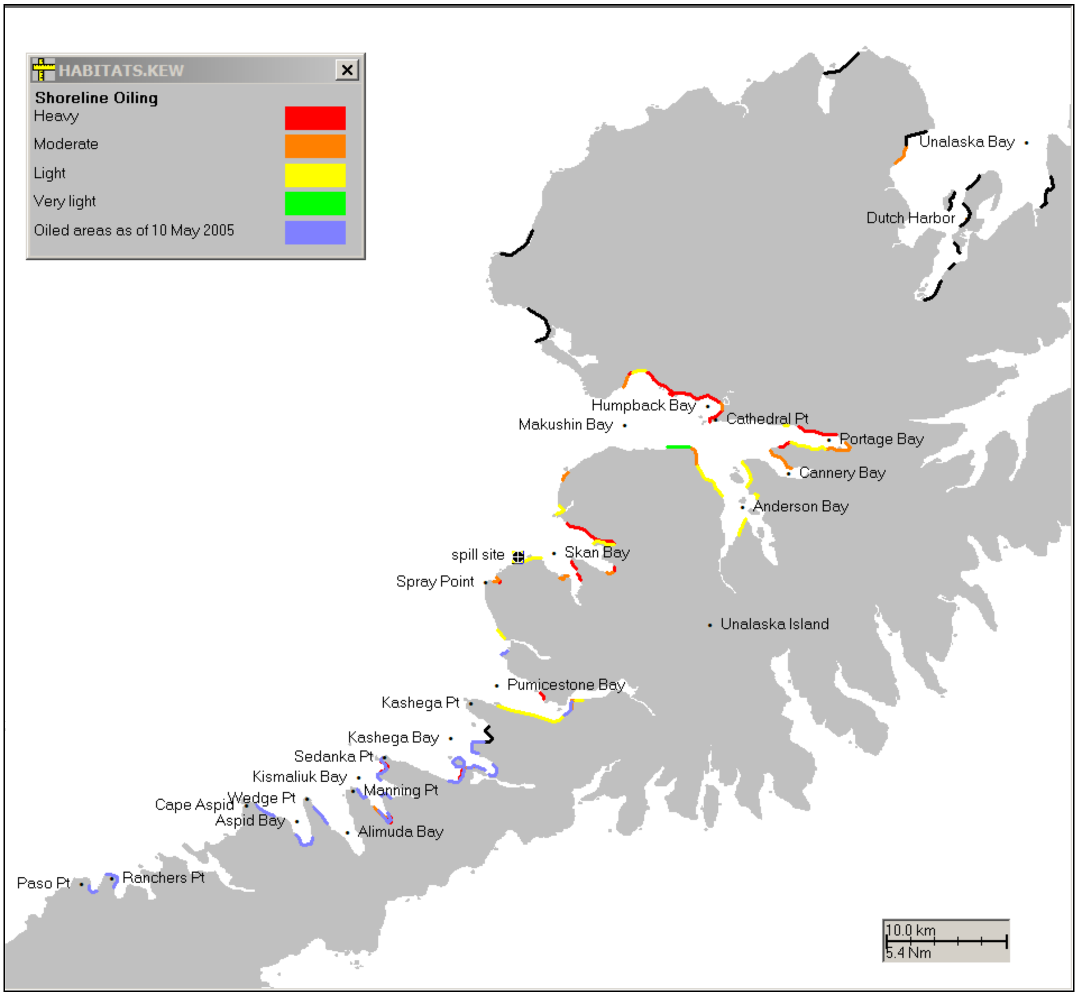

Figure B.2-1. Composite of SCAT oiling observations.

B.3 Water Contamination

Tarballs and sheens were observed during the water quality sampling program in January-February of 2005 as far northeast as Unalaska Bay and as far southwest as the extent of the Bering Sea coast of Unalaska Island (southwest of Paso Point in Figure B.2-1; Nuca Research and Planning Group, 2005).

APPENDIX C: HOURLY WIND SPEED AND DIRECTION AT AND AFTER THE TIME OF THE SPILL

Hourly wind speed and direction data were compiled from 2 stations in the vicinity of the spill-affected area. Data from Buoy 46072 were used until December 17th, at which time it went offline, and data from Buoy 46071 were used from that point until the end of February (NDBC, 2006). The data are listed in the following table.

Table C-1. Wind data from NDBC Buoys 46072 and 46071.

Source:
NOAA NDBC 46072 "Central Aleutians", 51.63° N, 172.16° W
(http://www.ndbc.noaa.gov/station_history.php?station=46072)
NOAA NDBC 46071 "Western Aleutians", 51.16° N, 179.05° W
(http://www.ndbc.noaa.gov/station_history.php?station=46071)

Year	Month	Day	Hour	Direction	Speed (m/s)
2004	11	30	15	236	16.33
2004	11	30	16	239	18.27
2004	11	30	17	236	19.44
2004	11	30	18	224	19.44
2004	11	30	19	211	20.22
2004	11	30	20	221	21.58
2004	11	30	21	239	20.22
2004	11	30	22	233	21.97
2004	11	30	23	220	19.05
2004	12	1	0	166	17.11
2004	12	1	2	222	14
2004	12	1	3	200	11.08
2004	12	1	4	198	8.36
2004	12	1	5	159	4.28
2004	12	1	6	106	3.11
2004	12	1	7	69	2.72
2004	12	1	8	31	6.22
2004	12	1	9	8	9.91
2004	12	1	10	17	11.47
2004	12	1	11	0	12.83
2004	12	1	12	344	13.8
2004	12	1	13	325	14.38
2004	12	1	14	348	16.72
2004	12	1	15	347	17.3
2004	12	1	16	333	17.88
2004	12	1	17	331	16.52
2004	12	1	18	271	14.19
2004	12	1	19	266	16.13
2004	12	1	20	302	14.19
2004	12	1	21	284	13.8

2004	12	1	22	283	13.02
2004	12	1	23	256	17.49
2004	12	2	0	270	12.05
2004	12	2	1	259	15.75
2004	12	2	2	262	21.77
2004	12	2	3	253	19.44
2004	12	2	4	249	23.52
2004	12	2	5	248	22.35
2004	12	2	6	249	20.6
2004	12	2	7	242	20.41
2004	12	2	8	242	18.86
2004	12	2	9	239	20.22
2004	12	2	10	257	19.05
2004	12	2	11	240	19.83
2004	12	2	12	236	20.8
2004	12	2	13	239	19.24
2004	12	2	14	248	17.88
2004	12	2	15	260	19.24
2004	12	2	16	235	23.71
2004	12	2	17	259	21.38
2004	12	2	18	246	20.6
2004	12	2	19	257	20.22
2004	12	2	20	236	16.72
2004	12	2	21	243	17.88
2004	12	2	22	235	14.77
2004	12	2	23	267	12.05
2004	12	3	0	136	13.61
2004	12	3	1	195	12.05
2004	12	3	2	190	14
2004	12	3	3	180	13.22
2004	12	3	4	184	15.94
2004	12	3	5	350	16.72
2004	12	3	6	353	19.05
2004	12	3	7	355	22.16
2004	12	3	8	345	21.77
2004	12	3	9	332	24.69
2004	12	3	10	79	25.08
2004	12	3	11	60	27.02
2004	12	3	12	62	29.16
2004	12	3	13	358	29.55
2004	12	3	14	51	32.46
2004	12	3	15	55	35.77
2004	12	3	16	56	35.77
2004	12	3	17	60	39.46
2004	12	3	18	59	37.71
2004	12	3	19	60	38.88
2004	12	3	20	63	43.54
2004	12	3	21	66	41.6
2004	12	3	22	70	38.49
2004	12	3	23	74	32.46
2004	12	4	0	233	27.6
2004	12	4	1	236	29.16

2004	12	4	2	244	33.43
2004	12	4	3	221	27.99
2004	12	4	4	225	26.63
2004	12	4	5	221	27.21
2004	12	4	6	188	22.16
2004	12	4	7	220	28.96
2004	12	4	8	215	26.83
2004	12	4	9	215	24.69
2004	12	4	10	206	26.05
2004	12	4	11	205	24.88
2004	12	4	12	200	24.88
2004	12	4	13	198	28.19
2004	12	4	14	226	30.71
2004	12	4	15	0	31.88
2004	12	4	16	0	34.99
2004	12	4	17	5	36.35
2004	12	4	18	233	34.21
2004	12	4	19	6	22.55
2004	12	4	20	231	26.83
2004	12	4	21	222	22.74
2004	12	4	22	211	22.35
2004	12	4	23	224	20.8
2004	12	5	0	211	16.13
2004	12	5	1	194	15.55
2004	12	5	2	180	14.19
2004	12	5	3	207	21.77
2004	12	5	4	218	21.97
2004	12	5	5	212	21.77
2004	12	5	6	210	19.44
2004	12	5	7	216	27.41
2004	12	5	8	224	24.49
2004	12	5	10	249	20.99
2004	12	5	11	239	24.88
2004	12	5	12	236	22.74
2004	12	5	13	235	24.88
2004	12	5	14	227	27.8
2004	12	5	15	228	22.55
2004	12	5	16	226	22.94
2004	12	5	17	229	20.6
2004	12	5	19	244	21.97
2004	12	5	20	256	26.44
2004	12	5	21	258	21.58
2004	12	5	22	255	21.97
2004	12	5	23	259	21.19
2004	12	6	0	62	17.88
2004	12	6	1	236	16.33
2004	12	6	2	223	17.88
2004	12	6	3	222	13.8
2004	12	6	4	232	16.33
2004	12	6	5	224	12.63
2004	12	6	6	222	9.33
2004	12	6	7	224	7.78

2004	12	6	9	329	4.86
2004	12	6	10	302	3.89
2004	12	6	12	240	6.61
2004	12	6	13	229	7.58
2004	12	6	14	286	9.72
2004	12	6	15	269	10.11
2004	12	6	16	289	6.8
2004	12	6	17	279	10.11
2004	12	6	18	326	20.99
2004	12	6	19	315	20.41
2004	12	6	20	340	22.35
2004	12	6	21	334	24.69
2004	12	6	22	348	22.55
2004	12	6	23	349	25.85
2004	12	7	0	128	23.13
2004	12	7	1	126	23.13
2004	12	7	2	38	24.49
2004	12	7	3	295	24.69
2004	12	7	4	294	26.63
2004	12	7	5	291	26.05
2004	12	7	6	303	27.6
2004	12	7	7	303	27.6
2004	12	7	8	305	27.6
2004	12	7	9	312	26.83
2004	12	7	10	320	26.44
2004	12	7	11	325	24.3
2004	12	7	12	338	24.3
2004	12	7	13	350	29.94
2004	12	7	14	73	25.27
2004	12	7	15	344	28.57
2004	12	7	16	350	24.88
2004	12	7	17	296	30.32
2004	12	7	18	304	26.83
2004	12	7	19	318	24.69
2004	12	7	20	321	28.38
2004	12	7	21	322	28.19
2004	12	7	22	329	28.77
2004	12	7	23	323	28.77
2004	12	8	0	83	34.21
2004	12	8	1	96	28.77
2004	12	8	2	128	28.19
2004	12	8	3	336	29.16
2004	12	8	4	313	31.88
2004	12	8	5	287	33.82
2004	12	8	6	303	31.68
2004	12	8	7	302	34.21
2004	12	8	8	308	30.71
2004	12	8	9	300	27.02
2004	12	8	10	300	25.08
2004	12	8	11	318	26.44
2004	12	8	12	320	29.55
2004	12	8	13	313	30.71

2004	12	8	14	318	28.96
2004	12	8	15	306	29.94
2004	12	8	16	307	27.6
2004	12	8	17	302	25.27
2004	12	8	18	293	25.08
2004	12	8	19	303	22.35
2004	12	8	20	300	23.91
2004	12	8	21	300	23.91
2004	12	8	22	309	19.24
2004	12	8	23	307	17.3
2004	12	9	0	309	14.58
2004	12	9	1	298	18.08
2004	12	9	2	286	16.72
2004	12	9	3	275	11.08
2004	12	9	4	245	9.33
2004	12	9	5	270	10.89
2004	12	9	6	220	9.33
2004	12	9	7	220	12.25
2004	12	9	8	220	19.83
2004	12	9	9	220	19.83
2004	12	9	10	220	23.13
2004	12	9	11	220	25.66
2004	12	9	12	220	24.88
2004	12	9	13	220	24.88
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2005	1	1	9	262	17.8

2005	1	1	10	265	19.4
2005	1	1	11	266	20.1
2005	1	1	12	267	19.6
2005	1	1	13	271	18.1
2005	1	1	14	275	17.9
2005	1	1	15	272	18.8
2005	1	1	16	280	16.7
2005	1	1	17	274	17.3
2005	1	1	18	278	15
2005	1	1	19	271	15.5
2005	1	1	20	272	14.4
2005	1	1	21	270	14.8
2005	1	1	22	257	11.6
2005	1	1	23	245	10.3
2005	1	2	0	220	10.9
2005	1	2	1	202	12.6
2005	1	2	2	196	12.7
2005	1	2	3	188	14.9
2005	1	2	4	163	19.3
2005	1	2	5	159	22.1
2005	1	2	6	166	24.9
2005	1	2	7	179	21.4
2005	1	2	8	186	19.8
2005	1	2	9	202	18.7
2005	1	2	10	206	19.4
2005	1	2	11	210	20.9
2005	1	2	12	209	19.5
2005	1	2	13	214	22.8
2005	1	2	14	224	23.8
2005	1	2	15	234	22.5
2005	1	2	16	246	20.7
2005	1	2	17	250	17.2
2005	1	2	18	253	17.9
2005	1	2	19	260	15.7
2005	1	2	20	258	17
2005	1	2	21	264	13.9
2005	1	2	22	262	14.9
2005	1	2	23	263	13
2005	1	3	0	262	12.8
2005	1	3	1	262	15.3
2005	1	3	2	260	13.1
2005	1	3	3	275	13.3
2005	1	3	4	293	12.4
2005	1	3	5	269	12.7
2005	1	3	6	270	12.2
2005	1	3	7	260	11.9
2005	1	3	8	268	11.9
2005	1	3	9	264	10.8
2005	1	3	10	266	11.7
2005	1	3	11	283	10.5
2005	1	3	12	277	10.4
2005	1	3	13	283	11.6

2005	1	3	14	265	10.6
2005	1	3	15	261	9.5
2005	1	3	16	253	8.5
2005	1	3	17	253	10.2
2005	1	3	18	244	11.4
2005	1	3	19	235	11
2005	1	3	20	238	11.2
2005	1	3	21	229	10.9
2005	1	3	22	230	11.4
2005	1	3	23	230	11.4
2005	1	4	0	232	12.7
2005	1	4	1	231	11.5
2005	1	4	2	234	11.6
2005	1	4	3	230	11.4
2005	1	4	4	226	10.4
2005	1	4	5	224	11.2
2005	1	4	6	223	11.4
2005	1	4	7	222	11.4
2005	1	4	8	219	10.1
2005	1	4	9	215	11.1
2005	1	4	10	212	10.7
2005	1	4	11	210	11.4
2005	1	4	12	209	11.6
2005	1	4	13	209	12.9
2005	1	4	14	214	12.2
2005	1	4	15	211	12.6
2005	1	4	16	215	11.9
2005	1	4	17	209	11.9
2005	1	4	18	205	11.7
2005	1	4	19	197	11
2005	1	4	20	185	10
2005	1	4	21	187	10.5
2005	1	4	22	181	10.7
2005	1	4	23	176	10.9
2005	1	5	0	169	11.6
2005	1	5	1	161	11.9
2005	1	5	2	158	11.6
2005	1	5	3	152	13.3
2005	1	5	4	150	13.5
2005	1	5	5	149	12.8
2005	1	5	6	145	13.5
2005	1	5	7	143	13.1
2005	1	5	8	147	11.8
2005	1	5	9	148	11.5
2005	1	5	10	141	11.7
2005	1	5	11	134	10.7
2005	1	5	12	129	11.6
2005	1	5	13	127	13
2005	1	5	14	120	12.8
2005	1	5	15	112	13.5
2005	1	5	16	111	16.1
2005	1	5	17	116	16

2005	1	5	18	121	14.4
2005	1	5	19	126	14.2
2005	1	5	20	127	13.4
2005	1	5	21	125	13.5
2005	1	5	22	127	14.2
2005	1	5	23	122	14.5

APPENDIX D: CURRENT DATA

The source and assumptions for the background current data are described in Section 3.3.

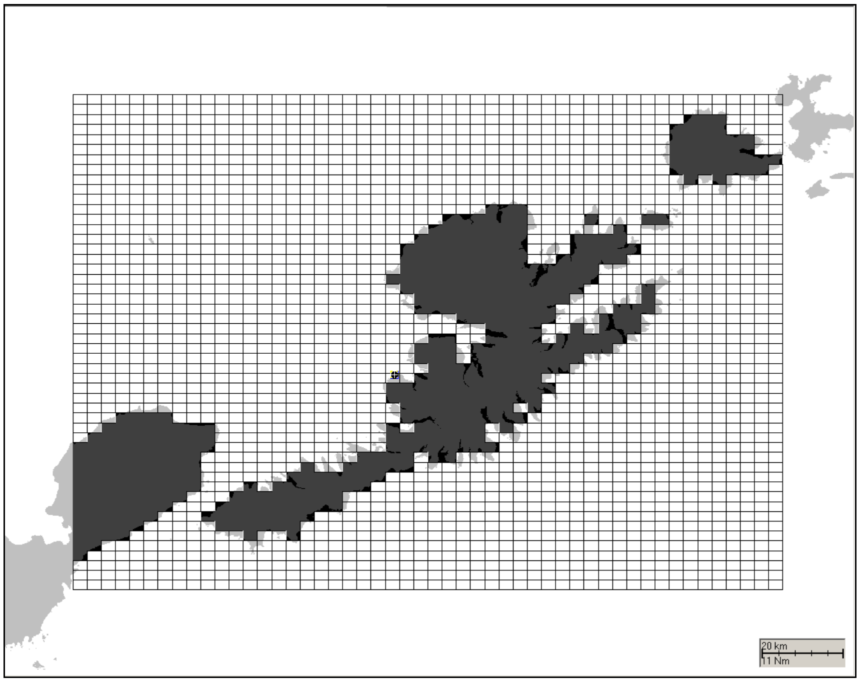

Figure D-1. Grid used for estimation of currents.

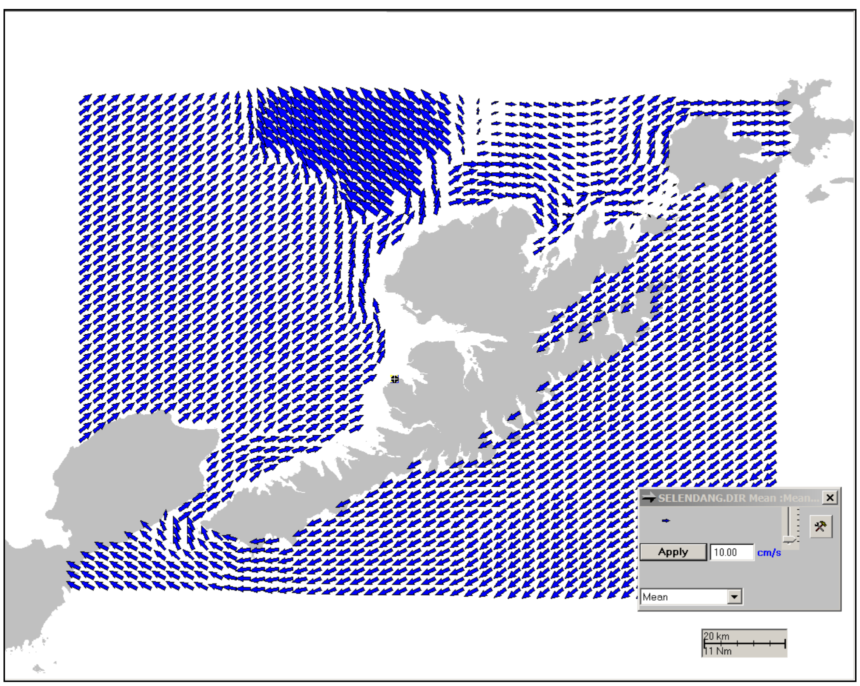

Figure D-2. Mean currents used for modeling scenarios.

APPENDIX E. INPUTS TO THE SIMAP PHYSICAL FATES MODEL

Table E-1. Inputs describing the IFO 380 scenario.

Name	Description	Units	Source(s) of Information	Value(s)
Spill Site	Location of the spill site	-	ADEC Situation Reports	0.5 mile offshore Unalaska Island between Spray Cape and Skan Bay
Spill Latitude	Latitude of the spill site	Degrees	ADEC Situation Reports (adjusted relative to grid map)	53^{o} 38'4" N
Spill Longitude	Longitude of the spill site	Degrees	ADEC Situation Reports (adjusted relative to grid map)	167^{o} 7'30" W
Depth of release	Depth below the water surface of the release	m	ADEC Situation Reports	0 m (surface)
Start time and date	Date and time the release began	Date, hr,min	ADEC Situation Reports	8 Dec 2004 19:14 AKST
Duration	Duration of the release	(hrs)	Based on Folley et al. (2006); assumed complete on Dec 12	Two releases, 12.5% at 0.25 hrs and 87.5% for 136 hrs
Total spill volume or mass	Total volume (or weight) released	bbl, gal., MT, kg, m^3	Folley et al., 2006; Barry, 2005	339,538 gal. (1271 MT)
Salinity	Surface water salinity	ppt	French et al. (1996)	32 ppt
Water Temperature	Surface water temperature	Degrees C	French et al. (1996)	$5^{o}C$ ($41^{o}F$)
Air Temper-ature	Air water temperature at water surface	Degrees C	(assume = water temperature)	$5^{o}C$
Fetch	Fetch = distance to land to N, S, E, W (if landfall not in model domain)	km	>0 km; 1000 km if open ocean	Charts
Wind drift speed	Speed oil moves down wind relative to wind	% of wind speed	ASCE, 1996	3.5
Wind drift angle	Angle to right of wind (in northern hemisphere) oil drifts	Deg. to right of downwind	ASCE, 1996	0
Horizontal turbulent diffusion coefficient	Randomized turbulent mixing parameter in x & y	m^2/sec	French et al. (1996, 1999) based on Okubo and Ozmidov (1970); Okubo (1971)	25-100 m^2/sec (high energy nearshore areas)
Vertical turbulent diffusion coefficient	Randomized turbulent mixing parameter in z (belowe surface layer)	m^2/sec	French et al. (1996, 1999) based on Okubo and Ozmidov (1970); Okubo (1971)	0.0001 m^2/sec
Suspended sediment concentration	Average suspended sediment concentration	mg/l	French et al. (1996)	10 mg/l
Suspended sediment settling rate	Net settling rate for suspended sediments	m/day	French et al. (1996)	1 m/day

Table E-2. Inputs describing the diesel scenario.

Name	Description	Units	Source(s) of Information	Value(s)
Spill Site	Location of the spill site	-	ADEC Situation Reports	0.5 mile offshore Unalaska Island between Spray Cape and Skan Bay
Spill Latitude	Latitude of the spill site	Degrees	ADEC Situation Reports (adjusted relative to grid map)	53^{o} 38'4" N
Spill Longitude	Longitude of the spill site	Degrees	ADEC Situation Reports (adjusted relative to grid map)	167^{o} 7'30" W
Depth of release	Depth below the water surface of the release	m	ADEC Situation Reports	0 m (surface)
Start time and date	Date and time the release began	Date, hr,min	ADEC Situation Reports	8 Dec 2004 19:14 AKST
Duration	Duration of the release	(hrs)	Based on Folley et al. (2006); assumed complete on Dec 12	One continous release over 136 hours
Total spill volume or mass	Total volume (or weight) released	bbl, gal., MT, kg, m^3	Folley et al., 2006; Barry, 2005	14,680 gal. (46.1 MT)
Salinity	Surface water salinity	ppt	French et al. (1996)	32 ppt
Water Temperature	Surface water temperature	Degrees C	French et al. (1996)	5^{o}C (41^{o}F)
Air Temper-ature	Air water temperature at water surface	Degrees C	(assume = water temperature)	5^{o}C
Fetch	Fetch = distance to land to N, S, E, W (if landfall not in model domain)	km	>0 km; 1000 km if open ocean	Charts
Wind drift speed	Speed oil moves down wind relative to wind	% of wind speed	ASCE, 1996	3.5
Wind drift angle	Angle to right of wind (in northern hemisphere) oil drifts	Deg. to right of downwind	ASCE, 1996	0
Horizontal turbulent diffusion coefficient	Randomized turbulent mixing parameter in x & y	m^2/sec	French et al. (1996, 1999) based on Okubo and Ozmidov (1970); Okubo (1971)	75 m^2/sec (areas as for the best IFO run)
Vertical turbulent diffusion coefficient	Randomized turbulent mixing parameter in z (belowe surface layer)	m^2/sec	French et al. (1996, 1999) based on Okubo and Ozmidov (1970); Okubo (1971)	0.0001 m^2/sec
Suspended sediment concentration	Average suspended sediment concentration	mg/l	French et al. (1996)	10 mg/l
Suspended sediment settling rate	Net settling rate for suspended sediments	m/day	French et al. (1996)	1 m/day

Table E-3. Oil name and properties for IFO 380.

Name	Description	Units	Source(s) of Information	Value(s)
Oil: name	Oil type or chemical released	(name)	Simecak-Beatty and Pichel (2006)	IFO 380 - Alaska
Oil: density	Density of the oil	g/cm^3 or API	Simecak-Beatty and Pichel (2006)	0.989 g/cm^3
Oil: viscosity	Viscosity of the oil	Centi-poise (cP)	Simecak-Beatty and Pichel (2006)	4,873.5 cP
Oil: volatile fraction	Fraction of oil with boiling point <180^{o}C	fraction	Boiling curve data for typical IFO 380	Jokuty et al. (1996)
Oil semi-volatile fraction	Fraction of with boiling point 180-265^{o}C	fraction	Boiling curve data for typical IFO 380	Jokuty et al. (1996)
Oil: low-volatility fraction	Fraction of oil with boiling point 265-380^{o}C	fraction	Boiling curve data for typical IFO 380	Jokuty et al. (1996)
Oil: initial water fraction	Fraction of initial spill volume which is water	fraction	(assumed)	0
Oil: water fraction in mousse	Fraction of oil mousse which is water (maximum)	fraction	(assumed)	0

Table E-4. Oil name and properties for the diesel fuel.

Name	Description	Units	Source(s) of Information	Value(s)
Oil: name	Oil type or chemical released	(name)	Simecak-Beatty and Pichel (2006)	Marine diesel - Alaska
Oil: density	Density of the oil	g/cm^3 or API	Simecak-Beatty and Pichel (2006)	0.839 g/cm^3
Oil: viscosity	Viscosity of the oil	Centi-poise (cP)	Simecak-Beatty and Pichel (2006)	8.39 cP
Oil: volatile fraction	Fraction of oil with boiling point <180^{o}C	fraction	Jokuty et al. (1999)[1]	0.186664
Oil semi-volatile fraction	Fraction of with boiling point 180-265^{o}C	fraction	Jokuty et al. (1999)[1]	0.426825
Oil: low-volatility fraction	Fraction of oil with boiling point 265-380^{o}C	fraction	Jokuty et al. (1999)[1]	0.000000
Oil: initial water fraction	Fraction of initial spill volume which is water	fraction	(assumed)	0
Oil: water fraction in mousse	Fraction of oil mousse which is water (maximum)	fraction	(assumed)	0

[1] – Total hydrocarbon data was taken from the Environment Canada Oil Property Database. The aromatic hydrocarbon fraction was subtracted from the total hydrocarbon fraction to obtain the aliphatic fraction.

APPENDIX F. FATES MODEL RESULTS

F.1 Results for Runs Included in the Sensitivity Analysis for IFO

The horizontal diffusion (randomized mixing) coefficient was varied from 10-100 m^2/sec. The percent of oil submerged (assumed by incorporation of sediment into the oil) was varied from 10% to 90%. The results for 10 m^2/sec are not shown below, as the oil did not disperse away from Skan Bay and the spill site area in those simulations.

Shoreline oil distribution for runs assuming horizontal diffusion of 25, 50, 75, and 100 m^2/sec and 10, 25, 50, 75, and 90 percent of oil submerged are shown in Figures F.1-1 to F.1-20. These oil distributions may be compared to the SCAT data results summarized in Figure B.2-1. The best match was obtained assuming a horizontal diffusion coefficient of 75 m^2/sec and 50% of the oil assumed submerged after release. Note that these figures do not show amount of oil on shore, only the general distribution. Amounts on shore are mapped in Section F.2. (Because these maps of oil amount on shore are to scale, the overall distribution of oiling is difficult to see on large-scale maps, as used in this section.)

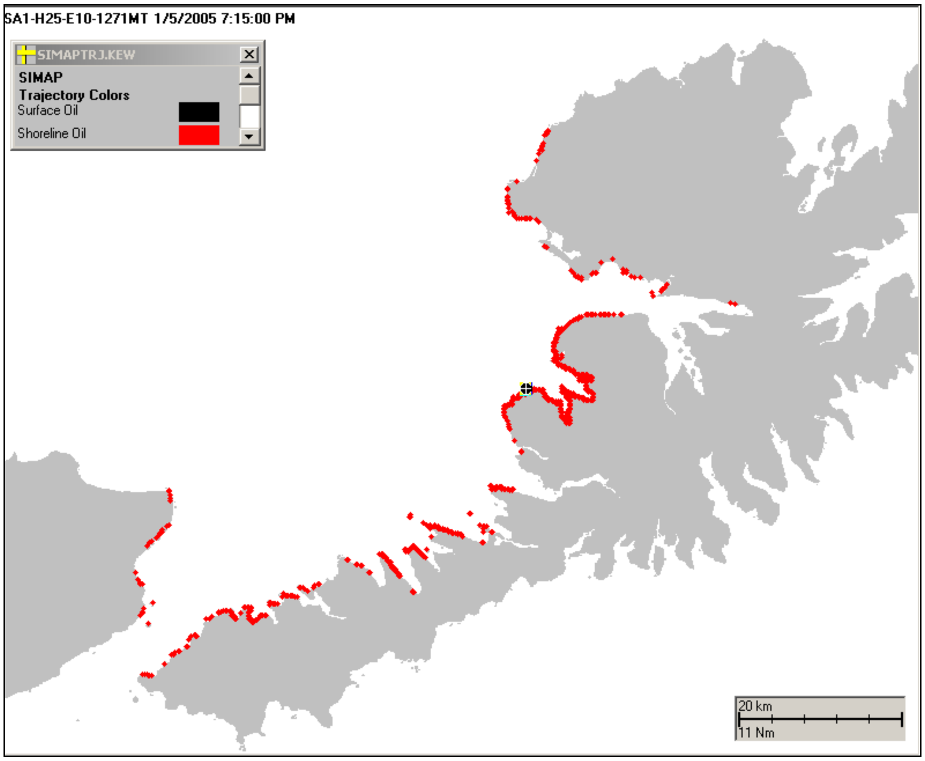

Figure F.1-1. Shoreline oiling for horizontal diffusion coefficient of 25 m^2/sec and 10% of the IFO assumed submerged after release.

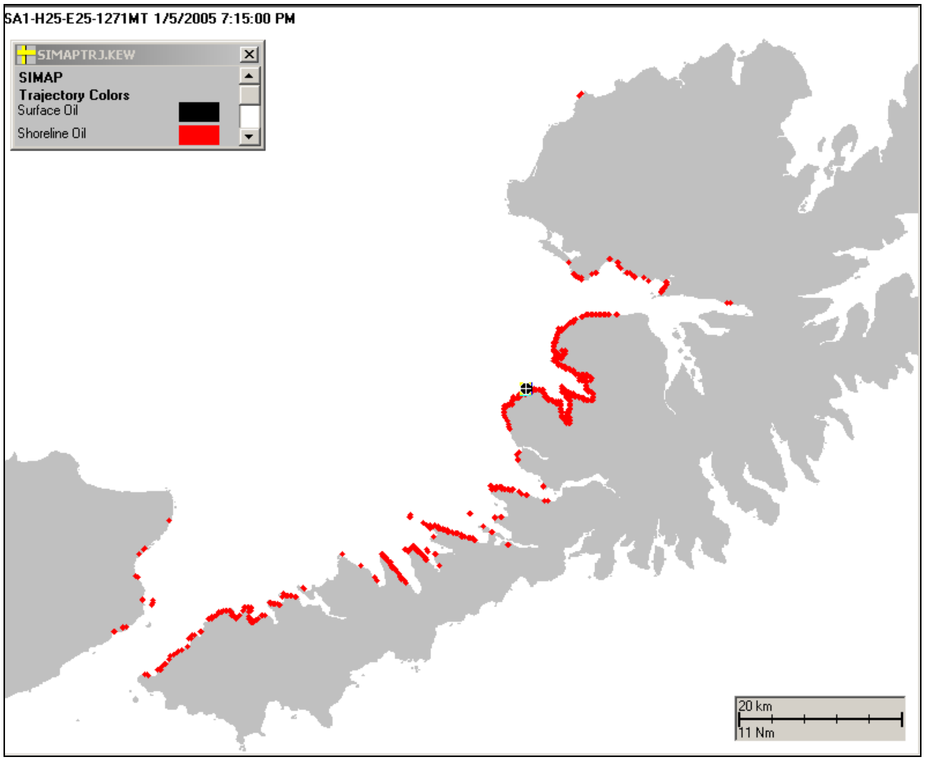

Figure F.1-2. Shoreline oiling for horizontal diffusion coefficient of 25 m^2/sec and 25% of the IFO assumed submerged after release.

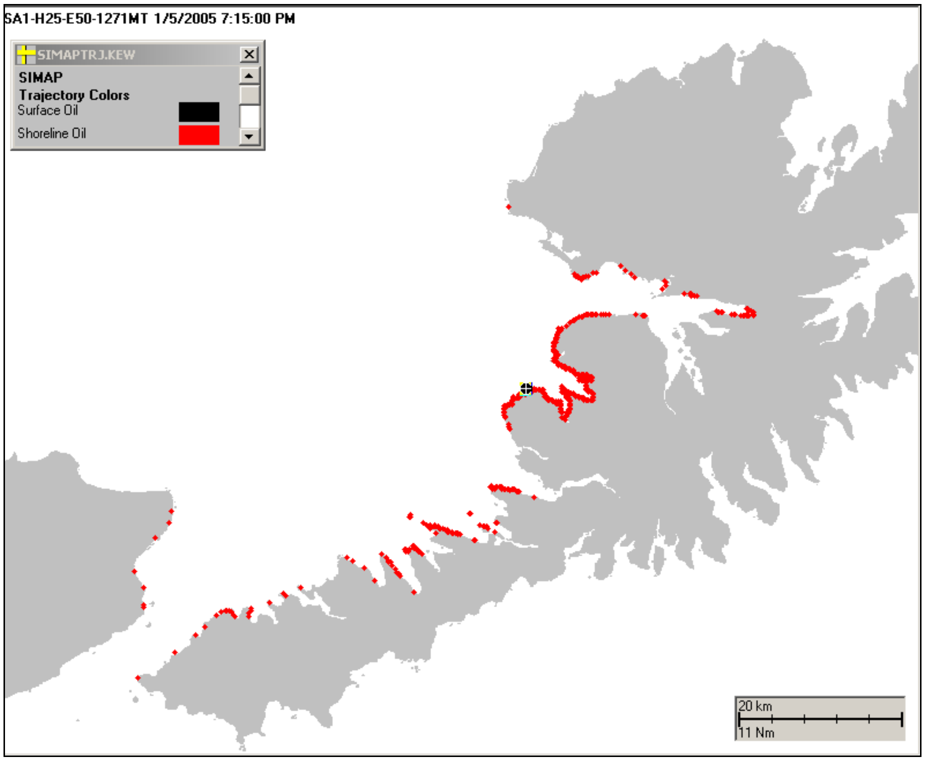

Figure F.1-3. Shoreline oiling for horizontal diffusion coefficient of 25 m^2/sec and 50% of the IFO assumed submerged after release.

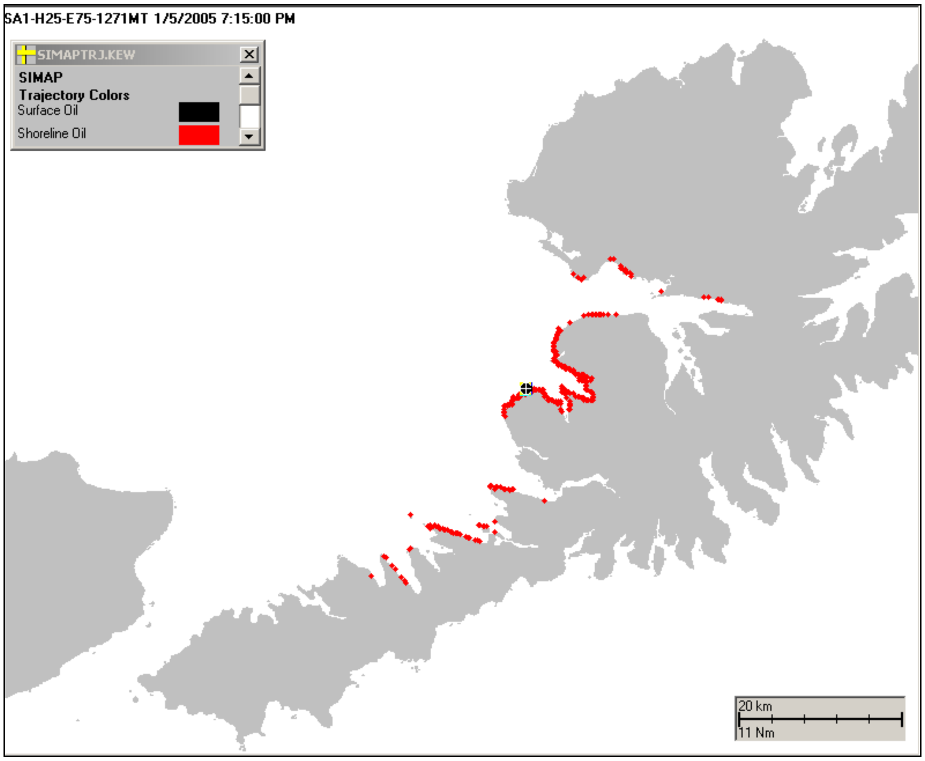

Figure F.1-4. Shoreline oiling for horizontal diffusion coefficient of 25 m^2/sec and 75% of the IFO assumed submerged after release.

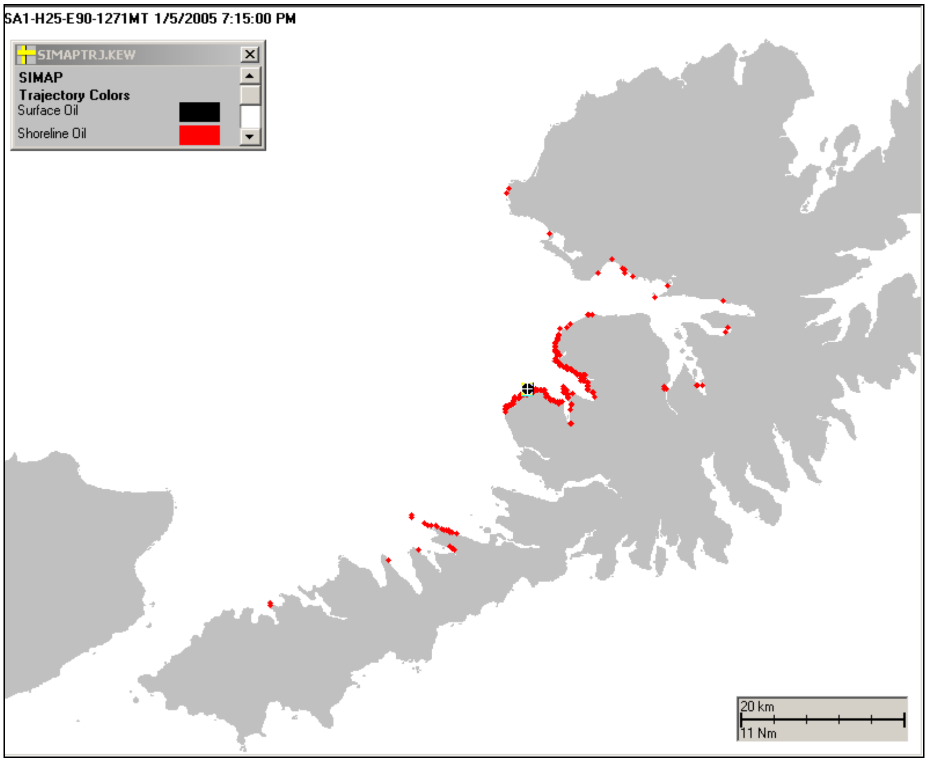

Figure F.1-5. Shoreline oiling for horizontal diffusion coefficient of 25 m^2/sec and 90% of the IFO assumed submerged after release.

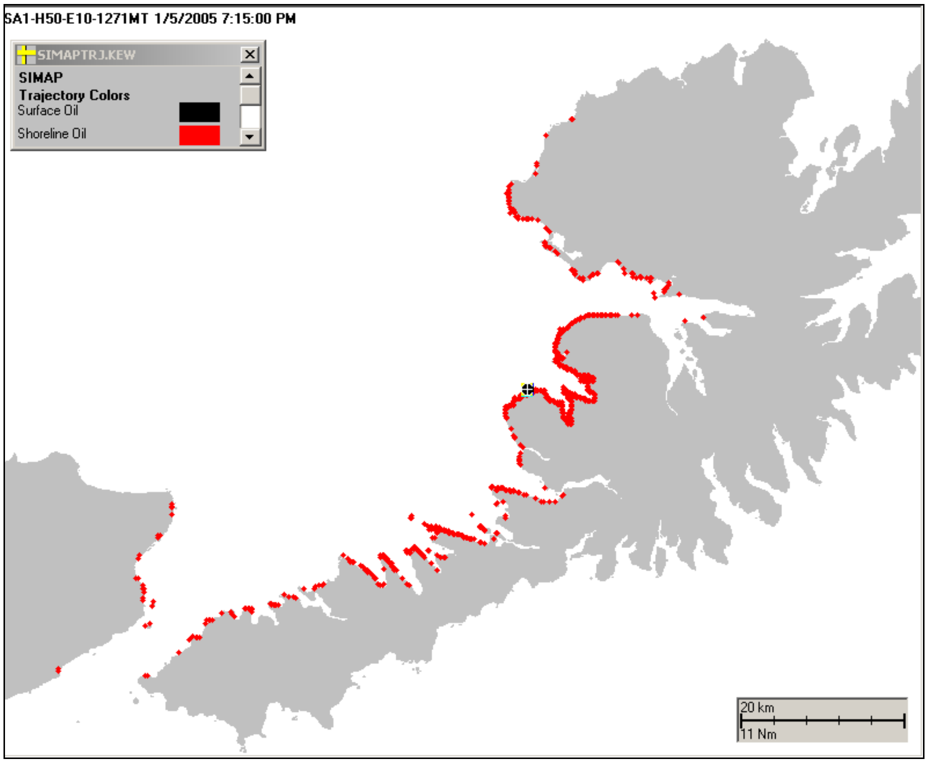

Figure F.1-6. Shoreline oiling for horizontal diffusion coefficient of 50 m^2/sec and 10% of the IFO assumed submerged after release.

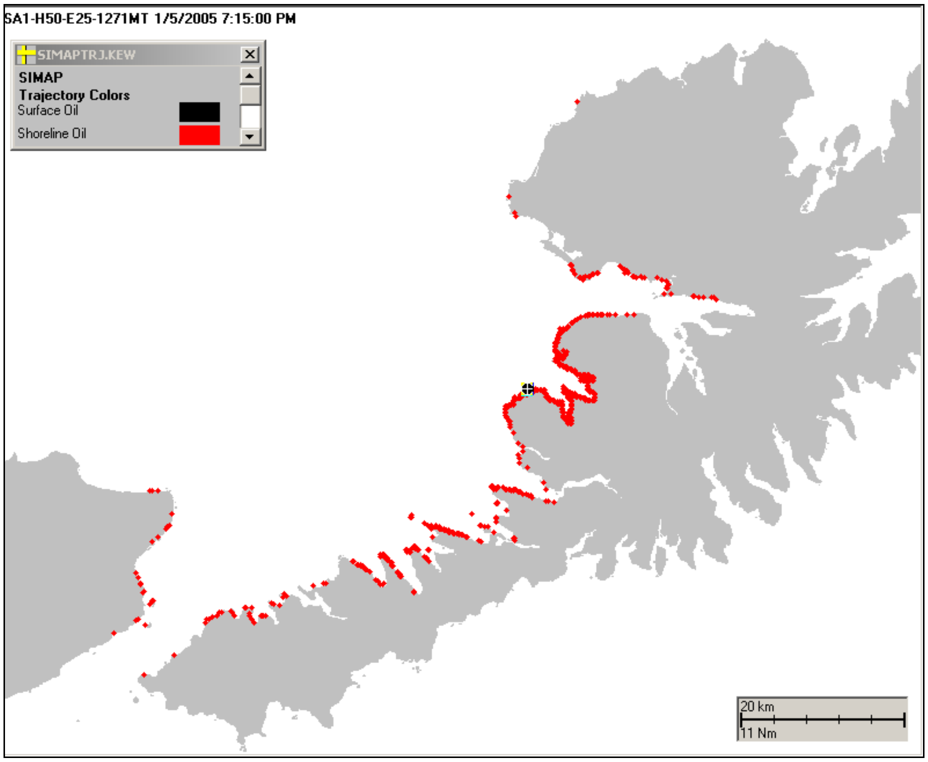

Figure F.1-7. Shoreline oiling for horizontal diffusion coefficient of 50 m^2/sec and 25% of the IFO assumed submerged after release.

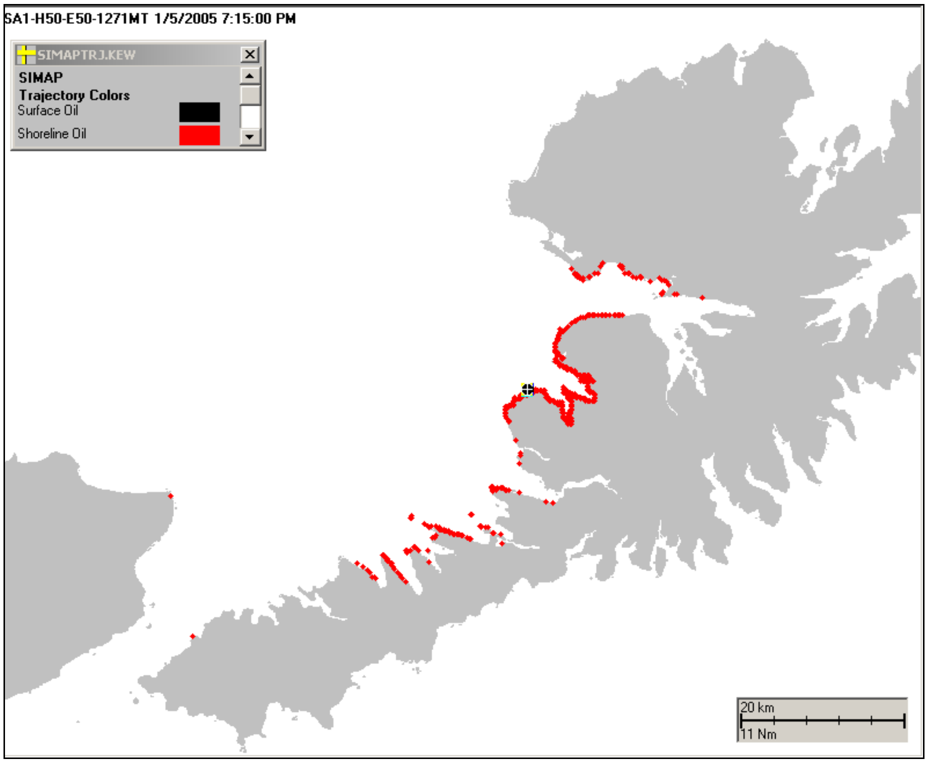

Figure F.1-8. Shoreline oiling for horizontal diffusion coefficient of 50 m^2/sec and 50% of the IFO assumed submerged after release.

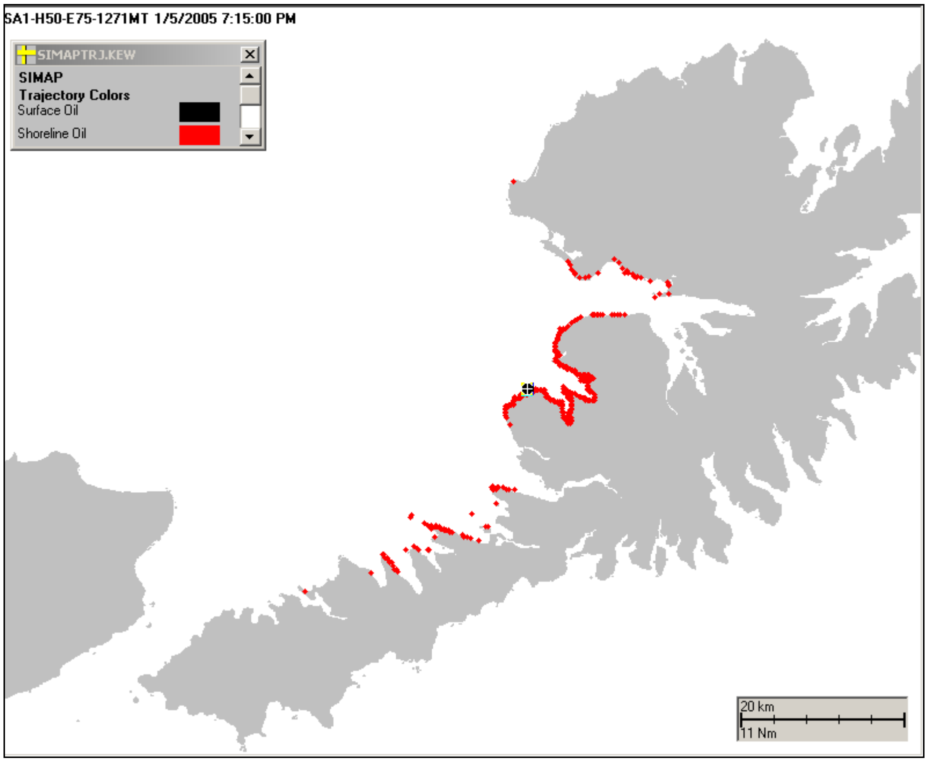

Figure F.1-9. Shoreline oiling for horizontal diffusion coefficient of 50 m^2/sec and 75% of the IFO assumed submerged after release.

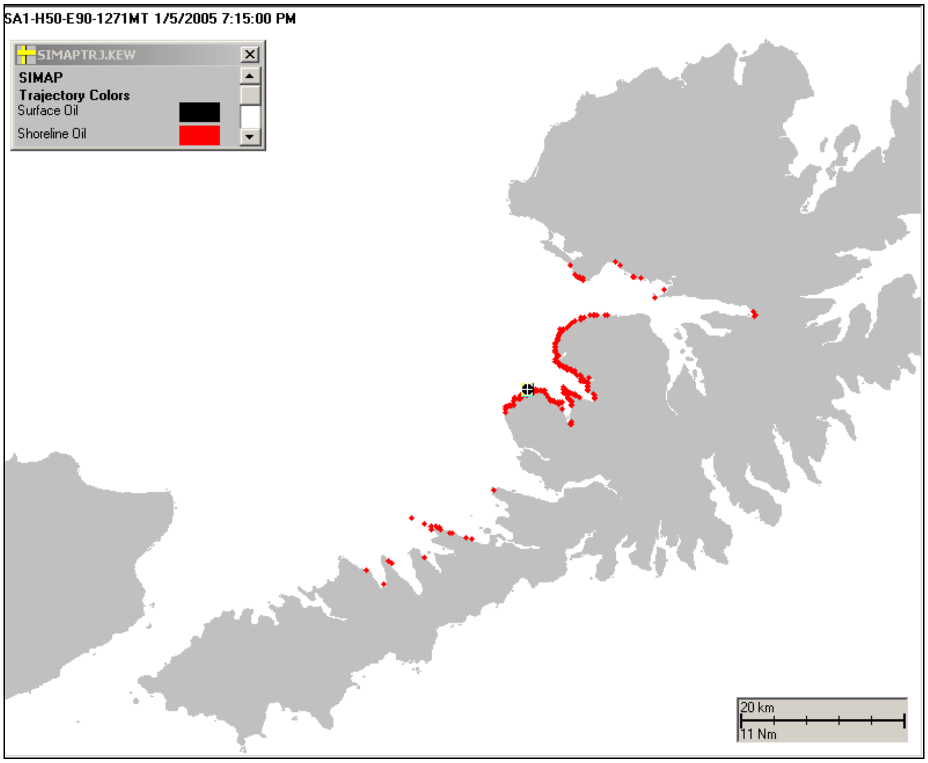

Figure F.1-10. Shoreline oiling for horizontal diffusion coefficient of 50 m^2/sec and 90% of the IFO assumed submerged after release.

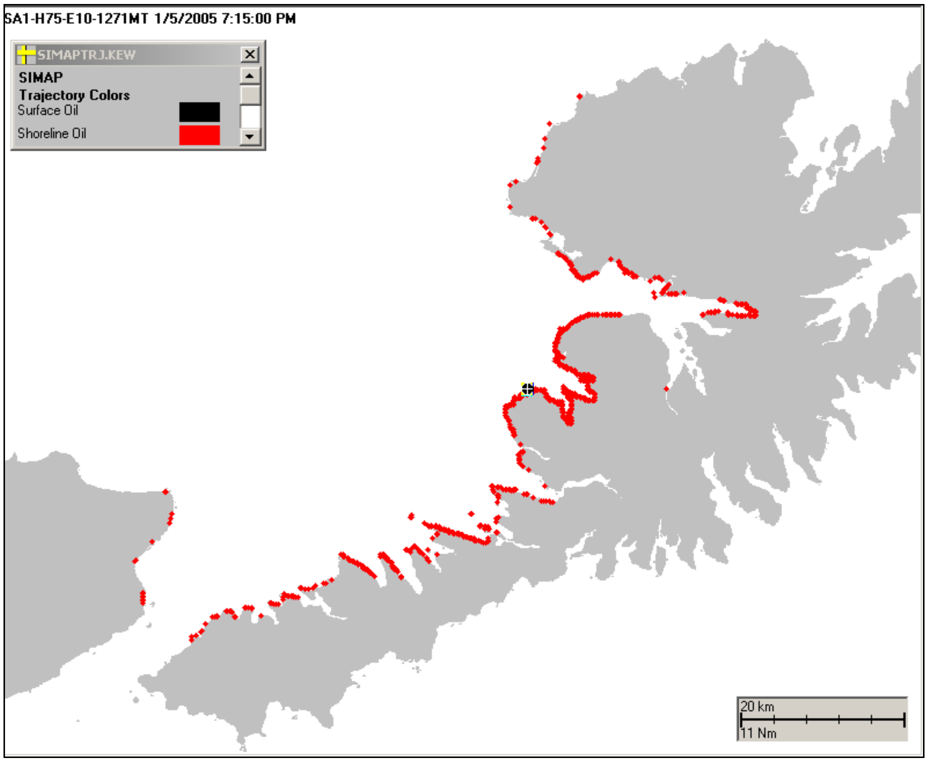

Figure F.1-11. Shoreline oiling for horizontal diffusion coefficient of 75 m^2/sec and 10% of the IFO assumed submerged after release.

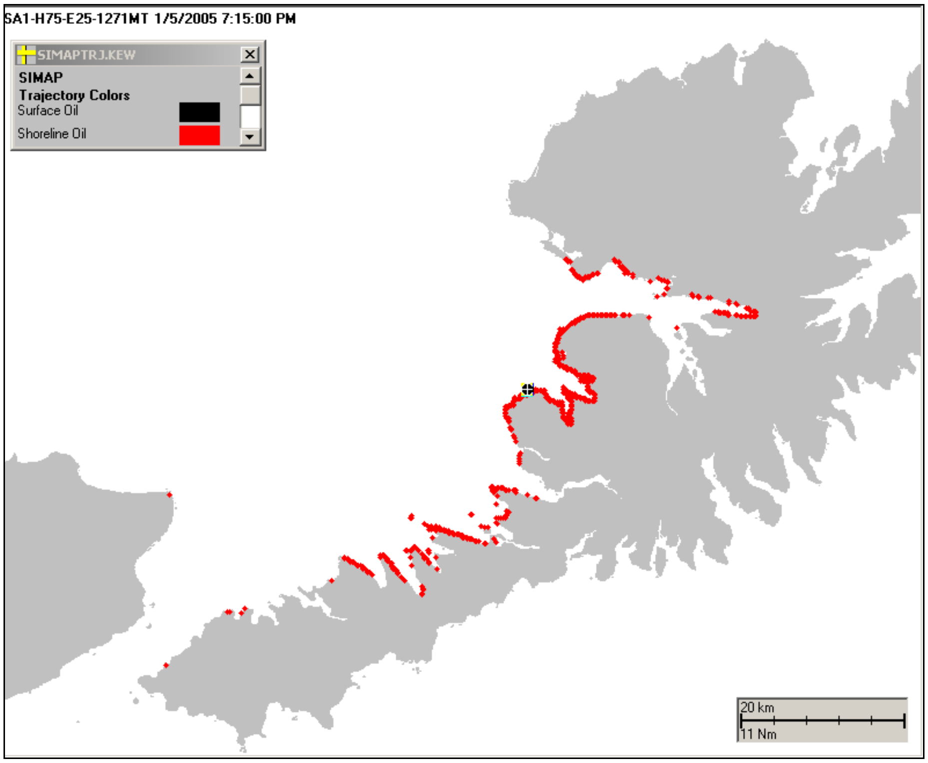

Figure F.1-12. Shoreline oiling for horizontal diffusion coefficient of 75 m^2/sec and 25% of the IFO assumed submerged after release.

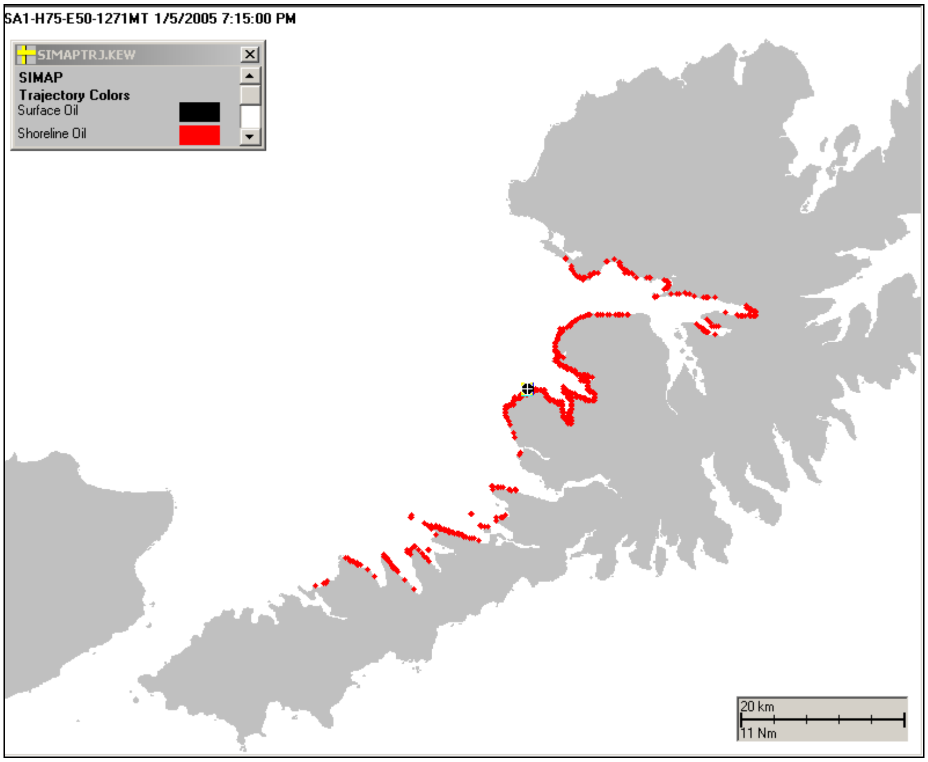

Figure F.1-13. Shoreline oiling for horizontal diffusion coefficient of 75 m^2/sec and 50% of the IFO assumed submerged after release.

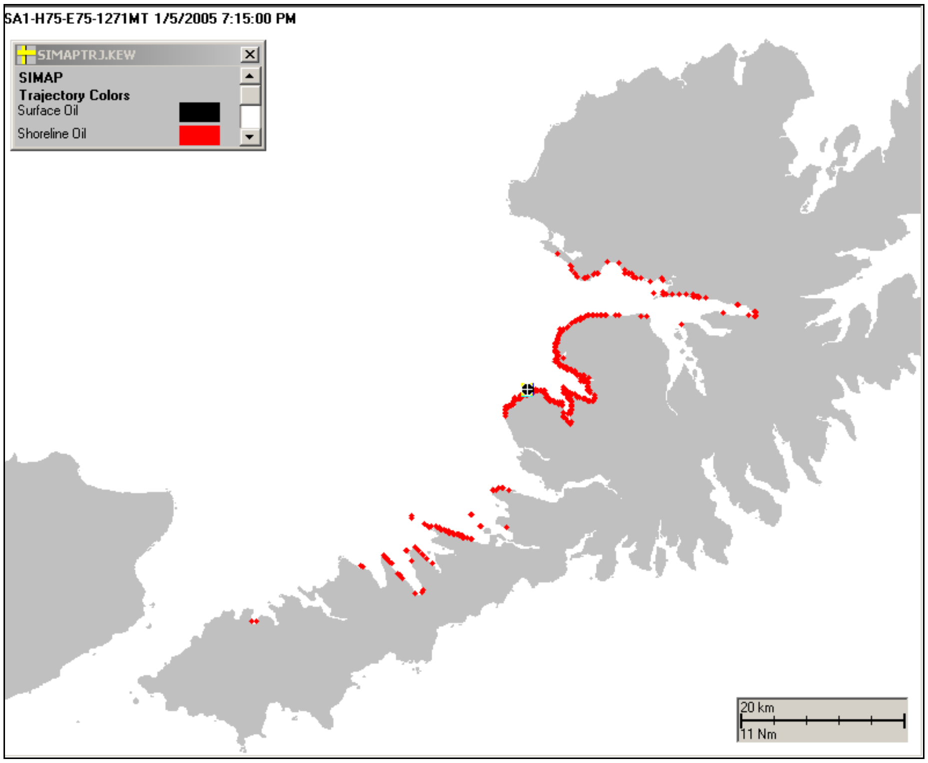

Figure F.1-14. Shoreline oiling for horizontal diffusion coefficient of 75 m^2/sec and 75% of the IFO assumed submerged after release.

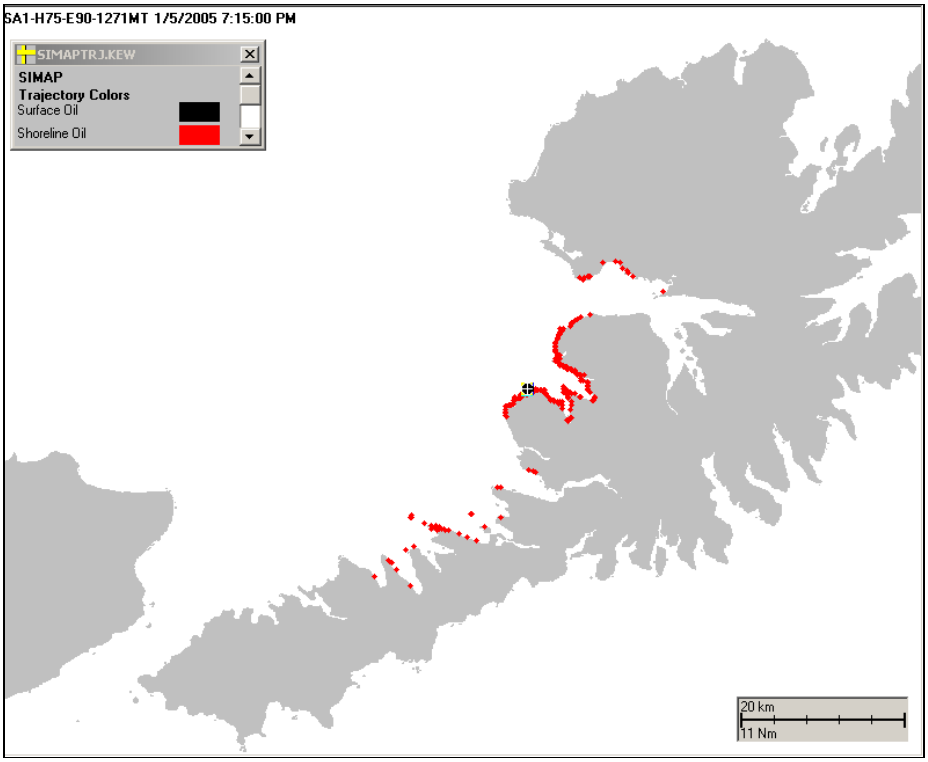

Figure F.1-15. Shoreline oiling for horizontal diffusion coefficient of 75 m^2/sec and 90% of the IFO assumed submerged after release.

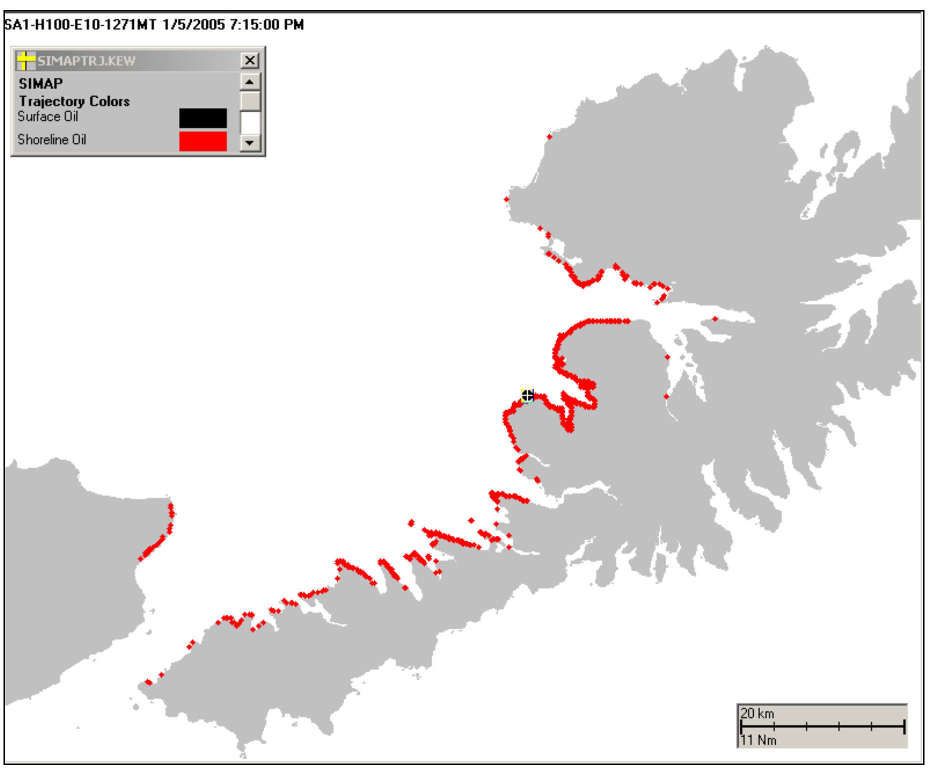

Figure F.1-16. Shoreline oiling for horizontal diffusion coefficient of 100 m^2/sec and 10% of the IFO assumed submerged after release.

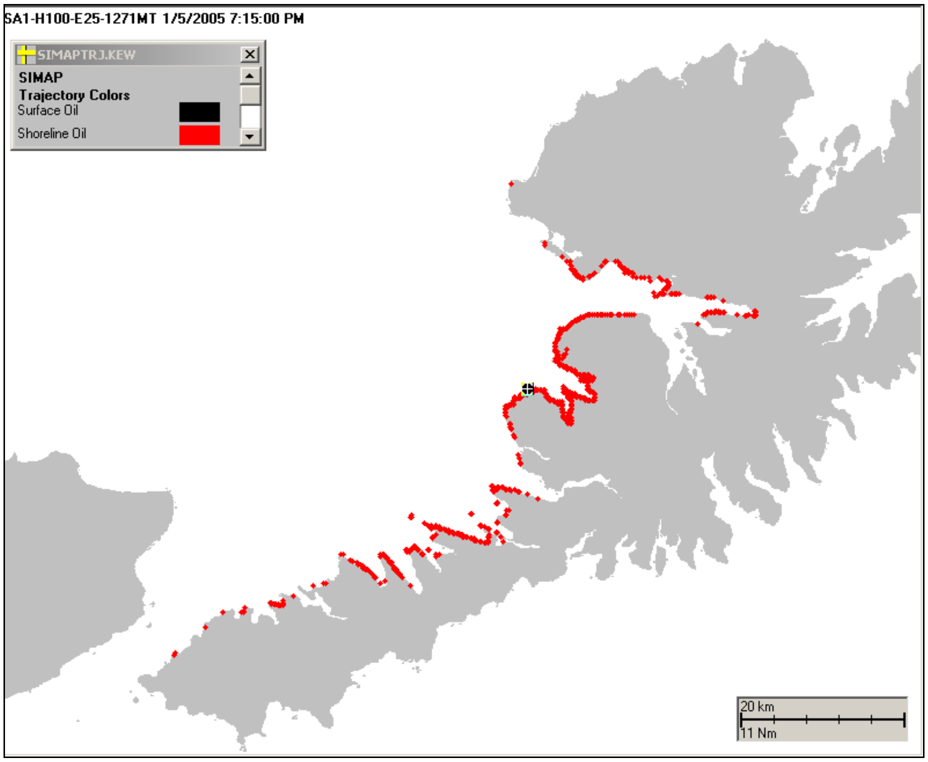

Figure F.1-17. Shoreline oiling for horizontal diffusion coefficient of 100 m^2/sec and 25% of the IFO assumed submerged after release.

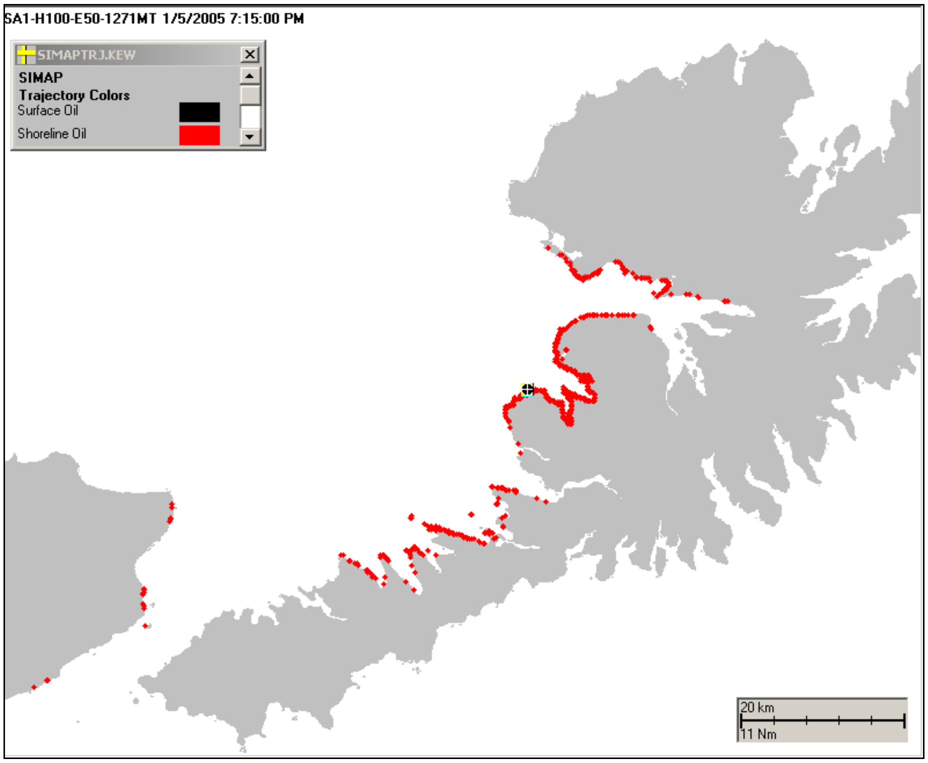

Figure F.1-18. Shoreline oiling for horizontal diffusion coefficient of 100 m^2/sec and 50% of the IFO assumed submerged after release.

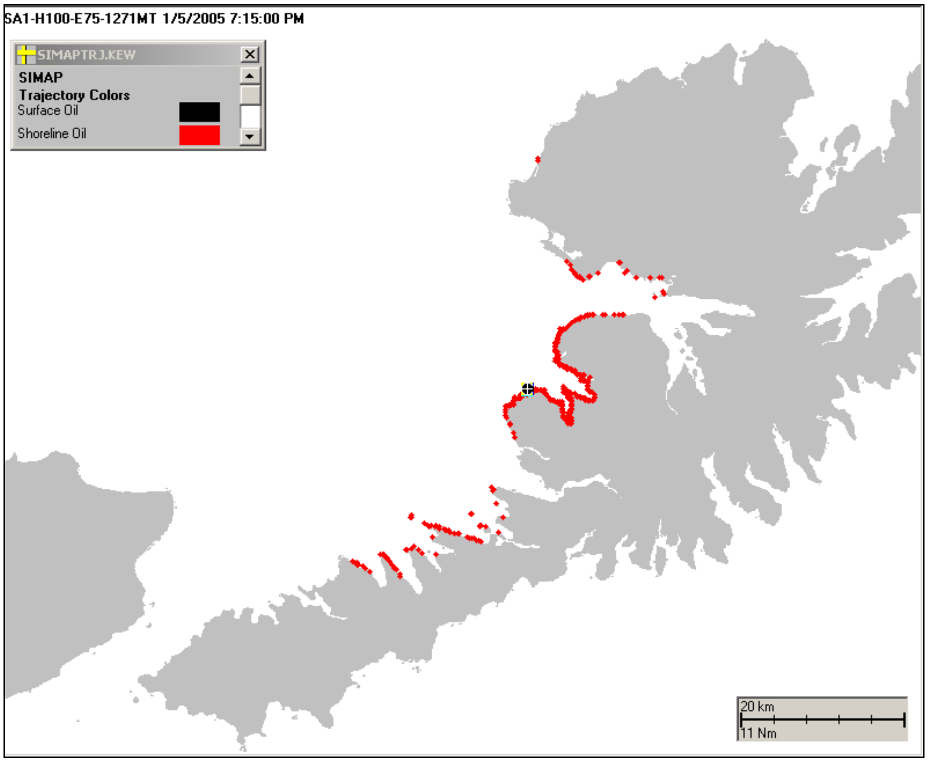

Figure F.1-19. Shoreline oiling for horizontal diffusion coefficient of 100 m^2/sec and 75% of the IFO assumed submerged after release.

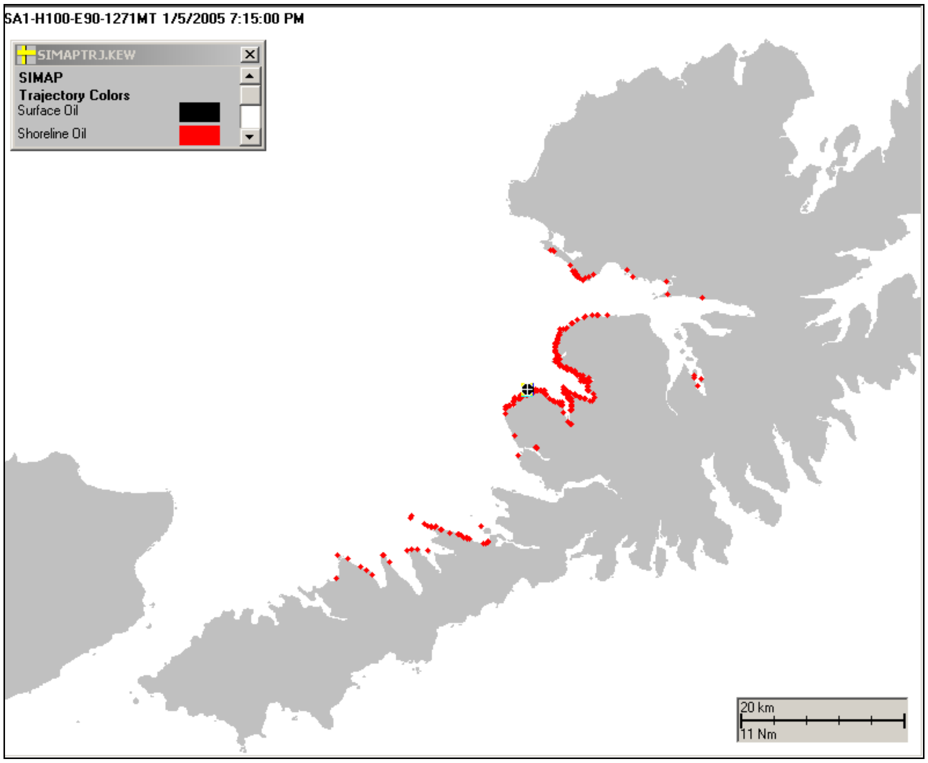

Figure F.1-20. Shoreline oiling for horizontal diffusion coefficient of 100 m^2/sec and 90% of the IFO assumed submerged after release.

F.2 Results for Best-fit Simulation of IFO

The figures in this appendix show the fates model results for the best simulation of the IFO spill: the scenario with the horizontal diffusion coefficient of 75 m^2/sec and 50% of the oil assumed submerged after release.

F.2.1 Mass Balance for IFO

The over-all mass balance of IFO hydrocarbons as a function of time is in Figure F.2-1. The apparent decline of the percent in the water column after 228 hours is caused by water-borne oil exiting the model domain. Thus, the water column percentage would actually continue a very slow decline (due to decay) from about 50% after that time.

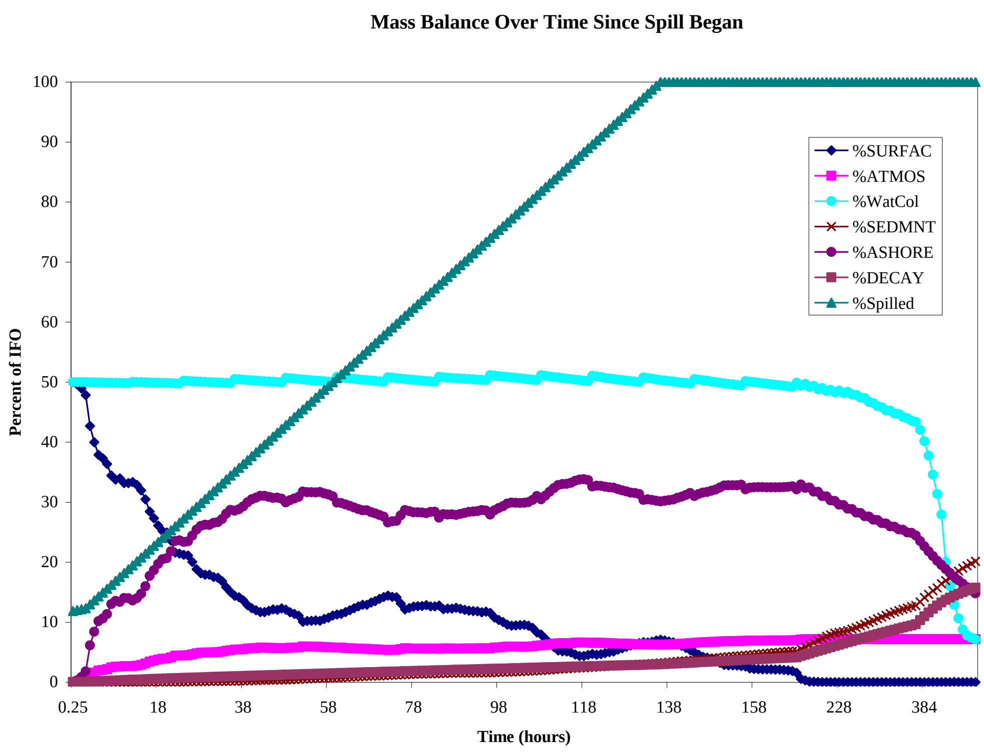

Figure F.2-1. Over all mass balance of IFO versus time after the spill for the best simulation (horizontal diffusion coefficient of 75 m^2/sec and 50% of the IFO assumed submerged after release).

F.2.2 Contamination on Shorelines for IFO

The following figures show the distribution of shoreline oiling and mass of total hydrocarbons remaining on shorelines at the end of the best IFO simulation (horizontal diffusion coefficient of 75 m^2/sec and 50% of the IFO assumed submerged after release). No shoreline cleanup was simulated in the model. Thus, IFO simply accumulates and remains on the shore.

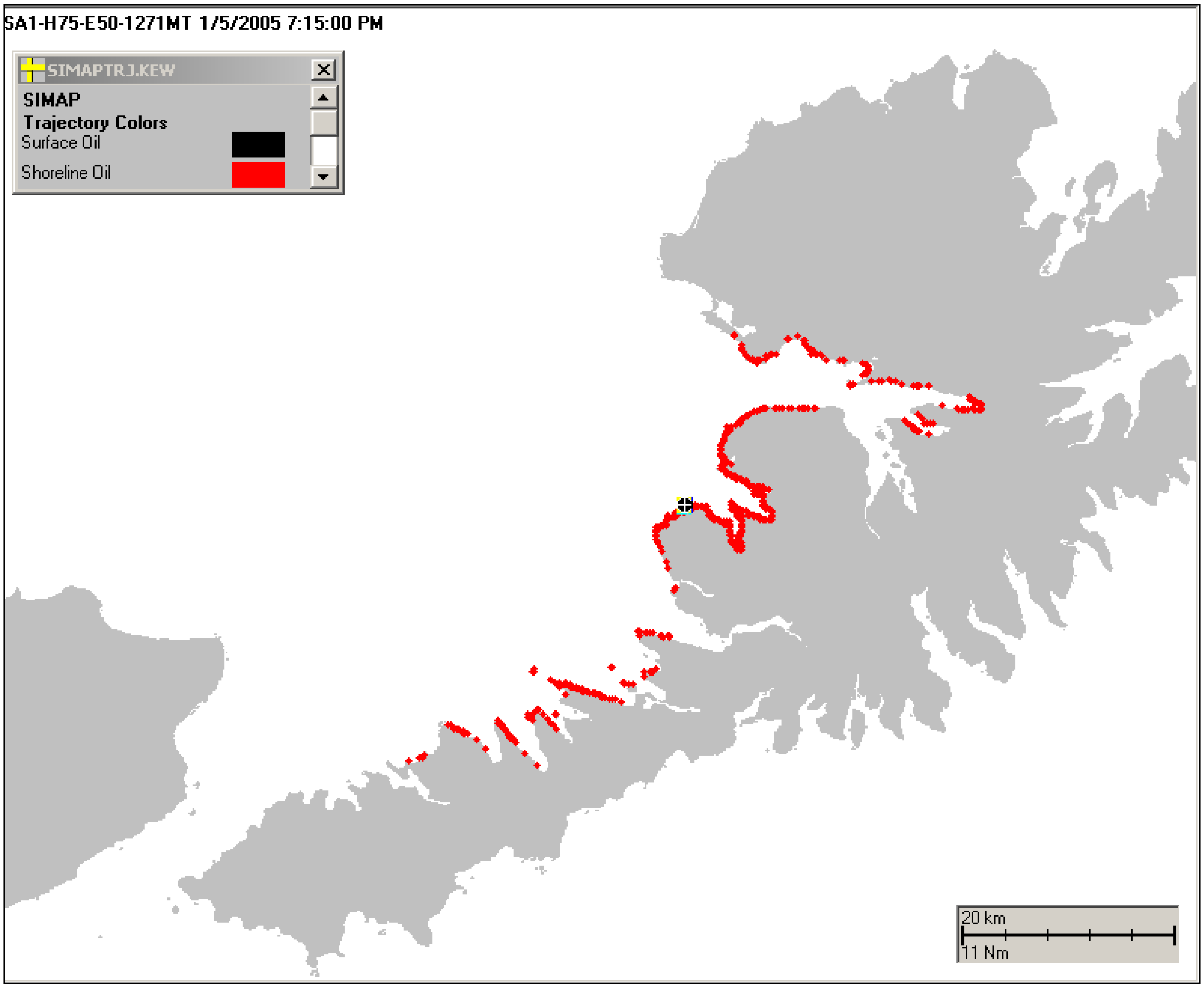

Figure F.2-2. Distribution of IFO on shorelines for the best simulation (horizontal diffusion coefficient of 75 m^2/sec and 50% of the IFO assumed submerged after release).

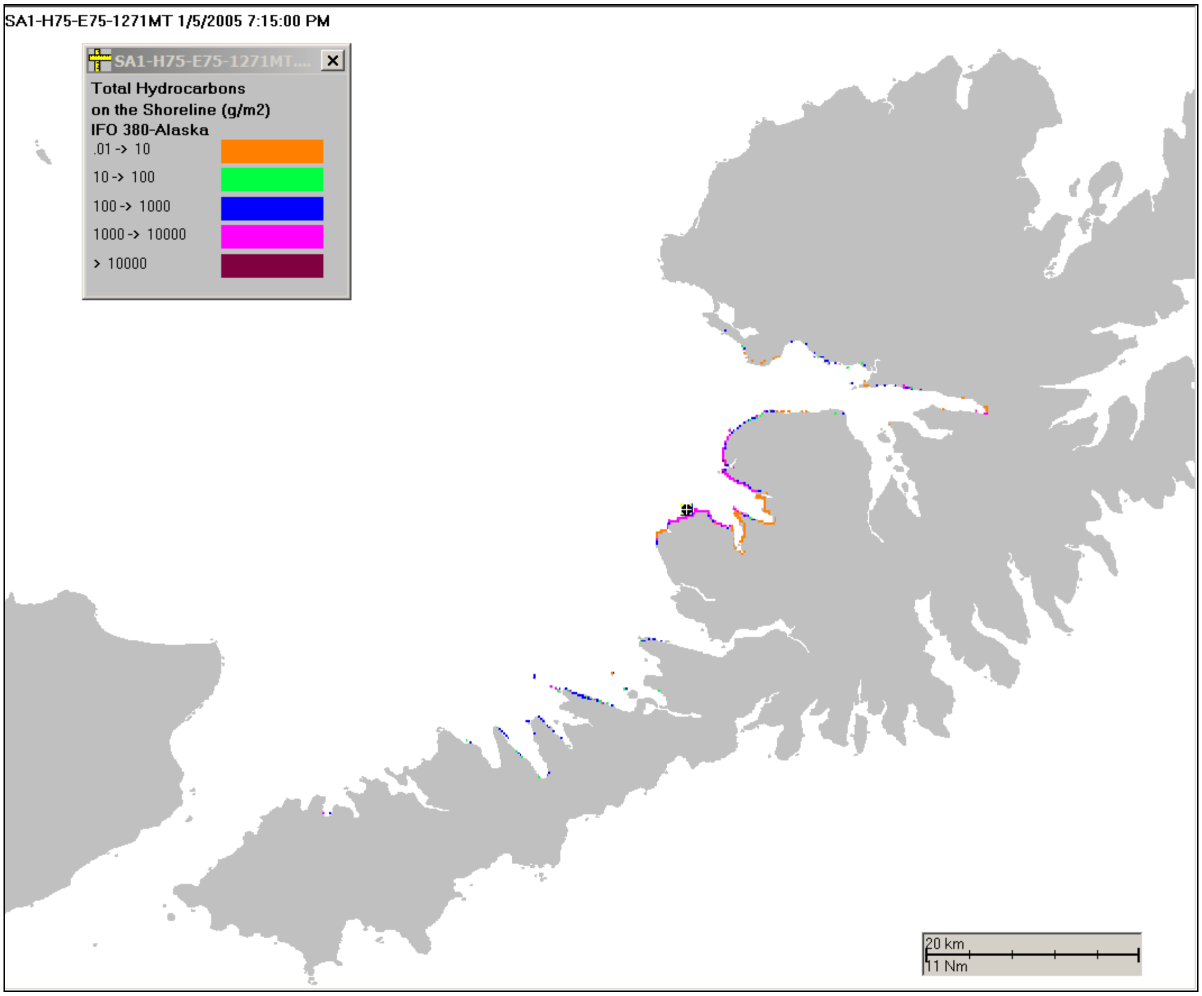

Figure F.2-3. Total hydrocarbons on shorelines for the best IFO simulation (Unalaska Island).

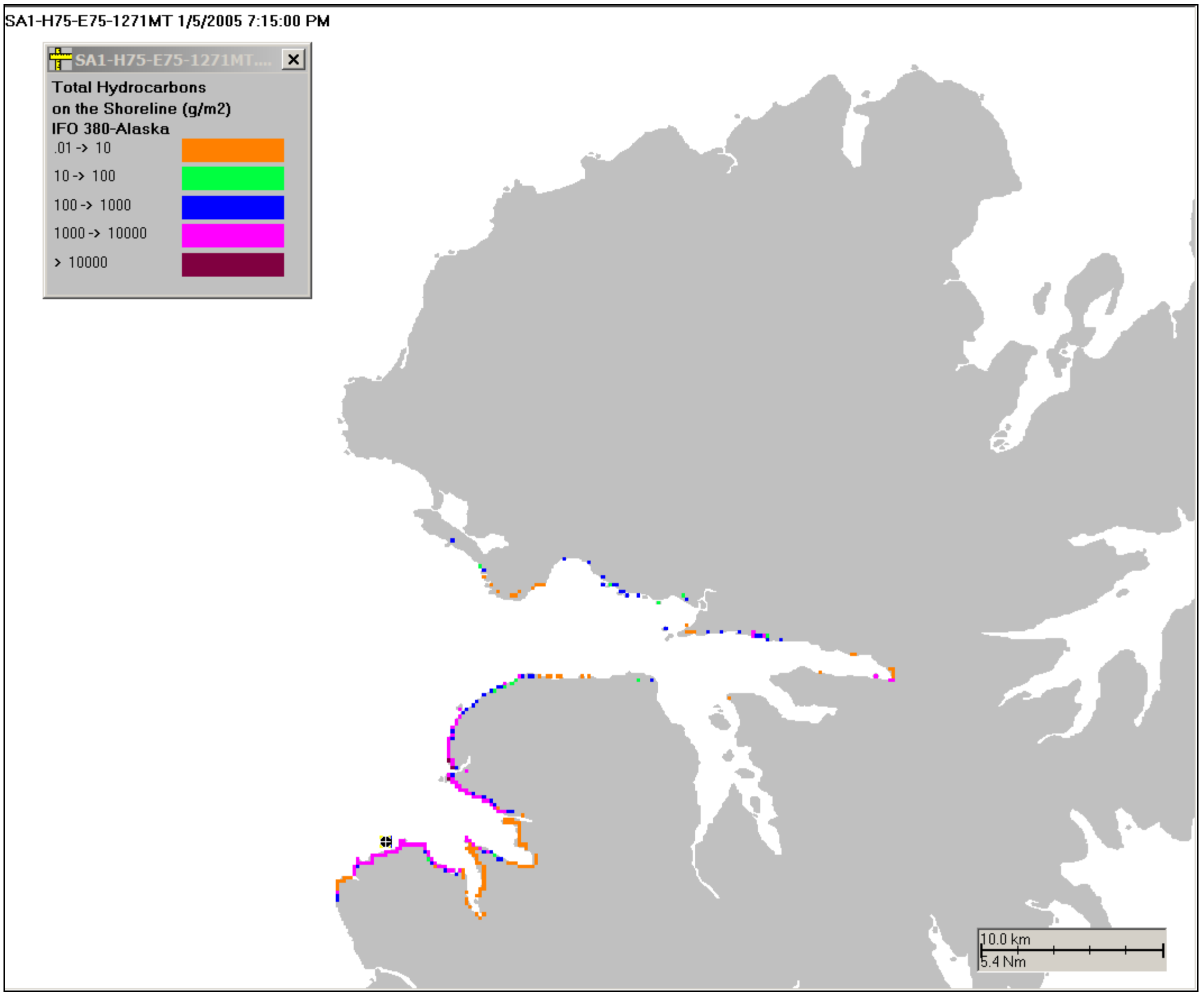

Figure F.2-4. Total hydrocarbons on shorelines for the best IFO simulation (northern Unalaska Island).

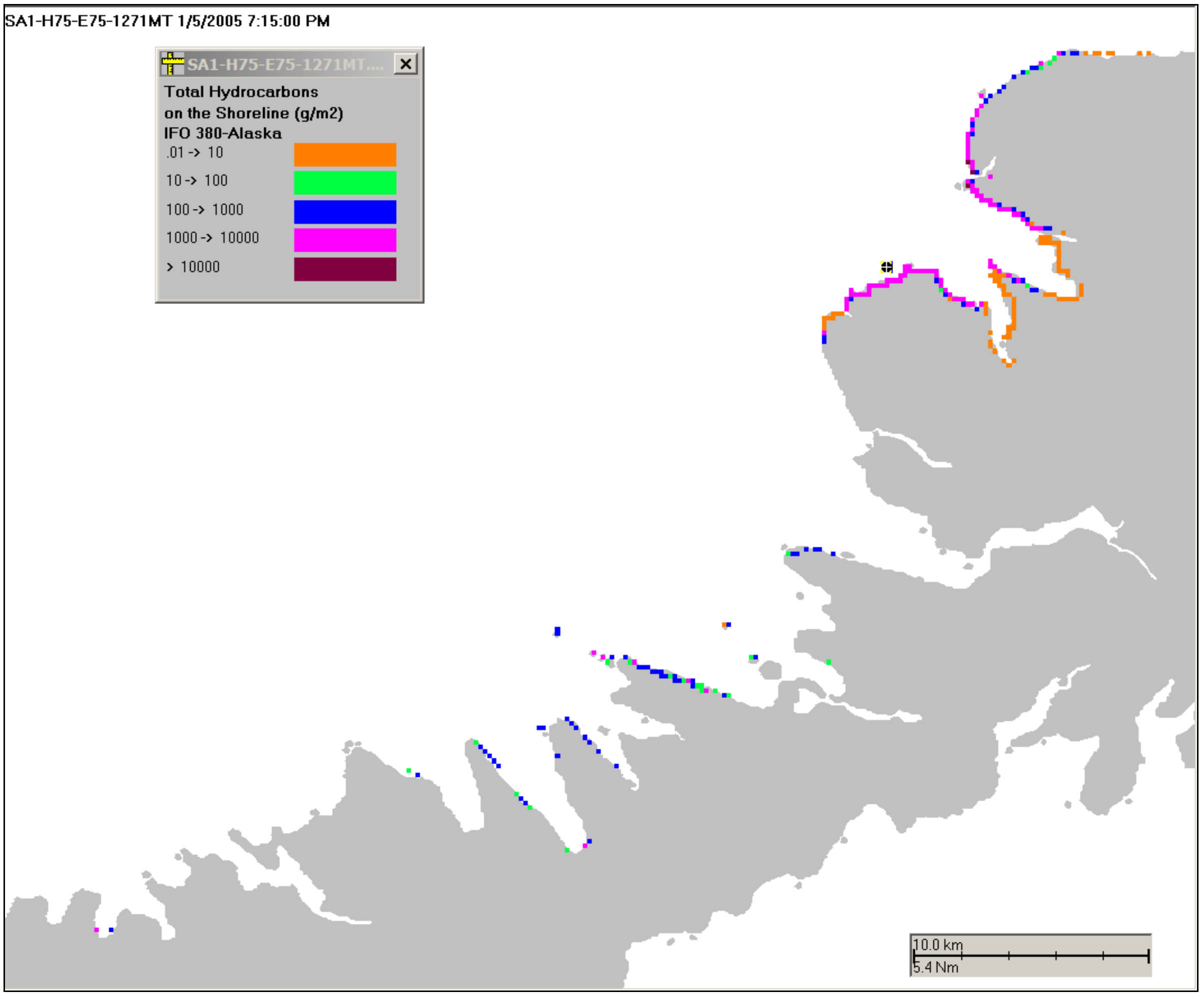

Figure F.2-5. Total hydrocarbons on shorelines for the best IFO simulation (western Unalaska Island).

F.3 Summary of Mass Balance and Sensitivity for IFO Scenarios

Tables F.3-1 to F.3-4 summarize the mass balance for the best and other model simulations of the IFO spill. The tables show that the amounts and percentages of the IFO on shore are more sensitive to the assumed percent of IFO that is submerged than to the horizontal diffusion coefficient used. For the best simulation (75 m^2/sec and 50% initially in the water column) and after 28 days of simulation, 7.2% evaporated, 14% remained ashore (48,080 gal) and 79% was dispersed at sea of the 354,218 gal spilled.

Table F.3-1. Mass Balance at the end of the IFO simulation (after 28 days) for all shorelines.

Horizonal disperson (m^2/sec)	Modeled % Entrained	% Evaporation	Gallons of IFO on Shore	% of IFO on Shore	% IFO at Sea
50	25	10.31	70,618	20.8	68.9
50	50	7.13	47,073	13.9	79.0
50	75	3.65	23,891	7.0	89.3
75	25	10.41	67,374	19.8	69.7
75	**50**	**7.17**	**48,080**	**14.2**	**78.7**
75	75	3.64	24,781	7.3	89.1
100	25	10.61	71,718	21.1	68.3
100	50	7.17	47,757	14.1	78.8
100	75	3.64	23,422	6.9	89.5

Table F.3-2. Mass Balance at the end of the IFO simulation (after 28 days) for rocky shorelines.

Horizonal disperson (m^2/sec)	Modeled % Entrained	MT of IFO on shore	Gallons of IFO on shore	% IFO on shore
50	25	0.30	81.11	0.02
50	50	0.17	44.11	0.01
50	75	0.02	5.56	0.002
75	25	0.24	65.23	0.02
75	**50**	**0.04**	**10.71**	**0.00**
75	75	0.02	4.16	0.001
100	25	0.16	43.54	0.01
100	50	0.04	9.71	0.00
100	75	0.02	5.38	0.002

Table F.3-3. Mass Balance at the end of the IFO simulation (after 28 days) for gravel (pebble or cobble) shorelines.

Horizonal disperson (m^2/sec)	Modeled % Entrained	MT of IFO on shore	Gallons of IFO on shore	% IFO on shore
50	25	197.6	52,784	15.5
50	50	141.3	37,743	11.1
50	75	77.8	20,788	6.1
75	25	211.7	56,536	16.7
75	**50**	**153.1**	**40,893**	**12.0**
75	75	79.1	21,119	6.2
100	25	226.2	60,425	17.8
100	50	153.0	40,856	12.0
100	75	73.8	19,699	5.8

Table F.3-4. Mass Balance at the end of the IFO simulation (after 28 days) for sand beach shorelines.

Horizonal disperson (m^2/sec)	Modeled % Entrained	MT of IFO on shore	Gallons of IFO on shore	% IFO on shore
50	25	2.1	555.8	0.16
50	50	0.1	19.6	0.01
50	75	0.0	0.0	0.00
75	25	0.03	7.9	0.00
75	**50**	**0.0**	**0.0**	**0.00**
75	75	0.0	0.0	0.00
100	25	0.0	0.0	0.00
100	50	3.0	805.8	0.24
100	75	0.0	0.0	0.00

Table F.3-5. Mass Balance at the end of the IFO simulation (after 28 days) for wetlands.

Horizonal disperson (m^2/sec)	Modeled % Entrained	MT of IFO on shore	Gallons of IFO on shore	% IFO on shore
50	25	64.4	17,197	5.06
50	50	34.7	9,266	2.73
50	75	11.6	3,097	0.91
75	25	40.3	10,765	3.17
75	**50**	**26.9**	**7,177**	**2.11**
75	75	13.7	3,658	1.08
100	25	42.1	11,249	3.31
100	50	22.8	6,085	1.79
100	75	13.9	3,718	1.10

F.4 Results for Diesel Simulation

The figures in this appendix show the fates model results for the simulation of the diesel spill, assuming the same model inputs as the best IFO scenario (Appendix F.2) with the horizontal diffusion coefficient of 75 m^2/sec and 50% of the oil assumed submerged after release.

F.4.1 Mass Balance for Diesel

The over-all mass balance of diesel hydrocarbons as a function of time is in Figure F.4-1. The apparent decline of the percent in the water column after 228 hours is caused by water-borne diesel exiting the model domain. Thus, the water column percentage would actually continue a slow decline (due to decay) from about 60% after that time.

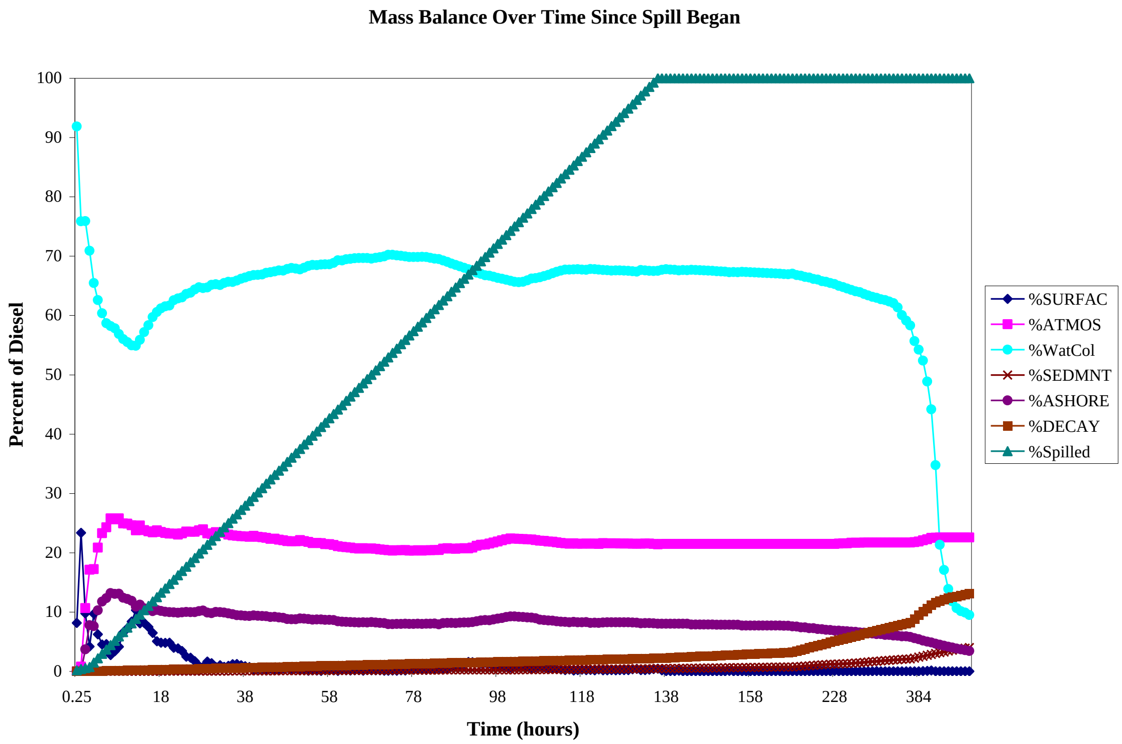

Figure F.4-1. Over all mass balance of diesel versus time after the spill for the simulation with the same assumptions as the best IFO scenario (horizontal diffusion coefficient of 75 m^2/sec and 50% of the oil assumed submerged after release).

Table F.4-1. Mass Balance at the end of the diesel simulation (after 28 days).

Compartment	% of Diesel
Atmosphere	22.57
Shoreline	3.43
water column	56.93
sediment	4.00
decay	13.06

Table F.4-2. Mass Balance at the end of 28 days, combining the diesel simulation with the best IFO model run.

Compartment	% of Diesel	% of IFO	% of IFO + Diesel
Atmosphere	22.57	7.17	7.81
Shoreline	3.43	14.16	13.72
water column	56.93	42.19	42.80
sediment	4.00	20.13	19.46
decay	13.06	15.72	15.61

F.4.2 Contamination on Shorelines

The following figures show the distribution of shoreline oiling and mass of total hydrocarbons remaining on shorelines at the end of the diesel simulation, assuming the same inputs as for the best IFO simulation (horizontal diffusion coefficient of 75 m^2/sec and 50% of the oil assumed submerged after release). No shoreline cleanup was simulated in the model. Thus, oil simply accumulates and remains on the shore.

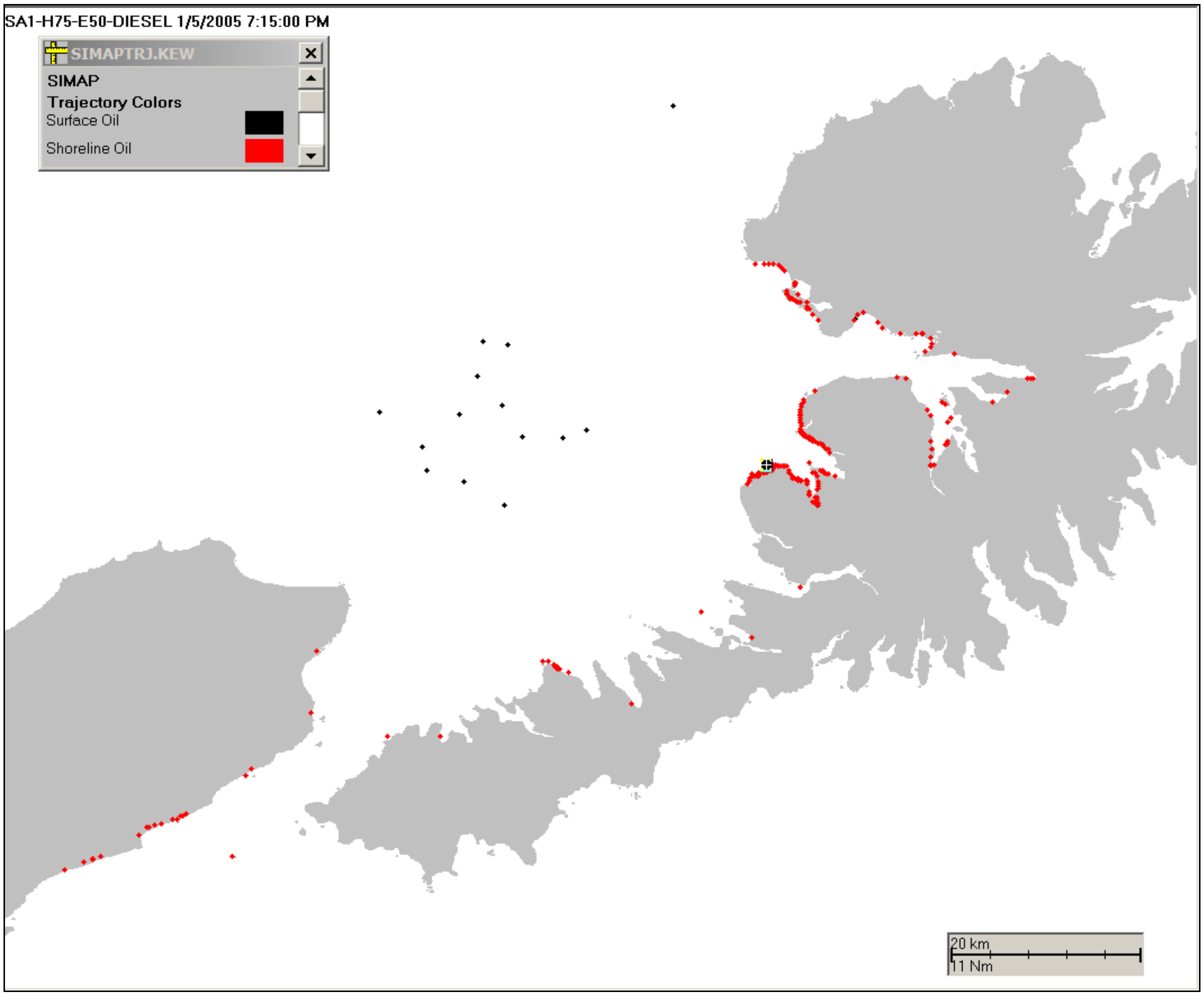

Figure F.4-2. Distribution of diesel on shorelines using model inputs for the best IFO simulation (horizontal diffusion coefficient of 75 m^2/sec and 50% of the IFO assumed submerged after release).

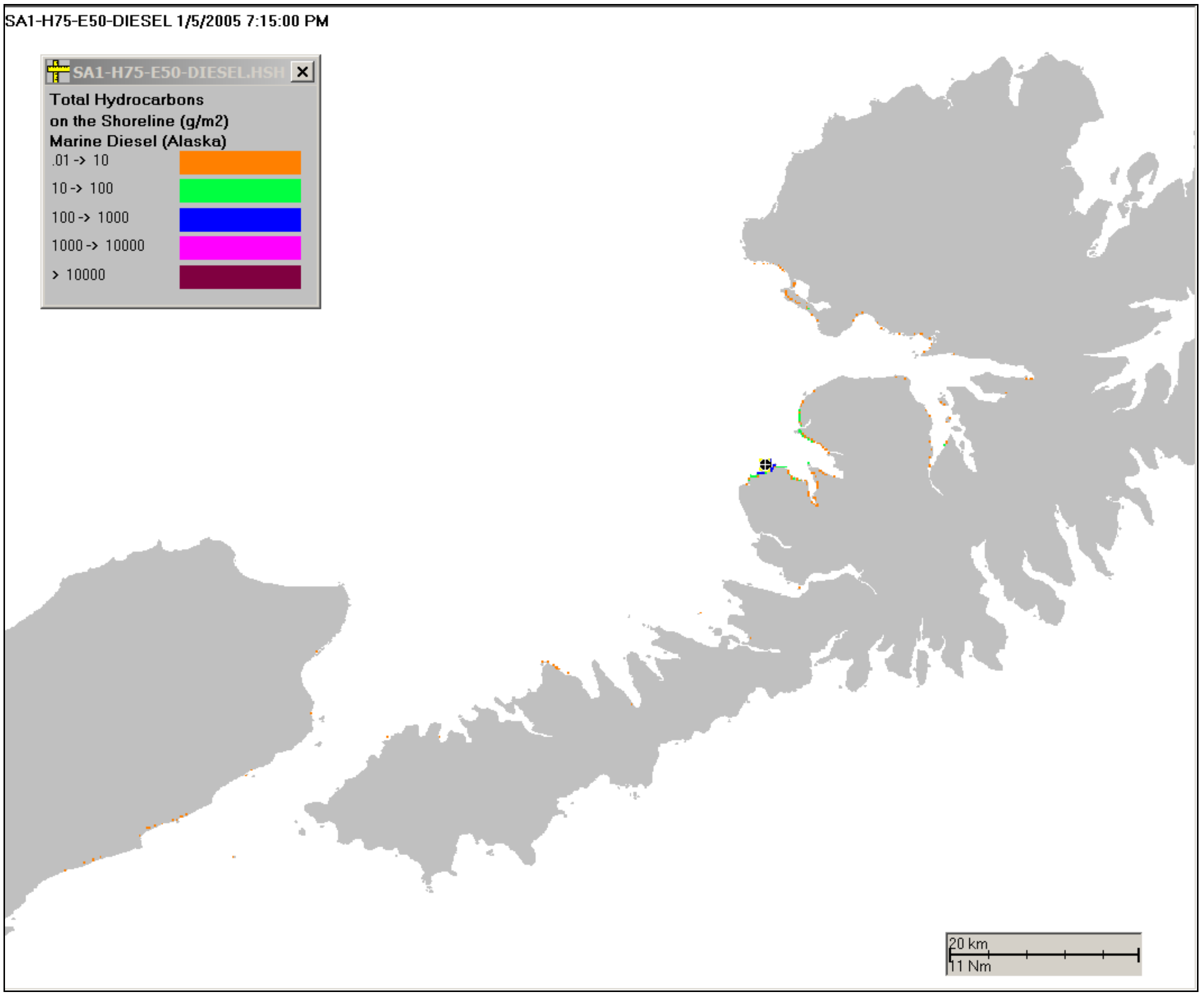

Figure F.4-3. Total hydrocarbons on shorelines for the diesel simulation (Unalaska Island).

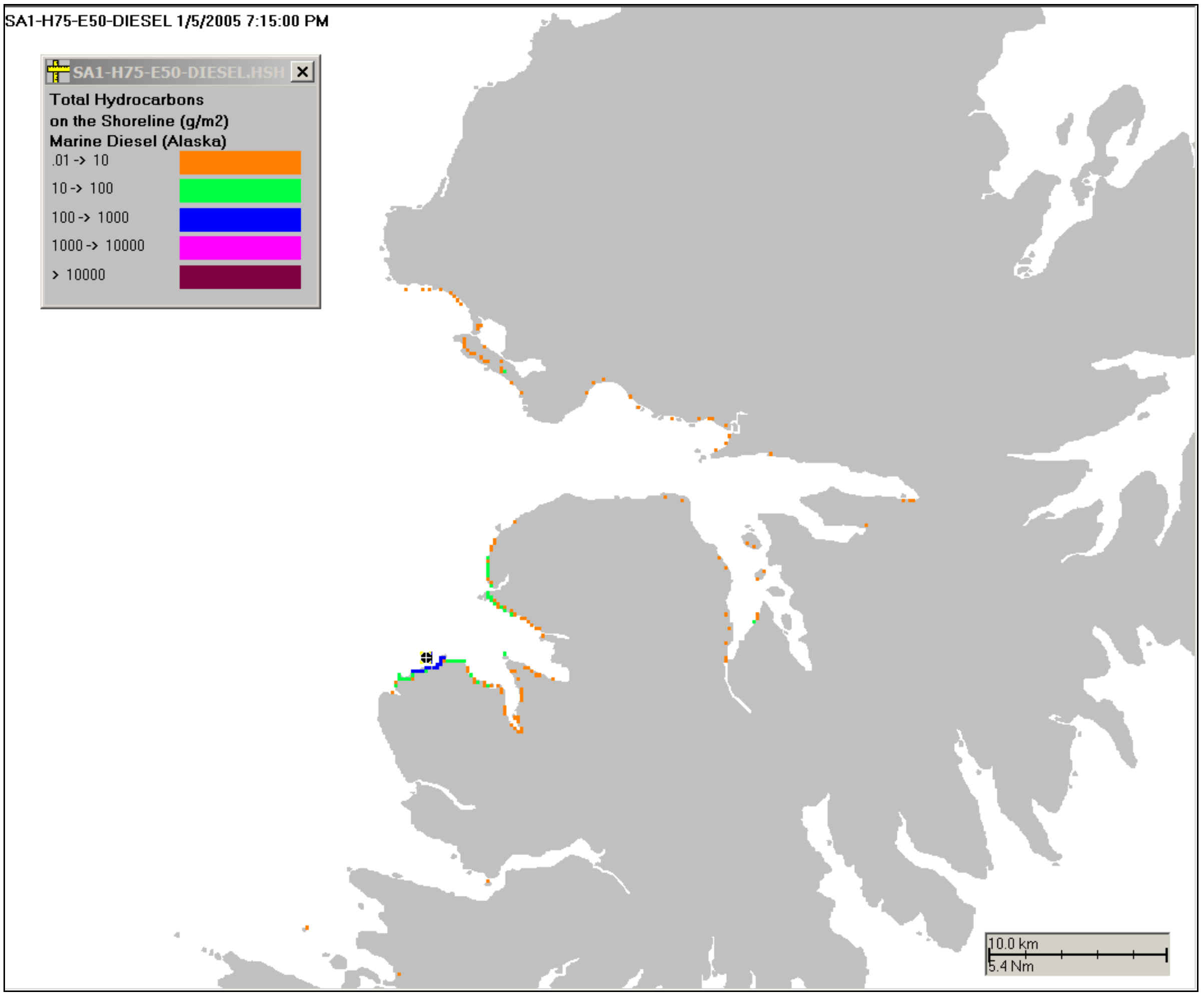

Figure F.4-4. Total hydrocarbons on shorelines for the diesel simulation (northern Unalaska Island).

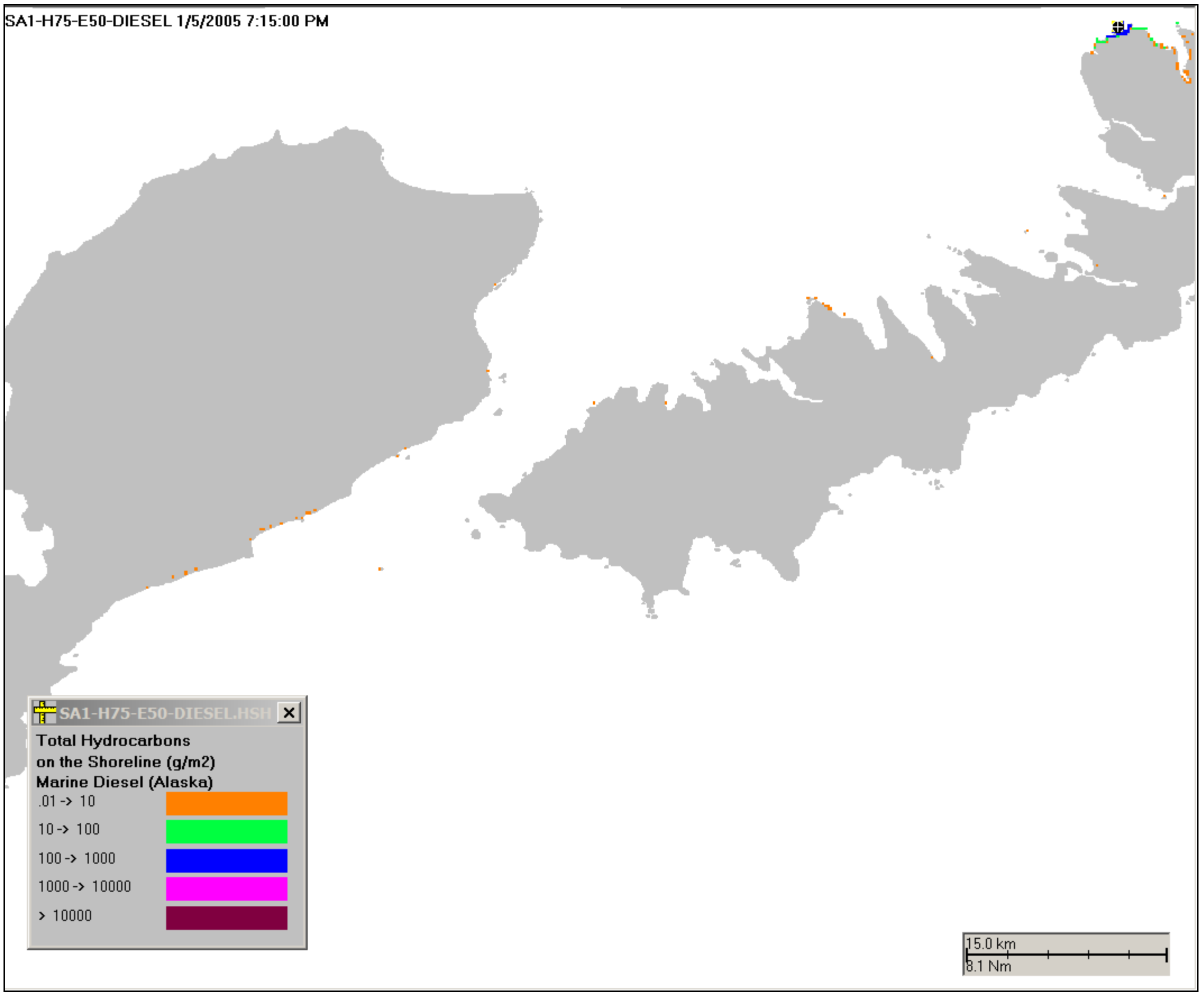

Figure F.4-5. Total hydrocarbons on shorelines for the diesel simulation (western Unalaska Island).