Aleutian Islands Risk Assessment
Phase A – Preliminary Risk Assessment

TASK 2B: Baseline Spill Study Report

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LIST OF ACRONYMS/ABBREVIATIONS

%	percent
3-D	Three-dimensional
ADEC	Alaska Department of Environmental Conservation
AIRA	Aleutian Islands Risk Assessment
ASA	Applied Science Associates, Inc
COSIM	Chemical and Oil Spill Impact Module
DWT	Dead Weight Tonnage
DNV	Det Norske Veritas
ERM	Environmental Resources Management (ERM-West, Inc.)
ESI	Environmental Sensitivity Index
ft	feet
g/cm^3	grams per cubic centimeter
GEBCO	General Bathymetric Chart of the Ocean
GEMSS	Generalized Environmental Modeling System
GFDL	Geophysical Fluid Dynamics Laboratory
GIS	Geographic Information System
IFO	intermediate fuel oil
km	kilometer
LNG	Liquefied Natural Gas
m	meter
MARCS	Marine Accident Risk Calculation System
mg/l	milligrams per liter
mm	millimeter
M/V	Motor Vessel
NFWF	National Fish and Wildlife Foundation
NOAA	National Oceanic and Atmospheric Administration
ppb	parts per billion
ppt	parts per trillion
U.S.	United States
USCG	United States Coast Guard

1.0 INTRODUCTION

The Aleutian Island Risk Assessment (AIRA) Program was created to produce a comprehensive evaluation of the risk of vessel accidents and spills in the Aleutian Islands, with the ultimate goal of identifying risk reduction measures that can be implemented to improve the level of safety related to shipping operations in the region. The Risk Analysis Team of Environmental Resources Management (ERM-West, Inc.) and Det Norske Veritas (U.S.A.), Inc. (DNV) are conducting the Phase A – Preliminary Risk Assessment following the process outlined in the AIRA Phase A Request for Proposal (NFWF, 2009). A baseline oil spill study was conducted by the Risk Analysis Team as part of the AIRA Program Phase A - Preliminary Risk Assessment – Task 2. This document, the Baseline Spill Study Report (Task 2B Report), summarizes the methodology and results of the activities included as part of subtasks 2B – develop the oil spill baseline and 2C – the baseline spill report.

This final Task 2B Report incorporates comments on the draft report received from the Management Team (consisting of the National Fish and Wildlife Foundation (NFWF), United States Coast Guard (USCG), and Alaska Department of Environmental Conservation (ADEC), the Advisory Panel members, and the Peer Review Panel.

The baseline spill study obtained available data to estimate the spill characteristics such as spill rates, substance, frequency, and location, etc. Frequency was developed from the traffic pattern for each type of ship. Consequence was then initially expressed in terms of the expected or average spill outflow, which together with the spill frequency defined the spill rate. This projection was designed to provide an understanding of the most important hazards and serve as a baseline for later assessment benefits. Data from the United States (U.S.) Coast Guard, State of Alaska, and national and international agencies were reviewed. Data augmentation was performed wherever necessary to fill in the missing information on spill data and on the climate drivers (currents, winds, tides and waves).

The types of accidents and the vessels involved were mapped against indicators of consequence, such as:

- the types of hazardous substances spilled,
- the maximum expected outflow (upper limit),
- the distribution of spill size,

- the likely location of spills, and
- the seasonality (likely time of year) of spills.

To address variations in the above indicators five spill scenarios were identified for modeling. This baseline projection assumed that no additional risk reduction interventions/measures would be implemented during the study period. The five scenarios selected for baseline study represents a hypothetical future without the potentially beneficial effects of the risk reduction options being investigated in the AIRA.

The spill baseline over the 25-year study period was obtained by using data from the past 25 years to get the statistical properties of climate drivers and other related information and used it to estimate the projected movements of oil and other hazardous materials in the study region. The findings of the baseline spill study are described in this report.

1.1 SCOPE AND OBJECTIVES

As described in the scope of work for the AIRA Request for Proposal (NFWF, 2009), the Phase A study is semi-quantitative. The scope of the baseline spill modeling consists of the following:

1) Estimate of the spill frequency and projected spill size distribution by vessel type and accident type; and
2) Develop the oil spill baseline over the 25-year study period as the product of the projected movements of oil and other hazardous materials and the estimated average spill rates.

The objective of the baseline spill modeling is to provide quantitative information for the assessment of potential impacts of spills on the shoreline and marine ecology in the neighboring waters off the Coast of the Aleutian Islands.

ERM used the Chemical and Oil Spill Impact Module (COSIM) model to conduct the baseline spill study, as described in the Risk Analysis Team's amended proposal (ERM and DNV, 2009). COSIM computes the fate and transport of cargo spills using spill scenarios developed based on the results from the Marine Accident Risk Calculation System (MARCS) model (described in Task 2A Marine Frequency and Spill

Report) and provides results for consequence analysis. A detailed description of COSIM and its usage is given in this report.

1.2 REPORT ORGANIZATION

This report covers Tasks 2B and 2C of the Phase A – AIRA Program (NFWF, 2009). The report is organized as follows:

- Section 1 provides a brief introduction of the study followed by its objectives;
- Section 2 describes the methodology, model selection and its assumptions;
- Section 3 presents the data management;
- Section 4 discusses the model setup including selection of baseline scenarios;
- Section 5 describes the calibration of the model;
- Section 6 presents the baseline scenario results;
- Section 7 presents the summary; and
- Section 8 lists the references.

2.0 METHODOLOGY

Environmental issues related to the accidental release of oil and chemicals from ocean going vessels require predictions of the transport and fate of its gas and liquid phase fractions. The factors affecting the initial transport include physical conditions (current speed, water column density structure), discharge conditions (rate of discharge, discharge depth). The transport of the spill on the water surface is then controlled by the tides, wind induced currents, and wave induced drift and dispersion. Dissolved particles in the water column are advected and dispersed using tides and wind induced currents that approximately decrease exponentially with depth. Surface spill characteristics such as area, thickness, viscosity, density, water content and water column characteristics such as benzene, toluene, ethyl benzene, and xylene; or polyaromatic hydrocarbon concentrations are then estimated or measured to evaluate bio and socio-economic impacts. In the current study, spill modeling was performed using a three-dimensional (3-D) spill model.

For the baseline spill study (Task 2B), the stochastic module of an established 3-D spill model was used to evaluate the impact of spills resulting for the scenarios developed from the marine traffic, spill frequency, and spill size information obtained from the Task 1 Semi-quantitative Traffic Study Report (Task 1 Report) and Task 2A Marine Spill Frequency and Size Report (Task 2A Report). The stochastic module was selected because of the forecasting and stochastic (probabilistic) approach involved in the estimation of impacts associated with spills. Also used were temporal and spatial variants of currents and winds, salinity and temperature (obtained from assimilated data from observations or hydrodynamic modeling, depending on availability) along with the spill characteristics (results from Task 1 and Task 2A) and properties.

Stochastic winds and currents were developed for the 25 year baseline study period (2009-2034) using the past 25 or more years of data. The input data needed for spill modeling was obtained from a wide variety of local, national and international public and private agencies. Meteorology, currents and hydrological information were obtained for 25 or more years from these agencies through their online data portals as well as direct communication. Additional site specific data such as bathymetry, shoreline and sediment characteristics and biologically sensitive regions also was obtained from these agencies for geographic information system (GIS) mapping of impacted areas for risk analysis.

2.1 SELECTION OF MODEL

As described in the AIRA Phase A Risk Analysis Teams' proposal, the models used in the present study is the COSIM module of the Generalized Environmental Modeling System (GEMSS®) (Kolluru, 2006), which is an integrated system of 3-D hydrodynamic and transport models embedded in a geographic information and environmental data system. GEMSS® was developed in the mid-1980s as a hydrodynamic platform for transport and fate modeling. The hydrodynamic platform ("kernel") provides 3-D flow fields from which the distribution of various constituents can be computed. The constituent transport and fate computations are grouped into modules. The COSIM module, created in the early 1990's was specifically designed to assess the fate and transport of oil and chemical spills. Its theoretical formulation can be found in Kolluru et al. (1994).

2.2 DESCRIPTION OF GEMSS-COSIM

GEMSS-COSIM is a plug-in component to ERM's GEMSS® for Surfacewaters, a numerical waterbody modeling package, capable of 1-, 2-, or 3-D hydrodynamic analyses. GEMSS can be applied to any type of waterbody and can compute the circulation and transport of water and any constituents, including water quality parameters and the chemical or oil constituents of concern.

As is evident when animations are viewed, each spill event in COSIM is simulated as a series of independent particles. Each particle has a mass, a specific chemical composition, and a weathering profile based on that particles composition. Each particle is affected by currents, tides, winds, and randomized dispersion factors, specific to its location at any given time.

The model tracks the fate of the released oil into its potential forms, including oil that is:

- part of a surface slick,
- stranded on a shoreline,
- evaporated into the atmosphere,
- dissolved or entrained in the water column, and/or
- deposited on the sediment.

Oil transitions from one fate to another via ten physical processes: advection, spreading, evaporation, dispersion, dissolution, emulsification, photo-oxidation, sinking, sedimentation, and biodegradation. Simultaneous mass balances are computed for oil constituents with similar properties referred to as "oil cuts." By individually tracking the fate of each cut rather than assuming a single homogenous liquid, the solubility, evaporation, and solids partitioning and other processes are simulated in a more accurate manner.

COSIM model was developed based on the earlier work performed by Dr. Venkat S. Kolluru on commercial and public domain spill models OILMAP[1], WOSM[2] (Kolluru et al., 1993; Anderson et al., 1993), NRDAM-CME and NRDAM-GLE[3]. The transport and fate processes are modeled using different types of algorithms based on currently available literature on oil and chemical spill modeling (ASCE, 1996). One of the strongest distinctions is COSIM's capability to examine in 3-D spatially varying water column and sediment concentrations of specific released contaminants. The theoretical formulation and real-world applications of COSIM has been published in many leading scientific conferences and journals that include AMOP (Kolluru et al., 1994, Kolluru and Mandelson, 1995), Spill Science and Technology Bulletin (Spaulding et al., 1994), IOSC (Fichera et al., 2003) and SETAC (Fichera et al, 2001).

The model includes four sub-models depending on the level of complexity involved in a typical spill impact study. They are listed in Table 2-1.

Table 2-1 Models Available in GEMSS-COSIM

Model Type	Purpose
Trajectory	• Quick estimation of spill transport. • Does not include the fate analysis of a spill.
Trajectory and Fate	• Transport and fate analysis with good forcing data (e.g. winds, tides, currents and waves). • Water column is combined as a single component with no spatial or temporal variation of spill concentration or mass.

[1] OILMAP is a commercial oil spill modeling software developed by Applied Science Associates, Inc (ASA).

[2] WOSM stands for World Oil Spill Model and it was developed by Applied Science Associates for a consortium of many oil and federal agencies.

[3] NRDAM-CME and NRDAM-GLE are public domain models developed by Applied Science Associates for the U.S. Department of the Interior.

Model Type	Purpose
Subsurface	• Similar to the previous sub-model. • Includes complete subsurface modeling that predicts the fate and transport of a spill in the water column. • Computes time and spatial variation of dissolved and adsorbed constituents in the water column and sediments.
Stochastic	• Similar to the subsurface sub-model. • Includes tidal currents. • Computes wind transition matrix using long wind records. • Performs several simulations with wind record changing over time for each simulation.
Receptor	• Reverse particle tracking to find possible sources for a specific oiled location or bio-sensitive region.

The model keeps track of number of moles (unit mass) available in each fraction with time after going through a series of weathering processes. The model writes output data for the particles on the surface and sub-surface and concentrations of each fraction in the water column for user specified output times and intervals. The concentrations are computed in a dynamic plume cubical grid that changes with time. This approach provides a better estimate of concentration peak values as compared to using fixed plume grid. The shoreline characteristics are used using the National Oceanic and Atmospheric Administration's (NOAA's) Environmental Sensitivity Index that ranges from 1 to 10. The classification allows different degrees of reflection or absorption of oil on each shoreline type and is achieved in the model using the shoreline-oil interactions processes.

2.3 *MODELING PROCEDURE*

COSIM was run in the stochastic analysis mode for oil spill simulations. Stochastic modeling approach is used in many leading oil spill software, such as ASA's OILMAP. In Phase A, stochastic modeling approach was used to predict the variations in the transport of oil for a specific scenario that would happen in the next 30 years. For each spill scenario, the model was run 25 times. Based on extensive experience using the model, 25 iterations seems to provide good spread in the stochastic randomness with reasonable computation time. Each run simulation time period was randomly selected from a specific season associated with the spill time period.

Stochastic modeling was performed using first order autoregressive Markvov model for winds. Markov model assumes that wind variations at time, t, are correlated to those at time t-1 (previous time). It also assumes discrete wind states (fixed direction/speed over a specific time interval) and calculates a wind transition probability matrix. The Markov wind matrix was constructed from 22 years of meteorological data obtained for the study region (1987-2009). The Markov wind matrix was then used to develop synthetic winds by generating a time series wind record using transition probability matrix and initial estimate of wind. The transition matrix can contain any number of wind direction and speed bins and one calm condition. In the current study, the number of wind direction and speed bins was set to 12 and 10, respectively. These numbers were selected based on the variability in the wind speed and direction identified through the use of wind rose diagrams. The synthetic time series winds developed from the Markov matrix for a specific season would then capture all types of wind events happened in the prehistoric data. It was assumed that synthetically derived winds would simulate real winds at any time during the next 30 years. The transport of oil using synthetic winds would approach results obtained using real time series winds by running many number of iterations (> 25) per scenario. In the current analysis, local transient wind events were not captured due to the limitation of 25 iterations per scenario but sufficient enough to estimate the impact probabilities, which sufficiently captures the objectives of the Phase A Preliminary Risk Assessment baseline oil spill study.

The advantages of using the Markov model include simplicity, correct first order correlation (persistence), and dispersion of spill trajectory independent of time step. But the model does not characterize spatial variations and it also ignores longer term persistence. However, these two limitations are normally minimized by using separate transition probability matrix for selected zones or months/seasons.

Salinity, temperature, wave and currents were obtained from the available spatial and temporal databases.

The results of the 25 simulations were then processed to provide outputs in terms of probable locations of surface water, water column and shoreline mass.

3.0 DATA MANAGEMENT

A systematic analysis of the data available for a spill modeling is needed to acquire high confidence level in the model results. This is normally achieved by obtaining data available for the study region and subsequently analyzing it for frequency, time-lines, missing data and validity (comparing with other data sources) etc. For the current study, an extensive data inventory was performed through web search and e-mail follow-up with local, federal and international organizations. Considerable effort was taken to obtain good quality data.

3.1 TYPES OF DATA

COSIM requires two types of data: spatial and temporal. Spatial data describes water bodies, shorelines, and bathymetry. Temporal data is time varying and describes currents and meteorological conditions at the specific point in space where they were measured. There can be no long gaps in the temporal datasets and the required datasets should be available during the proposed simulation period.

Spatial data is encoded primarily in two geo-referenced input files: the control and bathymetry files. Temporal data is contained in multiple files each representing a set of time-varying conditions, for example, one file would describe wind speed at a specific station, and separate file would describe air temperature at that station. Each record is stamped with a year-month-day-hour-minute address.

Each temporal data set is individually reviewed for quality assurance purposes. To do this, each record is plotted and visually inspected to detect trends and outliers. Temporal data can also be obtained for the entire study region as gridded output instead of series of specific station data.

In the current study, specific computer coding was developed to directly use the large spatially and temporally varying gridded datasets, directly downloaded from various websites instead of converting them to the standard formats (series of single station data) used in the selected model. This approach was taken so that subsequent tasks can be performed efficiently with less processing time in Phase A and Phase B of the AIRA Program.

3.2 DATA SOURCES

The data for the current study was collected on the following main topics:

1) GIS,
2) Oceanography,
3) Meteorology, and
4) Oil and chemical properties.

GIS data availability for the study region is shown in Table 3-1. GIS maps were obtained from global shoreline data available at National Geospatial Intelligence Agency. The data is available in geographical coordinates and in ARCGIS shapefile format. The data was converted into UTM zone 1N coordinates in meters (m) for its use in GEMSS. The satellite image of the study region was also obtained from Google Earth® along with the bathymetric terrain and is shown in Figure 3-1. Google Earth® was used wherever necessary to get a better geo-visual understanding of the study region. The names of most of the Aleutian Islands were also listed in Figure 3-1. The study region covers a wide area ranging from 170 °East to 160 °West along the longitude and from 50 °N to 57 °N along the latitude.

The bathymetry data was obtained from the General Bathymetric Chart of the Oceans (GEBCO) available at British Oceanographic Data Center. GEBCO provides bathymetric data for the entire world at a resolution of 30 arc-second. The bathymetric data for the study region obtained from GEBCO is shown in Figure 3-2. The depths around the Aleutian Islands vary from 0 to 500 m [0 to 1650 feet (ft)] with steep increase to a depth of 3000 m in the north-west and to a depth of 6000 m (20,000 ft) in the south.

Shoreline Environmental Sensitive Index (ESI) data was obtained from Office of Response and Restoration of NOAA's National Ocean Service and is shown in Figure 3-3a to Figure 3-3e. The shoreline classification indices vary from 1 (low bio-sensitivity) to 10 (high bio-sensitivity) in the Aleutian Islands. Same index with different symbols (e.g. characters such as +, A etc.) were used to differentiate key changes in the shoreline characteristics since NOAA ESI indices range only from 1 to 10.

The oceanography and meteorological data availability for the current study is shown in Table 3-2. Meteorological data available at different locations along the Aleutian Islands from National Data Buoy Center is shown in Figure 3-3. Data available at Stations 46073, 46072, 46075, ADKA2 and ATKA2 are temporally varying but at a specific location and were considered suitable for use in the current study. In addition, a large dataset of spatially varying winds at 6 hour interval was obtained from NOAA Ocean Watch North Pacific Demonstration Project. Ocean Watch wind data is available from 1987 to 2009 at 0.25° grid interval in both longitude and latitude. This data was used extensively in the current study to obtain Markov wind transition matrix described in Section 4.5.

The Ocean Watch data availability grid for the study region is shown in Figure 3-5. Additional wind data from other sources such as QuikSCAT was also obtained for the study region, but since the data frequency is at every 24 hours, it is presently considered not suitable for the current study.

Running a hydrodynamic model for Aleutian Islands using the hydrodynamic module of GEMSS along with freshwater inputs is outside the scope of work for Phase A. Instead, for Phase A analysis, an extensive online data search was conducted to obtain current data for the Aleutian Islands and it is listed in Table 3-3. After evaluating the data sources listed in Table 3-3, data from two types of models used at Naval Research Laboratory was identified as the most useful public data for the current study. The Naval Research Laboratory's Navy Layered Ocean Model (NRL-NLOM) 1/32° 30-day delayed nowcast model data was obtained from Asia Pacific Data Research Center for the study region. Daily averages of current data are available at 0.0325° (1/32°) grid interval in both longitude and latitude from 2005 to 2009. The NRL-NLOM 1/32° grid covering the study region is shown in Figure 3-6. In addition, daily averages of current data prior to year 2005 were obtained from NRL-NLOM 1/16° (0.0625°) nowcast model, which covers a time period of 2002 to 2006. The NRL-NCOM 1/16° grid covering the study region is shown in Figure 3-7.

The 1/32° global NLOM is an operational product run daily by the Naval Oceanographic Office (NAVOCEANO) with atmospheric forcing from the Navy Operational Global Atmospheric Prediction System (NOGAPS) and assimilation of SST and satellite altimeter data. The latter data is obtained via the NAVOCEANO Altimeter Data Fusion Center. The NLOM assimilation of altimeter data is performed using an OI deviation SSH analysis with the model SSH field as the first guess. NLOM and NCOM model includes freshwater fluxes (Rhodes et al., 2002). The model has been successfully applied to predict different current systems in the Bering Sea and off the coast of Alaska.

NRL-NOM data is available as daily average and not hourly, which is traditionally used in COSIM. Hourly data captures tidal excursion that is especially important in the shallow regions close to the shoreline. This is especially true for hindcasting spills. For stochastic spill modeling, spill modeling results are estimated as probabilities instead of deterministic values. For this reason, it was decided that both the grids (Figures 3.6 and 3.7) have sufficient resolution in the vicinity and in between the islands and were considered sufficient to represent the currents for the Phase A baseline spill study.

Daily temperature data is available from various data sources also listed in Table 3-3. After careful evaluation, NOAA daily temperature data was selected for the current study and the grid covering the study region is shown in Figure 3-8. Spatially varying sea surface temperature data is available from 1979 to 2009.

Salinity data was obtained from Geophysical Fluid Dynamics Laboratory (GFDL). This data is available as vertical profile (5 m to 5000 m) from 1979 to 2007 (partial). There is no data available for the complete baseline period of 2007 and 2008. So, data from the year 2006 was used to develop the profile salinity data for the study years. The salinity data grid domain for the study region is shown in Figure 3-9.

Correlation between various data sets identified for the preliminary spill modeling is not needed even though data came from different sources. This is because the data from different sources is available for the same time period of simulation. If the environmental data is obtained from different sources for different time periods, then correlation needs to be performed so that the data derived from other time periods can be used for the same time period of simulation.

Oil and chemical data was obtained from the Office of Response and Restoration of NOAA's National Ocean Service using ADIOS2 oil database. In addition, oil and chemical properties were obtained from NRDAM-CME, Environmental Science and Technology Centre of Environment Canada, and ERM's databases.

Table 3-1 GIS Data Sources for the Current Study

Data Type	Data Source	File Name	Website
Shoreline	National Geospatial Intelligence Agency	NGA_GlobalShoreline_cd24.shp NGA_GlobalShoreline_cd25.shp	http://www.nga.mil/portal/site/nga01/index.jsp?epi-content=GENERIC&itemID=9328fbd8dcc4a010VgnVCMServer3c02010aRCRD&beanID=1629630080&viewID=Article
Nautical Charts	NOAA Raster Nautical Chart	16006_1.KAP 16006_2.KAP 16006_3.KAP 16006_4.KAP	http://www.nauticalcharts.noaa.gov/mcd/Raster/download_agreement.htm
Coastal Images	National Ocean Service Data Explorer	2411 to 2418.tif 2552 to 2571.tif	http://www.nauticalcharts.noaa.gov/csdl/ctp/cm_vs.htm
Environmental Sensitive Index	Office of Response and Restoration; NOAA's National Ocean Service	AleutiansESI.mdb	http://response.restoration.noaa.gov/type_subtopic_entry.php?RECORD_KEY%28entry_subtopic_type%29=entry_id,subtopic_id,type_id&entry_id(entry_subtopic_type)=74&subtopic_id(entry_subtopic_type)=8&type_id(entry_subtopic_type)=3
Bathymetry	General Bathymetric Chart of the Oceans	GEBCO_08.nc	http://gebco.net

Table 3-2 Oceanography and Meteorology Data Availability for the Study Region

Data Type	Data Source	File Name	Frequency	Depth	Time Period	
					From	To
Currents						
East-West Currents	NRL NLOM 1/32° 30day delayed nowcast	nlom_u1_32_u_[m_s].nc	Daily	Surface	4/28/2005	12/23/2010
North-South Currents	NRL NLOM 1/32° 30day delayed nowcast	nlom_v1_32_v1_[m_s].nc	Daily	Surface	4/28/2005	4/28/2007
North-South Currents	NRL NLOM 1/32° 30day delayed nowcast	nlom_v1_32_v2_[m_s].nc	Daily	Surface	4/28/2007	4/28/2009
North-South Currents	NRL NLOM 1/32° 30day delayed nowcast	nlom_v1_32_v3_[m_s].nc	Daily	Surface	4/28/2009	12/23/2010
East-West Currents	GFDL currents	GFDL u-vel.nc	Monthly	Profile	1/15/1979	12/15/2007
North-South Currents	GFDL currents	GFDL v-vel.nc	Monthly	Profile	1/15/1979	12/15/2007
East-West & North-South Currents	OSCAR	OSCAR.nc	5 days	15 m below Water Surface	10/21/1992	12/1/2009
East-West Currents	NRL NLOM 1/16 30 day delayed nowcast	LASoutput-116_U.nc	Daily	Surface		
North-South Currents	NRL NLOM 1/16 30 day delayed nowcast	LASoutput-116_V.nc	Daily	Surface		
Zonal Currents	AVISO	LASOutput-U.nc	Daily	Surface	10/14/1992	10/8/2008
Meridional Currents	AVISO	LASOutput-V.nc	Daily	Surface	10/14/1992	10/8/2008
Temperature						
	NOAA SST (ERSST & OISST)	daily_sea_surface_temperature_deg c.nc	Daily	Water Surface	9/1/1981	12/31/2009
Salinity						
	GFDL	s_salinity_[1e-3].nc	Monthly	Profile (5 m to 5000 m)	1/15/1979	12/15/2007
	JPL	kf049f.nc_Salinity.nc	Monthly	Profile (5 m to 5000 m)	1/6/1993	3/27/2007

Data Type	Data Source	File Name	Frequency	Depth	Time Period	
					From	To
Winds						
North-South & East-West Winds	NOAA-OceanWatch	NCDC_seawinds_6hr.nc	6 hour	10 m above water surface	7/9/1987	10/31/2009
North-South Winds	JPL QuikSCAT	QuikSCAT_u.nc	1 day	10 m above water surface	1/1/1999	12/31/2009
East-West Winds	JPL QuikSCAT	QuikSCAT_v.nc	1 day	10 m above water surface	1/1/1999	12/31/2009
Waves						
Wave Height, Period and Direction	USACE Coastal and Hydraulics Laboratory		Hourly			
	Wave Information Studies	1981pac_L1.001 … 2004pac_L1.001		77 m	1981	2004

Table 3-3 Oil and Chemical Data Availability for the Current Study

Data Source	Website	Data Variables
Environment Canada	http://www.etc-cte.ec.gc.ca/databases/ChemicalSynonyms/Default.aspx	Oil and chemical properties for spill modeling
NOAA-Database of hazardous materials	www.cameochemicals.noaa.gov/	Chemical properties
Envirofacts Master Chemical Integrator (EMCI)	http://www.epa.gov/enviro/html/emci/chemref/complete_index.html	LC50 for various species
OSHA/U.S. Environmental Protection Agency Occupational Chemical Database	http://www.osha.gov/web/dep/chemicaldata/#target	Chemical properties
Office of Response and Restoration, NOAA's National Ocean Service	http://response.restoration.noaa.gov/type_catalog.php?RECORD_KEY%28type_chosen%29=type_id&type_id(type_chosen)=3	Oil and chemical properties for spill modeling

4.0 MODEL SETUP

The data described in Section 3.2 were formatted for its use in COSIM. The current, wind, salinity and temperature data are available in NETCDF format which is a widely used format by the scientific community for storage of complex scientific data. Instead of converting the NETCDF data to the standard formats used in COSIM, new computer algorithms were written to directly use them so that the model becomes more efficient for other tasks such as consequence analysis in Phases A and B. The selection of input data depends on the type of scenario to be modeled using COSIM. Thus, before preparing the model setup, a set of baseline scenarios were identified based on the results of the Task 1 traffic study and developed as part of Task 2A. The seasons were identified based on the time of spill occurrence identified for the scenarios developed using the MARCS results.

4.1 SPILL SCENARIOS

4.1.1 Scenarios from MARCS

The MARCS output files contain detailed, location-by-location (a location is roughly 0.5NM x 0.5NM) outputs of the accident frequency of each accidents type (e.g. collision, drift grounding, etc) that have occurred and which ship type and traffic lane number was involved in the accident. From this data MARCS also calculates the amount of bunker oil spill (from the ship size and ship type data) and the frequency of bunker oil spilling accidents. In addition, for ships with hazardous cargo, MARCS also calculates the amount of cargo spill (from the ship size and ship type data) and the frequency of cargo spilling accidents.

Examination of these results enables the identification of the higher frequency accident types (e.g. drift grounding, powered grounding and ship-to-ship collision), the higher frequency ship types (e.g. container ships, bulk carriers) and the higher frequency accident locations. The higher risk spill types (bunker spills, tank barge spills) can also be identified by this examination. This information was combined to generate representative spill scenarios to provide an input into the spill modeling work.

For baseline spill modeling purposes, six baseline scenarios were identified based upon an examination of the results from MARCS. In addition, a calibration scenario using the Selendang Ayu spill was performed to assess the model setup against a known release. The six baseline scenarios are representative example descriptions and are not direct outputs from MARCS. Each scenario could, in theory, result from a wide range of environmental conditions (different visibilities, wind speeds and directions, different sea states, etc.). Based on the probabilistic output from MARCS, the identified scenarios represent a range of release and environmental conditions to prepare the COSIM baseline oil spill model setup. Therefore, it is each scenario's release conditions, defined by examining the MARCS output, that bridge to the COSIM model. ERM has translated these descriptions into input data that would represent the scenario descriptions. COSIM and MARCs model share an overlapping environmental dataset (e.g. NOAA buoy data) in addition to their own unique dataset to process their respective output.

The six spill scenarios and calibration scenario are listed in Table 4-1 for a quick review of scenario characteristics. The spill scenario site locations are shown in Figure 4-1. Scenarios 1 through 6 were run in stochastic mode for baseline spill projections while the Calibration Scenario was run in deterministic hindcast mode to calibrate the COSIM spill model.

4.1.2 Baseline Spill Scenarios

The baseline scenarios described below were developed as part of Task 2A and are summarized below.

Scenario 1

50 thousand Dead Weight Tons (kDWT) container ship, laden with containers filled with non-hazardous cargo, lost power in the winter off the coast of Unalaska. In the winter storms it drifted onto the shoreline between Cape Sarichef and Scotch Cap (about 165°W, 54.5 °N) and punctured one of its two fuel tanks. The ship has a total fuel capacity of 3500 tons, but the fuel tanks were about 70 percent (%) full at the time of the accident. The grounding resulted in a tank puncture below the water line. Consequently the rate of release of the fuel in the one damaged tank (1225 tons total) was relatively low at an average of 20 tons per hour. Emergency response was prompt and effective, helped by an abatement of the storm conditions. After 18 hours the ship was re-floated using the high tide and local tugs. After 22 hours the leak of fuel was stopped by pumping out the remaining contents of the damaged tank. Total loss of fuel was about 440 tons, or 25% of the contents of the damaged tank, or nearly 13% of the total bunker oil capacity.

Scenario 2

A laden 80 kDWT liquefied natural gas (LNG) tanker was struck in the side by another vessel during summer fog while exiting the Unimak Pass (about 165.5W, 54.3 N). The tanker consisted of five cargo tanks and one cargo tank was punctured in the accident above the water line. Approximately 25% of the tank contents (that portion of the tank above the puncture) spilled onto the water rapidly in the first 20 minutes (4000 tons in 20 minutes = 12,000 tons per hour). The remaining portion of the damaged tank (12,000 tons) was spilled over 24 hours by a combination of evaporation and sea water entry into the tank through wave action. Fire or explosion did not occur.

Scenario 3

A 10 kDWT product tanker laden with diesel fuel failed to make a critical course change due to a combination of summer fog and crew distraction. The tanker went aground (powered grounding) on the coast of Sanak Island (about 163W, 54.3N). The initial grounding caused limited damage to the tanker (only the bow was damaged and no cargo tanks were penetrated), but the tanker remained on the rocks and was subsequently further damaged by efforts to re-float the tanker and the action of sea swell on the exposed coast. Over a period of five days a total of three tanks out of a total of eight were punctured before the tanker could be re-floated. The entire contents of the damaged tanks were gradually released into the water by the action of wave pumping. Thus, a total of 3750 tons of diesel was released over five days at an average release rate of about 31 tons per hour.

Scenario 4

A laden 50 kDWT crude oil tanker lost main power as it navigated past Agattu Island in the early spring. It was forced onto the rocks at Agattu Island (about 174E, 52.5N) and over a period of two days the tanker was further damaged in the heavy swells before any salvage could be attempted. A total of 50,000 tons of crude oil plus 2450 tons of bunker fuel was released into the sea at an average rate of 1093 tons per hour.

Scenario 5

A large car carrier was struck (collision) by another vessel in open water (about 179W, 54.2N) in the fall. A single bunker tank was damaged above the water line. The bunker tank had a capacity of 5,250 tons and contained 3,675 tons at the time of the accident. About 10% of the contents of the damaged tank were spilled in the first hour (368 tons per hour). The damaged ship was unable to immediately transfer the contents of the damaged fuel tank to a secure storage tank, so the car carrier continued to leak bunker oil at a rate of ten tons per hour for a further 48 hours, at which point response work prevented further spills. A total of 848 tons of bunker fuel was spilled.

Scenario 6

An Eastbound 50 kDWT container ship, laden with containers filled with mostly non-hazardous cargo, but also including some hazardous cargo, lost power in the winter off the coast of Unalaska. In the winter storms, it drifted onto the shoreline between Cape Sarichef and Scotch Cap (about 165 °W, 54.5 °N). Emergency response was prompt and effective, helped by an abatement of the storm conditions. After 18 hours, the ship was re-floated using the high tide and local tugs. During the grounding 15 containers were lost over the side of the ship. One container contained 20 tons of hazardous cargo in 30 separate drums. None of this secondary packaging was broken before the drums were recovered. However, another container that contained another 20 tons of hazardous cargo in 30 separate drums was smashed by wave action and the entire contents of the drums were spilled into the sea over a period of 4 hours. The other 13 containers only contained non-hazardous cargo.

It is to be noted that Scenario 6 is same as Scenario 1 except that Scenario 6 was focused on a cargo spill of hazardous chemicals and Scenario 1 was focused on Bunker C fuel spill.

4.2 CALIBRATION SCENARIO

The *M/V Selendang Ayu* grounding and eventual spill was selected to use as the calibration scenario. This event was chosen to calibrate the COSIM model since it occurred within the study region and modeling of the spill was preformed.

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 at a position of 53.634° N, 167.125° W. The contents of one of the vessel's double bottom fuel tanks were released immediately and the remaining oil from 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 intermediate fuel oil (IFO) no. 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. 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 a week. The release of diesel fuel was assumed to be constant over 136 hours.

Table 4-1 Characteristics of Baseline Spill and Calibration Scenarios

Scenario ID	Lon	Lat	Spill Rate (tons/hour)	Oil Type	Duration	Total Spilled (tons)	Ship Type	Weather Data Time Period	Spill Time Period
1	165 °W	54.5 °N	20	Bunker C	22 hours	440	Container	2007 & 2008	Sometime in Winter Type 1 Low, Jan-March
2	165.5 °W	54.3 °N	12000 for 20 minutes 500 for 24 hours	LNG	24 hours and 20 mins	16000	LNG Tanker	2007 & 2008	Summer - June to September
3	163 °W	54.3 °N	31	Diesel	120 hours	3750	Product Tanker	2007 & 2008	Summer - June to September
4	174°E	52.5 °N	crude oil – 1042 Bunker c - 51	Crude oil and Bunker C fuel	48 hours	Crude oil - 50,000 Bunker C - 2450	Oil Tanker	2007 & 2008	Early Spring - April to June
5	179°W	54.2 °N	368 for 1 hour 10 for additional 48 hours	Bunker C	49 hours	848	Large Car Carrier	2007 & 2008	Fall - October to December
6	165 °W	54.5 °N	5	Hazardous Cargo (Phorate and Linoleic Acid)	4	20	Container	2007 & 2008	Sometime in Winter Type 1 Low, Jan-March
Calibration Scenario	167.125° W	53.63 °N	42,442 gal of IFO - 0.25 hours 297096 gallons of IFO - 168 hours 14,680 gallons of Diesel - 0.25 hours	IFO 380 &Diesel	168 hours	339538 gallons of IFO 380 and 14680 gallons of Diesel	*M/V Selendang Ayu*	2004	7.14 pm December 8, 2004

Notes:
LNG = Liquefied Natural Gas
IFO = Intermediate fuel oil

4.3 SPILL MODEL GRID

The bathymetric data obtained for the study region was used along with the shoreline and ESI shapefiles to generate the spill model grid for each scenario. The grid was developed using the grid generator tool available in GEMSS. An approximate domain size was determined for each scenario based on the average wind speed for the time period of simulation. The grid was designed in such a way that a low resolution was obtained for the far-field and a high resolution was obtained for the near-field in the vicinity of the shoreline. The spill model grid for each scenario is described below.

Scenario 1: A 400x400 rectilinear grid was generated for Scenario 1 with far-field grid resolution of 800 m x 625 m and near-field grid resolution of 100 m x 75 m. The maximum depth in the grid domain is about 4725 m. The grid domain is shown in Figure 4-2. Depths were assigned for each far-field grid cell and both depths and shoreline type were assigned for each near-field grid cell. The grid domain covers the islands of Unimak, Akun, Akutan, Ugamak and Tigalda and northern portion of Unalaska. An insert is added to Figure 4-2 that provides names of the islands associated with Scenario 1 model grid domain. The shoreline classification is shown in Figure 4-3.

Scenario 2: A 300x300 rectilinear grid shown in Figure 4-4 was generated for Scenario 2 with far-field grid resolution of 760 m x 650 m and near-field grid resolution of 95 m x 81 m. The maximum depth identified in the grid domain is about 2200 m. The grid domain covers the islands of Akun, Akutan, Krenitzin and Tigalda and southern tip of Unimak. An insert is added to Figure 4-4 that provides names of islands associated with Scenario 2 model grid domain. The shoreline classification is shown in Figure 4-5.

Scenario 3: A 300x300 rectilinear grid shown in Figure 4-6 was generated for Scenario 3 with far-field grid resolution of 760 m x 625 m and near-field grid resolution of 95 m x 78 m. The maximum depth identified in the grid domain is about 6800 m. The grid domain covers the islands of Unimak, Sanak, Caton and Ugamak. An insert is added to Figure 4-6 that provides names of the islands associated with Scenario 3 model grid domain. The shoreline classification is shown in Figure 4-7.

Scenario 4: A 500x500 rectilinear grid shown in Figure 4-8 was generated for Scenario 4 with far-field resolution of 510 m x 570 m and near-field resolution of 64 m x 72 m. The maximum depth identified in the grid domain is about 7100 m. The grid domain covers the islands of Agattu,

Attu, Alaid Nizki, Shemya and Buldir Islands. An insert is added to Figure 4-8 that provides names of the islands associated with Scenario 4 model grid domain. The shoreline classification is shown in Figure 4-9 and it is mostly of shoreline types 1, 2 and 3.

Scenario 5: A 300x300 rectilinear grid shown in Figure 4-10 was generated for Scenario 5 with a far-field resolution of 2400 m x 1900 m and near-field resolution of 300 m x 238 m. The maximum depth identified in the grid domain is about 5300 m. The grid domain covers a wide open water Bering Sea in the north and the islands of Adak, Atka, Amlia, Great Sitkin and other small islands in the south. An insert is added to Figure 4-10 that provides names of the islands associated with Scenario 5 model grid domain. The shoreline classification is shown in Figure 4-11.

Scenario 6: A 300x300 rectilinear grid shown in Figure 4-12 was generated for Scenario 6 with a far-field resolution of 736 m x 535 m and near-field resolution of 74 m x 54 m. The maximum depth identified in the grid domain is about 4400 m. The grid domain covers the islands of Unalaska, Umnak, Unalga, Akutan and Akun. The spill site is in the Makushin Bay. An insert is added to Figure 4-12 that provides names of the islands associated with Scenario 6 model grid domain. The shoreline classification is shown in Figure 4-13.

The spatial variation of currents and winds from various data sources (e.g. NLOM, OceanWatch, GFDL, etc.) are extrapolated from their own rectilinear grid system to a Lagrangian particle location using a bilinear spatial interpolation and linear time interpolation. The grid dimension associated with various data sources does not resolve the shoreline characteristics of various Aleutian Islands. This was achieved by using an oil spill grid with fine sub grid cells at the shoreline as shown in Figure 4-2. The currents and winds at these sub grid cells are obtained using the nearest data grid cell and interpolation schemes. The interpolated currents and winds are then used in the shoreline/oil interaction program to estimate the amount of oil that needs to be deposited or entrained (depends on shoreline properties) from a shoreline.

4.4 *OIL/CHEMICAL PROPERTIES*

COSIM is capable analyzing oil or a chemical into its components rather than as a whole. This allows for greater accuracy in the mass balance and weathering calculations, as there are large differences in physical / chemical properties between the various components. The oil components are grouped generally by the type of hydrocarbon and the number of carbons in the molecule (for example, an 8-carbon alkane) ranging from monoaromatics to heavy insoluble residuals. Additionally, grouping chemical constituents of similar structure allows cut-specific particulate sorption. The tendency of polynuclear aromatic hydrocarbons to sorb to solids (reducing bioavailability and reducing the likelihood of acutely toxic effects) can vary greatly over the spectrum of aromatics of concern. The lighter aromatics are less likely to sorb to solids, more likely to dissolve, but may volatilize from the water column more rapidly than heavier aromatics. Modeling separate components therefore enables COSIM to better simulate the transfer of each oil cut into or out of the dissolved phase at cut-specific rates, thereby simulating variable toxic potential in the water column over time.

4.4.1 Oil Types and Properties

Four oil types were modeled: Bunker C (Fuel Oil No.6), a lighter refined hydrocarbon product (diesel – Fuel Oil No. 2), LNG and a generic crude oil. COSIM describes each cut based on the following parameters:

- Boiling point;
- Melting point;
- API gravity / density;
- Percent volume in liquid;
- Solubility at 25°C;
- Molecular weight;
- Vapor pressure at 25°C;
- Latent heat of liquid;
- Dynamic viscosity; and
- Diffusion coefficient.

These parameters are used within the model for various processes to calculate the fate of the oil. In Table 4-2, summaries are provided for each fate process and its dependant variables related to the oil components.

Table 4-2 Oil Fate Processes and Dependant Variables

	Dissolution	Evaporation	Volatilization	Entrainment	Spreading	Adsorption	Settling	Advection	Diffusion	Shoreline deposition
API gravity / density	X	X	X	X	X	X	X	X	X	X
Boiling point										
Diffusion coefficient					X				X	
Dynamic viscosity				X	X		X			
Latent heat of liquid		X								
Melting point										
Molecular weight	X	X	X	X	X	X	X	X	X	X
Oil-water partioning coefficient						X				
Percent volume in liquid										
Solubility at 25°C	X		X							
Vapor pressure at 25°C		X	X							

The values for the various oil component parameters were chosen from ERM's in-house database of oil properties, gathered from various sources through our professional experiences. Values were primarily obtained from the Merck Index (Tenth Edition, 1983) and the CRC Handbook of Chemistry and Physics (69th Edition, 1989). Additional information was obtained from Egloff (1940), and websites including the California Air Resources Board Home Page, Environment Canada's Environmental Science and Technology Centre, ChemYQ.com, Sciencestuff.com, J.T. Baker, and the University of Oxford's Physical and Theoretical Chemistry Laboratory.

A detailed chemical assay was obtained from a confidential client for previous studies on a North American crude oil and was used as a basis to describe a crude oil's constituents. Bunker C fuel oil was provided by the Colorado National Park Service (Irwin, 1997). Chemical analysis of diesel fuel oil came from the International Agency for Research on Cancer (IARC, 1989). IFO properties were obtained from French and Row (2006) and also from Environment Canada. The oil properties used in COSIM are provided in the following tables:

- Bunker C (Table 4-3),
- Diesel (Table 4-4),
- LNG (Table 4-5),

- Crude oil (Table 4-6), and
- IFO 380 (Table 4-7).

Table 4-3 Properties of Bunker C (No. 6 Fuel Oil)

Property	Cut Name													
	C12-C21 n-Paraffin	**C4-C5 iso-Paraffins**	**C10-C11 iso-Paraffins**	**Benzenes**	**Indane**	**C1-Naphthalenes**	**Acenaphthene**	**Acenaphthalene**	**Phenanthrene**	**Pyrene**	**Benzothiophene**	**Dibenzothiophene**	**Pentane**	**Resins**
Boiling point °C	174.1	20.8	162.5	80.0	178.0	241.9	279.0	280.0	340.0	404.0	221.5	332.5	36.0	400.0
Melting point °C	-99	-99	-99	5.5	-4.0	22.2	53.6	80.0	78.1	119.9	36.5	99.5	-129.8	200.0
Percent volume in liquid	2.2	5.9	12.4	2.0	2.0	2.4	2.4	7.3	13.0	1.3	1.2	0.6	21.5	25.8
Solubility at 25°C mg/l	0.05	48.05	1.20	1790.00	0	25.13	3.30	3.93	1.00	0.12	191.80	1.11	38.00	0.0002
Molecular weight (g/mole)	142.29	69.64	142.29	78.12	118.18	142.20	154.21	152.20	178.24	202.26	134.20	184.27	72.15	350.00
Vapor pressure (Pascals) at 25°C	2.54E+04	8.38E+06	3.92E+02	1.26E+04	1.96E+02	6.65E+00	3.33E-01	2.90E+01	1.49E-02	6.00E-04	2.39E-01	2.73E-02	6.85E+04	1.45E-05
Density gm/cm^3	0.730	0.599	0.698	0.877	0.964	1.013	1.222	0.899	0.980	1.271	1.148	1.105	0.626	1.013

Notes:
mg/l = milligrams per liter
g/mole = grams per mole
gm/cm^3 = gram per cubic centimeter

Table 4-4 Properties of Diesel (No. 2 Fuel Oil)

Property	Cut Name																
	Pentane	Hexane	Benzene	Heptane	Methylcyclohexane	Toluene	Octane	Ethylbenzene	Xylenes	Indane	Indene	Decalin	Decane	Napthalenes	Acenaphthene	Fluorene	Phenanthrenes
Boiling point C	36.0	68.7	80.0	98.5	101.0	110.6	125.6	136.1	140.6	178.0	181.0	190.0	174.1	271.7	280.0	295.0	340.0
Melting point C	-129.8	-95.0	5.5	-90.6	- 126.3	-59.2	-57.0	-46.9	6.7	-4.0	-4.0	-43.0	-27.9	47.2	95.0	116.0	100.0
% Volume in liquid	7.2	7.2	0.1	7.2	22.1	0.7	7.2	1.1	4.0	4.1	1.8	11.9	12.5	8.2	2.6	1.4	0.7
Solubility at 25°C mg/l	38.00	9.50	1790. 0	3.40	0	526.00	0.66	169.00	167.00	0	0	0	0.05	6.00	0.39	1.89	1.15
Molecular weight (g/mole)	72.15	86.18	78.12	100.21	98.19	92.14	114.23	106.17	106.17	118.18	116.16	138.25	142.29	170.25	154.21	166.2 2	178.24
Vapor pressure (Pascals) at 25°C	6.85E +04	2.02E+ 04	1.26E +04	6.13E+ 03	6.13 E+03	3.79E+ 03	1.87E+ 03	1.28E +03	1.06E+ 03	1.96E+ 02	1.96E+ 02	3.07E+ 02	1.91E+ 02	9.65E- 01	3.33E- 01	1.12E +00	1.49E-02
Density gm/cm^3	0.626	0.655	0.877	0.684	0.769	0.867	0.699	0.867	0.869	0.964	0.992	0.881	0.730	0.997	1.222	1.202	0.980

Table 4-5 Properties of Liquefied Natural Gas (LNG)

Property	Cut Name															
	Benzene	Toluene	Ethylbenzene	Xylenes	Napthalenes	Acenaphthene	Fluorene	Phenanthrenes	N_2	CO_2	C1 n-Paraffin	C2 n-Paraffin	C3 n-Paraffin	C4 iso-Paraffin	C4 n-Paraffin	C5 iso-Paraffin
Boiling point C	80	110.6	136.1	140.6	271.7	280.0	295.0	340.0	-195.8	-78.5	-161.5	-88.2	-42.1	11.7	-0.5	27.9
% Volume in liquid	1.18	1.29	1.50	1.50	1.91	1.91	3.18	3.18	0.04	0.32	16.07	4.73	5.11	1.12	2.96	1.46
Solubility at 25°C mg/l	1790	526.0	169	167	6	0.4	1.9	1.2	18100	1449	26	56	67	53	72	0
Molecular weight (g/mole)	78.12	92.14	106.17	106.17	170.25	154.21	166.22	178.24	28.01	44.01	16.04	30.07	44.10	58.12	58.12	72.15
Vapor pressure (Pascals) at 25°C	1.26E+04	3.79E+03	1.28E+03	1.06E+03	9.65E-01	3.33E-01	1.12E+00	1.49E-02	8.45E+03	6.44E+06	3.79E+03	3.85E+06	8.45E+05	3.14E+05	1.15E+05	1.21E+05
Density gm/cm³	0.877	0.867	0.867	0.869	0.997	1.222	1.202	0.980	0.806	0.468	0.426	0.377	0.500	0.549	0.584	0.626

Notes:

mg/l = milligrams per liter

g/mole = grams per mole

gm/cm^3 = gram per cubic centimeter

Table 4-6 Properties of Crude Oil

Property	Cut Name															
	C5 n-Paraffin	nC6 - Hexane	nC7 - Heptane	Methylcyclo-hexane	nC8 - Octane	nC9 - Nonane	Indane/Indene	nc10 - Decane	nc11 - Undecane	C16-C18 n-Paraffin	C19-C21 n-Paraffin	C22-C25 n-Paraffin	C26-C30 n-Paraffin	C31-C36 n-Paraffin	C37-C45 n-Paraffin	C46-C80 n-Paraffin
Boiling point C	36.1	68.7	98.5	101.0	125.6	150.8	180.5	174.1	199.1	568.9	639.6	715.0	800.4	883.3	976.3	1145.1
% Volume in liquid	1.6	1.2	1.3	1.3	1.5	1.8	1.8	1.9	1.9	5.9	5.2	5.9	5.9	5.2	4.9	5.2
Solubility at 25°C mg/l	38.0	9.5	3.4	0	0.7	220.0	0	0.1	0.0200	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molecular weight (g/mole)	72.15	86.18	100.21	98.19	114.23	128.26	117.17	142.29	156.31	235.83	275.53	323.31	385.34	461.47	561.97	769.63
Vapor pressure (Pascals) at 25	6.85E+04	2.02E+04	6.13E+03	6.13E+03	1.87E+03	5.93E+02	1.96E+02	1.87E+02	5.97E+01	1.45E-05	1.45E-05	1.45E-05	1.45E-05	1.45E-05	1.45E-05	1.45E-05
Density gm/cm³	0.626	0.655	0.684	0.769	0.699	0.718	0.978	0.730	0.740	0.849	0.866	0.883	0.902	0.921	0.942	0.976

Notes:
mg/l = milligrams per liter
g/mole = grams per mole
gm/cm³ = gram per cubic centimeter

Table 4-7 Properties of IFO 380

Property	Description of property	Value				
MolecularWeight	Molecular weight (g/mole)	186				
Density	Density (g/cm^3)	0.9712				
Solubility	Solubility (mg/l) at 25° C	2				
VaporPressure	Vapor pressure (Pascals) at 25° C	133				
DynamicViscosity	Dynamic viscosity (cP) at 25° C	4000				
ViscosityConstantB	Viscosity exponent for variation with temperature	24923				
SurfaceTension	Surface tension (mN/M)	36				
WaterContent	Emulsion constant	0				
MinimumThickness	Minimum thickness (mm)	0.01				
InitialBoilingPoint	Initial boiling point in °K	580				
GradientOfDistillationCurve	Gradient of distillation curve in °K	239.28				
CoefficientA	Coefficient A	147.78				
CoefficientB	Coefficient B	84.67				
ToxicFactor	Percent Toxicity	N/A				
NumberOfCuts	Number of distillation cuts	5				
Cut Variables	**Cut Parameter**	**1**	**2**	**3**	**4**	**5**
CutName	CutName	Cut 1	Cut 2	Cut3	Cut 4	Cut 5
CutBoilingPoint	Boiling point for each distillation cut C	533.75	533.75	533.75	533.75	533.75
CutMeltingPoint	Melting point for each distillation cut C	N/A	N/A	N/A	N/A	N/A
CutAPIGravity	API gravity for each distillation cut	14.20	14.20	14.20	14.20	14.20
CutPercentVolume	Percent volume, in liquid	20	20	20	20	20
CutSolubilityAt25° C	Solubility at 25 degrees C for each distillation cut mg/l	2	2	2	2	2
CutMolecularWeight	Molecular weight (g/mole)	186	186	186	186	186
CutVaporPressureAt25° C	Vapor pressure (Pascals) at 25 degrees C	133	133	133	133	133
CutDensity	Density gm/cc	0.9712	0.9712	0.9712	0.9712	0.9712
CutViscosity	Cut Viscosity cP	N/A	N/A	N/A	N/A	N/A
CutDiffusivity	Cut Diffusion coefficient	N/A	N/A	N/A	N/A	N/A

4.4.2 *Chemical Properties*

Two chemicals were selected for baseline spill modeling: a highly toxic high density and low density chemical. Chemicals were chosen based on categories of hazardous containerized chemicals which could potentially be released at sea in a catastrophe due to regular marine traffic near the Aleutian Islands. The list of the top 40 hazardous commodities based on total weight are provided in Table 4-8.

Table 4-8 List of Containerized Hazardous Commodities

Top	Imported or Exported "Hazardous" Commodities	Weight (kg)
1	2931 Organo-inorganic Compounds Nesoi	106,790,359
2	2815 Sodium Hydrox; Potass Hydrox; Sod Or Potass Perox	102,542,126
3	3811 Antiknock Preps & Other Additives For Mineral Oils	89,572,795
4	3604 Fireworks, Signalling Flares, Rain Rockets Etc.	85,562,176
5	3206 Coloring Matter Nesoi; Coloring Prep Nesoi, Etc.	83,873,912
6	2710 Oil (not Crude) From Petrol & Bitum Mineral Etc.	71,422,140
7	2933 Heterocyclic Comp, Nit Hetero-atoms Only	60,176,393
8	2802 Sulfur, Sublimed Or Precipitated; Collodial Sulfur	59,834,714
9	2918 Carboxylic Acid, Added Oxygen & Anhy Etc, Hal Etc	51,191,314
10	3808 Insecticides, Rodenticides; Fungicides Etc, Retail	51,154,313
11	2835 Phosphinates, Phosphonates, Phosphates & Polyphosp	47,988,492
12	2907 Phenols; Phenol-alcohols	46,455,433
13	3824 Binders For Found Molds; Chemical Prod Etc Nesoi	38,571,939
14	2922 Oxygen-function Amino-compounds	37,753,261
15	2922 Oxygen-function Amino-compounds	36,167,600
16	2917 Polycarboxylic Acids & Anhyd Etc, Halog, Sulf Etc	35,339,675
17	2821 Iron Oxides & Hydroxides; Earth Colors Nun 70% Ir	35,037,231
18	2811 Inorganic Acids & Inorganic Oxy Nonmet Comp Nesoi	35,012,807
19	2833 Sulfates; Alums; Peroxosulfates (persulfates)	34,458,866
20	3824 Binders For Found Molds; Chemical Prod Etc Nesoi	31,745,336
21	2936 Provitamins And Vitamins & Derivatives & Intermixs	30,805,911
22	2903 Halogenated Derivatives Of Hydrocarbons	30,631,403
23	2921 Amine-function Compounds	29,536,943
24	2711 Petroleum Gases & Other Gaseous Hydrocarbons	29,307,142
25	3102 Mineral Or Chemical Fertilizers, Nitrogenous	28,175,487

Top Imported or Exported "Hazardous" Commodities		Weight (kg)
26	2903 Halogenated Derivatives Of Hydrocarbons	27,628,057
27	2827 Chlorides Etc; Bromides Etc; Iodides Etc.	27,495,539
28	2825 Hydrazine Etc, Oth Inorg Bases; Metal Oxides Etc	27,324,211
29	3105 M Or Ch Fertiliz, Nun2of3el; Fert Nesoi; Fert Pack	27,128,276
30	2712 Petroleum Jelly; Mineral Waxes & Similar Products	26,452,898
31	2713 Petroleum Coke, Petroleum Bitumen & Other Residues	25,640,130
32	2905 Acyclic Alcohols & Halogenat, Sulfonatd Etc Derivs	25,250,624
33	2916 Unsat Acyclic & Cyclic Monocarbox Acid & Anhyd Etc	24,997,346
34	2840 Borates; Peroxoborates	24,821,587
35	3809 Finishing Agents Etc For Textiles, Paper Etc Nesoi	24,747,872
36	2804 Hydrogen, Rare Gases And Other Nonmetals	24,382,634
37	2803 Carbon, Nesoi (including Carbon Black)	24,065,148
38	2905 Acyclic Alcohols & Halogenat, Sulfonatd Etc Derivs	23,953,304
39	2818 Artfl Corundum W/nt Chem Defnd Alum Oxid/hydroxide	21,721,425
40	2930 Organo-sulfur Compounds	21,604,210

Chemical categories from the hazardous commodities lists were cross referenced to chemicals in the database available in the NOAA NRDAM/CME model (French, et al., 1997). Chemicals in the database were sorted based on toxicity using the adult fish 96-hour lethal concentration 50, or LC_{50} (i.e., the concentration in which 50% of test organisms die after exposure to constant conditions over a 96-hour period). The first most toxic, endrin, was not chosen since the pesticide is currently banned in many countries. The second choice therefore was the organophosphate pesticide, phorate, which is categorized under Hazardous Commodity #10 in Table 4-8. Phorate is denser than sea water; with a density of 1.156 g/cm^3 [sea water at 25°C and 35 (parts per trillion (ppt) salinity is 1.023 g/cm^3]. Phorate is named on several lists of priority substances of concern. These lists rank chemicals based on many factors including toxicity, volume, and frequency of historical releases. According to a summary table published with the Proceedings of the Eight Technical Seminar on Chemical Spills (Fingas et al., 1991), phorate is listed on six out of 19 priority lists identified. These lists include:

- EC 1990 Chemical Spill Priority List (Top 500)
- US Reportable Quantities (Top 100)
- EPA Extreme Danger List (Top100)
- SARA List of Extremely Hazardous Substances (Top100)

- CERLCA Hazardous Substances (Top100)
- RCRA Hazardous List (Top100)

EC = Environment Canada
EPA = US Environmental Protection Agency
SARA = Superfund Amendments and Reauthorization Act of 1986
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act of 1980
RCRA = Resource Conservation and Recovery Act of 1976

A second chemical, less dense than water, was chosen from the model's list of chemicals. Linoleic acid was the most toxic chemical on the list that had a density less dense than water (0.905 g/cm^3). Linoleic acid is a carboxylic acid and a polyunsaturated fatty acid, used in making soaps, emulsifiers, and quick-drying oils. It is categorized under Hazardous Commodity #9 in Table 4-8. Chemical properties for both chemicals, provided by NOAA's model, are listed in Table 4-9.

Table 4-9 Chemical Properties

Property	Phorate	Linoleic Acid
Molecular Weight (g/mole)	260.364	280.45
Density (g/cm^3)	1.156	0.905
Solubility (mg/L) at 25°C	50	0.01
Vapor Pressure (atm) at 25°C	1.11E-06	1.09E-04
Degradation Rate in Water (per day)	0.00109	0.11
Degradation Rate in Sediments (per day)	0.00109	0.11
Adsorbed/Dissolved Partition Coefficient, K_{oc}	6363	166000
Viscosity (cp) at 25°C	14.23	25.63
LC_{50} for 96 hrs - Fish, adult (25°C, ppb)	0.1842	3.05
LC_{50} for 96 hrs - Eggs and larvae (25°C, ppb)	0.0115	0.34
EC_{50} for growth - Benthos (25°C, ppb)	206.8	10.06
EC_{50} for growth - Zooplankton (25°C, ppb)	0.0422	0.43
EC_{50} for growth - Plants (25°C, ppb)	374.7	9.76

Notes:
ppb = parts per billion
LC_{50} = concentration in which 50% of test organisms die after exposure to constant conditions over a 96-hour period; used for water column organisms
EC_{50} = Effects concentration, the concentration in which 50% of test organisms exhibit reduced effect (growth) after exposure to constant conditions compared to control; used for benthic (sediment) organisms

4.5 OCEANOGRAPHY

The oceanography data for the time period specified in Table 4-1 for the five Baseline Scenarios were obtained from NRL-NLOM 1/32° 30 day delayed nowcast database. For the Calibration Scenario, current data was obtained from NRL-NLOM 1/16° nowcast database.

4.5.1 *Current*

The current pattern for each scenario time period is shown in Figure 4-14, Figure 4-15, Figure 4-16 and Figure 4-17 for winter, spring, summer and fall seasons. The current pattern in the month of December 2004 and January 2005 are shown in Figure 4-18 and Figure 4-19 for the Calibration Scenario. These figures show that the currents are highly chaotic with many eddies circulating in most areas of the study region. There is a strong current flowing on the southern side of the Aleutian Islands from north-east to south-west. A detailed description of currents in the Aleutian Islands is given in (Fett et al., 2003).

4.5.2 *Current Rose*

Time series of currents were obtained at each scenario location from the NRL-NLOM 1/32° nowcast database for the time period 2007 to 2009. This data was then used to develop the current rose diagram for each season and they are shown in Figure 4-20, Figure 4-21, Figure 4-22 and Figure 4-23, Figure 4-24 for Scenarios 1 and 6, Scenario 2, Scenario 3, Scenario 4 and Scenario 5, respectively. For winter season, the currents are directed between north-west to south-west with speed reaching as high as 35 cm/sec. For summer season, currents are directed 50 % of the time towards south-west and 20% of the time directed north-east with speed reaching as high as 40 cm/sec. For spring, currents are mostly directed northeast and southwest with higher frequency of occurrence directed towards southwest with speed reaching as high as 50 cm/sec. For the fall season, currents are directed between north-east and north-west with speed reaching as high as 35 cm/sec.

For the Calibration Scenario, current rose diagrams are shown for the month of December and January in Figure 4-25 and Figure 4-26, respectively. For the month of December, the currents are directed towards south and south-east and north with speed reaching as high as 50 cm/sec. In the first week of January 2005, the currents are directed towards south east with speed reaching as high as 50 cm/sec.

4.5.3 *Salinity and Temperature*

The temperature for the Aleutian Islands is shown in Figure 4-27 for winter, spring, summer and fall seasons. The temperature data was obtained from NOAA. The temperature vary between 3 to 4° C for most of the islands during all the seasons except in the winter and spring, the temperatures fall below zero on islands north Unalaska.

The seasonal variation of salinity at the water surface is shown for the year 2007 in Figure 4-28 for winter, spring, summer and fall seasons. The salinity on the surface varies from 32.5 to 33 ppt for all the seasons south of Unalaska, where as it varies from 30 to 32 ppt north of Unalaska.

4.6 METEOROLOGY

The wind data was obtained from Ocean Watch for each scenario simulation time period. Typical wind characteristics for each season are described below.

- Winter: wind pattern in the Aleutian Islands is shown on 15 February 2008 in Figure 4-29 (note that land mass is represented by the dark gray polygons). Wind is from north-west in the eastern part of the islands, from north in the middle part, and from east in the western part of the islands with an average speed of 20 m/sec.
- Spring: wind pattern in the Aleutian Islands is shown on May 15, 2008 in Figure 4-30. Wind is from north in the eastern half of the islands and changes to east in the middle part of the islands. In the western part of the islands, wind is from north resulting in an anti-clockwise circulation south of the islands with an average speed of 14 m/sec.
- Summer: wind pattern is shown on August 15, 2008 in Figure 4-31. The wind is mostly from south-west for the Aleutian Islands with an average speed of 11 m/sec.
- Fall: wind pattern is shown on November 15, 2008 in Figure 4-32. Wind is from south for the upper (eastern) part and from west for the lower (western) part of the islands.

For the Calibration Scenario, wind patterns for the month of December 2004 and January 2005 are shown in Figure 4-33 and Figure 4-34, respectively. At the start of the spill, winds were blowing from north-west towards the northern shore of the islands with an average speed of 27 m/sec. A week into the spill, winds were blowing from north-east pushing the spill towards south-west with an average speed of 25 m/sec. Similar trend exists during the second week into the spill. In the third week into the spill, winds were from South with an average speed of 21 m/sec. In the first week of January 2005, winds were blowing from east with a mean magnitude of 22 m/sec.

4.6.1 Wind Rose Diagrams

The wind rose diagrams for each scenario simulation time period were obtained at the spill site location. The wind rose diagrams and seasonal characteristics for each baseline spill scenario are summarized in Table 4-10.

Table 4-10 Wind Rose Summary for Each Scenario

Scenario	Figure No.	Season	Wind Direction	Wind Speed (m/sec)
1, 6	4-35	Winter	Wind blows from all directions with a slightly higher probability from northwest. The frequency of occurrence in each direction varies in the range 6 to 8%.	maximum wind speed is higher than 20 m/sec
2	4-36	Summer	Wind blows from all directions but with higher probability of occurrence between northwest and southwest.	maximum wind speed is 18 m/sec
3	4-37	Summer	Wind blows from all directions with higher probability of occurrence in northwest.	maximum wind speed is 18 m/sec
4	4-38	Spring	Wind blows from all directions with higher probability of occurrence between northwest and southwest.	maximum wind speed is 18 m/sec.
5	4-39	Fall	Wind again blows from all directions with higher probability of occurrence between northwest and southwest.	maximum wind is higher than 20 m/sec

The wind rose diagram for the month of December (Day 8 to Day 31) and January used in the Calibration Scenario is shown in Figure 4-40 using data from Station 46073. The wind in the month of December was from all directions with higher probability of occurrence in north-east. Maximum wind speeds were higher than 25 m/sec. In the first week of January 2005, wind was mostly between east and west with higher probability of occurrence in the west and north-west with maximum wind speed reaching 25 m/sec.

4.6.2 *Frequency-Speed Matrix Development for Wind*

The frequency-speed matrix development for wind was based on 25 or more years of available data, prior to 2009. The scenarios were run using stochastic winds since a spill can occur at any time during the simulation time period of two to three months. The stochastic winds were generated from a wind transition matrix developed for each spill site location. The wind transition matrix was developed using the Markov's first order autoregressive model using time varying wind data for each spill site location to perform the stochastic modeling of spill fate and transport. Markov model provides more realistic time structure by allowing the wind components at time, t, to be functions of the components at time, t-1 (Aksoy et al., 2004).

A schematic diagram is shown in Figure 4-41. Also shown in the same figure is a sample wind transition matrix. For the current study, ten wind speed bins with one additional bin for calm conditions and 12 directional speed bins were used to obtain the wind transition matrix. The wind matrix was then used to develop stochastic wind time series at hourly intervals for each iteration of a spill scenario simulation. The spill start time was randomly selected from the scenario time period and wind time series data was generated from the randomly selected start date to the end of the simulation length. Wind transition matrix was generated for the five scenarios.

4.7 *WAVE*

The wave induced drift velocities are very important, especially in the vicinity of the islands. The wave induced drift velocities are large in the Aleutian Islands due to the existence of big waves resulting from large wind speeds. The wave data availability in the study region is shown in Figure 4-42. The wave data was obtained from USCOE Waterways Experiment Station. The wave data from Station 1 and Station 6 were used for the scenarios. The wave height and period were obtained from these stations and the wave direction was assumed to be in phase with the wind direction. The wave rose diagram for Station 1 and Station 6 are shown in Figure 4-43.

A spatial and temporal variation of wave height data for the study region could not be identified during the current study. Nevertheless, COSIM also computes wave heights based on methodology provided in U. S. Army Corps of Engineers Shore Protection Manual equations for deep and shallow water wave forecasting based on wind fetch and duration (CERC, 1984). Both actual wave heights measured at a specific location and COSIM were combined to get a realistic estimate for stochastic wind conditions. The wave data is used to compute wave drift velocity for the advection of spill. This analysis is sufficient for Phase A semi-quantitative analysis.

5.0 MODEL CALIBRATION

The calibration was performed by hindcasting the *M/V Selandang Ayu* spill. The description of the spill incident is given in Section 4.1. An earlier modeling work performed by ASA (French and Row, 2006) for this spill was reviewed and obtained the necessary input data for setting up the *Selandang Ayu* spill model. Missing data was filled in using the set of databases compiled for the current study. The 2006 analysis of the *Selandang Ayu* spill used the Spill Impact and Mapping (SIMAP) model. The ASA report does not provide much information about the trajectory of the spill for comparison purposes. Instead, a series of shoreline impact figures and tables for different hydrodynamic and release conditions were available for COSIM model calibration. A detailed analysis of this spill or the 2006 modeling is beyond the scope of the current work and instead only limited calibration was performed by simulating selective scenarios from the 2006 report.

The wind data available in the 2006 report was directly used in the calibration run. In addition, Ocean Watch spatially and temporally varying wind data was also used for checking the spatial wind with the localized meteorological data used in the 2006 report. The currents were obtained from NRL-NLOM 1/16° nowcast database. The temperature and salinity were obtained from the NOAA and GFDL databases. The spill simulation was run for 28 days from December 8, 2004 at 7.14 pm to 5 January 2005. The spill parameters used from the *Selandang Ayu* spill for the calibration are summarized in Table 5-1.

Table 5-1 Spill Parameter Values for Selandang Ayu Spill

Spill Parameter	Value
Longitude	167.125° W
Latitude	53.634° N
Spill Rate	42,442 gal in 0.25 hours 297,096 gal for a week 14,680 gal for a week
Oil Type	IFO 380 and Marine Diesel
Duration	120 hours
Total Spilled	339,539 gal of IFO 380 and 14680 gal of Marine Diesel
Ship Type	Oil Container
Weather Data Time Period	December 5, 2004 to January 5, 2005
Spill Time Period	December 8, 2004 to January 5, 2005

The observed oil on December 15 (exact time was not given) is shown in Figure 5-1. The COSIM model-predicted shoreline oiling for the same date (at 11:00 am) is shown in Figure 5-2. The COSIM model-predicted shoreline oiling compares well with the observations shown in Figure 5-1, which was obtained from SCAT observations.

The SIMAP predicted shoreline oiling for a horizontal diffusion coefficient of 50 m^2/second is shown in Figure 5-3. COSIM predicted shoreline oiling for the same horizontal dispersion coefficient is shown in Figure 5-4 and the comparison is good. For calibration purpose only, IFO 380 spill was considered. The Shoreline Cleanup Assessment Team's (SCAT) oil observations are shown in Figure 5-5. COSIM predicted shoreline oiling at the end of 28 days is shown in Figure 5-6. COSIM-predicted shoreline oiling results were compared with flight observations on December 12^{th}, 13^{th} and 15^{th} of 2004 obtained from the Alaska Department of Environmental Conservation website and are shown in Figures 5.7 and 5.8 (http://www.dec.state.ak.us/spar/perp/response/sum_fy05/041207201/041207201_flt_index.htm). COSIM model predicted the location of shoreline oiling reasonably well 3 to 5 days after the start of the spill. The mass balance at the end of 28 days is shown in Table 5-2 for SIMAP and COSIM models.

The results shown in this section confirms the spill modeling capabilities of COSIM to predict fate and transport of any type of hazardous substance in the Aleutian Islands. A complete calibration of COSIM for the Selandang Ayu spill is outside the scope of work since the intention here is to show that COSIM is able to predict overall mass balance and spread of a spill within the study area.

Table 5-2 Mass Balance Comparison between SIMAP and COSIM at the end of 28 days for IFO 380 Spill

Environmental Compartment	SIMAP %	COSIM %
Water Surface	N/A	-
Water Column	42.19	41.1
Atmosphere	7.17	4
Shoreline	14.16	19
Sediment	20.13	24.5
Decay	15.72	11.4

6.0 ANALYSIS OF SCENARIOS

Scenarios described in Section 4.1 were modeled using stochastic winds. Currents and waves were not supplied as stochastic since sufficient data is not available to capture the seasonal variability. Instead, actual data available for the baseline timeframe was used. Salinity, temperature, wave and current data were directly obtained from the various databases for the simulation time period. The scenario simulations were made during the 2007-2008 time period, except the Calibration Scenario was run in the hindcast mode from December 2004 to January 2005.

The seasonality was identified based on each spill scenario description provided in Section 4.1. For example, Scenario 1 was hypothesized to occur in the winter based on its scenario description. The long wind record (1987-2009) was then used to develop the Markov wind matrix for the winter season. The winter season months were selected based on the Aleutian seasons as defined in Chapter 4 (Basic Weather Regimes of the Aleutian Islands) of Forecasters Handbook for the Bering Sea, Aleutian Islands and Gulf of Alaska (R. W. Fett and R. E. Englebretson and D. C. Perryman, 1993).

A three-tier modeling approach was used for the baseline spill study. MARCS (tier-1) and COSIM (tier-2) models were used in Task 2 to characterize the risk associated with movement ocean-going vessels or barges and the movement of oil or hazardous chemical from these vessels. This characterization was done by first using tier-1 MARCS as a coarse level probabilistic model to obtain accident characteristics based on traffic and environmental data. Wind data from NOAA buoy station 46073 (extracted 4 wind speeds and 8 directions probability distribution data) was used to represent the environmental field conditions for the study domain. This approach is sufficient for the traffic study and subsequent oil spill baseline because the MARCS model computes results in terms of risk probabilities. That is, MARCS modeling does not result in a deterministic output. The MARCS output annual trend remains the same with possibility of some seasonal variations. Seasonal variation is addressed in the tier-2 COSIM model.

The critical scenarios developed based on the results of MARCS were modeled in COSIM by selecting a specific time period for each spill accident to evaluate the seasonal variations. The time period for each spill scenario was selected based on the Aleutian Islands basic weather regimes (as previously defined in Section 4.0). Environmental data such as wind, current, salinity and temperature were obtained for each season to assess the impact on the movement of a spilled substance in the study region. This approach captured the seasonal variability in the study domain and the COSIM results remain in the probabilistic mode.

A set of 25 stochastic iterations were made by randomly selecting the starting date within each of the scenario seasonal time period. Once the start date was selected, a new set of wind data was generated using the Markov transition matrix developed at hourly intervals from the start date to the length of the simulation, which was set at seven days (1 week). The 1 week simulation period was selected based on the response time from a typical emergency response team for a spill. For the Phase A baseline spill study, it was assumed that 1 week simulation results provide enough qualitative information that it can be analyzed and adjust scenario specifications, if any, in Phase B. For each iteration, newly established wind data was used, along with the current, temperature and salinity obtained from the various databases selected for this study. Each stochastic simulation was run by including both fate and transport at surface, subsurface, shoreline and sediments. Each scenario simulation was run for 1 week, as described above. Model output is saved for each stochastic iteration and also as cumulative of the iterations for final probabilistic calculations.

The number of particles (Lagrangian Elements) to represent the spill was selected based on the spill mass, rate and duration. The computational time increases as the square of the number of particles. The number of particles ranged from 1,000 to 5,000 both on water surface and subsurface to keep the computational time to a reasonable value but at the same time preserve the predictability of the model. The number of particles in the model was kept within the user specified maximum value at any time during the simulation by using a series of methods either to combine or split particles. If the total number at a given time is at or near the maximum, and additional particles are needed to allow continuous input of contaminant, the model performs a compression of the particle arrays. This compression is based on the identification of geometrically "nearest-neighbors", and the combining of their attributes: mass, time-since-release, x-, y-, and z-locations. A new particle is created with mass equal to the sum of the masses of the two nearest-neighbor particles, and location and time-since-release are computed based on linear-weighting of the existing values based on the mass of each particle. This process is continued until sufficient "free space" is created in the arrays to allow the program to proceed. This results in a relatively uniform spatial distribution of particles as the program proceeds.

The results for oil spills were analyzed by using surface and shoreline impacts, where as chemical spills were analyzed by using subsurface concentrations in the water column. This is based on the assumption that most of the oil impact is on the water surface and shoreline than in the water column. Thus, the baseline spill modeling for oil focuses on travel time, area coverage, impact probability, and oil thickness. Since oil is a not a single component and it is made up of many fractions, concentrations are not compared to chemical-specific threshold values. A toxic analysis will be done during the consequence analysis phase.

For chemical spills, it assumed that most of the impact is in the water column due to dissolved and adsorbed concentrations that could be toxic to marine organisms. Since chemical-specific threshold values are available for water column and benthic species, predicted chemical spill concentrations were compared to threshold values for comparative purposes only. Threshold values selected for the baseline scenario included LC_{50} concentration (concentration in which 50% of test organisms die after exposure to constant conditions over a 96-hour period) for water column organism, or the EC_{50} concentration (concentration in which 50% of test organisms exhibit reduced effect (growth) after exposure to constant conditions compared to control) used for benthic (sediment) organisms.

The following types of contour outputs were analyzed for each scenario:

1) Travel time in hours on water surface and water column (chemical spills only);
2) Probability of spill impact on the water surface in percentage;
3) Probability of spill impact on the shoreline in percentage;
4) Probability of spill impact in the water column for chemical spills
5) Probability of spill impact on the bottom sediments for chemical spills
6) Percent oil/chemical remaining on water surface in percentage;
7) Percent oil/chemical lost by evaporation in percentage;
8) Maximum water column concentration at any vertical location in parts per billion (ppb);

9) Maximum averaged concentration over all iterations at any vertical location in ppb;

10) Maximum concentration on bottom sediments (chemical spills only) and

11) Maximum oil thickness in millimeter (mm).

These types of plots provide an estimate of the spill impact for baseline studies.

6.1 SCENARIO 1

The scenario 1 simulation time period was set between January and March to represent the winter conditions in the Aleutian Islands. Scenario 1 spill characteristics and COSIM model input data parameters are summarized in Table 6-1 and 6-2, respectively.

Table 6-1 Scenario 1 Spill Characteristics

Spill Parameter	Value
Longitude	165° W
Latitude	54.5° N
Spill Rate	20 tons per hour
Oil Type	Bunker C oil
Duration	22 hours
Total Spilled	440 tons
Ship Type	Container
Weather Data Time Period	2007 and 2008
Spill Time Period	Winter (January - March)

Table 6-2 Input Data Parameters Used for Scenario 1

Name	Description	Value(s)	Rationale
Location of release	x and y coordinates of release in UTM meters	North Unimak Pass 165°W 54.5 °N	
Depth of release	Depth below the water surface of the release	0 m (surface)	Hypothetical releases will be on the surface or near the surface but will quickly rise to the top
Start time and date	Date and time the release began	Randomly selected between Jan 01 to Mar 30th	Starting time is randomly selected for the stochastic simulation and analysis of Scenario 1
Duration	Duration of the release	22 hrs	Reasonable release durations considering vessel and amount of oil

Name	Description	Value(s)	Rationale
Total spill volume or mass	Total volume (or weight) released	440 MT	Reasonable release volumes considering type of vessel and amount of product stored on board
Spill properties	Physical and chemical properties	Properties of Bunker C fuel oil	Researched values from various literature
Winds	Stochastic winds	Markov wind matrix for each scenario	Used statistics of a long-period of measured meteorological data available as gridded output for every 6 hours – Ocean Watch
Salinity	Surface water salinity	Time and spatially varying database	Best record discovered - 28 year record from the Geophysical Fluid Dynamics Laboratory
Water Temperature	Surface water temperature	Time and spatially varying database	Best record discovered - 30 year record from NOAA
Wave	Wave height and period	Time varying	Best record discovered - Hourly data from ACOE
Wind drift speed	Percentage of wind speed influencing oil/chemical movement on the surface	3.50%	Typical literature value (ASCE (1996), Spaulding 1988, Youssef & Spaulding 1993)
Wind drift angle	Wind direction angle shift clockwise (in northern hemisphere) affecting oil drifts (in degrees)	0°	Valid 1st approximation (ASCE (1996), Spaulding 1988, Youssef & Spaulding 1993)
Horizontal turbulent diffusion coefficient	Randomized turbulent mixing parameter in x & y direction	10 m^2/sec	Typical literature value varies between 5 to 100 m^2/sec
Vertical turbulent diffusion coefficient	Randomized turbulent mixing parameter in z direction (below surface layer)	0.0001 m^2/sec	French et al. (1996, 1999) based on Okubo and Ozmidov (1970); Okubo (1971)
Suspended sediment concentration	Average suspended sediment concentration	10 mg/l	French et al. (1996)
Suspended sediment settling rate	Net settling rate for suspended sediments	1 m/day	French et al. (1996)
Oil density (g/cm^3)	Density of oil as a whole	1.0057	Calculated from oil chemistry
Number of surface particles	Number of Lagrangian particles used to represent the oil mass on the surface	500	Value selected based on computation resources
Number of subsurface particles	Number of Lagrangian particles used to represent the dissolved oil mass in the water column	1000	Value selected on computation resources
Stochastic simulations	Number of model iterations	25	Tested value, sufficient for estimating patterns of distribution

Name	Description	Value(s)	Rationale
Advection and Diffusion Processes	Switch to Use Advection and Diffusion Processes	On	Included for full fates processing
Spreading Processes	Switch to Use Spreading Processes	On	Included for full fates processing
Evaporation Processes	Switch to Use Evaporation Processes	On	Included for full fates processing
Emulsification Processes	Switch to Use Emulsification Processes	On	Included for full fates processing
Entrainment Processes	Switch to Use Entrainment Processes	On	Included for full fates processing
Dissolution Processes	Switch to Use Dissolution Processes	On	Included for full fates processing
Volatilization Processes	Switch to Use Volatilization Processes	On	Included for full fates processing
Biodegradation Processes	Switch to Use Biodegradation Processes	On	Included for full fates processing
Sedimentation Processes	Switch to Use Sedimentation Processes	On	Included for full fates processing
Shoreline Deposition and Floatation	Switch to Use Shoreline Deposition	On	Included for full fates processing

Figure numbers for each of the contour plot described in Section 6.0 are listed in Table 6-3 for Scenario 1.

Table 6-3 Figure Numbers for Scenario 1

Contour Type	Figure Number
Travel Time	Figure 6-1
Probability of impact on water surface	Figure 6-2
Probability of impact on shoreline	Figure 6-3
Percent remaining on water surface	Figure 6-4
Percent lost by evaporation from water surface	Figure 6-5
Maximum oil thickness	Figure 6-6
Maximum water column concentration	Figure 6-7
Maximum vertically averaged water column concentration	Figure 6-8

The travel time contour map (Figure 6-1) shows that within 24 hours, most of the southern portion of the Unimak Island and northern portion of the Ugamak Island are impacted by the spill. For other regions, the spill travel time varies between 4 and 7 days. Figure 6-1 also shows that the spill also impacts Sanak Island. The spread of the spill in Figure 6-1 is due to the cumulative plot of 25 runs and should not be confused as result for a single run. Travel time contour of 24 hours covers an area of 1,100 square kilometers (km^2). The average mass balance of 25 iterations for Scenario 1 is shown below.

Water Surface	-	14.2%
Water Column	-	31.9%
Shore	-	7.1%
Atmosphere	-	35%
Dissolution	-	3%
Biodegradation	-	0.3%
Sediments	-	8.5%

The travel time contour map shows only the time it takes for a spill to reach a specific location. It does not provide information about how often it would affect a specific place or what would be the availability of spill mass at the impact location. So, the probability of impact on water surface and shoreline were developed to check impact frequency.

Figure 6-2 shows that 24 hour contour area has a probability of impact greater than 50%. The probability of impacting Tigalda or Sanak Islands is less than 5%. Similarly Figure 6-3 shows that shoreline impact greater than 50% covers 37 km, mostly covering the southern portion of the Unimak Island in the Unimak Pass.

Figure 6-4 shows that greater than 70% of oil is stranded in the Unimak pass during the first 24 hours. Fifty-percent of the oil is stranded on the water surface for the rest of the spill simulation covering a wide range on the either side of the Unimak Island. Figure 6-5 shows that 30% to 40% of oil is lost before the spill moves to the upper part of the Unimak Island by evaporation.

Maximum oil thickness contour plot is shown in Figure 6-6. A maximum oil thickness of 0.01 mm exists around the spill site in the Unimak Pass and also around the edges of the Unimak shoreline. In other regions, the maximum oil thickness decreases to 0.001 mm. The maximum oil thickness reaches 0.00005 mm around Sanak and Tigalda Islands.

In Figure 6-7, the water column concentration at any vertical location from the iterations reaches a maximum value of 160 ppb while the water column concentration averaged over the iterations at any vertical location reaches a maximum value of 0.1 ppb in Figure 6-8. The total concentration is calculated as the sum of the fractions, except the last residual fraction. In this baseline scenario, the high concentration region exists only in the Unimak pass.

6.2 *SCENARIO 2*

The Scenario 2 simulation time period was set between June and September to represent the summer conditions in the Aleutian Islands. The scenario 2 spill characteristics and COSIM model input data parameters are shown in Table 6-4 and Table 6-5, respectively.

Table 6-4 Scenario 2 Spill Characteristics

Spill Parameter	Value
Longitude	165.5° W
Latitude	54.3° N
Spill Rate	12000 tons/hour for 20 minutes 500 tons per hour for 24 hours
Oil Type	LNG
Duration	24.33 hours
Total Spilled	16000 tons
Ship Type	LNG Tanker
Weather Data Time Period	2007 and 2008
Spill Time Period	Summer (June to September)

Table 6-5 Input Data Parameters Used for Scenario 2

Name	Description	Value(s)	Rationale
Location of release	x and y coordinates of release in UTM meters	Unimak Pass 165.5"W 54.3"N	
Depth of release	Depth below the water surface of the release	0 m (surface)	Hypothetical releases will be on the surface or near the surface but will quickly rise to the top
Start time and date	Date and time the release began	Randomly selected between June 01 to September 30th	Starting time is randomly selected for the stochastic simulation and analysis of Scenario 2
Duration	Duration of the release	24 hrs and 20 mins	Reasonable release durations considering vessel and amount of oil
Total spill volume or mass	Total volume (or weight) released	16,000 tons	Reasonable release volumes considering type of vessel and amount of product stored on board
Spill properties	Physical and chemical properties	LNG	Researched values from various literature
Winds	Stochastic winds	Markov wind matrix for each scenario	Used statistics of a long-period of measured meteorological data available as gridded output for every 6 hours – Ocean Watch

Name	Description	Value(s)	Rationale
Salinity	Surface water salinity	Time and spatially varying database	Best record discovered - 28 year record from the Geophysical Fluid Dynamics Laboratory
Water Temperature	Surface water temperature	Time and spatially varying database	Best record discovered - 30 year record from NOAA
Wave	Wave height and period	Time varying	Best record discovered - Hourly data from ACOE
Wind drift speed	Percentage of wind speed influencing oil/chemical movement on the surface	3.50%	Typical literature value (ASCE (1996), Spaulding 1988, Youssef & Spaulding 1993)
Wind drift angle	Wind direction angle shift clockwise (in northern hemisphere) affecting oil drifts (in degrees)	0°	Valid 1st approximation (ASCE (1996), Spaulding 1988, Youssef & Spaulding 1993)
Horizontal turbulent diffusion coefficient	Randomized turbulent mixing parameter in x & y direction	10 m^2/sec	Typical literature value varies between 5 to 100 m^2/sec
Vertical turbulent diffusion coefficient	Randomized turbulent mixing parameter in z direction (below surface layer)	0.0001 m^2/sec	French et al. (1996, 1999) based on Okubo and Ozmidov (1970); Okubo (1971)
Suspended sediment concentration	Average suspended sediment concentration	10 mg/l	French et al. (1996)
Suspended sediment settling rate	Net settling rate for suspended sediments	1 m/day	French et al. (1996)
Oil density (g/cm^3)	Density of oil as a whole	0.68	Calculated from oil chemistry
Number of surface particles	Number of Lagrangian particles used to represent the oil mass on the surface	500	Value selected based on computer resources
Number of subsurface particles	Number of Lagrangian particles used to represent the dissolved oil mass in the water column	1000	Value selected based on computer resources
Stochastic simulations	Number of model iterations	25	Tested value, sufficient for estimating patterns of distribution
Advection and Diffusion Processes	Switch to Use Advection and Diffusion Processes	On	Included for full fates processing
Spreading Processes	Switch to Use Spreading Processes	On	Included for full fates processing

Name	Description	Value(s)	Rationale
Evaporation Processes	Switch to Use Evaporation Processes	On	Included for full fates processing
Emulsification Processes	Switch to Use Emulsification Processes	On	Included for full fates processing
Entrainment Processes	Switch to Use Entrainment Processes	On	Included for full fates processing
Dissolution Processes	Switch to Use Dissolution Processes	On	Included for full fates processing
Volatilization Processes	Switch to Use Volatilization Processes	On	Included for full fates processing
Biodegradation Processes	Switch to Use Biodegradation Processes	On	Included for full fates processing
Sedimentation Processes	Switch to Use Sedimentation Processes	On	Included for full fates processing
Shoreline Deposition and Floatation	Switch to Use Shoreline Deposition	On	Included for full fates processing

Figure numbers for each of the contour plot described for baseline Scenario 2 are listed in Table 6-6.

Table 6-6 Figure Numbers for Scenario 2

Contour Type	Figure Number
Travel Time assuming large persistence time	Figure 6-9
Travel Time assuming small persistence time	Figure 6-10
Probability of impact on water surface	Figure 6-11
Probability of impact on shoreline	Figure 6-12
Percent remaining on water surface	Figure 6-13
Percent lost by evaporation from water surface	Figure 6-14
Maximum oil thickness	Figure 6-15
Maximum water column concentration	Figure 6-16
Maximum vertically averaged water column concentration	Figure 6-17

Travel time of up to 24 hours contour map covers an area of 1,440 km^2, encompassing the northern portion of Akun Island and a large portion of Unimak Pass in Figure 6-9. The 48 hours travel time contour map reaches

Akutan and lower portion of Unimak Islands. The time travel contour plot shown in Figure 6-9 was obtained by assuming long persistence time for a spill. This simulation was performed to show the impact of any spill other than LNG occurring at the spill site. Figure 6-10 shows time travel contour plot for LNG spill with less persistence time. The time travel 24 hours contour map covers only 680 km^2 while the 48 hours travel time map barely impacts the Akutan or Unimak Islands. This is because most of LNG spill is lost by evaporation as indicated in the mass balance table shown in Figure 6-10. The mass balance information is also listed below.

Water Surface	-	0.04%
Water Column	-	0.000005%
Shore	-	3.3%
Atmosphere	-	96.2%
Dissolution	-	0.43%
Biodegradation	-	0.002%
Sediments	-	0.04%

The probability of impact that is greater than 50% covers only a small area of 87 km^2 in the vicinity of the spill site (Figure 6-11). This corresponds to the travel time that is less than 3 hours (Figure 6-12). The probability of impact is less than 5% by the time the spill has a time travel of 48 hours. Figure 6-12 shows only the northern portion of the Akun is impacted by the LNG spill. The deposited shoreline mass eventually will be lost by evaporation which is not included in the current simulation. Figure 6-13 shows that the amount of LNG left on the water surface decreases drastically to a small value within few hours of the spill. This is evident in Figure 6-14 which shows that within the few hours of the spill, most of LNG is lost by evaporation resulting in a 90% to 100% evaporation mass contour covering the entire dispersion region. The maximum thickness of > 0.01 mm covers an area of 72 km^2 (See Figure 6-15). The maximum thickness at the outer edge of the dispersion region reduces to 0.000001 mm. The water column concentration at any vertical location from the iterations reaches a maximum value of 2,100 ppb in Figure 6-16 while the water column concentration at any vertical location averaged over the iterations reaches a maximum value of 5 ppb in Figure 6-17.

6.3 SCENARIO 3

The simulation time period was set between June and September for Scenario 3 to represent the summer conditions in the Aleutian Islands. The scenario 3 spill characteristics and COSIM model input data parameters are shown in Table 6-7 and Table 6-8, respectively.

Table 6-7 Scenario 3 Spill Characteristics

Spill Parameter	Value
Longitude	163° W
Latitude	54.3° N
Spill Rate	31 tons per hour
Oil Type	Diesel
Duration	120 hours
Total Spilled	3750 tons
Ship Type	Product Tanker
Weather Data Time Period	2007 and 2008
Spill Time Period	Summer June to September

Table 6-8 Input Data Parameters Used for Scenario 3

Name	Description	Value(s)	Rationale
Location of release	x and y coordinates of release in UTM meters	Coast of Sanak Island 163 "W 54.3°N	
Depth of release	Depth below the water surface of the release	0 m (surface)	Hypothetical releases will be on the surface or near the surface but will quickly rise to the top
Start time and date	Date and time the release began	Randomly selected between June 01 to September 30th	Starting time is randomly selected for the stochastic simulation and analysis of Scenario 3
Duration	Duration of the release	120 hrs	Reasonable release durations considering vessel and amount of oil
Total spill volume or mass	Total volume (or weight) released	3750 MT	Reasonable release volumes considering type of vessel and amount of product stored on board
Spill properties	Physical and chemical properties	Properties of diesel oil	Researched values from various literature
Winds	Stochastic winds	Markov wind matrix for each scenario	Used statistics of a long-period of measured meteorological data available as gridded output for every 6 hours

Name	Description	Value(s)	Rationale
Salinity	Surface water salinity	Time and spatially varying database	Best record discovered - 28 year record from the Geophysical Fluid Dynamics Laboratory
Water Temperature	Surface water temperature	Time and spatially varying database	Best record discovered - 30 year record from NOAA
Wave	Wave height and period	Time varying	Best record discovered - Hourly data from ACOE
Wind drift speed	Percentage of wind speed influencing oil/chemical movement on the surface	3.50%	Typical literature value (ASCE (1996), Spaulding 1988, Youssef & Spaulding 1993)
Wind drift angle	Wind direction angle shift clockwise (in northern hemisphere) affecting oil drifts (in degrees)	0°	Valid 1st approximation (ASCE (1996), Spaulding 1988, Youssef & Spaulding 1993)
Horizontal turbulent diffusion coefficient	Randomized turbulent mixing parameter in x & y direction	10 m^2/sec	Typical literature value varies between 5 to 100 m^2/sec
Vertical turbulent diffusion coefficient	Randomized turbulent mixing parameter in z direction (below surface layer)	0.0001 m^2/sec	French et al. (1996, 1999) based on Okubo and Ozmidov (1970); Okubo (1971)
Suspended sediment concentration	Average suspended sediment concentration	10 mg/l	French et al. (1996)
Suspended sediment settling rate	Net settling rate for suspended sediments	1 m/day	French et al. (1996
Oil density (g/cm^3)	Density of oil as a whole	0.863	Calculated from oil chemistry
Number of surface particles	Number of Lagrangian particles used to represent the oil mass on the surface	500	Value selected based on computer resources
Number of subsurface particles	Number of Lagrangian particles used to represent the dissolved oil mass in the water column	1000	Value selected based on computer resources
Stochastic simulations	Number of model iterations	25	Tested value, sufficient for estimating patterns of distribution

Name	Description	Value(s)	Rationale
Advection and Diffusion Processes	Switch to Use Advection and Diffusion Processes	On	Included for full fates processing
Spreading Processes	Switch to Use Spreading Processes	On	Included for full fates processing
Evaporation Processes	Switch to Use Evaporation Processes	On	Included for full fates processing
Emulsification Processes	Switch to Use Emulsification Processes	On	Included for full fates processing
Entrainment Processes	Switch to Use Entrainment Processes	On	Included for full fates processing
Dissolution Processes	Switch to Use Dissolution Processes	On	Included for full fates processing
Volatilization Processes	Switch to Use Volatilization Processes	On	Included for full fates processing
Biodegradation Processes	Switch to Use Biodegradation Processes	On	Included for full fates processing
Sedimentation Processes	Switch to Use Sedimentation Processes	On	Included for full fates processing
Shoreline Deposition and Floatation	Switch to Use Shoreline Deposition	On	Included for full fates processing

Figure numbers for each of the contour plot for baseline Scenario 3 are listed in Table 6-9.

Table 6-9 Figure Numbers for Scenario 3

Contour Type	Figure Number
Travel Time	Figure 6-18
Probability of impact on water surface	Figure 6-19
Probability of impact on shoreline	Figure 6-20
Percent remaining on water surface	Figure 6-21
Percent lost by evaporation from water surface	Figure 6-22
Maximum oil thickness	Figure 6-23
Maximum water column concentration	Figure 6-24
Maximum vertically averaged water column concentration	Figure 6-25

The travel time contour map up to 24 hours covers a region of 1,100 km^2 impacting Long and Sanak Islands in Figure 6-18. The travel time contour map of 48 hours impacts Caton Islands and Cape Pankof of Unimak Islands. The mass balance for Scenario 3 is given below.

Water Surface	-	2.7%
Water Column	-	0.1%
Shore	-	2.6%
Atmosphere	-	62.5%
Dissolution	-	12%
Biodegradation	-	0.1%
Sediments	-	20%

The probability of impact of 50% or greater on the water surface covers an area of 1,700 km^2 including all Sanak Islands (Figure 6-19). The probability of impact of 50% or greater on the shoreline covers an area of 95 km (Figure 6-20).

Figure 6-21 shows that the amount of oil available on the water surface that is greater than 40% covers only a small area of 7 km^2 while greater than 10% covers a large area of 3,462 km^2. This shows that within few hours of the spill, lot of diesel is lost by high rate of evaporation. This figure also shows that by the time the spill hits the shoreline region, the amount of oil left on the water surface is less than 10% resulting in less deposition of oil. This analysis is substantiated by the percent oil lost by evaporation in Figure 6-22.

The maximum oil thickness in the vicinity of the spill site and south of the Sanak Island reaches as high as 0.01 mm (Figure 6-23). In the far region of the spill, the maximum thickness reduces to a value between 0.0001 to 0.00001 mm. The water column concentration at any vertical location from the iterations reaches a maximum value of 16,000 ppb in Figure 6-24 while the water column concentration at any vertical location averaged over the iterations reaches a maximum value of 15 ppb in Figure 6-25.

6.4 SCENARIO 4

The simulation time period for Scenario 4 was set between April and June to represent the spring conditions in the Aleutian Islands. The scenario 4 spill characteristics and COSIM model input data parameters are shown in Table 6-10 and Table 6-11, respectively.

Table 6-10 Scenario 4 Spill Characteristics

Spill Parameter	Value
Longitude	174 °E
Latitude	52.5 °N
Spill Rate	1042 tons per hour of crude oil, 51 tons per hour of Bunker C fuel oil
Oil Type	Crude oil and Bunker C fuel oil
Duration	48 hours
Total Spilled	50,000 tons of crude oil and 2450 tons of Bunker C fuel
Ship Type	Oil Tanker
Weather Data Time Period	2007 and 2008
Spill Time Period	Early Spring April to June

Table 6-11 Input Data Parameters Used for Scenario 4

Name	Description	Value(s)	Rationale
Location of release	x and y coordinates of release in UTM meters	Agattu Island 174 °E 52.5° N	
Depth of release	Depth below the water surface of the release	0 m (surface)	Hypothetical releases will be on the surface or near the surface but will quickly rise to the top
Start time and date	Date and time the release began	Randomly selected between April 1st to June 30th	Starting time is randomly selected for the stochastic simulation and analysis of Scenario 4
Duration	Duration of the release	48 hrs	Reasonable release durations considering vessel and amount of oil
Total spill volume or mass	Total volume (or weight) released	50,000 tons (crude), 2,450 tons (Bunker C)	Reasonable release volumes considering type of vessel and amount of product stored on board
Spill properties	Physical and chemical properties	Properties of crude oil and Bunker C	Researched values from various literature
Winds	Stochastic winds	Markov wind matrix for each scenario	Used statistics of a long-period of measured meteorological data available as gridded output for every 6 hours – Ocean Watch

Name	Description	Value(s)	Rationale
Salinity	Surface water salinity	Time and spatially varying database	Best record discovered - 28 year record from the Geophysical Fluid Dynamics Laboratory
Water Temperature	Surface water temperature	Time and spatially varying database	Best record discovered - 30 year record from NOAA
Wave	Wave height and period	Time varying	Best record discovered - Hourly data from ACOE
Wind drift speed	Percentage of wind speed influencing oil/chemical movement on the surface	3.50%	Typical literature value (ASCE (1996), Spaulding 1988, Youssef & Spaulding 1993)
Wind drift angle	Wind direction angle shift clockwise (in northern hemisphere) affecting oil drifts (in degrees)	0°	Valid 1st approximation (ASCE (1996), Spaulding 1988, Youssef & Spaulding 1993)
Horizontal turbulent diffusion coefficient	Randomized turbulent mixing parameter in x & y direction	10 m^2/sec	Typical literature value varies between 5 to 100 m^2/sec
Vertical turbulent diffusion coefficient	Randomized turbulent mixing parameter in z direction (below surface layer)	0.0001 m^2/sec	French et al. (1996, 1999) based on Okubo and Ozmidov (1970); Okubo (1971)
Suspended sediment concentration	Average suspended sediment concentration	10 mg/l	French et al. (1996)
Suspended sediment settling rate	Net settling rate for suspended sediments	1 m/day	French et al. (1996)
Oil density (g/cm^3)	Density of oil as a whole	0.8615 (crude), 1.0057 (Bunker C)	Calculated from oil chemistry
Number of surface particles	Number of Lagrangian particles used to represent the oil mass on the surface	500	Value selected based on computer resources
Number of subsurface particles	Number of Lagrangian particles used to represent the dissolved oil mass in the water column	1000	Value selected based on computer resources
Stochastic simulations	Number of model iterations	25	Tested value, sufficient for estimating patterns of distribution
Advection and Diffusion Processes	Switch to Use Advection and Diffusion Processes	On	Included for full fates processing
Spreading Processes	Switch to Use Spreading Processes	On	Included for full fates processing
Evaporation Processes	Switch to Use Evaporation Processes	On	Included for full fates processing

Name	Description	Value(s)	Rationale
Emulsification Processes	Switch to Use Emulsification Processes	On	Included for full fates processing
Entrainment Processes	Switch to Use Entrainment Processes	On	Included for full fates processing
Dissolution Processes	Switch to Use Dissolution Processes	On	Included for full fates processing
Volatilization Processes	Switch to Use Volatilization Processes	On	Included for full fates processing
Biodegradation Processes	Switch to Use Biodegradation Processes	On	Included for full fates processing
Sedimentation Processes	Switch to Use Sedimentation Processes	On	Included for full fates processing
Shoreline Deposition and Floatation	Switch to Use Shoreline Deposition	On	Included for full fates processing

Figure numbers for each of the contour plots produced for baseline Scenario 4 are listed in Table 6-12.

Table 6-12 Figure Numbers for Scenario 4

Contour Type	Figure Number
Travel Time	Figure 6-26
Probability of impact on water surface	Figure 6-27
Probability of impact on shoreline	Figure 6-28
Percent remaining on water surface	Figure 6-29
Percent lost by evaporation from water surface	Figure 6-30
Maximum oil thickness	Figure 6-31
Maximum water column concentration	Figure 6-32
Maximum vertically averaged water column concentration	Figure 6-33

In Figure 6-26, the travel time contour for 24 hours covers an area of 700 km^2 with shoreline impacts on the North Cape of Atka Island. The 48 hour travel time contour covers an area of 1,300 km^2 with impact on either side of North Cape. The mass balance for this scenario is given below.

Water Surface – 52%
Water Column – 4%
Shore – 0.8%
Atmosphere – 42%
Dissolution - 0.78%

Biodegradation	-	0.26%
Sediments	-	0.16%

The probability of impact of 50% (Figure 6-26) or greater (covers an area of 1,650 km^2) on the water surface covers approximately the same area (1,532 km^2) that is covered by the 24 hour time travel contour region (Figure 6-27). The probability of impact <= 4% reaches the southern part of Attu Island. There is a 50% probability of impact on the eastern shores of Agattu Island, Nizki and Shemya Islands and a 20% probability of impact on the Alaid Island. Figure 6-28 shows the length of shoreline oiled by the spill. The northern tip of Agattu Island has 40 – 50% probability of shoreline oiling and the probability gradually decreases for the rest of the island, thus reaching a value of 4% at the western tip of the Agattu Island. The southeastern tip of the Shemya and Nizki Islands has 30 to 40% probability of shoreline oiling and it decreases gradually for the rest of the islands shorelines. The 30 to 50% probability of shoreline oiling in Agattu, Nizki and Shemya Islands covers a distance of approximately 50 km.

As shown on Figure 6-29, the amount of oil that remains on the water surface and water column decreases to 60% within area of 64 km^2 while only an additional 10% is lost from the water surface and water column during the dispersion of the spill to an area of 20,000 km^2 in the far-field. This is clearly seen in percent oil lost by evaporation shown in Figure 6-30. In an open sea spill most of the oil is lost by evaporation as shown by Figure 6-30. The amount of oil left on the surface is still around 40% by the time it reaches the Attu Island.

The maximum oil thickness in the immediate vicinity of the spill site is between 5 to 10 mm followed by a region of 1 to 2 mm covering an area of 470 km^2. The maximum oil thickness eventually decreases to 0.1 mm for the rest of the dispersion region. As the crude oil accumulates near the shoreline and with favorable winds and currents, the oil thickness gradually increases and reaches a maximum value of 2 to 5 mm on most of the eastern shores and a small portion on the northern shores of Agattu Island. The water column concentration at any vertical location from the iterations reaches a maximum value of 200 ppb in Figure 6-32 while the water column concentration at any vertical location averaged over the iterations reaches a maximum value of 0.1 ppb in Figure 6-33.

6.5 SCENARIO 5

The simulation time period for Scenario 5 was set between October and December to represent the fall conditions in the Aleutian Islands. The scenario 5 spill characteristics and COSIM model input parameters are shown in Table 6-13 and 6-14.

Table 6-13 Scenario 5 Spill Characteristics

Spill Parameter	Value
Longitude	179°W
Latitude	54.2° N
Spill Rate	368 tons per hour for 1 hour; 10 tons per hour for additional 48 hours
Oil Type	Bunker C fuel oil
Duration	49 hours
Total Spilled	848 tons
Ship Type	Large Car Carrier
Weather Data Time Period	2007 and 2008
Spill Time Period	Fall October to December

Table 6-14 Input Data Parameters Used for Scenario 5

Name	Description	Value(s)	Rationale
Location of release	x and y coordinates of release in UTM meters	Open Water (North of Adak Island) 179° W 54.2° N	
Depth of release	Depth below the water surface of the release	0 m (surface)	Hypothetical releases will be on the surface or near the surface but will quickly rise to the top
Start time and date	Date and time the release began	Randomly selected between October 1st to December 31st	Starting time is randomly selected for the stochastic simulation and analysis of Scenario 5
Duration	Duration of the release	49 hrs	
Total spill volume or mass	Total volume (or weight) released	848 MT	Reasonable release volumes considering type of vessel and amount of product stored on board
Spill properties	Physical and chemical properties	Bunker C fuel oil	Researched values from various literature
Winds	Stochastic winds	Markov wind matrix for each scenario	Used statistics of a long-period of measured meteorological data available as gridded output for every 6 hours – Ocean Watch

Name	Description	Value(s)	Rationale
Salinity	Surface water salinity	Time and spatially varying database	Best record discovered - 28 year record from the Geophysical Fluid Dynamics Laboratory
Water Temperature	Surface water temperature	Time and spatially varying database	Best record discovered - 30 year record from NOAA
Wave	Wave height and period	Time varying	Best record discovered - Hourly data from ACOE
Wind drift speed	Percentage of wind speed influencing oil/chemical movement on the surface	3.50%	Typical literature value (ASCE (1996), Spaulding 1988, Youssef & Spaulding 1993)
Wind drift angle	Wind direction angle shift clockwise (in northern hemisphere) affecting oil drifts (in degrees)	0°	Valid 1st approximation (ASCE (1996), Spaulding 1988, Youssef & Spaulding 1993)
Horizontal turbulent diffusion coefficient	Randomized turbulent mixing parameter in x & y direction	10 m^2/sec	Typical literature value varies between 5 to 100 m^2/sec
Vertical turbulent diffusion coefficient	Randomized turbulent mixing parameter in z direction (below surface layer)	0.0001 m^2/sec	French et al. (1996, 1999) based on Okubo and Ozmidov (1970); Okubo (1971)
Suspended sediment concentration	Average suspended sediment concentration	10 mg/l	French et al. (1996)
Suspended sediment settling rate	Net settling rate for suspended sediments	1 m/day	French et al. (1996)
Oil density (g/cm^3)	Density of oil as a whole	1.0057	Calculated from oil chemistry
Number of surface particles	Number of Lagrangian particles used to represent the oil mass on the surface	500	Value selected based on computational resources
Number of subsurface particles	Number of Lagrangian particles used to represent the dissolved oil mass in the water column	1000	Value selected based on computational resources
Stochastic simulations	Number of model iterations	25	Tested value, sufficient for estimating patterns of distribution

Name	Description	Value(s)	Rationale
Advection and Diffusion Processes	Switch to Use Advection and Diffusion Processes	On	Included for full fates processing
Spreading Processes	Switch to Use Spreading Processes	On	Included for full fates processing
Evaporation Processes	Switch to Use Evaporation Processes	On	Included for full fates processing
Emulsification Processes	Switch to Use Emulsification Processes	On	Included for full fates processing
Entrainment Processes	Switch to Use Entrainment Processes	On	Included for full fates processing
Dissolution Processes	Switch to Use Dissolution Processes	On	Included for full fates processing
Volatilization Processes	Switch to Use Volatilization Processes	On	Included for full fates processing
Biodegradation Processes	Switch to Use Biodegradation Processes	On	Included for full fates processing
Sedimentation Processes	Switch to Use Sedimentation Processes	On	Included for full fates processing
Shoreline Deposition and Floatation	Switch to Use Shoreline Deposition	On	Included for full fates processing

Figure numbers for each of the contour plots for baseline Scenario 5 are listed in Table 6-15.

Table 6-15 Figure Numbers for Scenario 5

Contour Type	Figure Number
Travel Time	Figure 6-34
Probability of impact on water surface	Figure 6-35
Probability of impact on shoreline	No impact / no figure
Percent remaining on water surface	Figure 6-36
Percent lost by evaporation from water surface	Figure 6-37
Maximum oil thickness	Figure 6-38
Maximum water column concentration	Figure 6-39
Maximum vertically averaged water column concentration	Figure 6-40

In Figure 6-34, the travel time contour for 24 hours covers an area of 2,400 km^2 with more or less circular spreading. Other travel time contours though show circular dispersion appears to have more dispersion in the south (towards the islands). The southern dominance is shown by the probability of the water surface impact contour that is 50% or greater in Figure 6-35.

Both Figure 6-36 and Figure 6-37 shows that 35% of the oil is lost from the surface and water column with an area of 1,000 km^2 while an additional 30% is lost from the water surface when the dispersion reaches an area of 15,000 km^2. Since the spill site is quite far from the Aleutian Islands, it would have minimal impact on its shorelines. The mass balance for this scenario at the end of 7 days is given below.

Water Surface	–	1.6 %
Water Column	–	29%
Shore	–	0%
Atmosphere	–	21%
Dissolution	–	48%
Biodegradation	–	0.4%
Sediments	–	0%

Figure 6-38 shows that the maximum oil thickness >= 0.005 mm covers an area of 600 km^2 while the maximum oil thickness >= 0.0001 mm covers an area of 20,000 km^2. Because of large depths, it takes more than 7 days for the oil to reach the bottom sediments. A large percentage of oil dissolves and adsorbs in the water column. Also, a large amount of oil entrains into the water column due to the existence of large wind speeds creating more mixing near the water surface. The water column concentration at any vertical location from the iterations reaches a maximum value of 200 ppb in Figure 6-39 and the water column concentration at any vertical location averaged over the iterations reaches a maximum value of 0.5 ppb in Figure 6-40.

6.6 SCENARIO 6

Spill Scenario 6 was developed to represent a hazardous chemical spill from a cargo container. It is described in Section 4.1.1. Two chemical spill simulations (phorate and linoleic acid) were performed to represent the different types of hazardous materials carried by the cargo ships travelling in the vicinity of the Aleutian Islands. The properties of these two chemicals are described in Section 4.3.2. The Scenario 6 simulation time period was set between January and March to represent the winter conditions in the Aleutian Islands. Scenario 6 spill characteristics are summarized in Table 6-16. The input parameters used for Scenario 6 is same as Scenario 1 except for the properties of spilled medium (phorate and linoleic acid).

Table 6-16 Scenario 6 Spill Characteristics

Spill Parameter	Value
Longitude	165° W
Latitude	54.5° N
Spill Rate	5 tons per hour
Cargo Type	phorate and linoleic acid
Duration	4
Total Spilled	20
Ship Type	Container
Weather Data Time Period	2007 and 2008
Spill Time Period	Winter (January - March)

In addition to the weathering and transport processes, the chemical reaction between the chemical and the water is also considered in the current spill modeling. For both linoleic acid and phorate, hydrolysis is the main chemical reaction that occurs in water. Phorate is unstable in water especially under alkaline conditions. As it breaks down in water, non-toxic water soluble products are formed. The result of the chemical reaction of linoleic acid and water is a saturated hydroxyl fatty acid.

The current scope of spill modeling does not focus on the non-toxic byproducts. But it is included in the spill model as a mechanism to remove certain amount of the chemical in the mass balance calculations. Hydrolysis is normally achieved similar to the biodegradation process using a proper decay coefficient that depends on the pH of water. In COSIM, hydrolysis process is simulated using first and second order decay models.

6.6.1 Phorate Spill

The phorate chemical is denser than sea water and so contour maps related to water column and sediments were developed for subsequent analysis in addition to water surface and shoreline contour maps shown in the draft report for other scenarios. The figure numbers for the phorate spill contour maps are listed in Table 6-17.

Table 6-17 Figure Numbers for Scenario 6 Phorate Spill

Contour Type	Figure Number
Water surface travel time	Figure 6-41
Water column travel time	Figure 6-42
Probability of impact on water surface	Figure 6-43
Probability of impact in water column	Figure 6-44
Probability of impact on shoreline	Figure 6-45
Probability of impact on bottom sediment	Figure 6-46

Contour Type	Figure Number
Percent remaining on water surface	Figure 6-47
Percent lost by evaporation from water surface	Figure 6-48
Maximum water column at concentration at any vertical location from all the iterations	Figure 6-49
Maximum water column concentration at any vertical location averaged over all iterations	Figure 6-50
Maximum bottom sediment concentration	Figure 6-51

The travel time contour map (Figure 6-41) shows that there is no dispersion and spread of phorate chemical spill on the water surface because of its higher density than ambient sea water. The phorate chemical spill is represented by discrete number of particles that sinks into the water column and entrains ambient water as during this process. The entrainment of ambient water into each particle is a function of sinking velocity. In addition, the density of the chemical particle decreases due to the entrainment of ambient water. The entrainment reduces the sinking velocity and subsequent reduction in the entrainment of ambient water into the particle. This process continues until the chemical particle gets either trapped at a certain depth in the water column or continues to sink and eventually settles to the bottom depending on the density stratification. During the sinking process, the chemical particle is subjected to horizontal advection due to winds and currents, as well as dispersion in horizontal and vertical directions. The influence of wind decreases approximately exponentially with depth and after a certain depth, the advection is purely controlled by hydrodynamic currents and dispersion. The average mass balance of 25 iterations for Scenario 6 phorate spill is shown below.

Water Surface	-	0%
Water Column	-	11.5%
Shore	-	51%
Atmosphere	-	0%
Dissolution	-	19%
Biodegradation	-	2.5%
Sediments	-	23%

During the transport of chemical in the water column, the mass is lost due to deposition on the shoreline, dissolved and adsorbed components, and biodegradation.

The minimum time taken by each particle to hit a specific horizontal location and any vertical location is shown in Figure 6-42. The travel time up to 24 hours covers an area of 368 km^2 around the spill site and close to the southern tip of Unimak Island in the Unimak Pass. The chemical spill could reach coastal waters near the Sanak Island on the east and Urilia Bay on the west of Unimak after 7 days into the spill. Figure 6-43 shows that there is no probability of impact on the water surface where as Figure 6-44 shows that the water column is significantly affected by the spill. As expected, the impact contour map looks similar to the travel time contour map (Figure 6-42).

The probability of water column impact greater than 50% covers a very small area of 86 km^2 near the spill site. The probability of impact in the water column near Urilia Bay (west coast of Unimak Island) and Otter Cove and Sanak Island (east coast of Unimak Island) is less than 10%. The probability of shoreline impact greater than 50% covers an area of 54 km near the spill site and is shown in Figure 6-45. A considerable section of west of Unimak Island near Cape Sarichef has a 20 – 30% impact and similar impact is also seen near Seal Cape.

The probability of shoreline impact less than 10% is seen around Tigalda Island. During the water column transport, a portion of the chemical is adsorbed on the suspended sediment particles (partitioning between adsorbed and dissolved phases, see Table 4-9) resulting in deposition on the bottom sediments; the probability of impact is shown in Figure 6-46. The impact does not have a specific pattern like the way it is seen for surface and shoreline impact contour maps. This is because of the deposition depending on the bottom bathymetry in addition to the other controls such as hydrodynamics.

There is no chemical left on the water surface since the chemical sinks instantaneously at the spill site (see Figure 6-47). Also, there is no mass of chemical lost due to evaporation or volatilization from the water column due to very low vapor pressure (see Table 4-9), as depicted in Figure 6-48. The dissolved component of the chemical in the water column obtained from the dissolution process is used to develop the concentration contour map shown in Figure 6-49. The maximum concentration greater than 0.01 ppb at any vertical location (see Table 4-8 LC_{50} toxicity values) covers an area 1,775 km^2 resulting in significant short term biological impact near the spill site, Cape Sarichef, Unimak Bight and near Ugamak Islands. Figure 6-50 shows that the area covered by simulation averaged concentration greater than 0.01 ppb at any vertical location is only 12 km^2 suggesting that the long term impact is confined only to a small region near the spill site. The maximum bottom sediment concentration (see Figure 6-51) is around 200 ppb, which is slightly less than EC_{50} toxic criteria for benthos (See Table 4-9).

6.6.2 Linoleic Acid Spill

The linoleic acid spill simulation was performed using the same conditions shown in Table 6-13. The types of contour maps used for phorate spill analysis were also developed for linoleic acid spill and they are listed in Table 6-18.

Table 6-18 Figure Numbers for Scenario 6 Linoleic Acid Spill

Contour Type	Figure Number
Water surface travel time	Figure 6-52
Water column travel time	Figure 6-53
Probability of impact on water surface	Figure 6-54
Probability of impact on water column	Figure 6-55
Probability of impact on shoreline	Figure 6-56
Probability of impact on bottom sediment	Figure 6-57
Percent remaining on water surface	Figure 6-58
Percent lost by evaporation from water surface	Figure 6-59
Maximum water column concentration at any vertical location averaged over all iterations	Figure 6-60
Maximum water column concentration averaged over all iterations at any vertical location	Figure 6-61
Maximum bottom sediment concentration	Figure 6-62

The linoleic acid chemical is lighter than ambient sea water and so it floats on the water surface. Since it is a pure chemical there is no emulsification and there is no increase in viscosity due to the weathering processes. Because of low viscosity and low density, only minimum energy is required to break the spill on the water surface. Since high wind persists near the Aleutian Islands, most of the linoleic acid entrains into the water column during the spill simulation time period.

The travel time of up to 24 hours contour map covers an area of 792 km^2 that includes Unimak Pass close to the southern portion of the Unimak Island, Cape Sarichef and Seal Cape in Figure 6-52. The 48-hour travel time contour map reaches coastal waters near Cape Mordvinof in the west and Unimak Bight in the east. The mass balance information for the linoleic acid spill is listed below (See Figure 6-52).

Water Surface	-	12%
Water Column	-	15 %
Shore	-	19.3 %
Atmosphere	-	0.006 %
Dissolution	-	0.129%
Biodegradation	-	54%
Sediments	-	0.006%

The travel time in the water column is shown in Figure 6-53. The travel time in the water column looks similar to Figure 6-52 except that it is more aligned with Unimak Island shoreline. Also, the chemical on the water surface is subjected to entrainment resulting in the release of particles in the water column as it moves around the island. The probability of impact that is greater than 50% covers an area of 862 km^2 in the vicinity of the spill site and extending further into the coastal waters south of Cape Mordvinof in the west and Seal Cape to the east (See Figure 6-54). This corresponds to the travel time that is less than 48 hours (See Figure 6-52). The probability of impact in the water column shown in Figure 6-55 looks similar to water surface impact due to the continuous entrainment and resurfacing of chemical into and from the water column. Similar analysis holds good for shoreline impact which is shown in Figure 6-56. The probability of impact on the shoreline that is greater than 50 % covers an area of 110 km with higher probability close to the spill site. The probability of impact on the sediments greater than 90% covers part of the lower region of Unimak Island coast due to the continuous settling of adsorbed sediment particles (see Figure 6-57). The vapor pressure of linoleic acid is also very small and so there is no mass lost by evaporation. But considerable amount of chemical is lost due to the biodegradation of the chemical resulting in the gradual decrease of availability of chemical on the water surface as shown in Figure 6-58. The chemical availability on the water surface also fluctuates due to the continuous entrainment and resurfacing processes. There is zero or minimal amount of chemical lost by evaporation as shown in Figure 6-59. Since the linoleic acid solubility is very small, the dissolved component in the water column is also very small resulting in very low concentrations as shown in Figure 6-60. The maximum water column concentration range of > 0.01 ppb but less than 0.12 ppb at any vertical location from all the 25 iterations covers an area of 35 km^2 right near the southern tip of Unimak Island. The maximum concentration is well below the threshold toxicity values for eggs, larva and zooplankton (See Table 4-9).

All iterations average maximum concentration range at any vertical location greater than 0.00001 ppb but less than 0.001 ppb covers an area of 1 km^2 near the southern tip of the Unimak and is shown in Figure 6-61. The averaged concentration is much less than the threshold toxicity values listed in Table 4-9 (see Figure 6-62). The maximum bottom sediment concentration is very low (0.002 ppb) as shown in Figure 6-62, which is also less than the toxicity threshold value for benthic organisms. The amount of chemical settling on bottom sediments is very small because of the low solubility even though the adsorbed to dissolved partitioning coefficient is higher than the phorate chemical.

The linoleic acid chemical spill simulation shows that there is a possibility of higher deposition all along the sediments near the coast of Unimak Island. So, if there is a chemical spill with higher solubility and partitioning coefficient, it would increase the sediment concentrations to the benthic toxic threshold levels.

7.0 SUMMARY

Baseline spill modeling for the Phase A - AIRA Program was performed using ERM's COSIM model and spill scenarios developed from DNV's MARCS model. A total of 6 scenarios were selected based on baseline traffic studies using the year 2008 to 2009 datasets. One additional scenario related to *M/V Selendang Ayu* spill incident was used to calibrate the COSIM model. The model predicted shoreline oiling was compared with the published data and also observations. The calibration results show that the model is able to reproduce the observed and published data on oiling on the shorelines of Unalaska. The calibration run confirms that the COSIM model set up is completed for the Aleutian Islands and is available for subsequent scenario simulations for baseline spill studies and consequence analysis.

An extensive data inventory was developed for the current study by searching many local, national and international websites. Databases needed for the baseline scenario simulations were retrieved from the data inventory. Spill simulations were carried out using stochastic approach using Markov wind transition matrix for each scenario. The wind transition matrix of 12 direction bins and 10 speed bins for each scenario was obtained by processing 22 years of Ocean Watch six-hr gridded wind data. A total of 25 iterations were performed for each spill scenario. During each specific scenario iteration, hourly time series wind data was randomly created using the corresponding wind transition matrix. The simulations were run for 7 days. Spill model output was analyzed by creating contour plots of travel time, shoreline and surface impact probabilities, percent of oil remaining on water surface and lost by evaporation, maximum oil thickness, and maximum water column concentration at any vertical location and maximum vertically averaged concentration.

Summaries of each of the Baseline Spill Scenario results are provided below.

- Bunker C fuel spill in Scenario 1 impacts lower part of Unimak Island and Unimak Pass. The concentration in the water column at any vertical location from the iterations has a maximum value of 160 ppb while the concentration at any vertical location averaged over the iterations has a maximum value of 0.1 ppb. The maximum oil thickness varies in the range of 0.1 to 0.01 mm in the Unimak Pass.
- Scenario 2 involves a LNG spill which is predicted to have minimum impact on the shoreline of Akun and other Islands since most of the

spill mass is lost by evaporation because of high volatility. On the other hand, the water column concentration at any vertical location from the iterations has a maximum value of 2,100 ppb while the water column concentration at any vertical location averaged over the iterations has a maximum value of 0.5 ppb.

- The diesel spill in Scenario 3 impacts all of Sanak Islands with >= 50% probability. It takes approximately 24 hours to reach Long and Sanak Islands where as it takes approximately 48 hours to reach Caton Islands and Cape Pankof of Unimak Islands. The total length of shoreline oiled is approximately 504 km while 95 km of shoreline has a probability >= 50%. Most of the diesel is lost by evaporation and by the time the spill hits the shoreline region, the amount of oil left on the water surface is considerably less resulting in less shoreline impact. The maximum water column concentration at any vertical location from all the iterations reaches a maximum value of 16,000 ppb while the water column concentration at any vertical location averaged over the iterations reaches a maximum value of 15 ppb.

- The generic crude oil spill in Scenario 4 has higher impact of 50% on the northern tip of Agattu Island. The impact decreases with distance from the northern tip for the rest of the island resulting in < 4% impact at the western end of the Agattu Island. Similar impact is seen for the Shemya and Nizki and Alaid islands. Spill with a probability of 4% or less reaches the southeast shorelines of Attu Island, Hungry Bays in the east and Karovin Bay on the west of the Atka Island. The total length of shoreline oiled is approximately 325 km during the 7 day simulation. The length of shoreline oiled with a 30 to 50% probability is approximately 50 km. A maximum oil thickness of 1 to 2 mm exists at the spill site; where as close to the eastern shore of Agattu Island, the oil thickness has maximum thickness varying in the range 2 to 5 mm. The water column concentration at any vertical location from the iterations reaches a maximum value of 200 ppb near the spill site while the iterations averaged water column concentration at any vertical location reaches a maximum value of 0.1 ppb.

- Bunker C fuel spill in Scenario 5 has no impact on the lower portion (west) of the Aleutian Islands. This is because the spill site is about 300 kilometers away from the Aleutian Islands. The maximum oil thickness reaches a value of 0.03 mm in the vicinity of the spill site while it reaches a value of 0.0001 mm in the far-field region of the spill. The water column concentration at any vertical location from the iterations has a maximum value of 2,000 ppb while the iterations averaged concentration at any vertical location has a maximum value of 3 ppb.

The hazardous cargo spill was simulated using phorate and linoleic acid chemicals which were selected from the Containerized Hazardous Commodities. The hazardous commodities codes include a vast number and diverse group of chemicals. A screening process was used to select hazardous chemicals for baseline spill modeling based on toxicity values for fish. In addition, these two chemicals have distinct different properties that affect the spill transport and fate.

- The phorate chemical is denser than the ambient sea water and so it is subjected to sinking process. This results in reduction in sinking velocity due to the entrainment of ambient sea water into the spill particles. During the sinking process, the chemical is subjected to dissolution and adsorption on to the suspended sediments resulting in deposition on the bottom sediments. There is no impact on the water surface and also there is no mass lost from evaporation due to very low vapor pressure. But the chemical is subjected to advection and dispersion in the water column resulting in the spread of the chemical around the Unimak Island. The spread of the chemical in the water column is purely controlled by the horizontal currents. The phorate chemical spill travels close to Cape Mordvinof in the west, Unimak Bight in the west and Tigalda Island in the south.

  The maximum water column concentration at any vertical location is higher than the LC_{50} threshold limit of 0.01 ppb for fish. In addition, the averaged maximum concentration for all iterations is also higher than the 0.01 ppb threshold limit suggesting potential impact on biological organisms in the Unimak Pass and coastal waters surrounding the lower part of Unimak Island. The sediment concentration has a maximum value of 200 ppb which is slightly less than the EC_{50} threshold limit of 206.8 ppb for benthos. This suggests that any spill bigger than the current release of 20 tons will have potential impact on the benthic organisms.

- The linoleic acid is lighter than the ambient sea water and so it spreads mostly on the water surface. In addition, the vapor pressure and solubility are very low resulting in minimal evaporation and dissolution. On the other hand, it is subjected continuous entrainment from the water surface due to low viscosity, density and large wind speeds. The entrained chemical also resurfaces depending on the mixing depth variation due to wind speed. It is also subject to refloatation from the shoreline. Because of all these processes, the surface and water column impact contour maps look very similar with more spread on the water surface due to winds. The maximum dissolved chemical concentration at any vertical location is < 0.12 ppb, which is within the range of toxic threshold values used water column organisms. There is no build up of chemical on the bottom sediments even though high impact is seen all along the southern coast of Unimak Island. Impact on the shoreline may have potential impact on the biological organisms that reside near the shoreline. Most of the spill mass is lost by biodegradation of the chemical on the water surface, water column, shoreline and sediment. This amounts to approximately 54% of total chemical spilled after 1 week into the spill.

The results from the six scenarios show that the COSIM model has been used successfully for the baseline spill studies. The different types of results analyzed for the six scenarios can be used to perform consequence analysis with customization on the plots.

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Figures

Figure 3-1 Map of Aleutian Islands

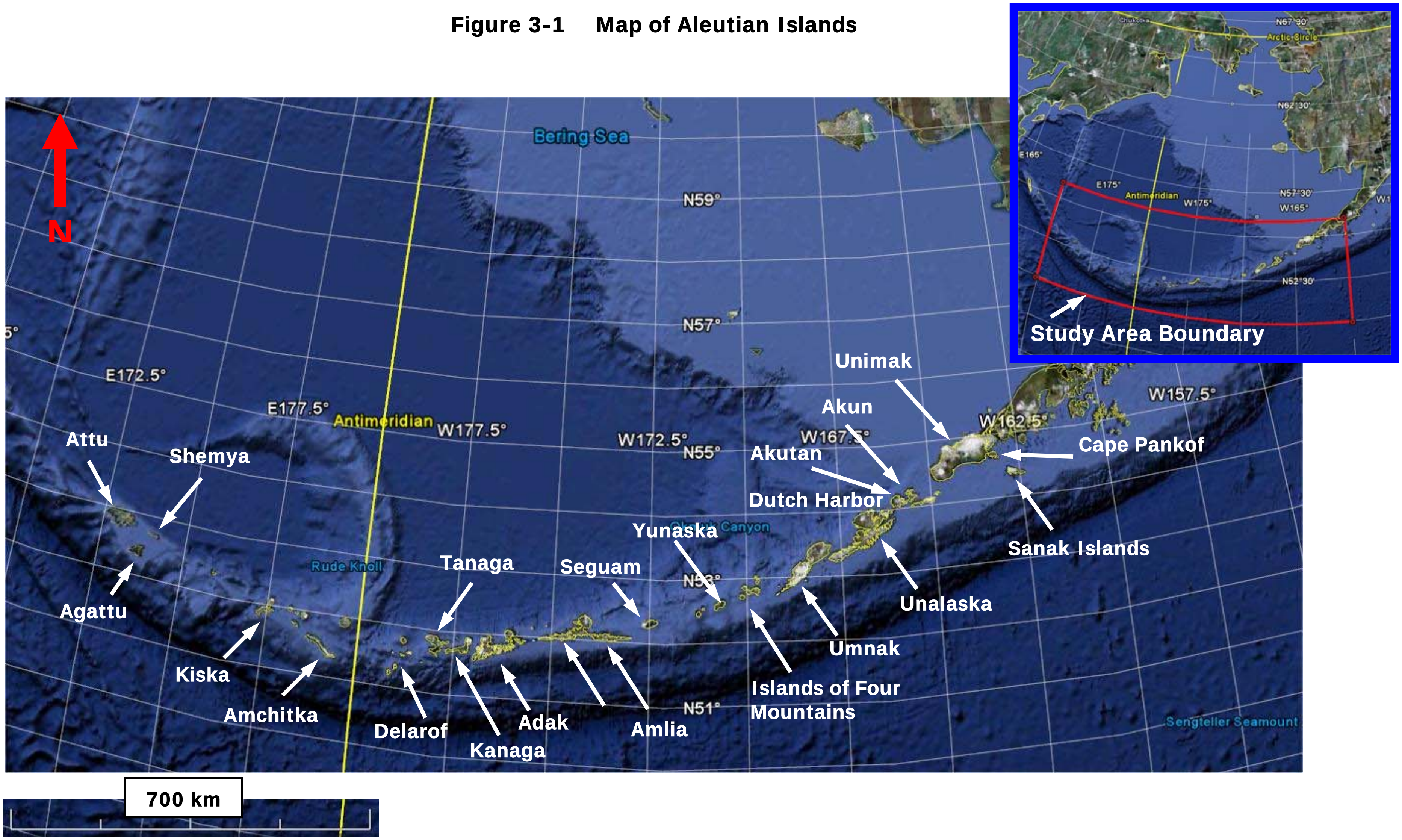


Figure 3-2 Bathymetry map of Aleutian Islands

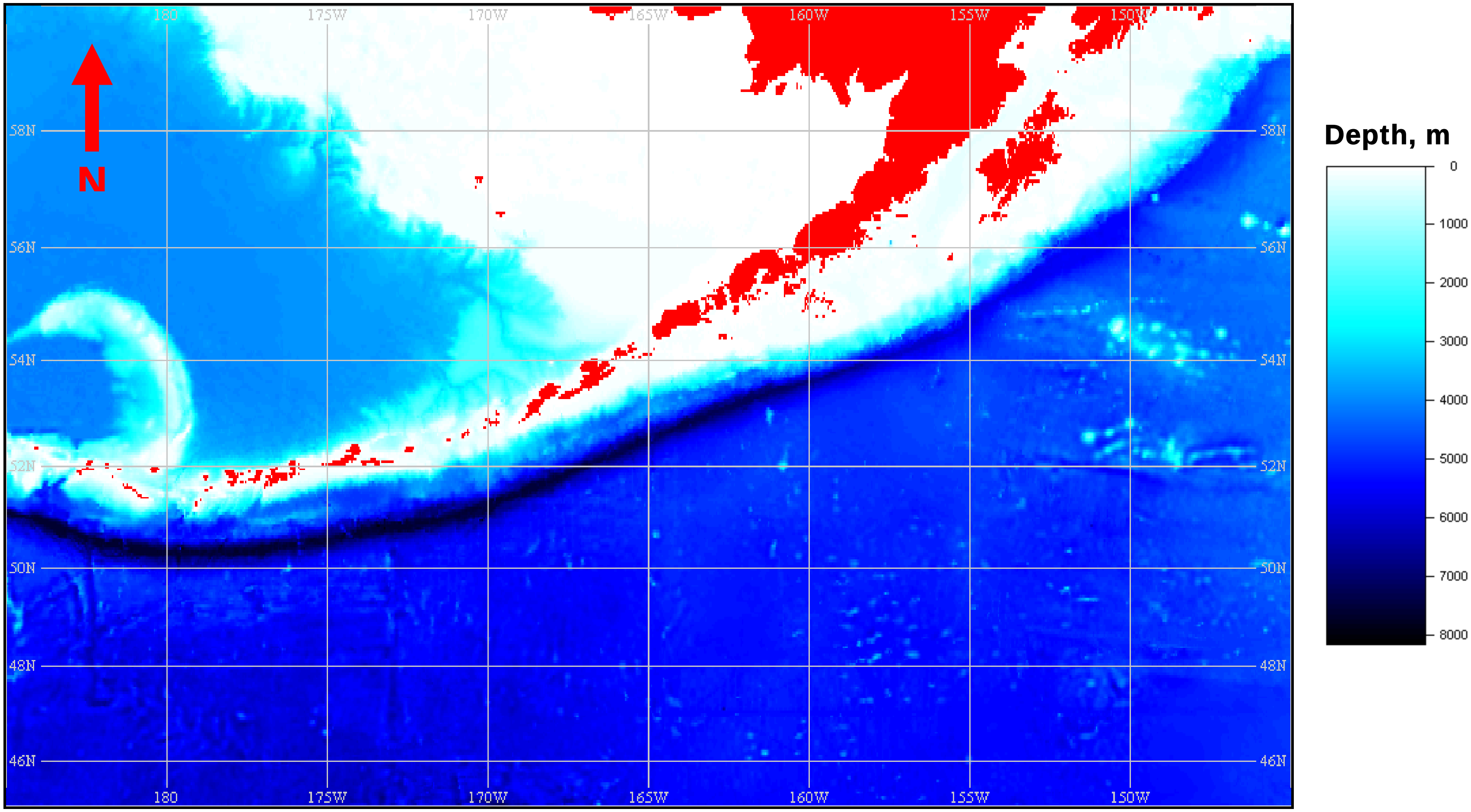
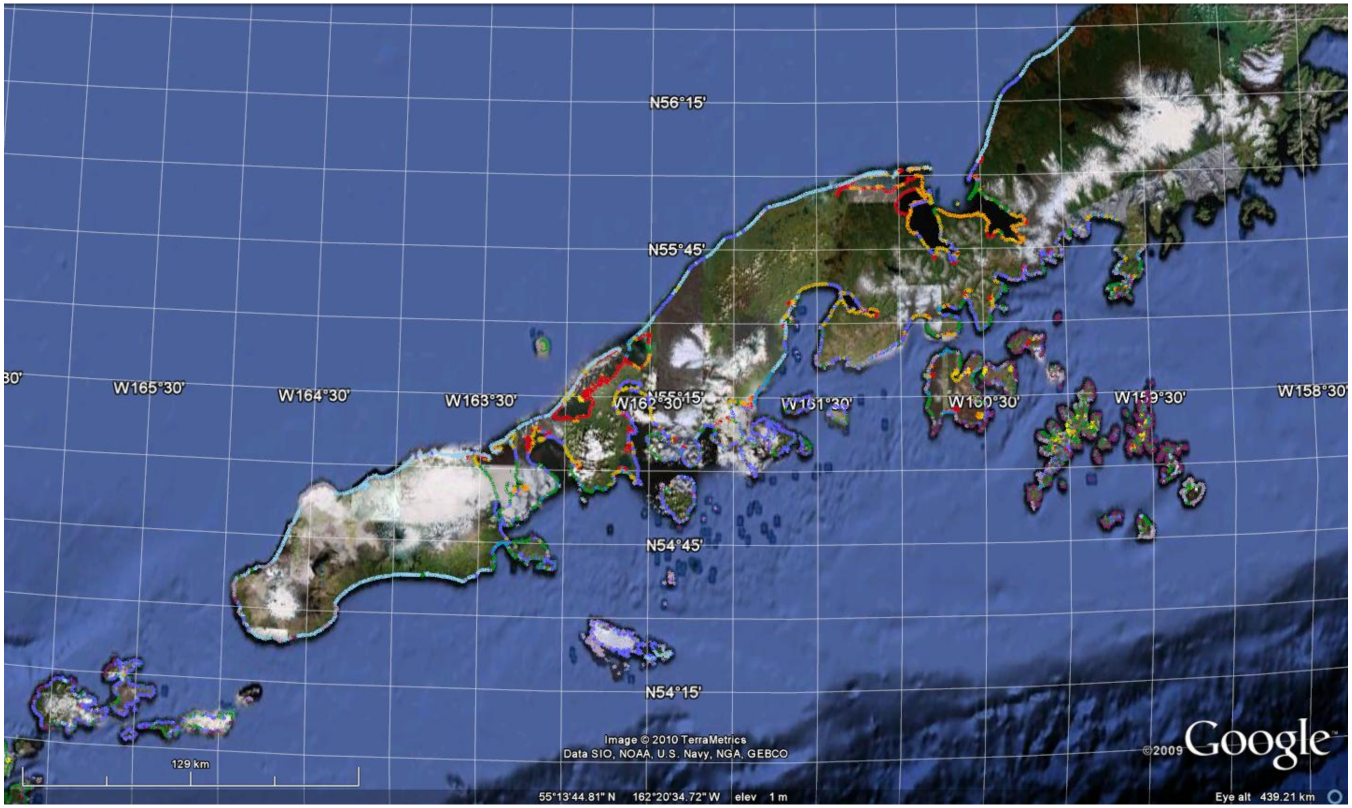
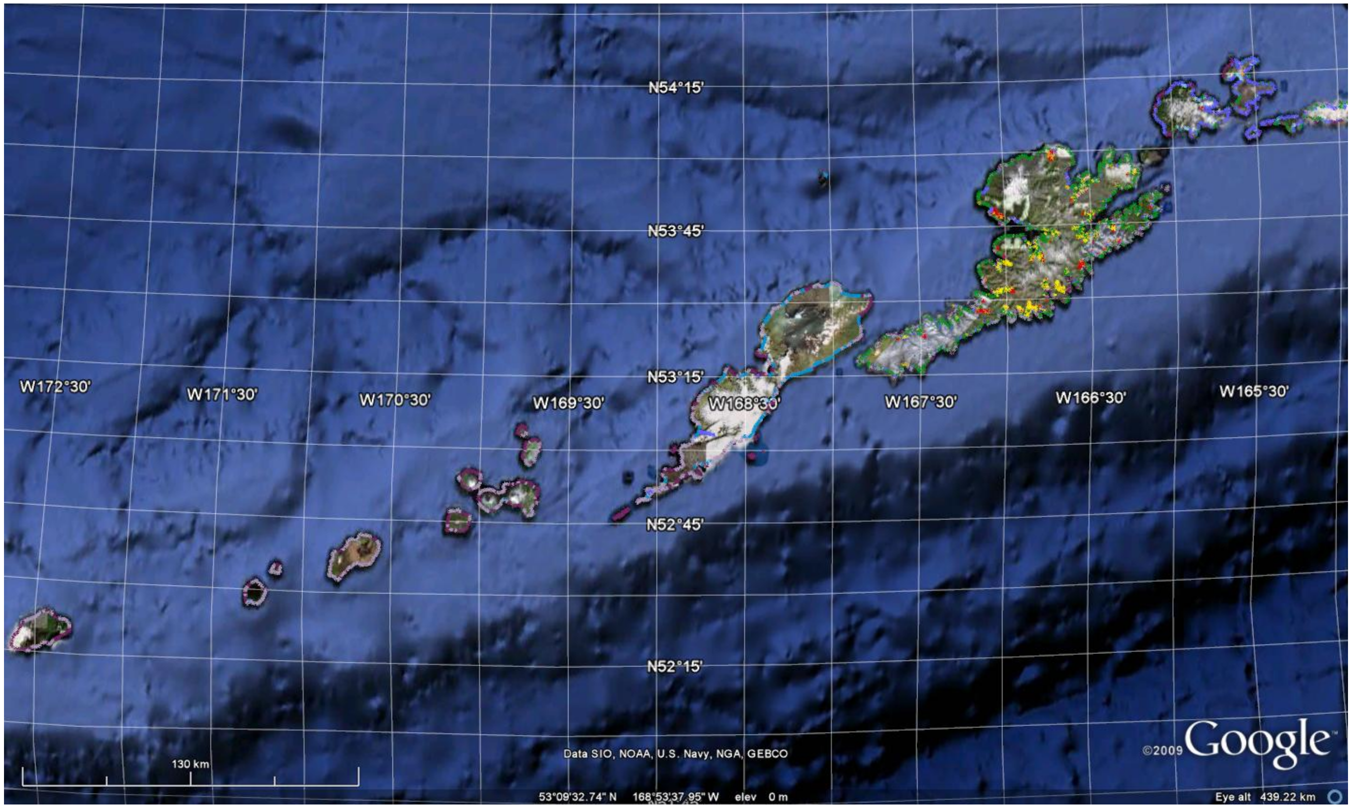


Figure 3-3a ESI map of Aleutian Islands



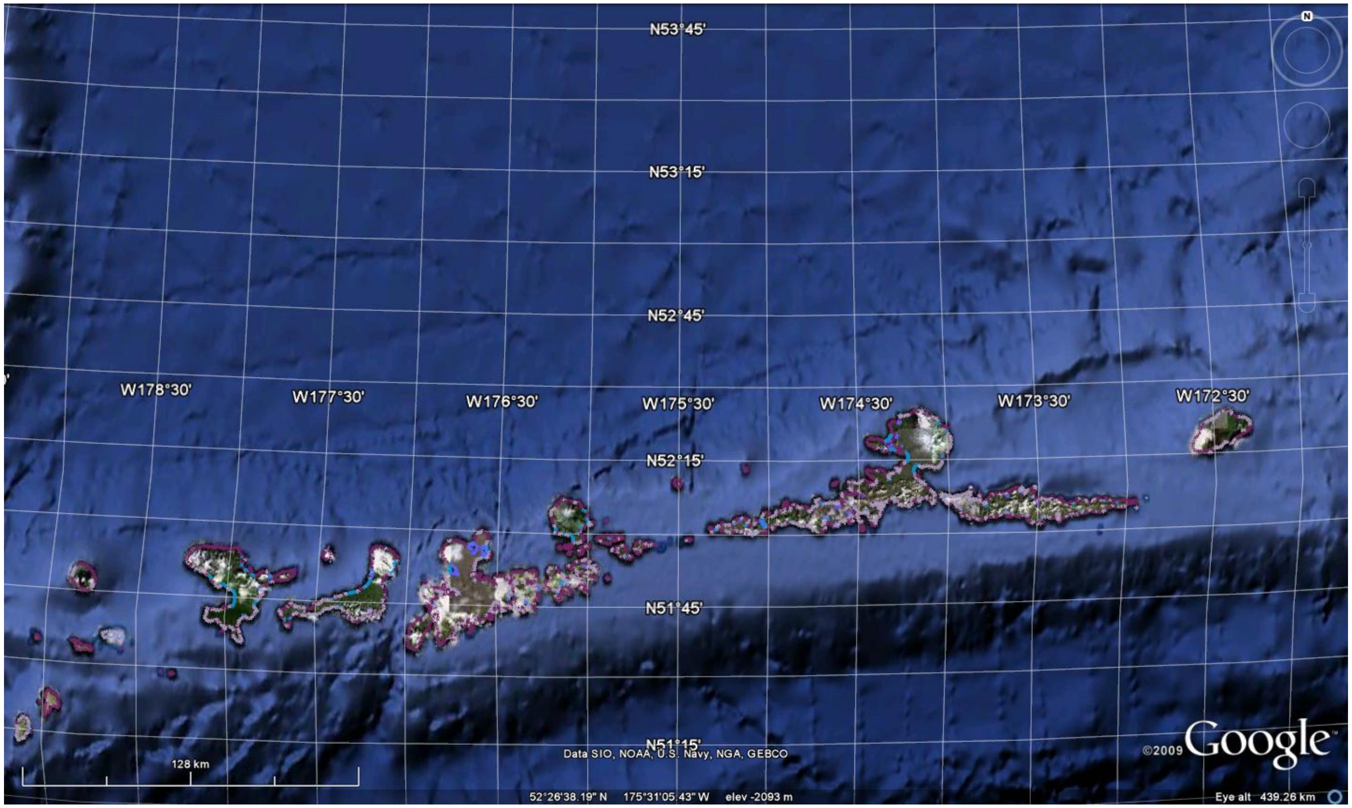
- 10A+-Salt- _brackish-water marshes (most sens)
- 10A-Salt- _brackish-water marshes
- 9B-Vegetated low banks
- 9A+-Sheltered tidal flats (most sens)
- 9A-Sheltered tidal flats
- 8C+-Sheltered riprap (most sens)
- 8C-Sheltered riprap
- 8B+-Sheltered, solid man-made structures (most sens)
- 8B-Sheltered, solid man-made structures
- 8A+-Sheltered rocky shores (most sens)
- 8A-Sheltered rocky shores
- 7+-Exposed tidal flats (most sens)
- 7-Exposed tidal flats
- 6B+-Riprap (most sens)
- 6B-Riprap
- 6A+-Gravel beaches (most sens)
- 6A-Gravel beaches
- 5+-Mixed sand _gravel beaches (most sens)
- 5-Mixed sand _gravel beaches
- 4+-Coarse-grained sand (most sens)
- 4-Coarse grained-sand
- 3A+-Fine- to medium-grained sand (most sens)
- 3A-Fine- to medium-grained sand
- 3+-Beaches (fine-, medium-, coarse-sand, gravel) (most sens)
- 3-Beaches (fine-, medium-, coarse-sand, gravel)
- 2A+-Rocky shoals; Bedrock ledges (most sens)
- 2A-Rocky shoals; Bedrock ledges
- 2-Exposed high energy shoreline
- 1B-Exposed, solid man-made structures
- 1A-Exposed rocky cliffs
- 1-Exposed rocky shores with or without wave-cut platforms

Figure 3-3b Bathymetry map of Aleutian Islands



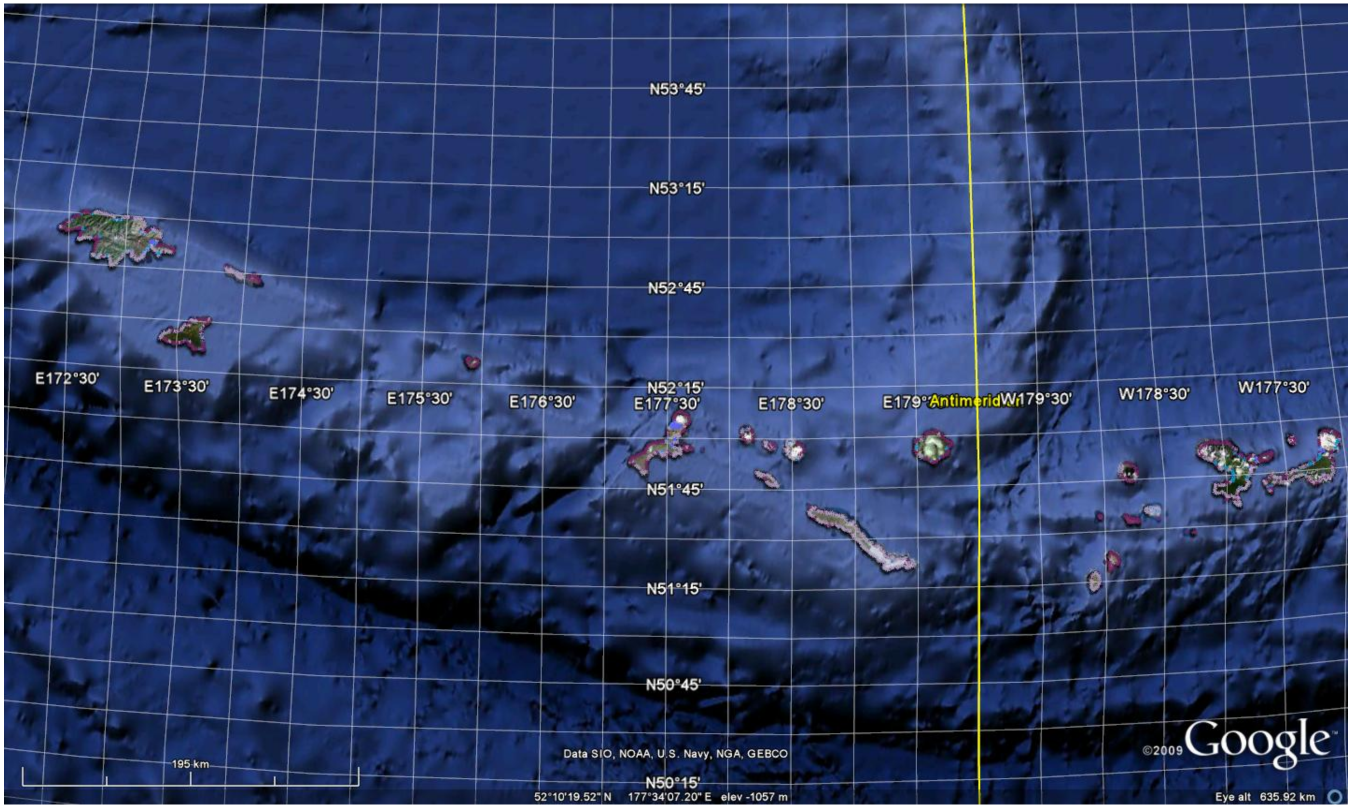
- 10A+-Salt- brackish-water marshes (most sens)
- 10A-Salt- brackish-water marshes
- 9B-Vegetated low banks
- 9A+-Sheltered tidal flats (most sens)
- 9A-Sheltered tidal flats
- 8C+-Sheltered riprap (most sens)
- 8C-Sheltered riprap
- 8B+-Sheltered, solid man-made structures (most sens)
- 8B-Sheltered, solid man-made structures
- 8A+-Sheltered rocky shores (most sens)
- 8A-Sheltered rocky shores
- 7+-Exposed tidal flats (most sens)
- 7-Exposed tidal flats
- 6B+-Riprap (most sens)
- 6B-Riprap
- 6A+-Gravel beaches (most sens)
- 6A-Gravel beaches
- 5+-Mixed sand gravel beaches (most sens)
- 5-Mixed sand gravel beaches
- 4+-Coarse-grained sand (most sens)
- 4-Coarse grained-sand
- 3A+-Fine- to medium-grained sand (most sens)
- 3A-Fine- to medium-grained sand
- 3+-Beaches (fine-, medium-, coarse-sand, gravel) (most sens)
- 3-Beaches (fine-, medium-, coarse-sand, gravel)
- 2A+-Rocky shoals; Bedrock ledges (most sens)
- 2A-Rocky shoals; Bedrock ledges
- 2-Exposed high energy shoreline
- 1B-Exposed, solid man-made structures
- 1A-Exposed rocky cliffs
- 1-Exposed rocky shores with or without wave-cut platforms

Figure 3-3d Bathymetry map of Aleutian Islands



- 10A+-Salt- brackish-water marshes (most sens)
- 10A-Salt- brackish-water marshes
- 9B-Vegetated low banks
- 9A+-Sheltered tidal flats (most sens)
- 9A-Sheltered tidal flats
- 8C+-Sheltered riprap (most sens)
- 8C-Sheltered riprap
- 8B+-Sheltered, solid man-made structures (most sens)
- 8B-Sheltered, solid man-made structures
- 8A+-Sheltered rocky shores (most sens)
- 8A-Sheltered rocky shores
- 7+-Exposed tidal flats (most sens)
- 7-Exposed tidal flats
- 6B+-Riprap (most sens)
- 6B-Riprap
- 6A+-Gravel beaches (most sens)
- 6A-Gravel beaches
- 5+-Mixed sand gravel beaches (most sens)
- 5-Mixed sand gravel beaches
- 4+-Coarse-grained sand (most sens)
- 4-Coarse grained-sand
- 3A+-Fine- to medium-grained sand (most sens)
- 3A-Fine- to medium-grained sand
- 3+-Beaches (fine-, medium-, coarse-sand, gravel) (most sens)
- 3-Beaches (fine-, medium-, coarse-sand, gravel)
- 2A+-Rocky shoals; Bedrock ledges (most sens)
- 2A-Rocky shoals; Bedrock ledges
- 2-Exposed high energy shoreline
- 1B-Exposed, solid man-made structures
- 1A-Exposed rocky cliffs
- 1-Exposed rocky shores with or without wave-cut platforms

Figure 3-3e Bathymetry map of Aleutian Islands



10A+-Salt- _brackish-water marshes (most sens)
10A-Salt- _brackish-water marshes
9B-Vegetated low banks
9A+-Sheltered tidal flats (most sens)
9A-Sheltered tidal flats
8C+-Sheltered riprap (most sens)
8C-Sheltered riprap
8B+-Sheltered, solid man-made structures (most sens)
8B-Sheltered, solid man-made structures
8A+-Sheltered rocky shores (most sens)
8A-Sheltered rocky shores
7+-Exposed tidal flats (most sens)
7-Exposed tidal flats
6B+-Riprap (most sens)
6B-Riprap
6A+-Gravel beaches (most sens)
6A-Gravel beaches
5+-Mixed sand _gravel beaches (most sens)
5-Mixed sand _gravel beaches
4+-Coarse-grained sand (most sens)
4-Coarse grained-sand
3A+-Fine- to medium-grained sand (most sens)
3A-Fine- to medium-grained sand
3+-Beaches (fine-, medium-, coarse-sand, gravel) (most sens)
3-Beaches (fine-, medium-, coarse-sand, gravel)
2A+-Rocky shoals; Bedrock ledges (most sens)
2A-Rocky shoals; Bedrock ledges
2-Exposed high energy shoreline
1B-Exposed, solid man-made structures
1A-Exposed rocky cliffs
1-Exposed rocky shores with or without wave-cut platforms

Figure 3-3 NDBC station locations for the study region

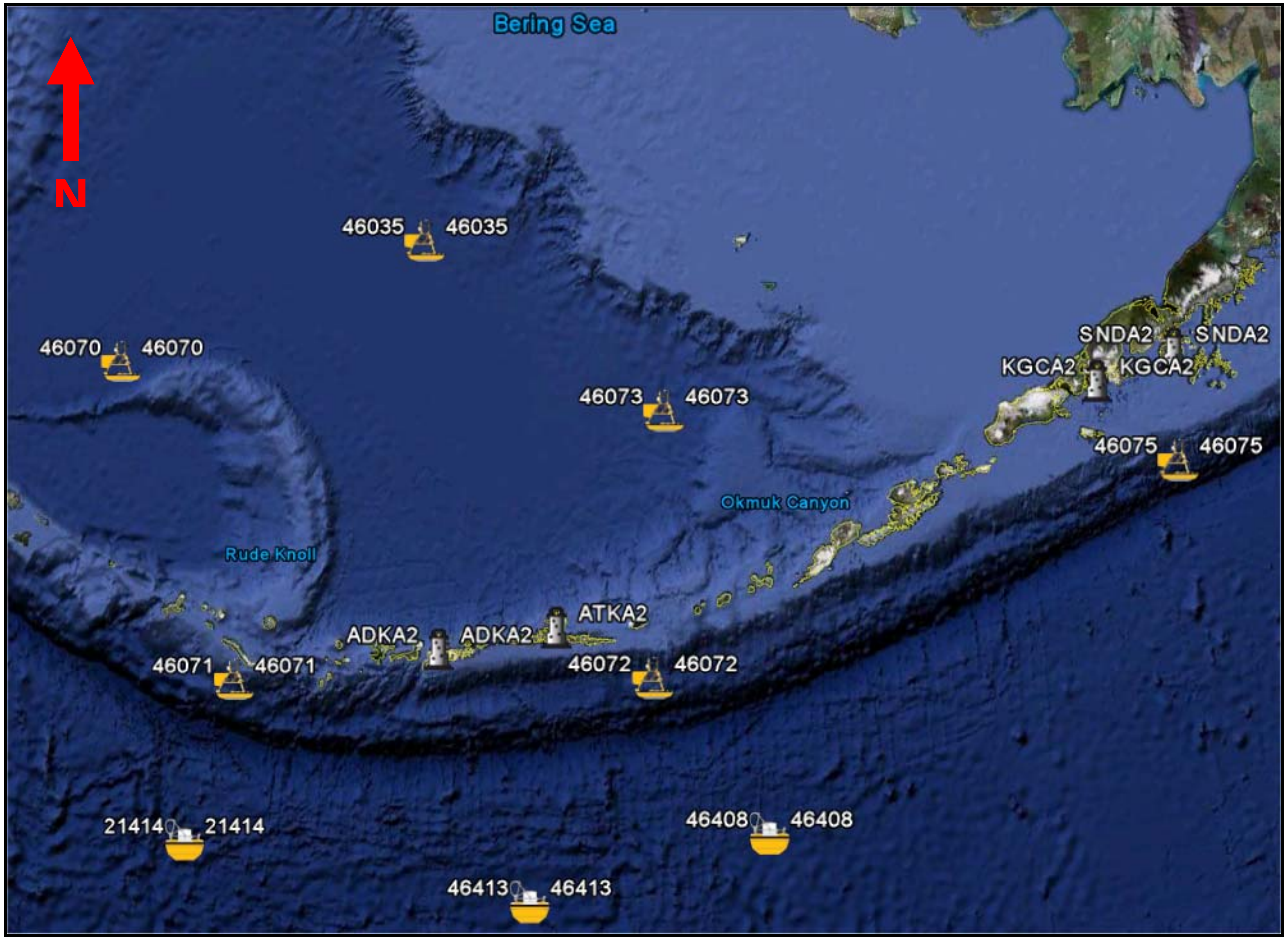


Figure 3-4 Ocean Watch meteorological grid domain for the study region

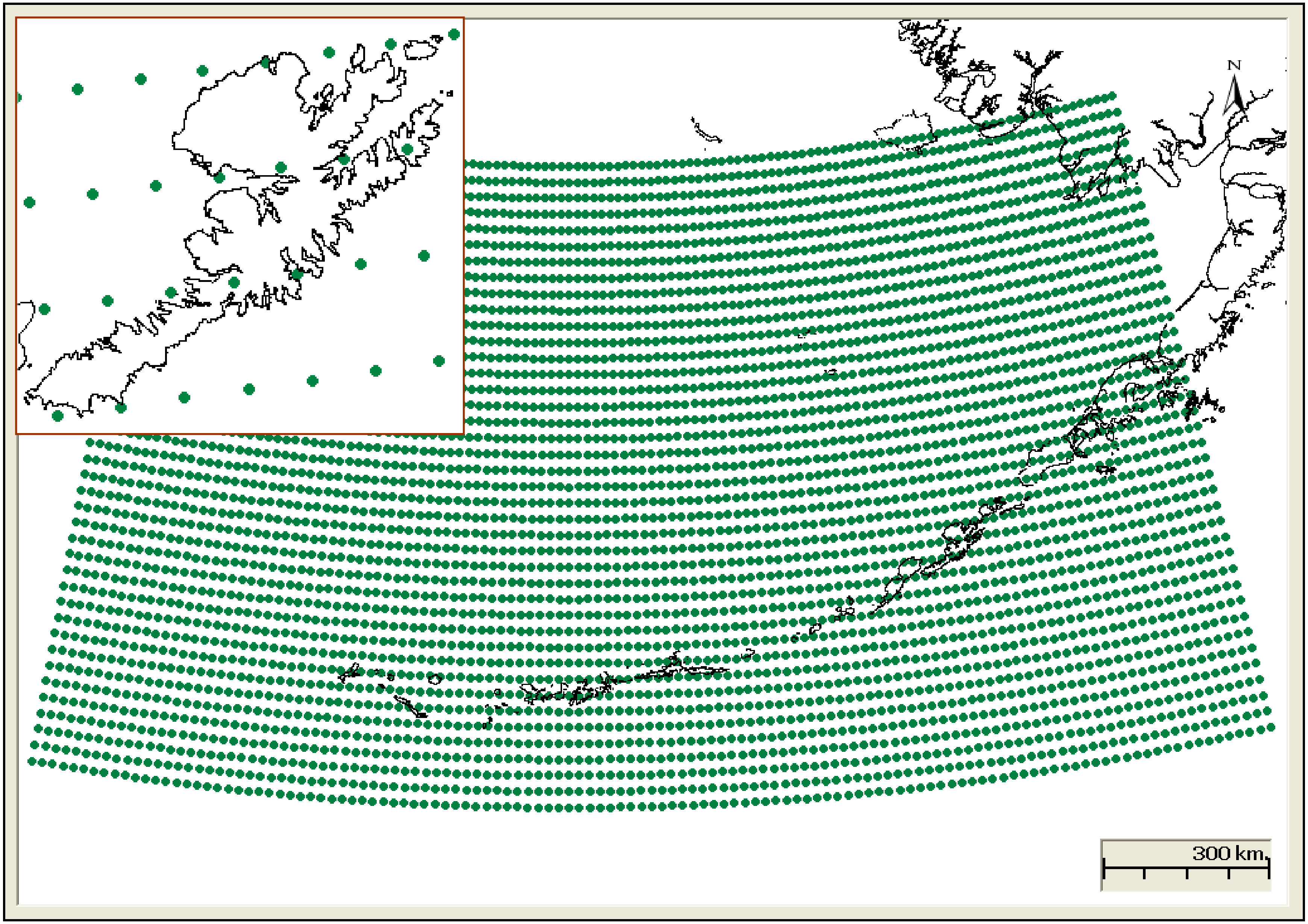


Figure 3-5 NRL NLOM 1/32° 30day delayed nowcast hydrodynamic currents availability grid for the study region

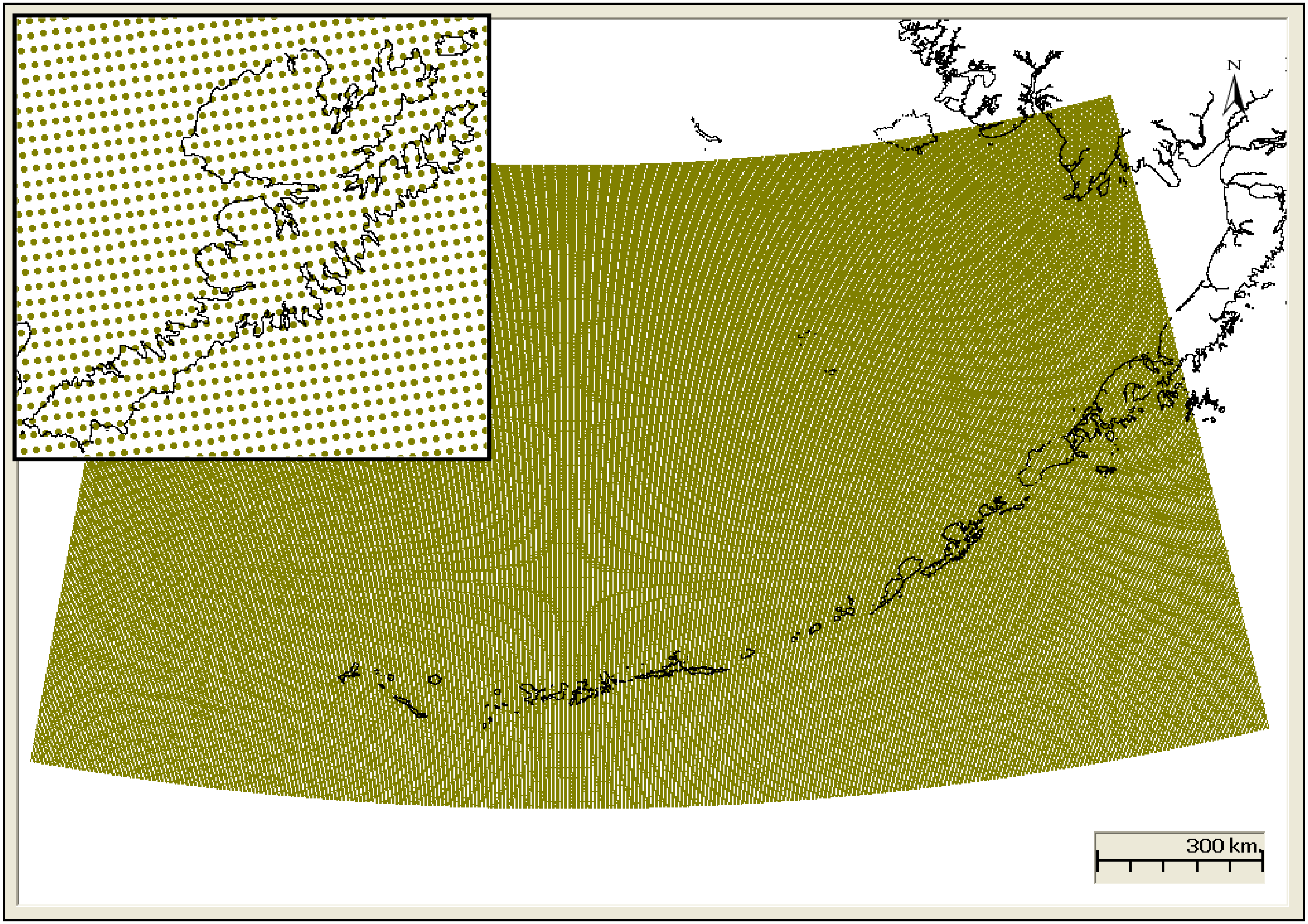


Figure 3-6 NRL NLOM 1/16° nowcast hydrodynamic currents availability grid for the study region

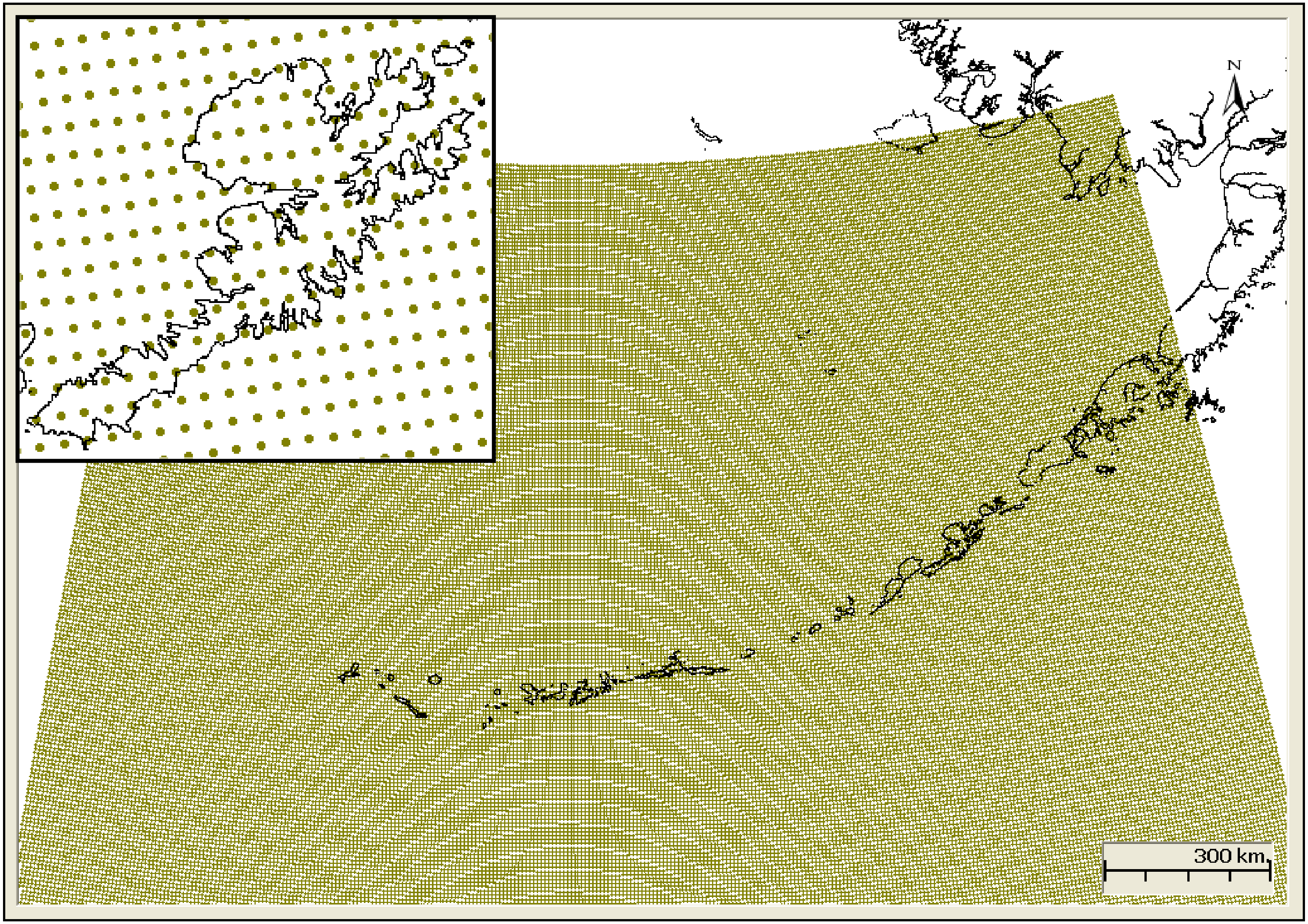


Figure 3-7 NOAA 1/4° daily temperature data availability grid domain for the study region

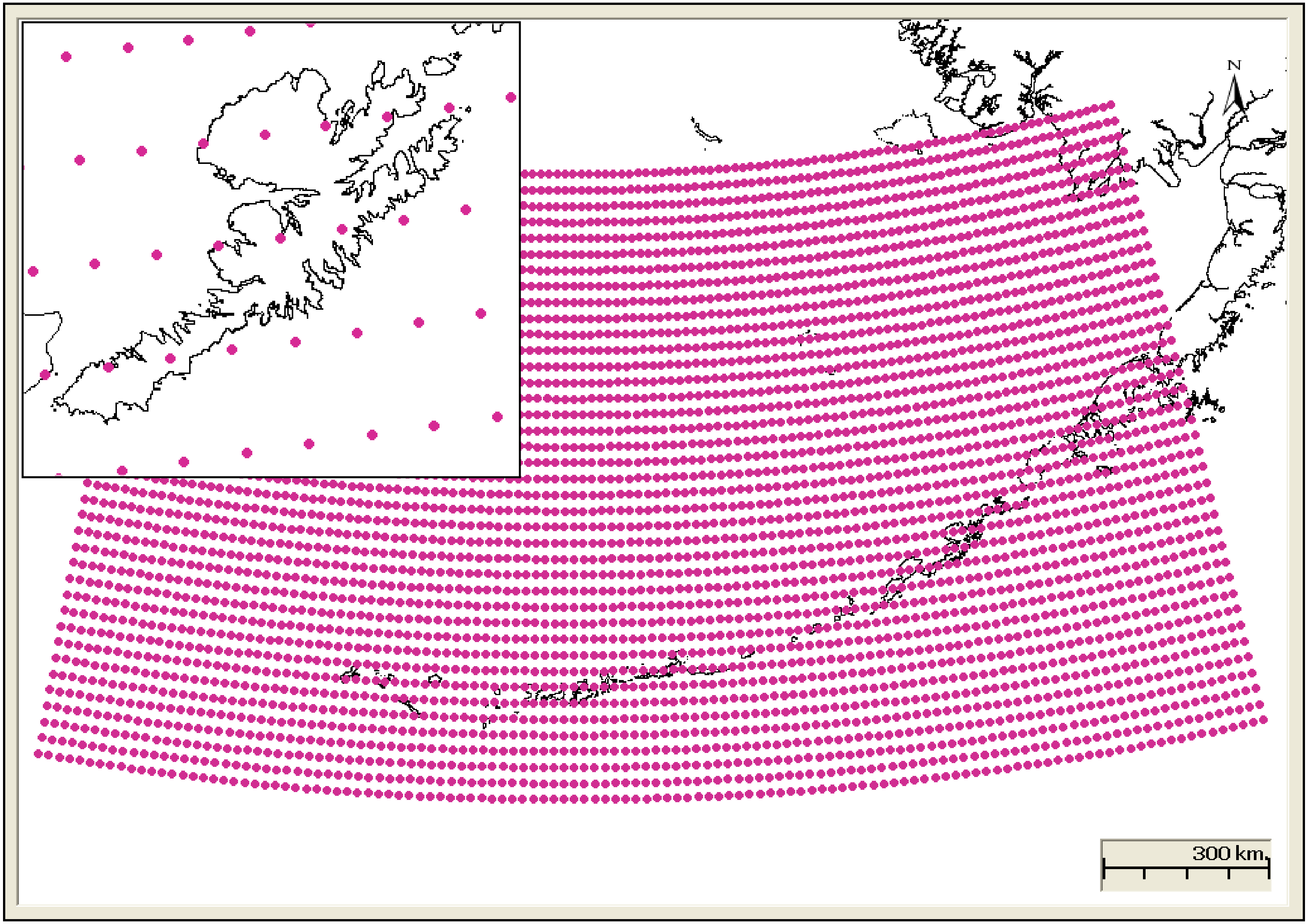


Figure 3-8 GFDL monthly salinity profile availability data grid domain for the study region

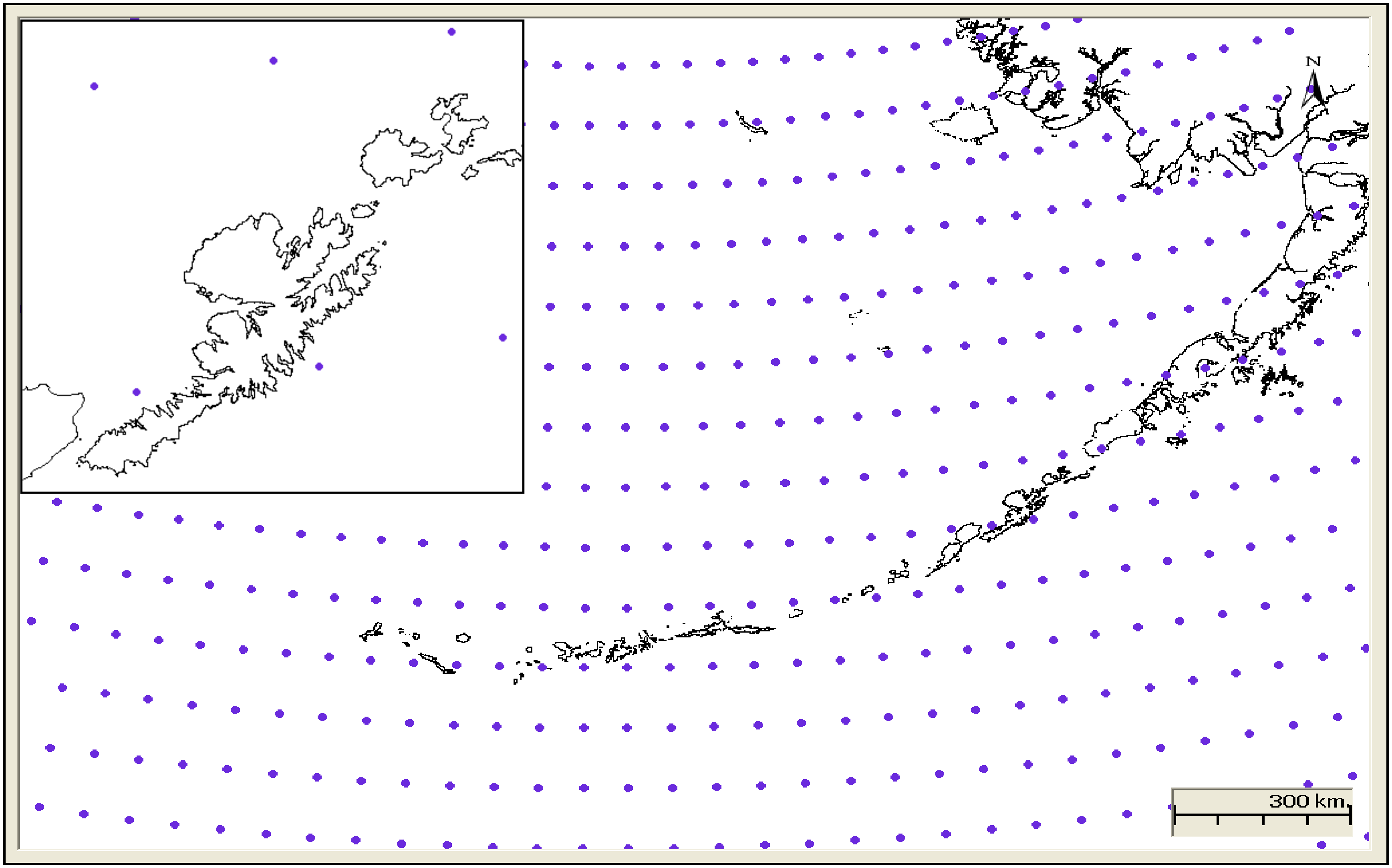


Figure 4-1 Location of six spill scenarios identified based on the traffic study

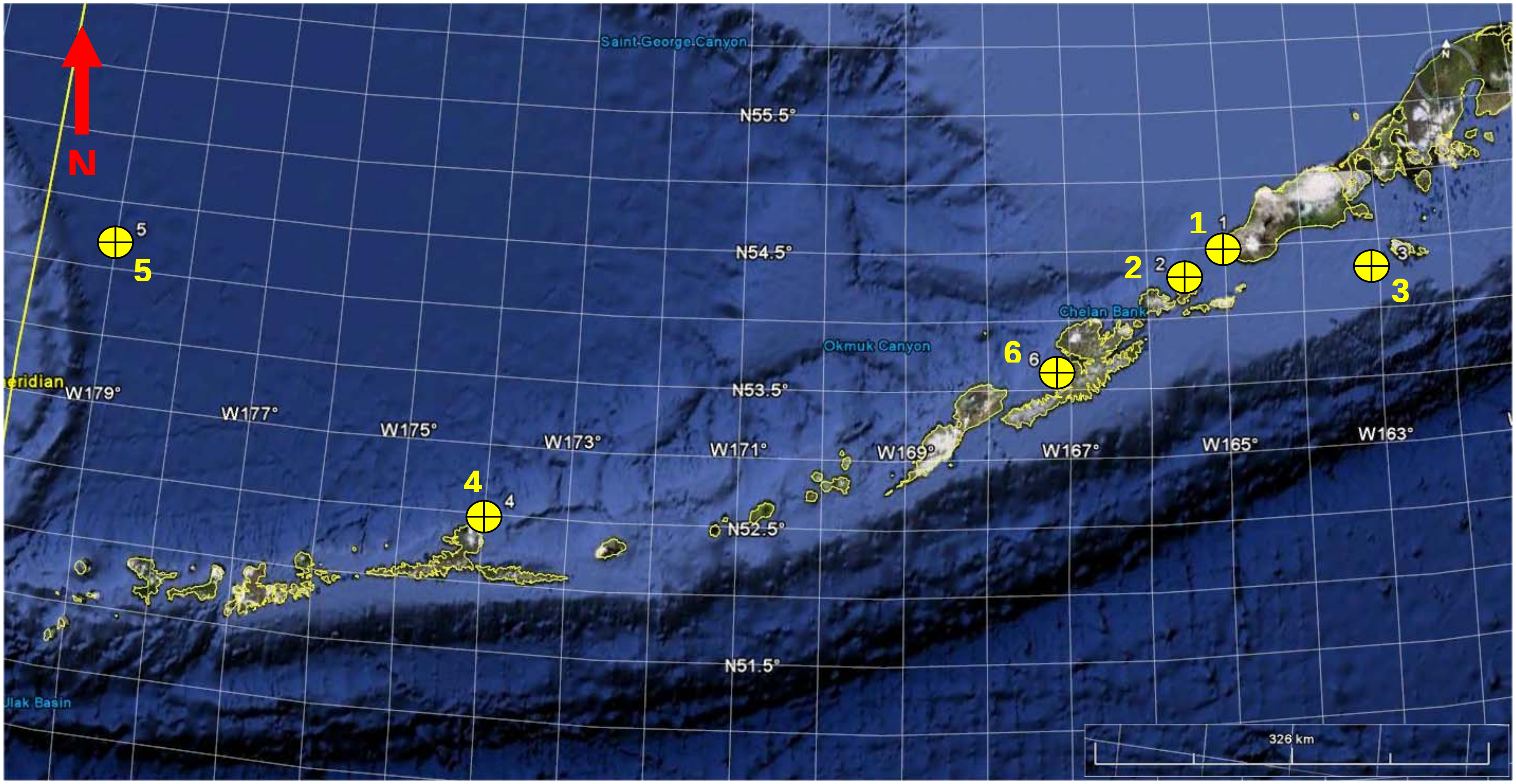


Figure 4-2 COSIM oil spill grid for Scenario 1

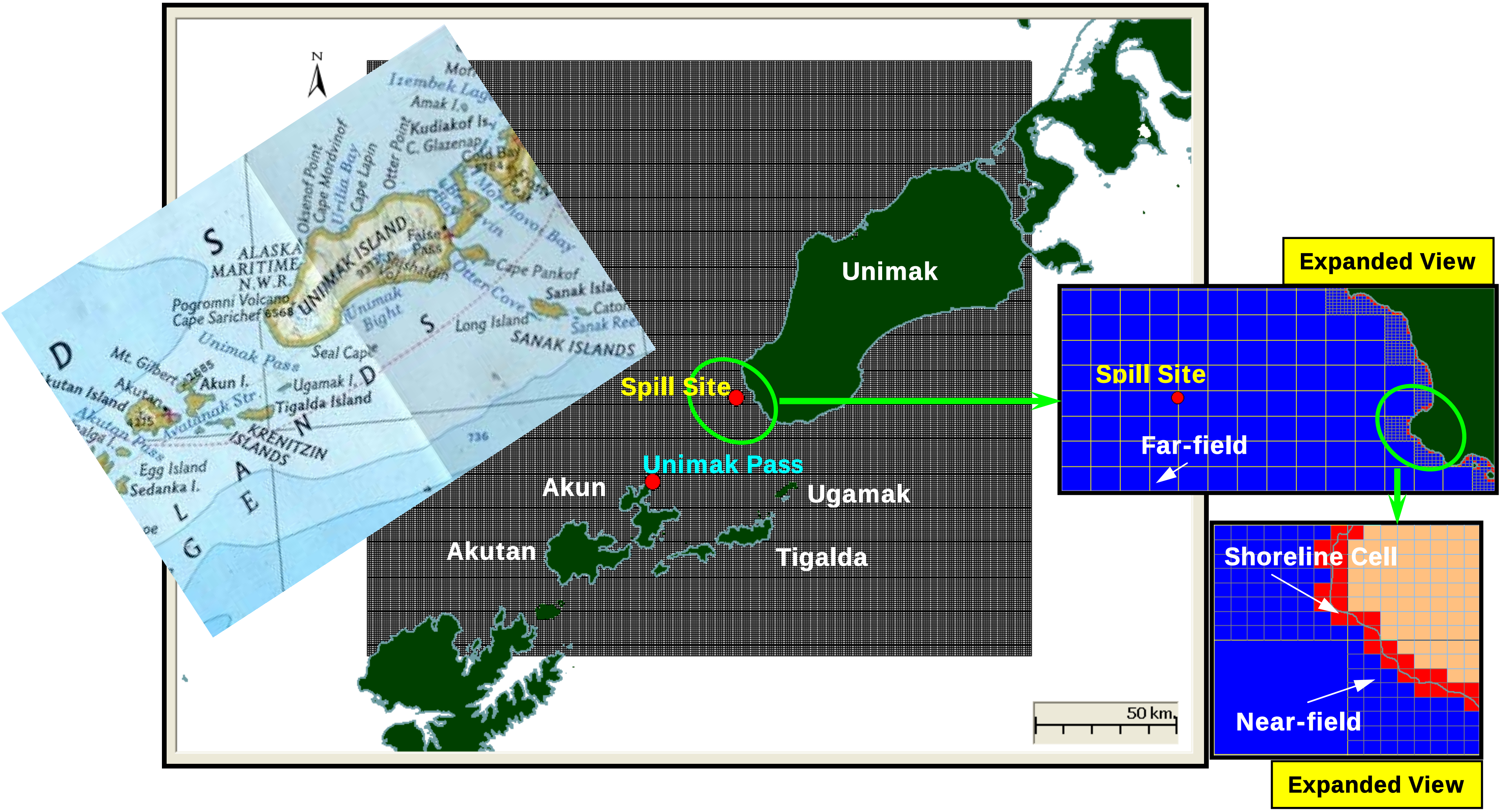


Figure 4-3 ESI map of Aleutian Island in the vicinity of Scenario 1

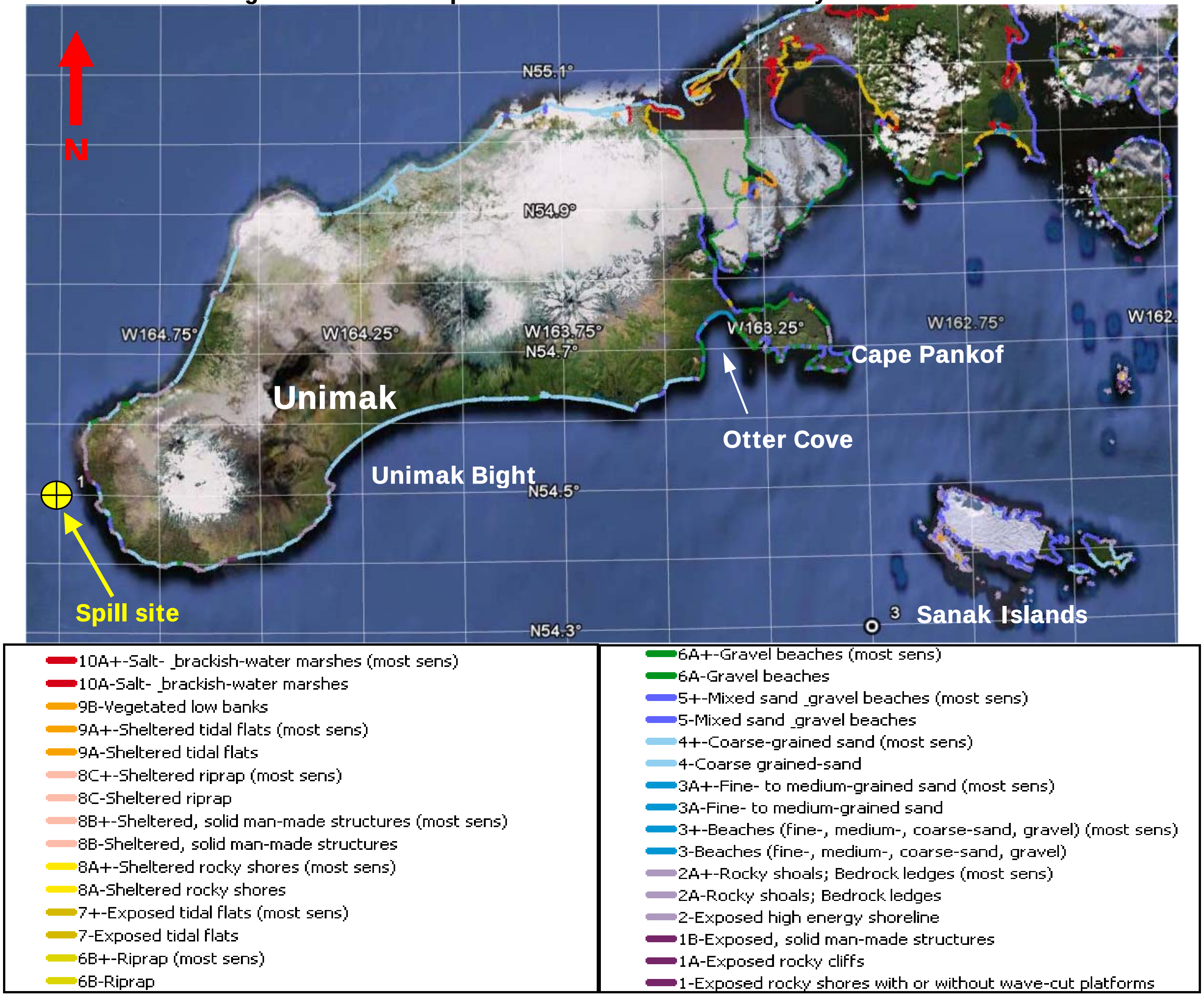


Figure 4-4 COSIM oil spill grid for Scenario 2

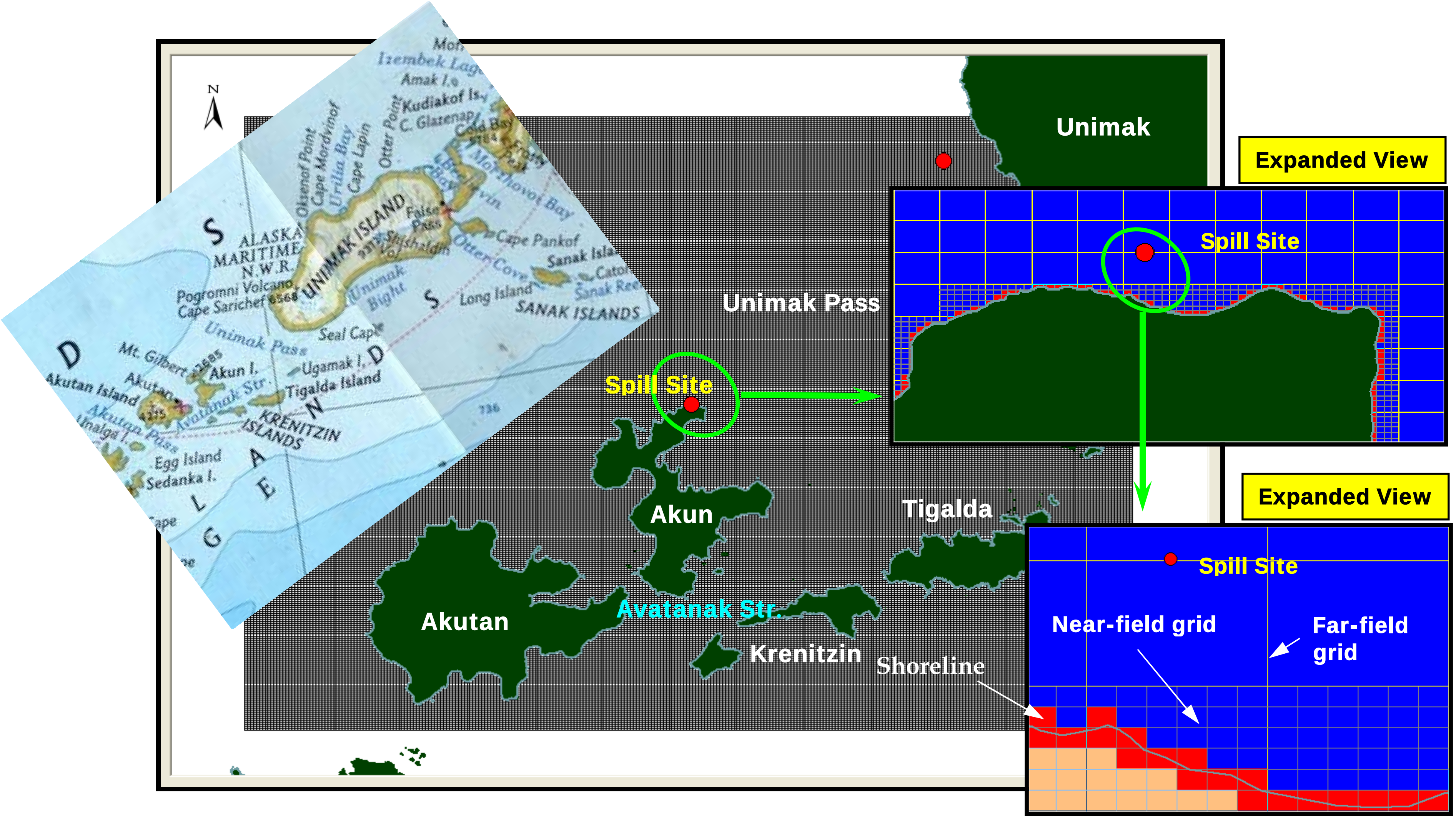
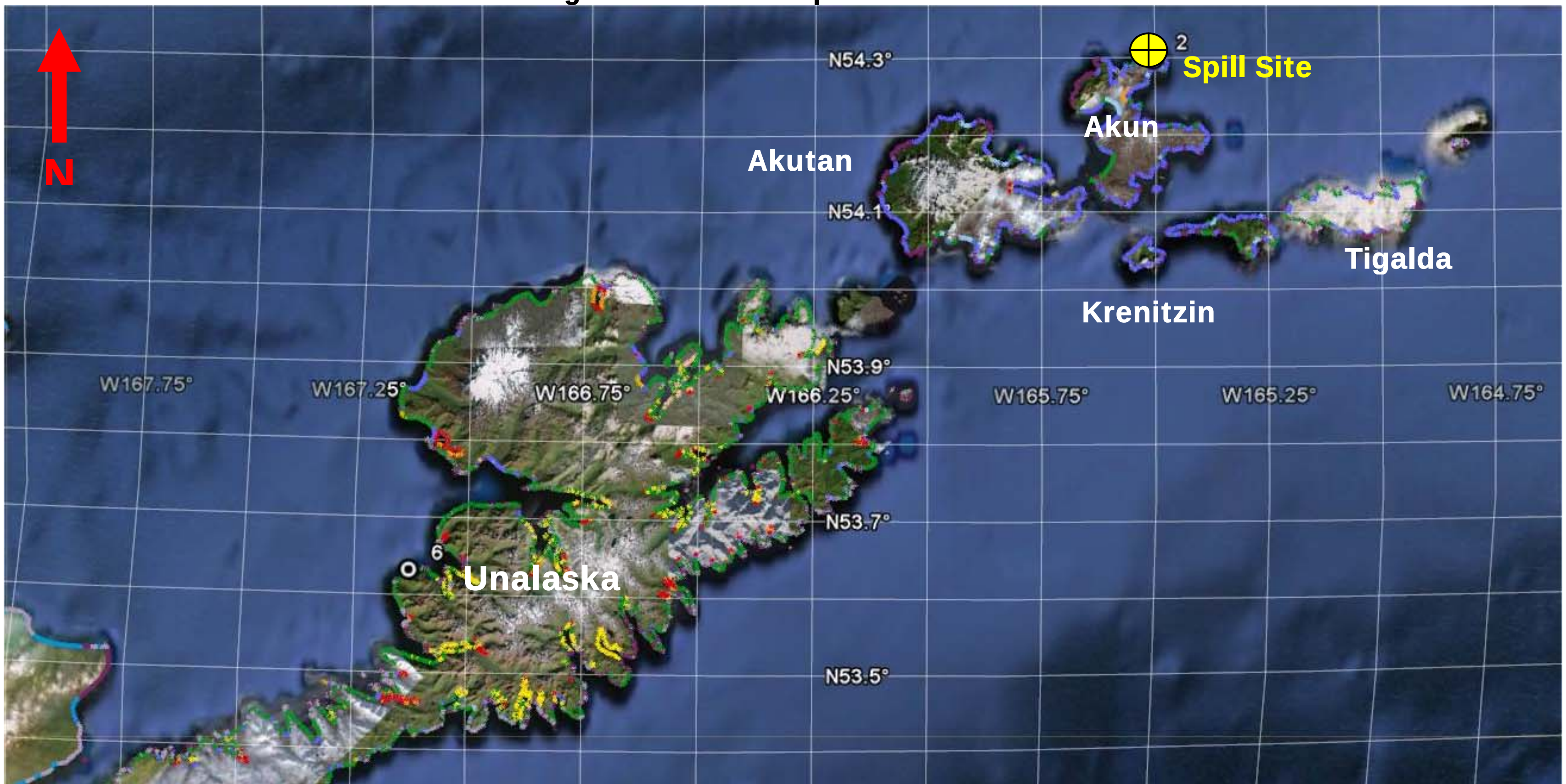


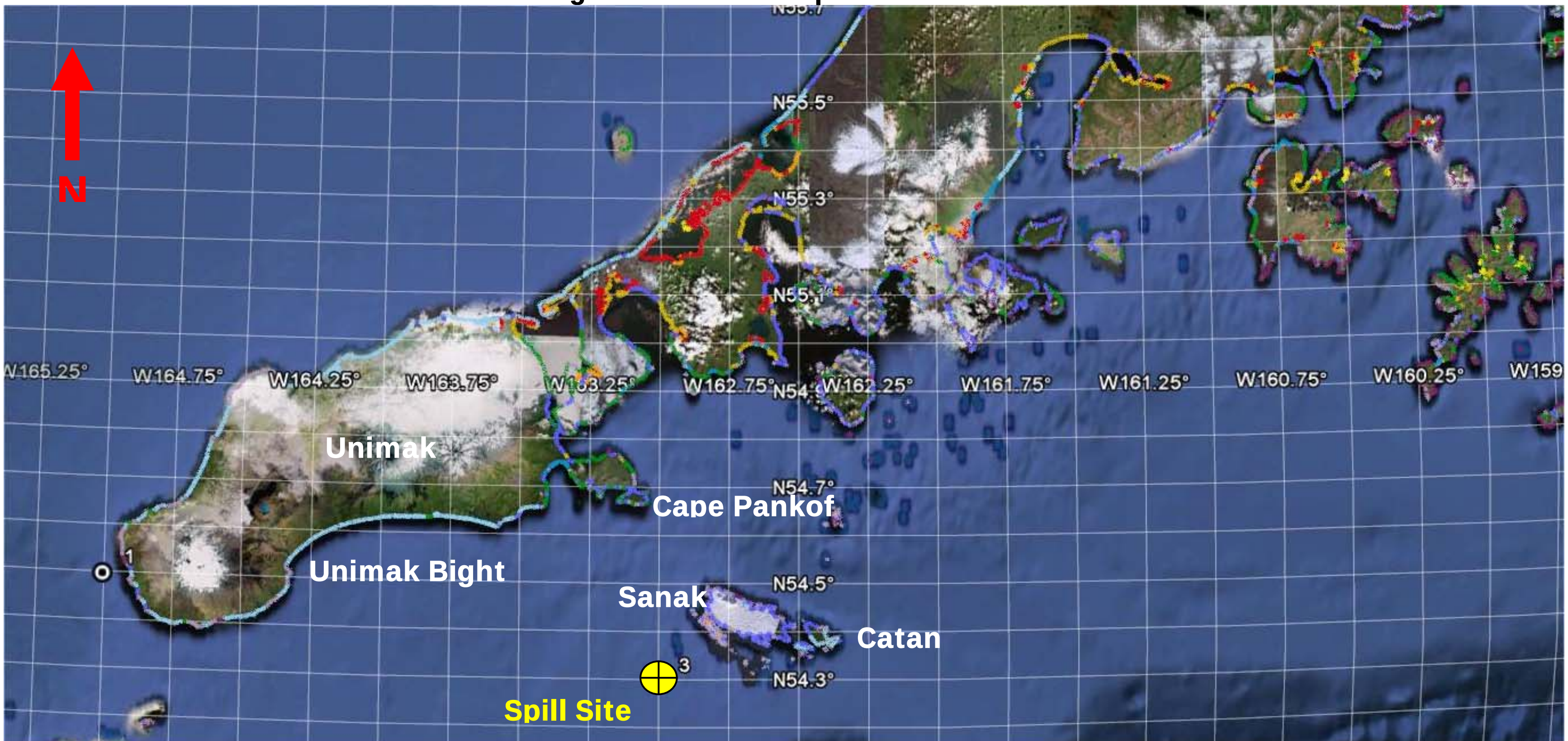
Figure 4-5 ESI map for Scenario 2



10A+-Salt- _brackish-water marshes (most sens)
10A-Salt- _brackish-water marshes
9B-Vegetated low banks
9A+-Sheltered tidal flats (most sens)
9A-Sheltered tidal flats
8C+-Sheltered riprap (most sens)
8C-Sheltered riprap
8B+-Sheltered, solid man-made structures (most sens)
8B-Sheltered, solid man-made structures
8A+-Sheltered rocky shores (most sens)
8A-Sheltered rocky shores
7+-Exposed tidal flats (most sens)
7-Exposed tidal flats
6B+-Riprap (most sens)
6B-Riprap
6A+-Gravel beaches (most sens)
6A-Gravel beaches
5+-Mixed sand _gravel beaches (most sens)
5-Mixed sand _gravel beaches
4+-Coarse-grained sand (most sens)
4-Coarse grained-sand
3A+-Fine- to medium-grained sand (most sens)
3A-Fine- to medium-grained sand
3+-Beaches (fine-, medium-, coarse-sand, gravel) (most sens)
3-Beaches (fine-, medium-, coarse-sand, gravel)
2A+-Rocky shoals; Bedrock ledges (most sens)
2A-Rocky shoals; Bedrock ledges
2-Exposed high energy shoreline
1B-Exposed, solid man-made structures
1A-Exposed rocky cliffs
1-Exposed rocky shores with or without wave-cut platforms

Figure 4-6 Oil spill grid for Scenario 3

Figure 4-7 ESI map for Scenario 3



10A+-Salt- _brackish-water marshes (most sens)
10A-Salt- _brackish-water marshes
9B-Vegetated low banks
9A+-Sheltered tidal flats (most sens)
9A-Sheltered tidal flats
8C+-Sheltered riprap (most sens)
8C-Sheltered riprap
8B+-Sheltered, solid man-made structures (most sens)
8B-Sheltered, solid man-made structures
8A+-Sheltered rocky shores (most sens)
8A-Sheltered rocky shores
7+-Exposed tidal flats (most sens)
7-Exposed tidal flats
6B+-Riprap (most sens)
6B-Riprap
6A+-Gravel beaches (most sens)
6A-Gravel beaches
5+-Mixed sand _gravel beaches (most sens)
5-Mixed sand _gravel beaches
4+-Coarse-grained sand (most sens)
4-Coarse grained-sand
3A+-Fine- to medium-grained sand (most sens)
3A-Fine- to medium-grained sand
3+-Beaches (fine-, medium-, coarse-sand, gravel) (most sens)
3-Beaches (fine-, medium-, coarse-sand, gravel)
2A+-Rocky shoals; Bedrock ledges (most sens)
2A-Rocky shoals; Bedrock ledges
2-Exposed high energy shoreline
1B-Exposed, solid man-made structures
1A-Exposed rocky cliffs
1-Exposed rocky shores with or without wave-cut platforms

Figure 4-8 Oil spill grid for Scenario 4

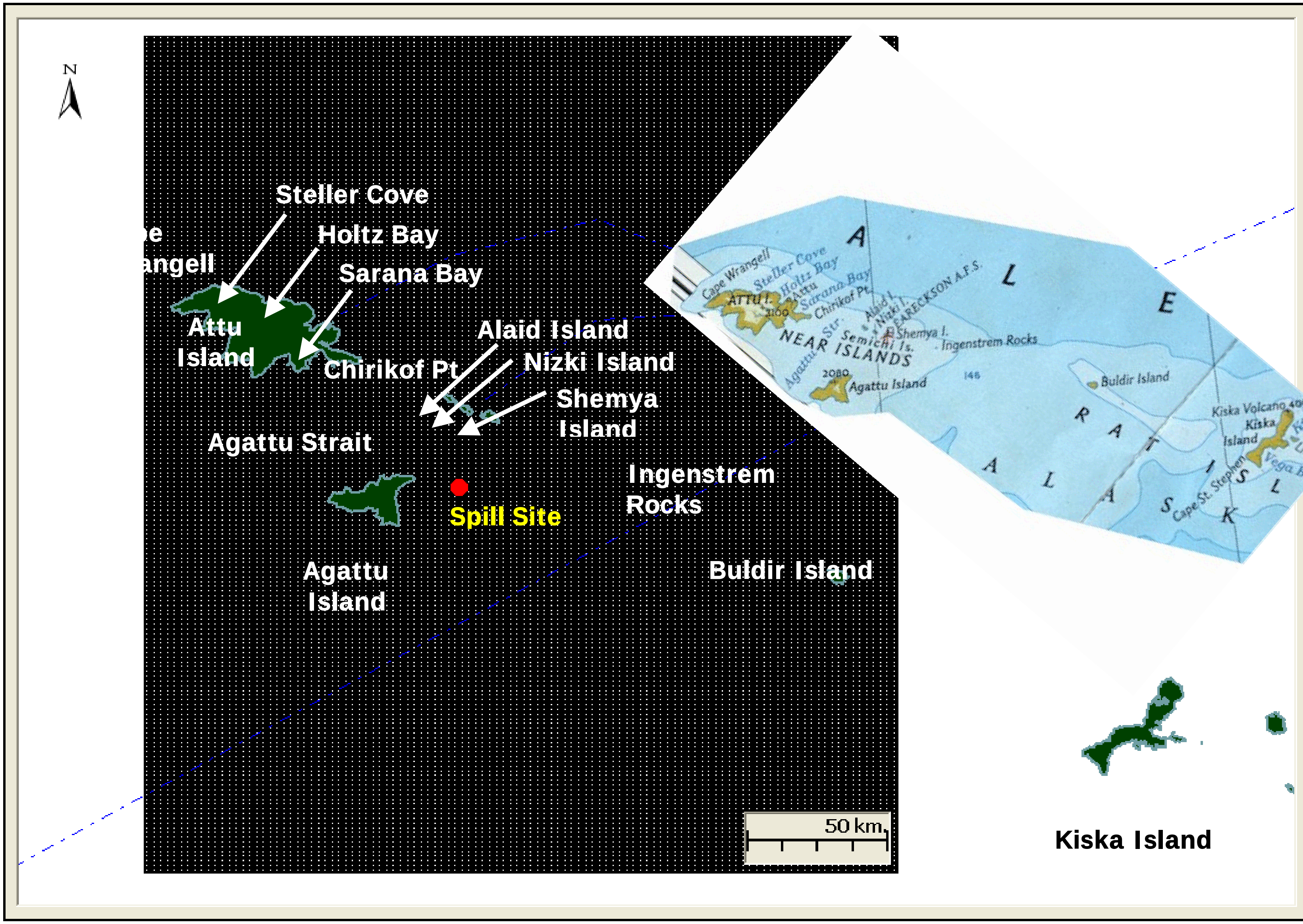


Figure 4-9 ESI map for Scenario 4

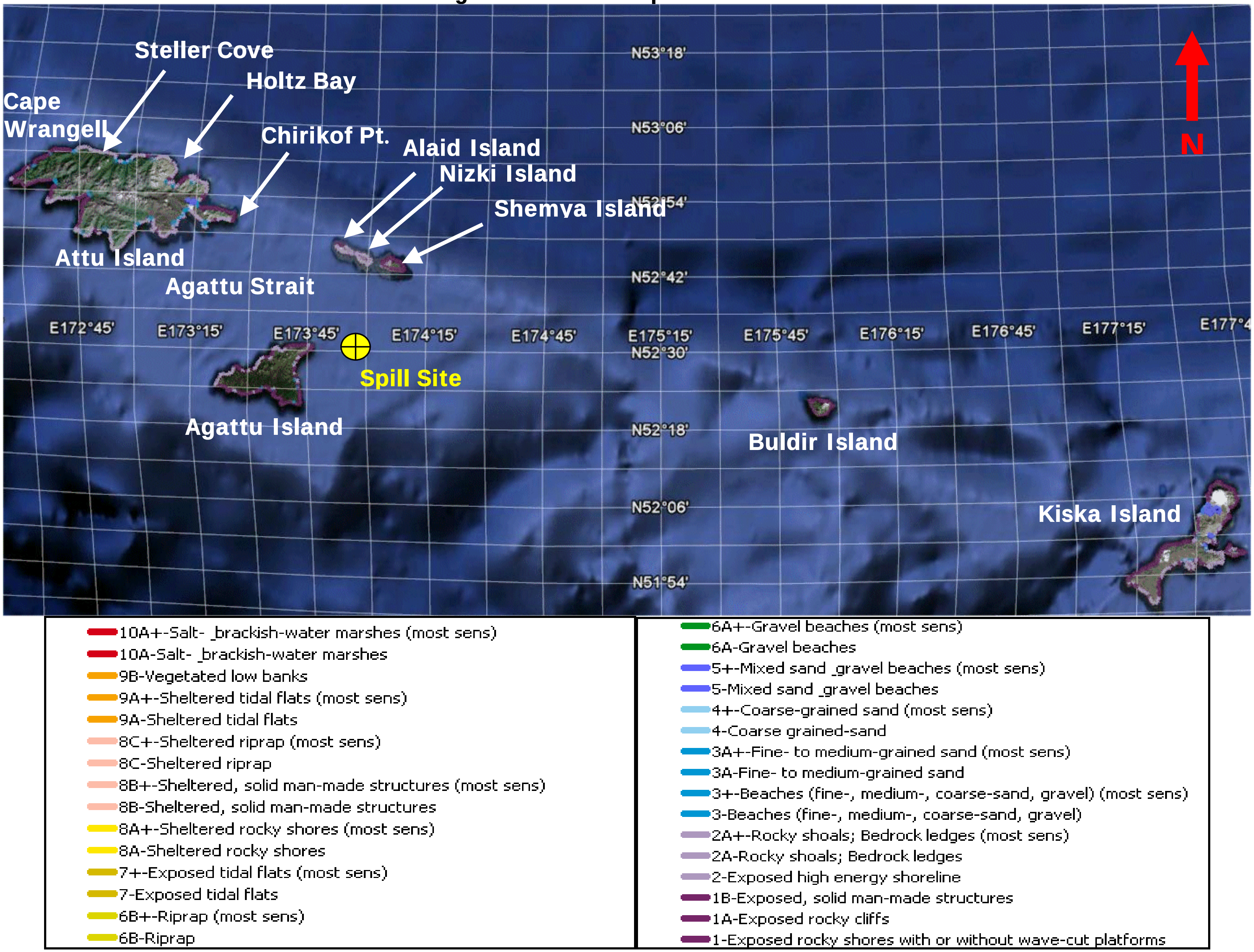


Figure 4-10 Oil spill grid for Scenario 5

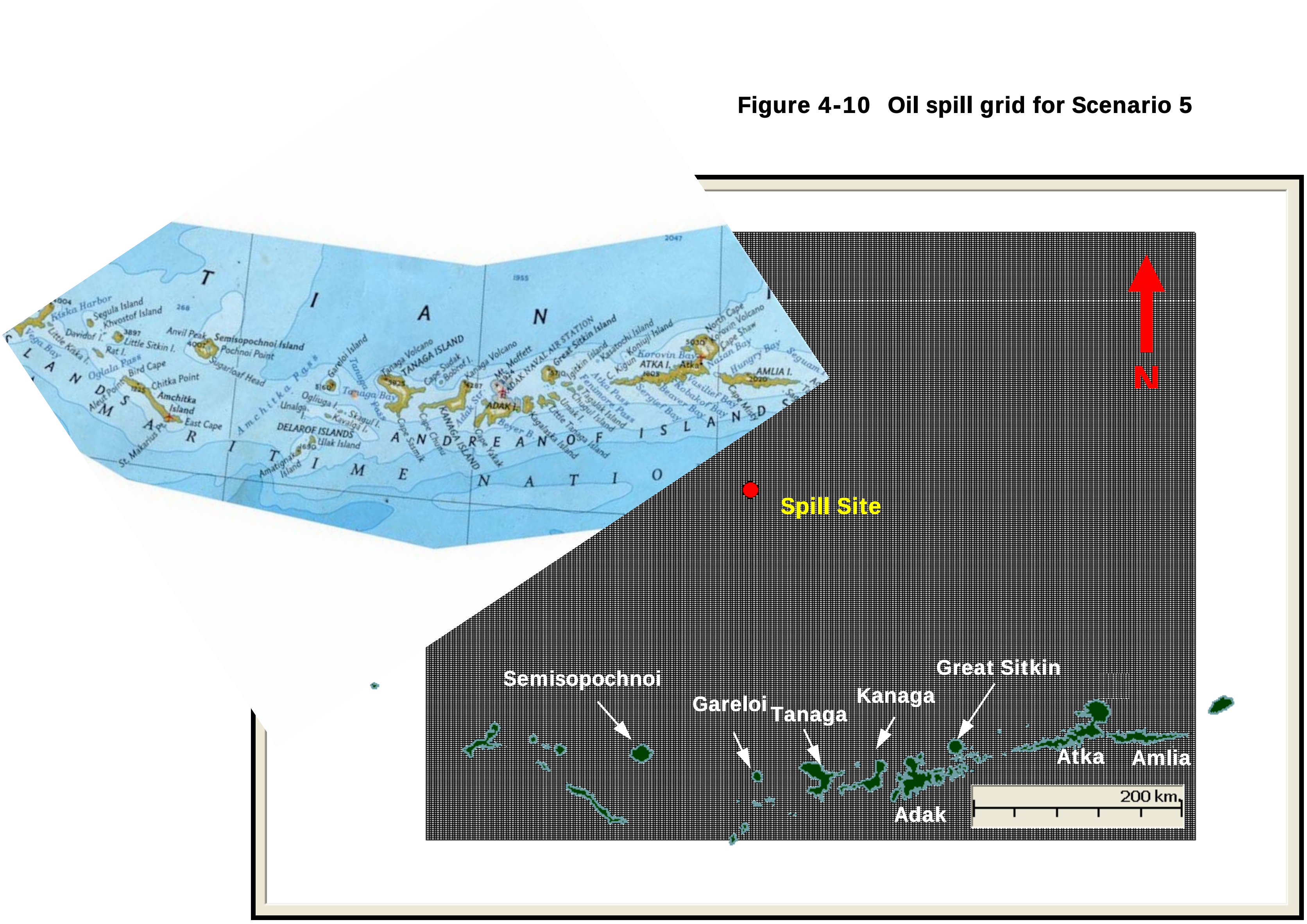


Figure 4-11 ESI map for Scenario 5

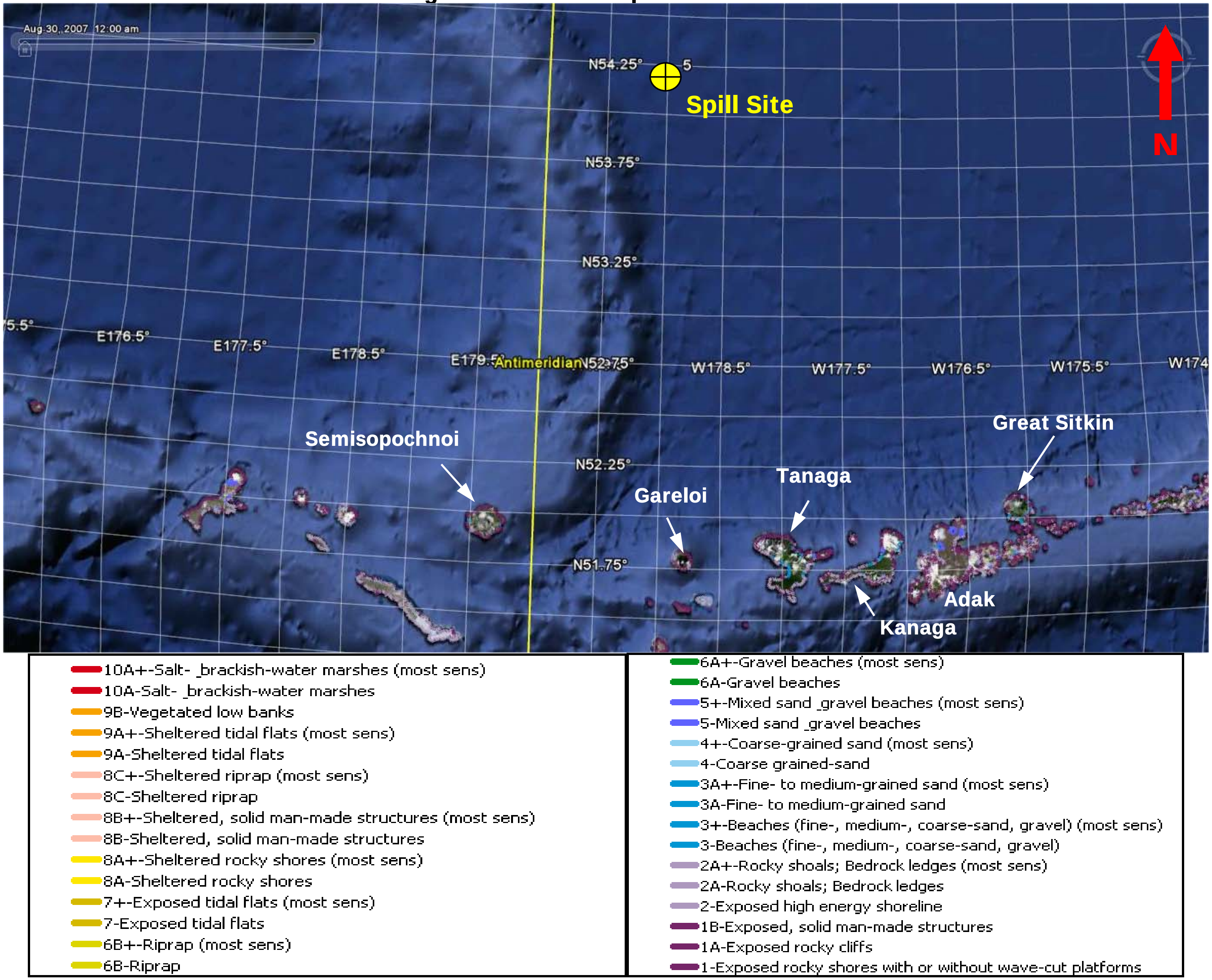


Figure 4-12 Oil spill grid for Scenario 6

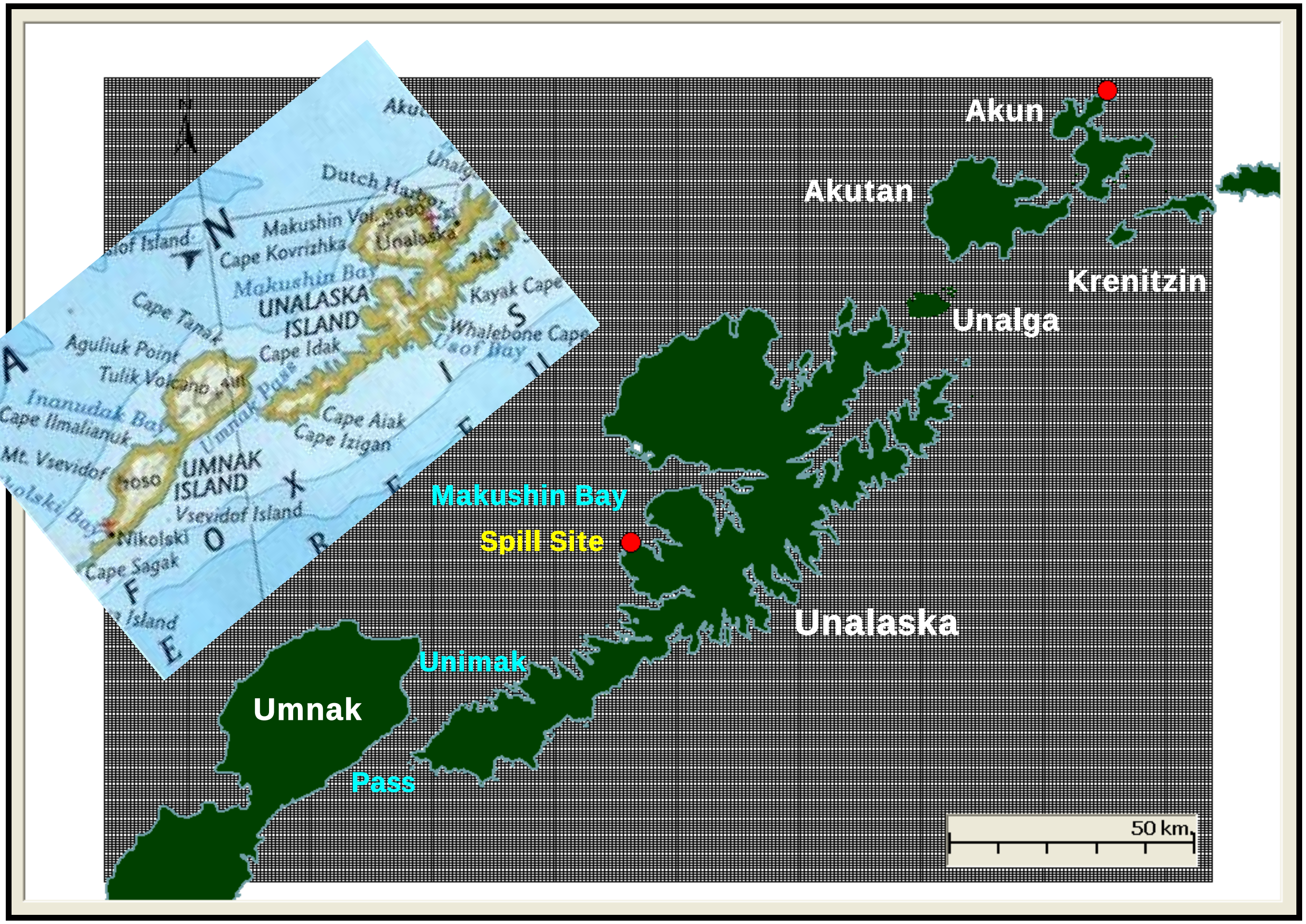


Figure 4-13 ESI map for Scenario 6

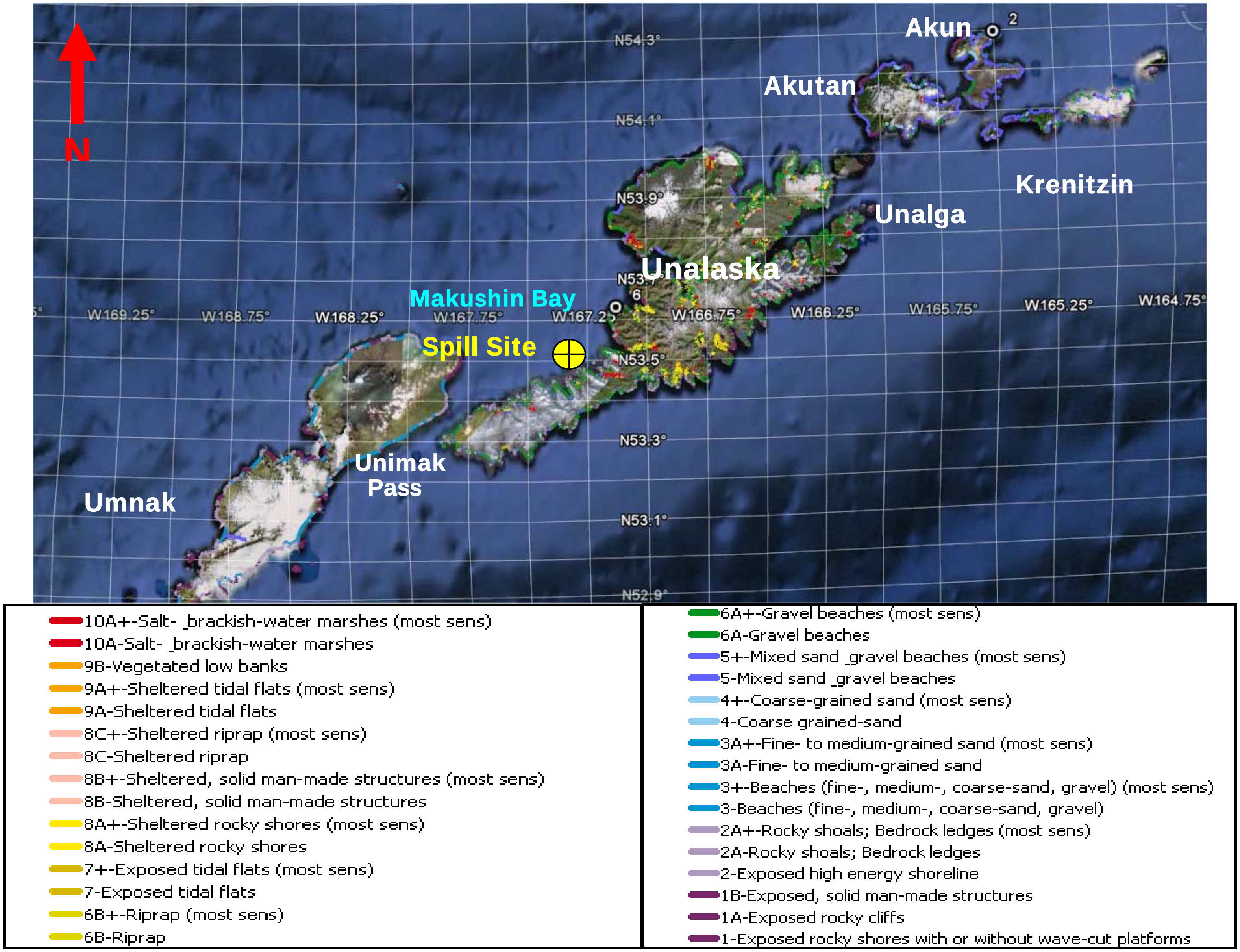


Figure 4-14 Typical winter currents for the Aleutian Islands

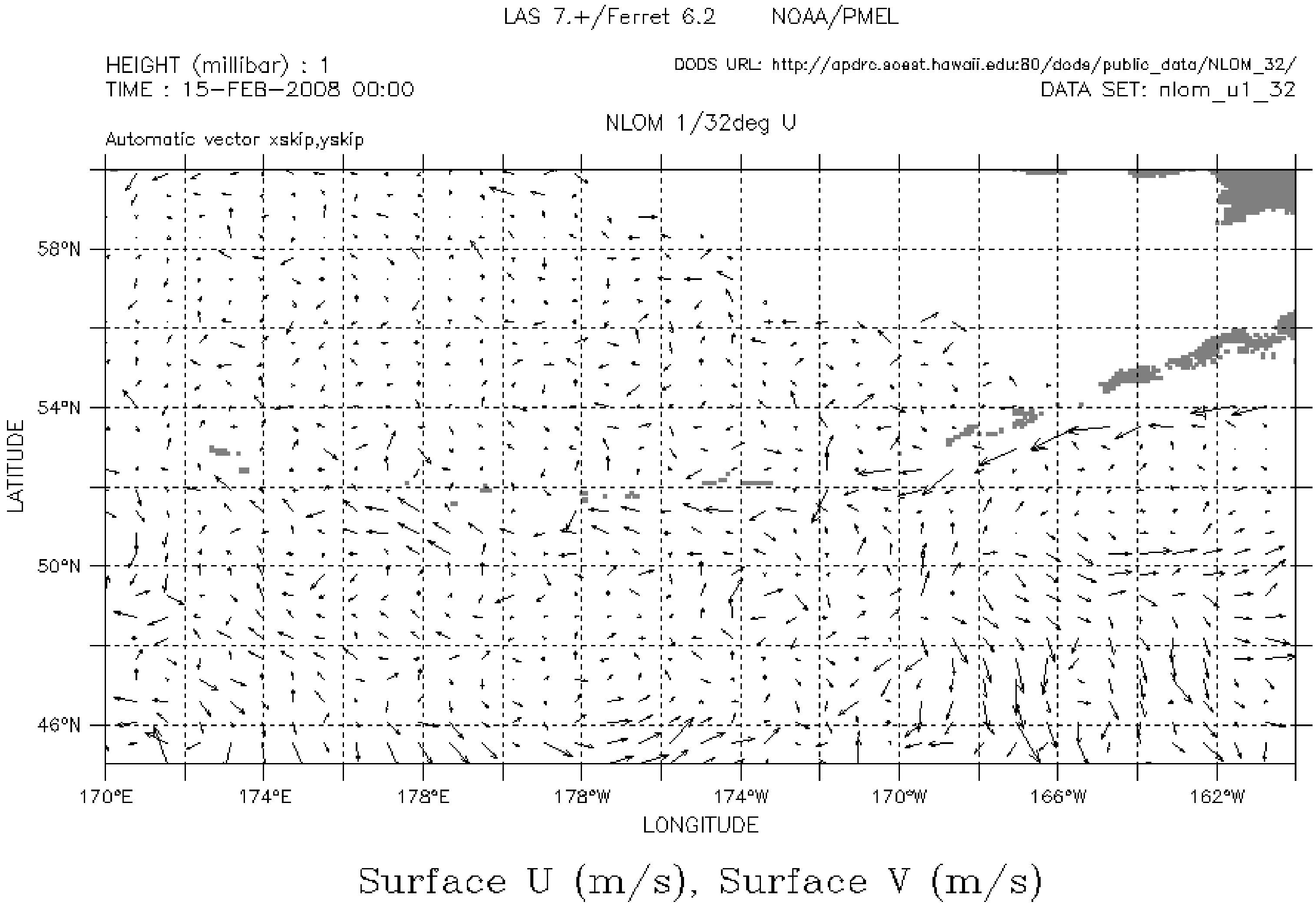


Figure 4-15 Typical spring currents for the Aleutian Islands

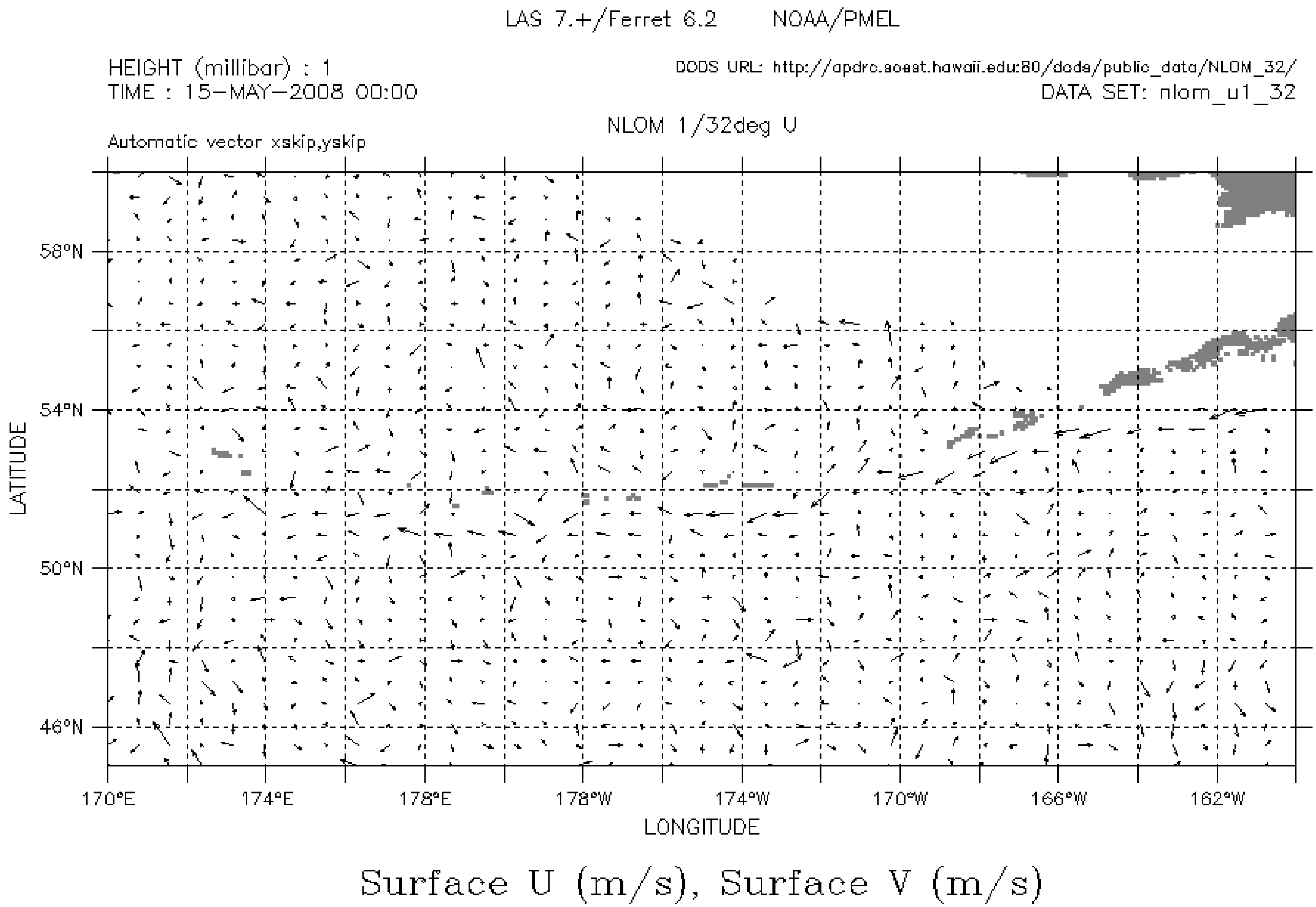


Figure 4-16 Typical summer currents for the Aleutian Islands

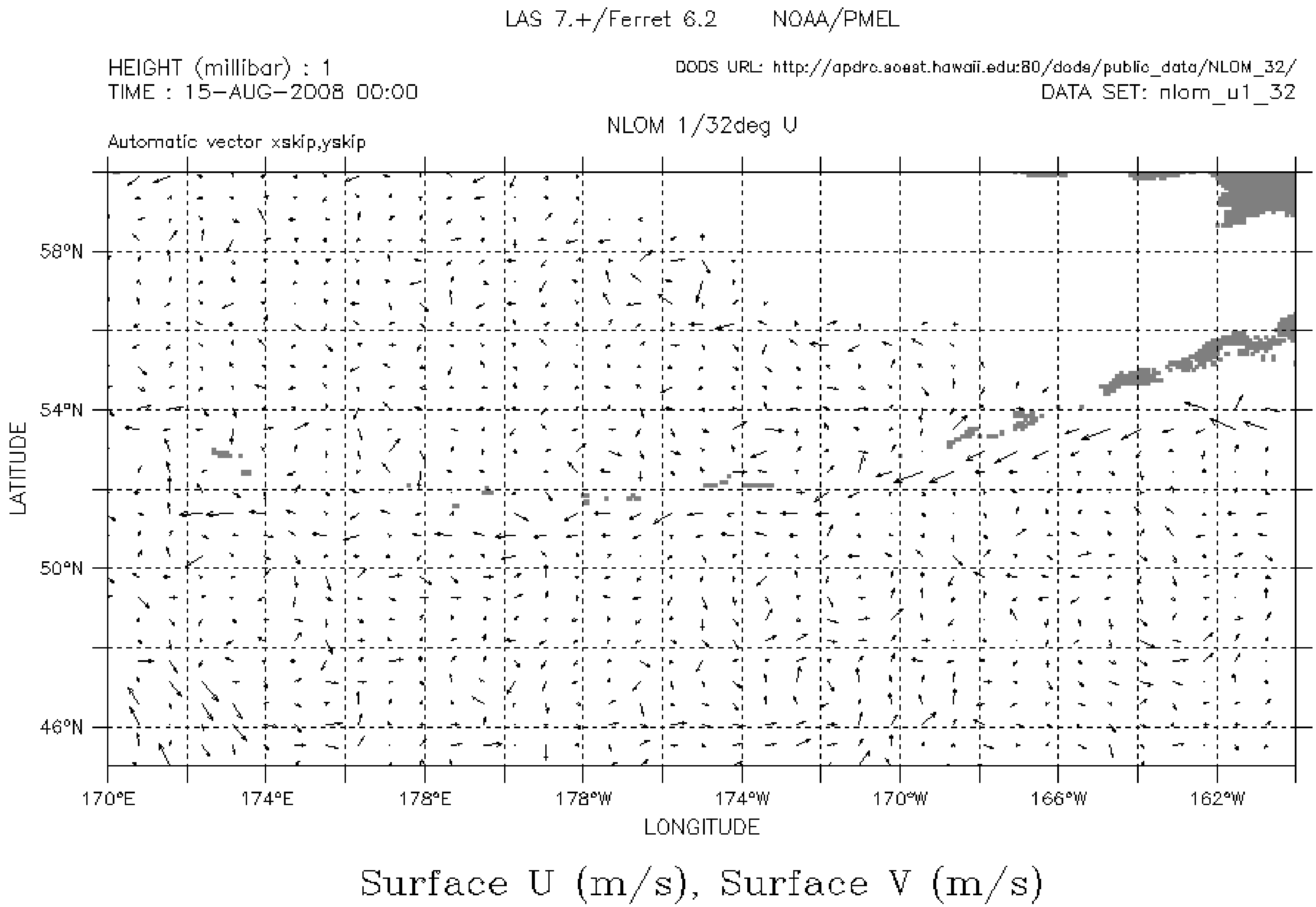


Figure 4-17 Typical fall currents for the Aleutian Islands

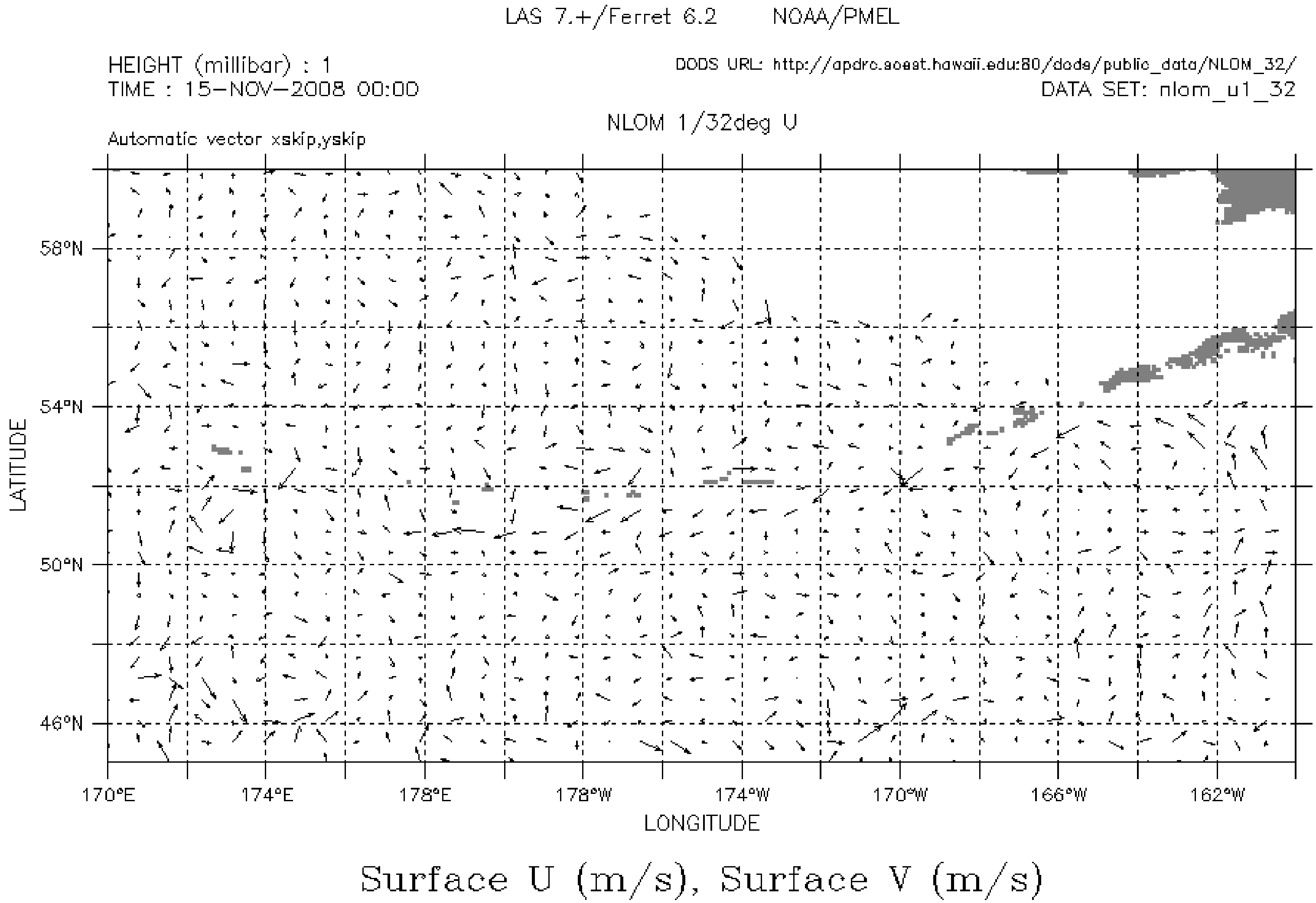


Figure 4-18 Currents on Dec 8, 2004 few hours after the incident of *Selendang Ayu* spill

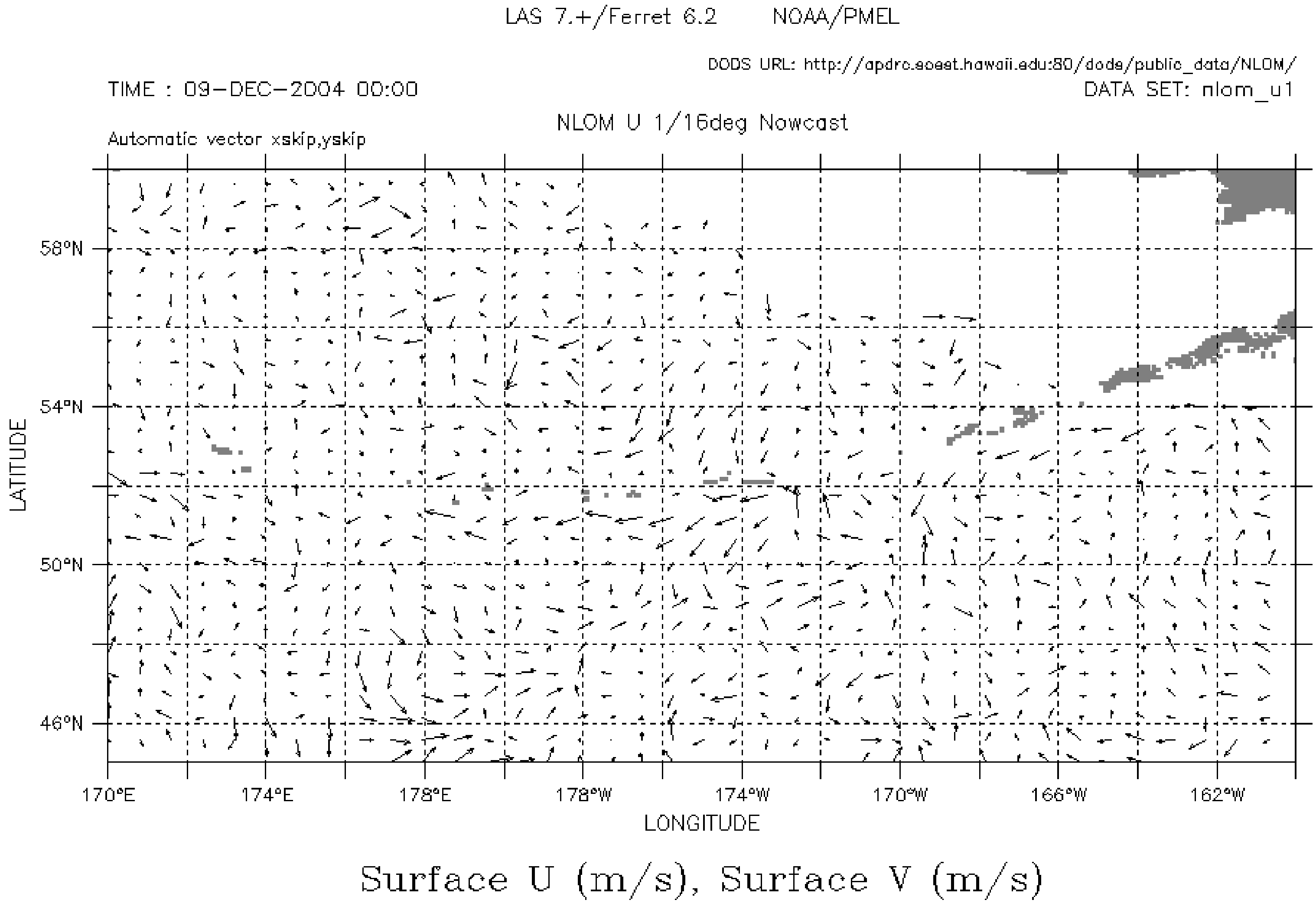


Figure 4-19 Currents on Jan 7, 2005 approximately one month after the incident of *Selendang Ayu* spill

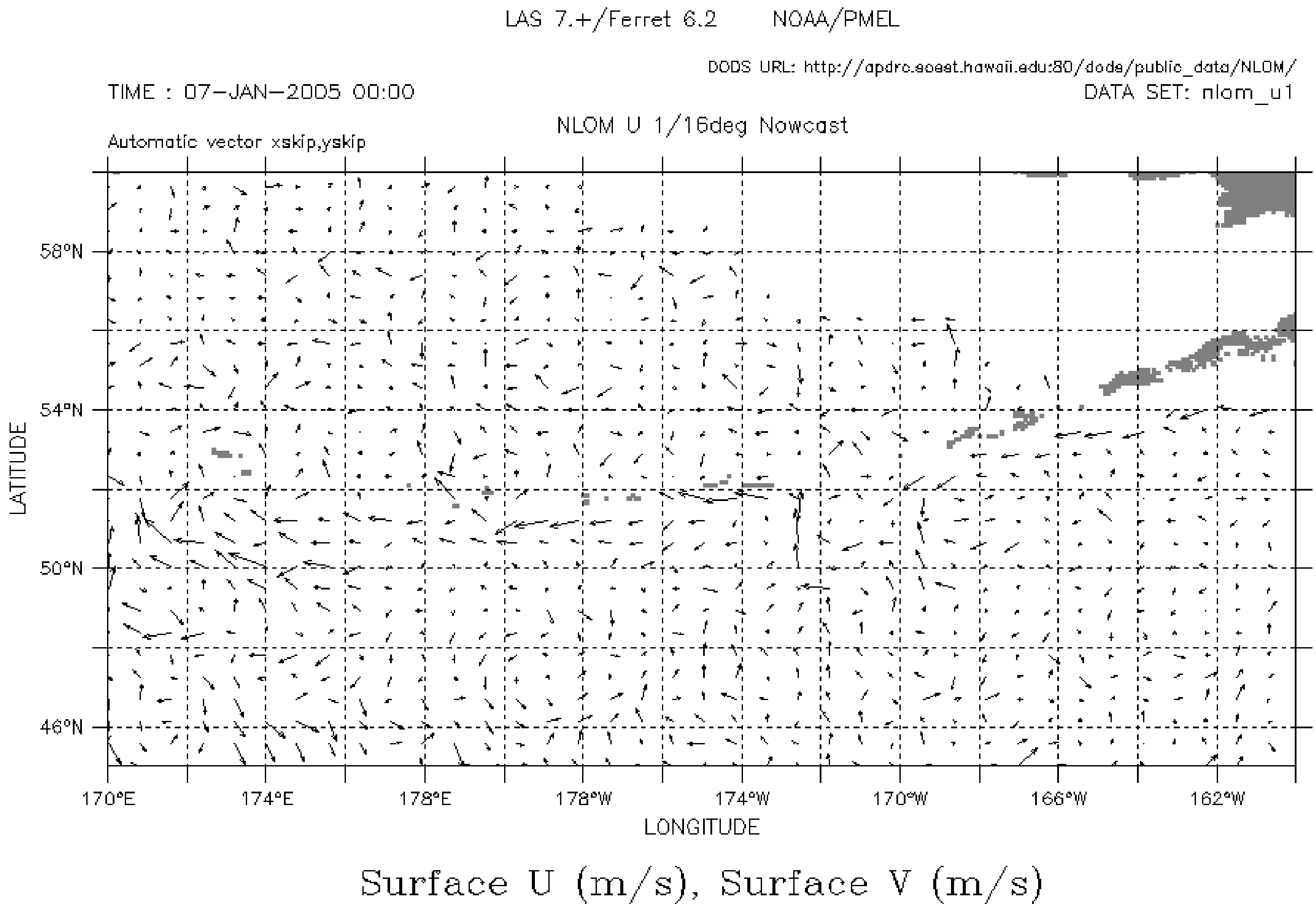


Figure 4-20 Current rose diagram for Scenario 1 (January – March)

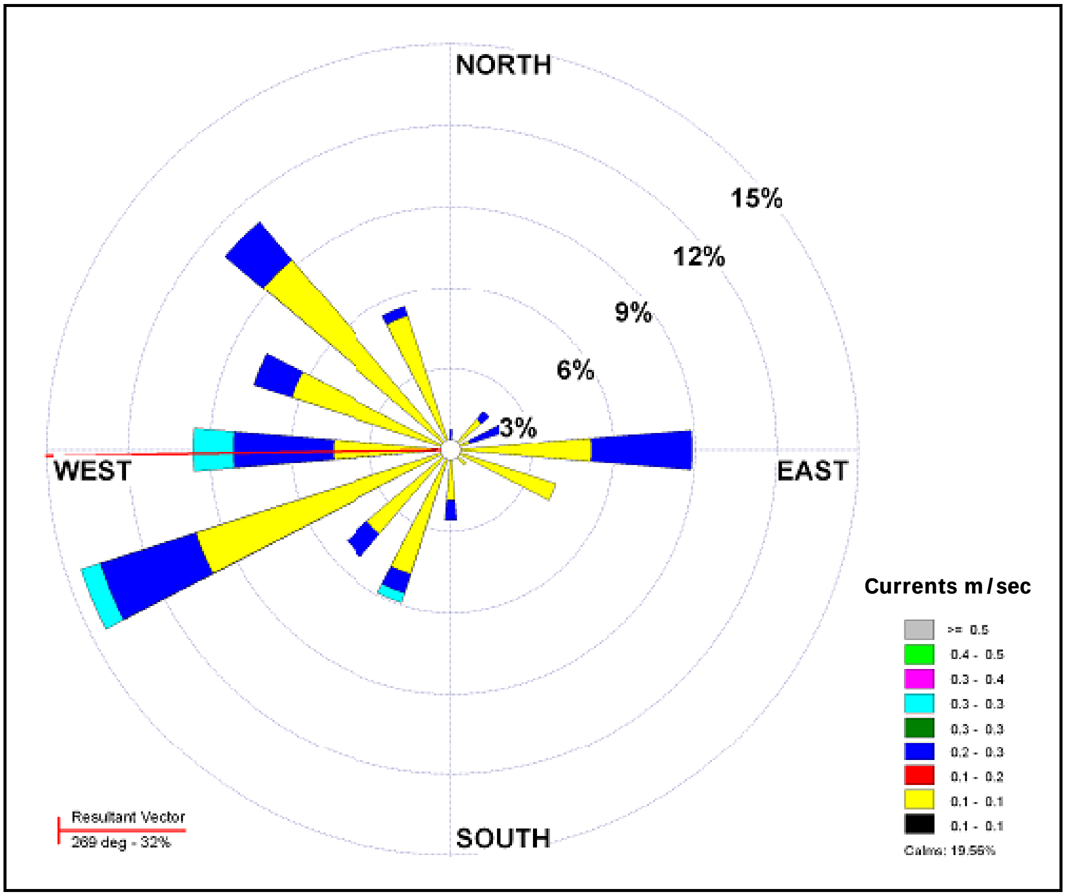


Figure 4-21 Current rose diagram for Scenario 2 (June – September)

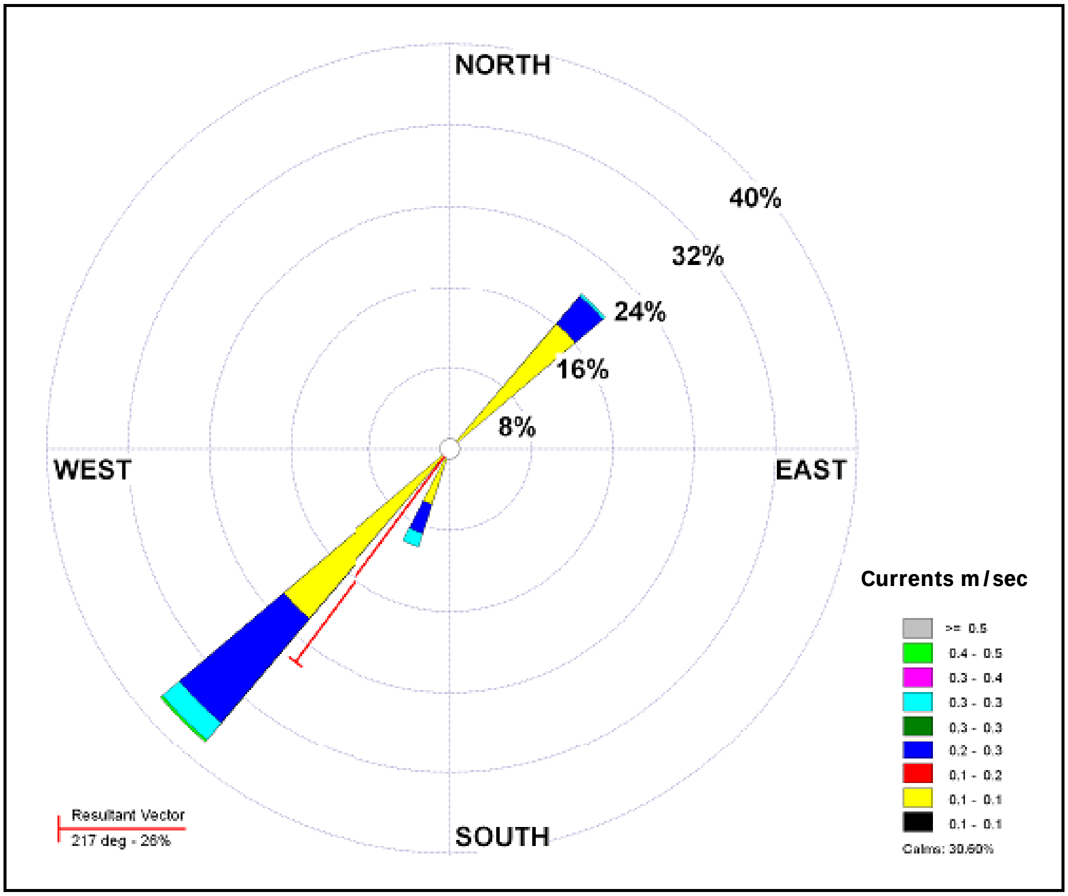


Figure 4-22 Current rose diagram for Scenario 3 (June – September)

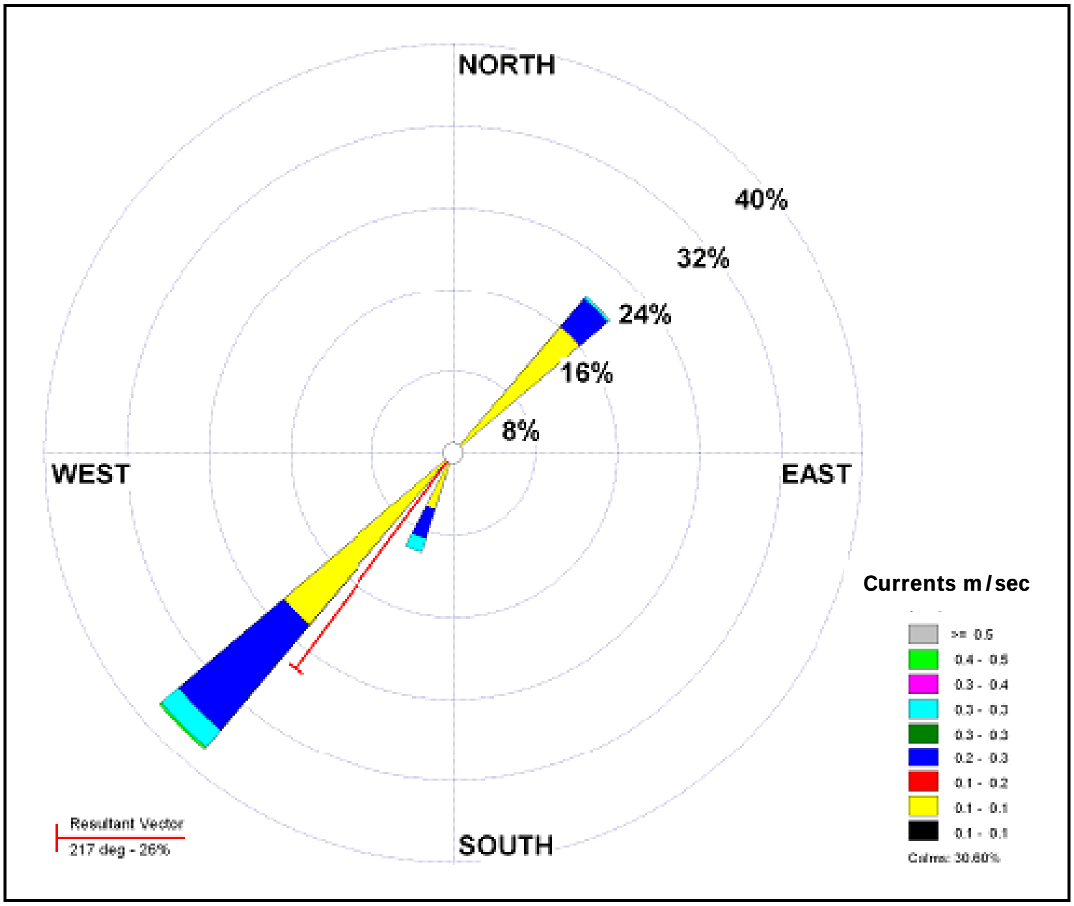


Figure 4-23 Current rose diagram for Scenario 4 (April – June)

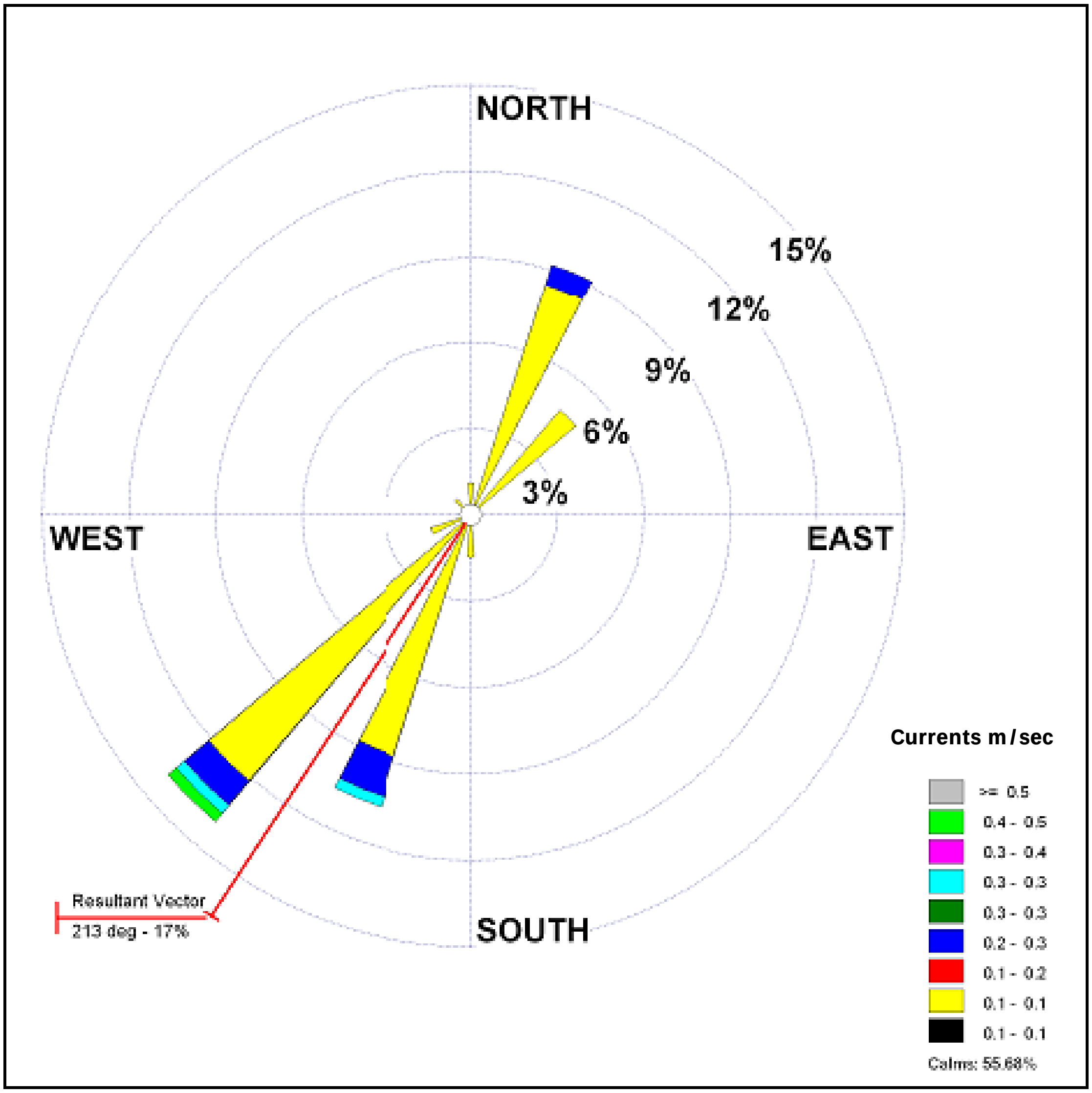


Figure 4-24 Current rose diagram for Scenario 5 (April – June)

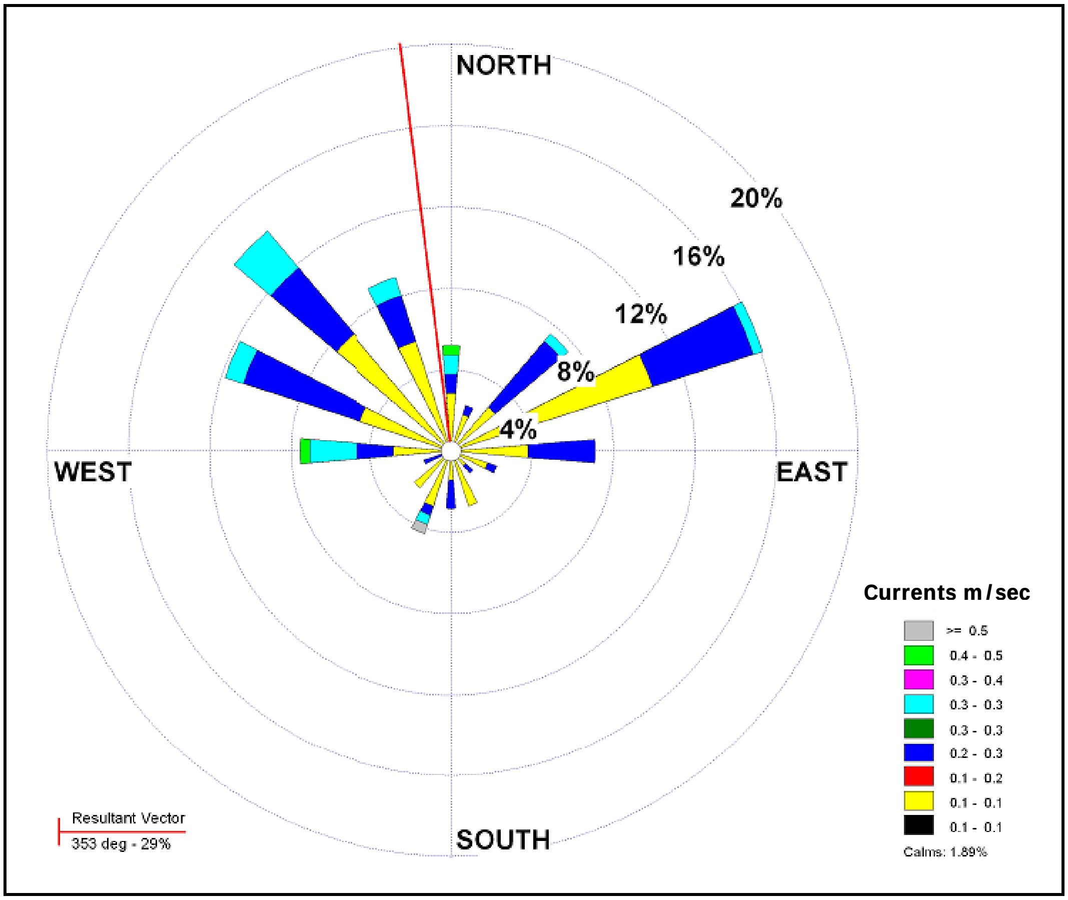


Figure 4-25 Current rose diagram for Scenario 6 (December 2004)

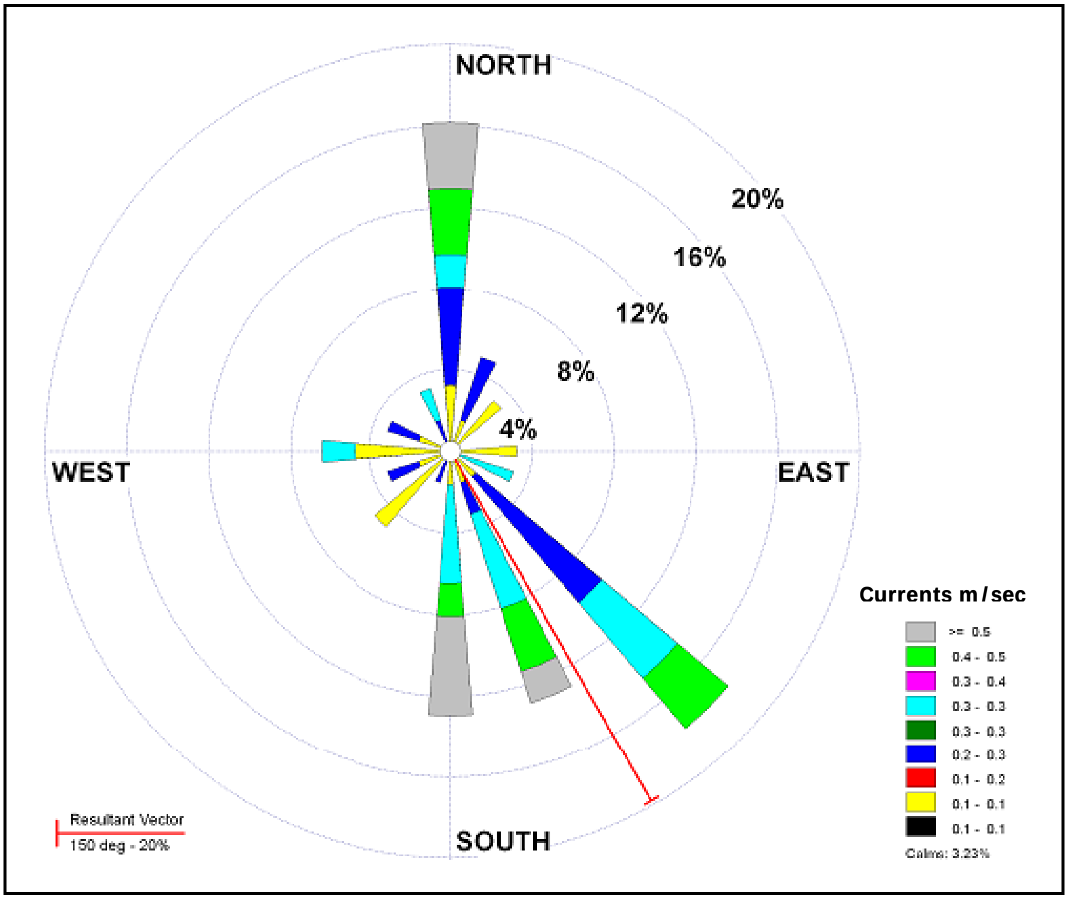


Figure 4-26 Current rose diagram for Scenario 6 (January 2005)

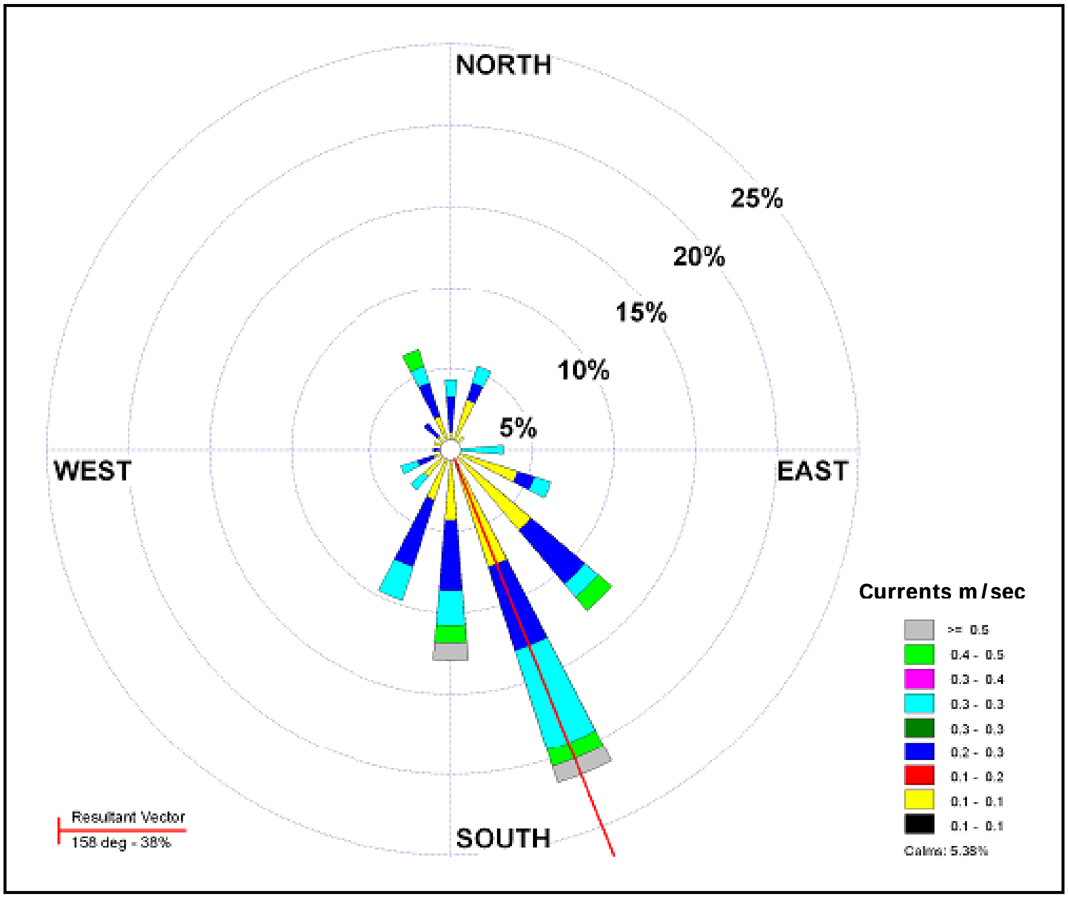


Figure 4-27 Seasonal temperature variation in the Aleutian Islands for the year 2008

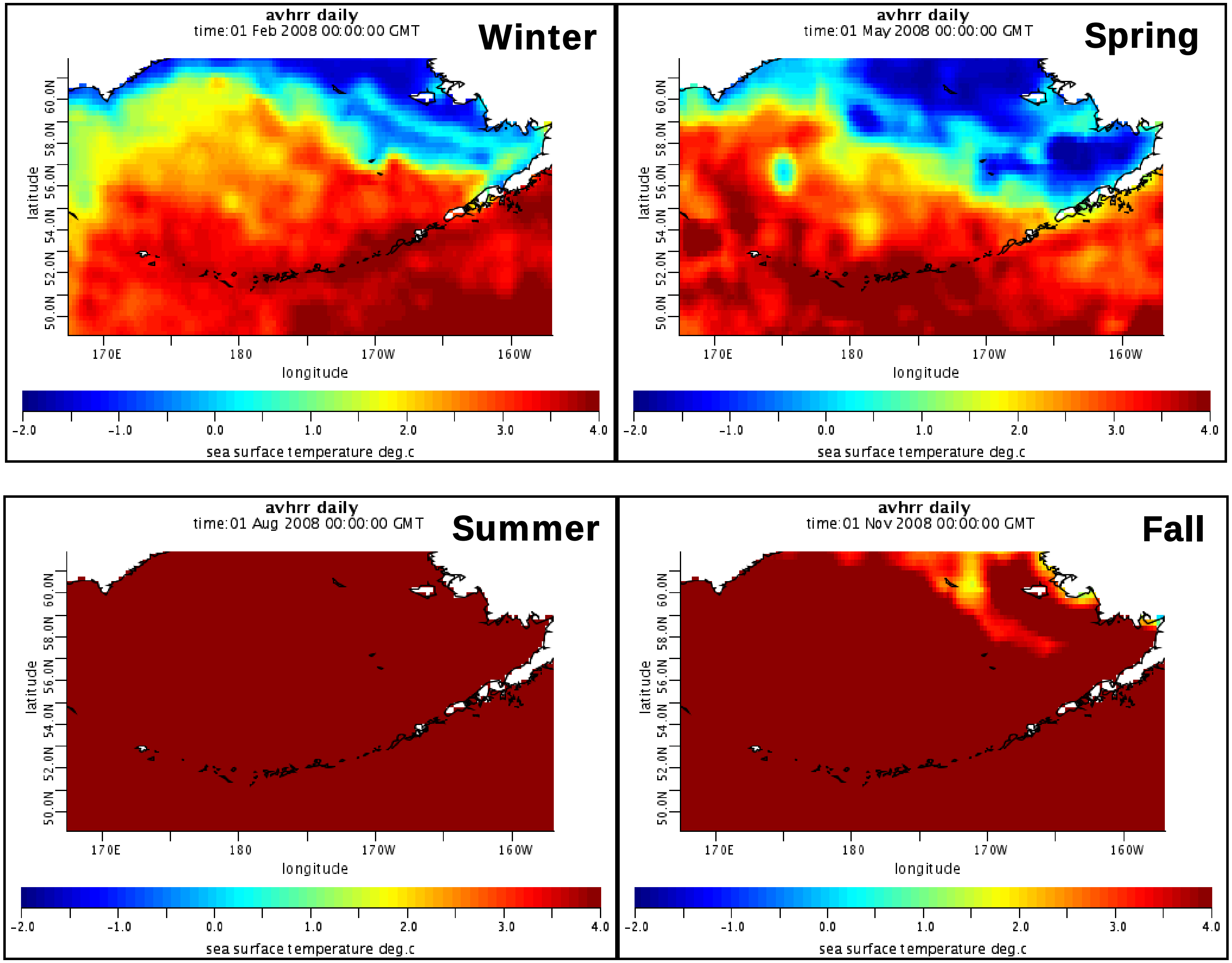


Figure 4-28 Seasonal surface salinity variation in the Aleutian Islands for the year 2007

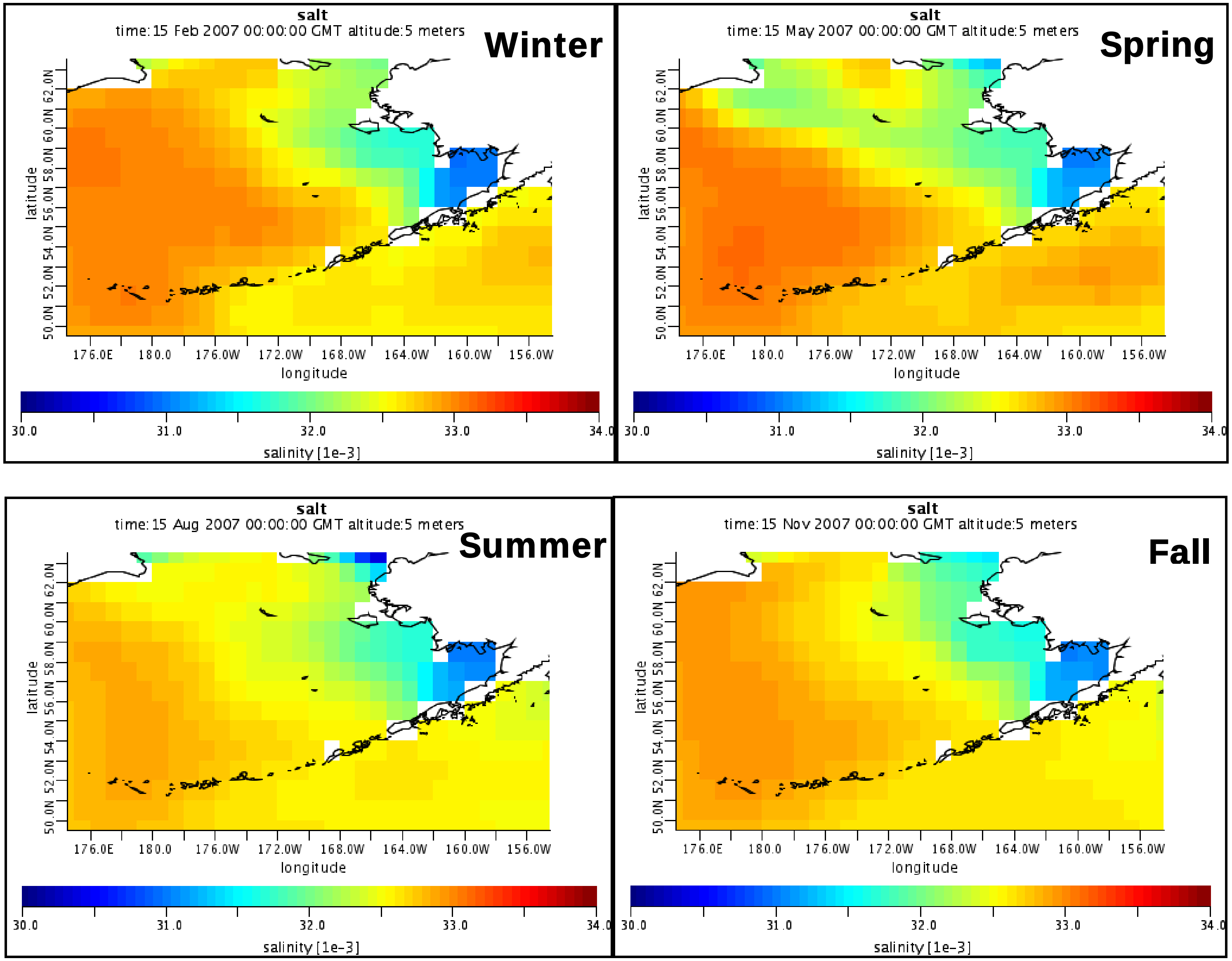


Figure 4-29 Typical winter wind pattern in the Aleutian Islands (Scenario 1)

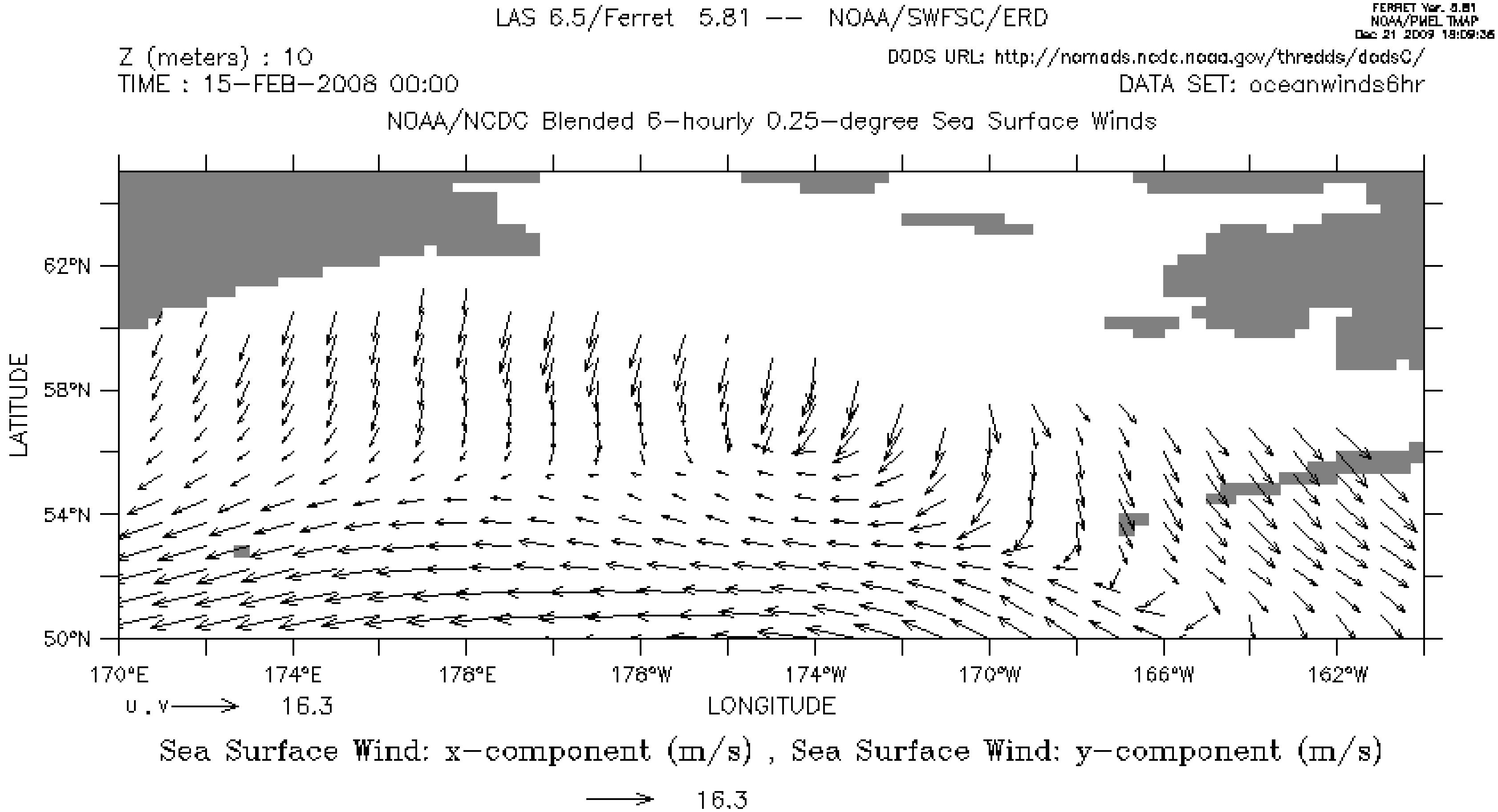


Figure 4-30 Typical spring wind pattern in the Aleutian Islands (Scenario 4)

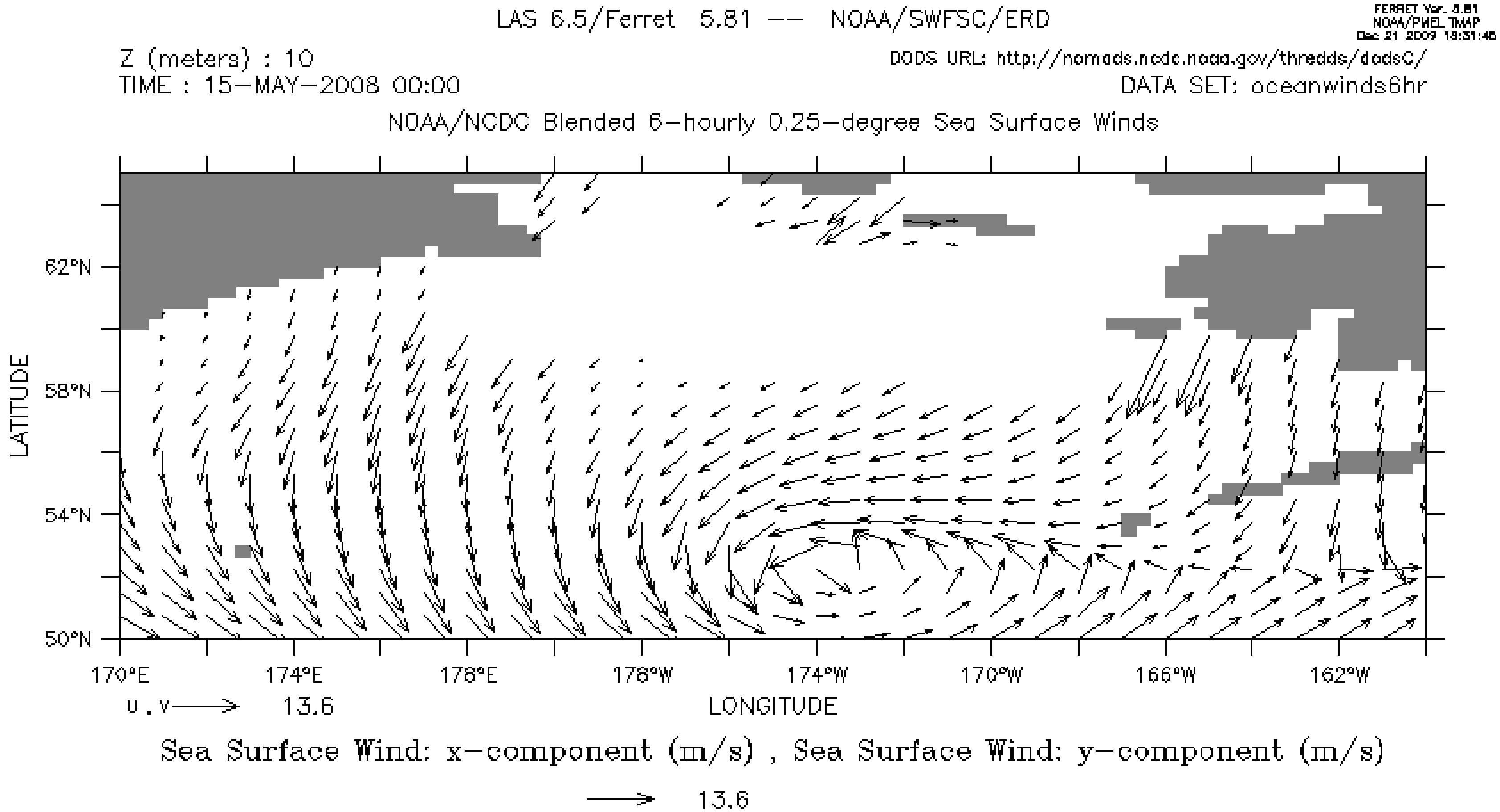


Figure 4-31 Typical summer wind pattern in the Aleutian Islands (Scenario 2 and 3)

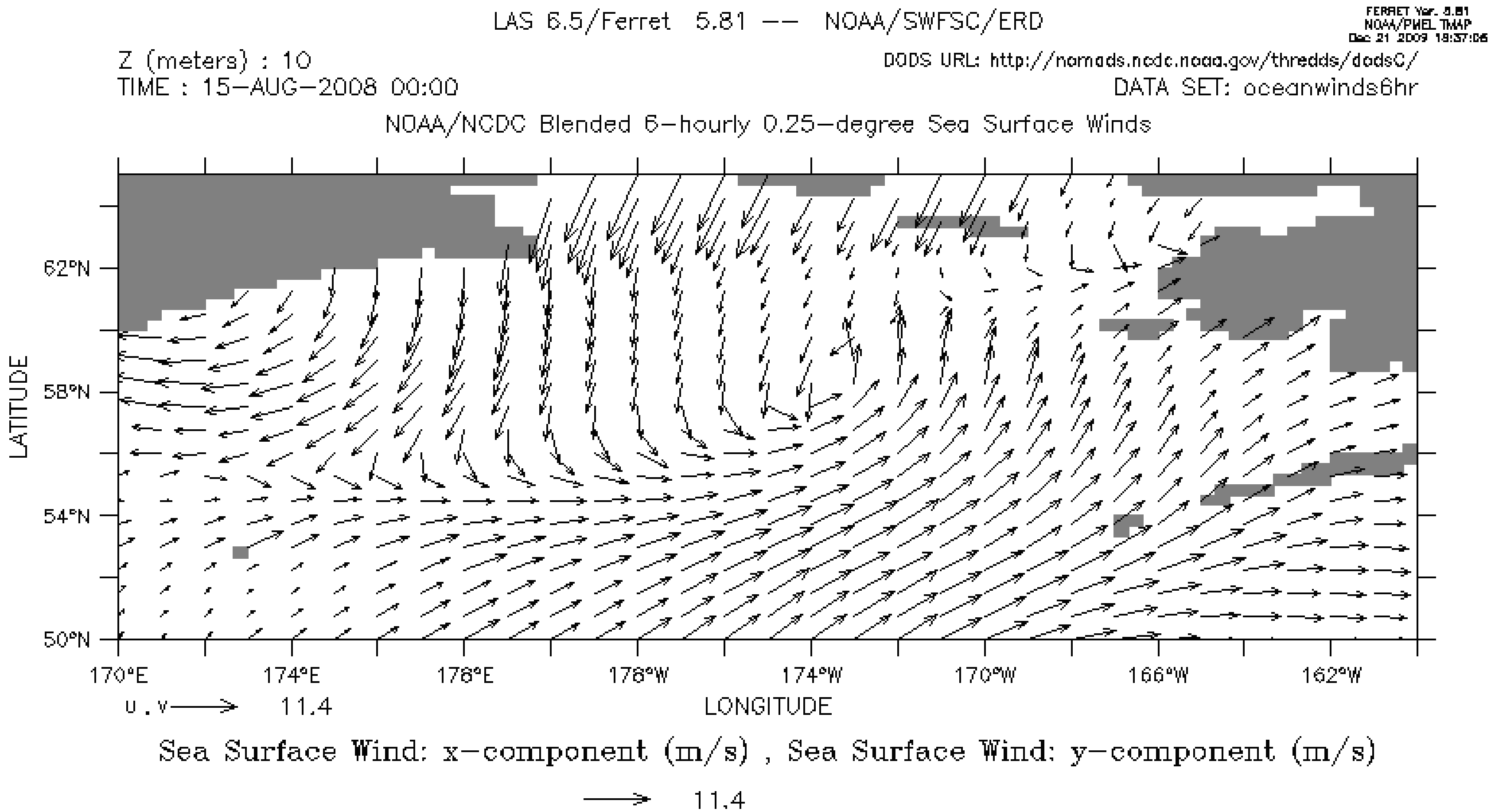


Figure 4-32 Typical fall wind pattern in the Aleutian Islands (Scenario 5)

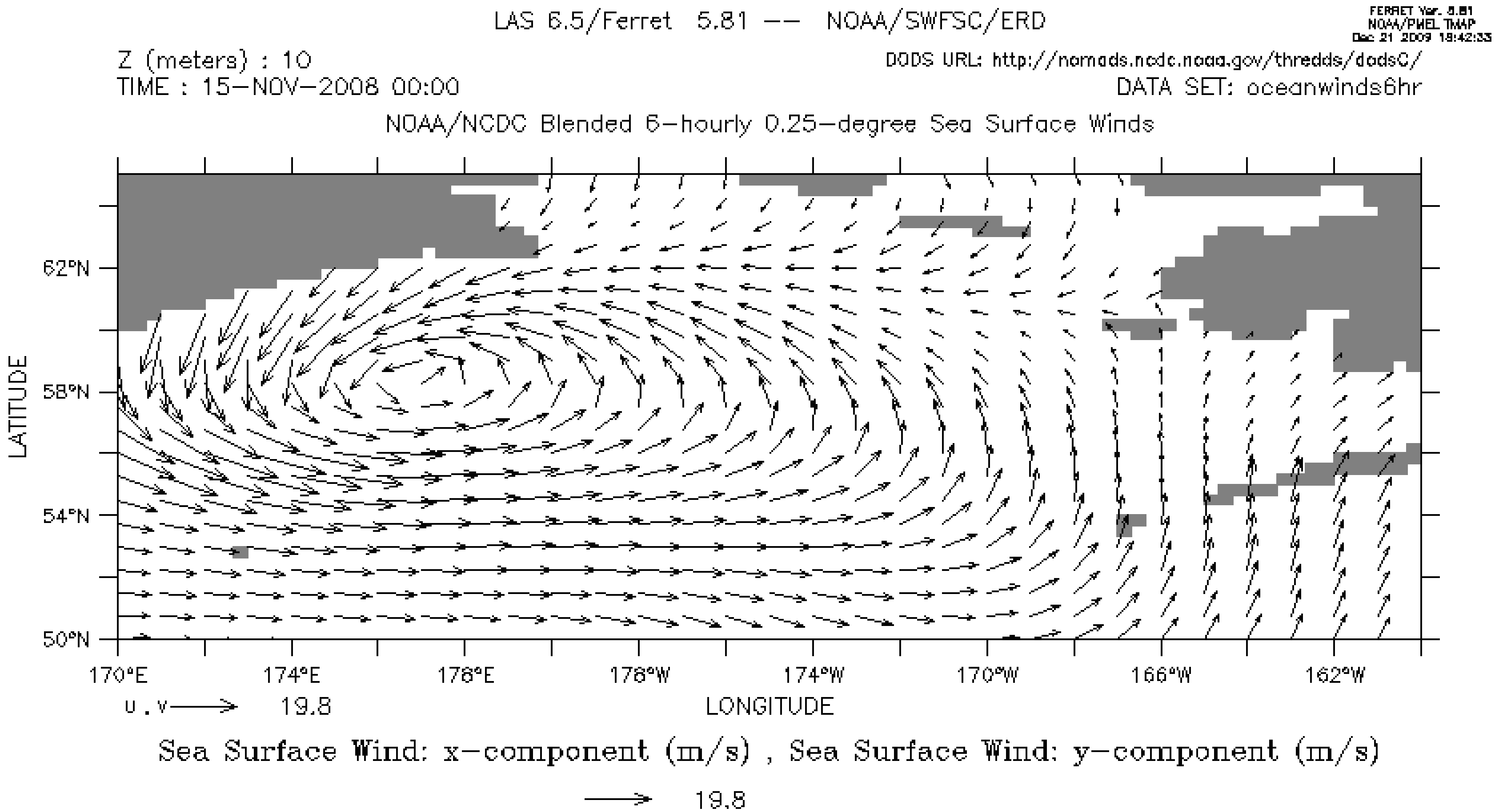


Figure 4-33 Wind patterns on the start date, 1 and 2 weeks after the spill occurrence for Scenario 6

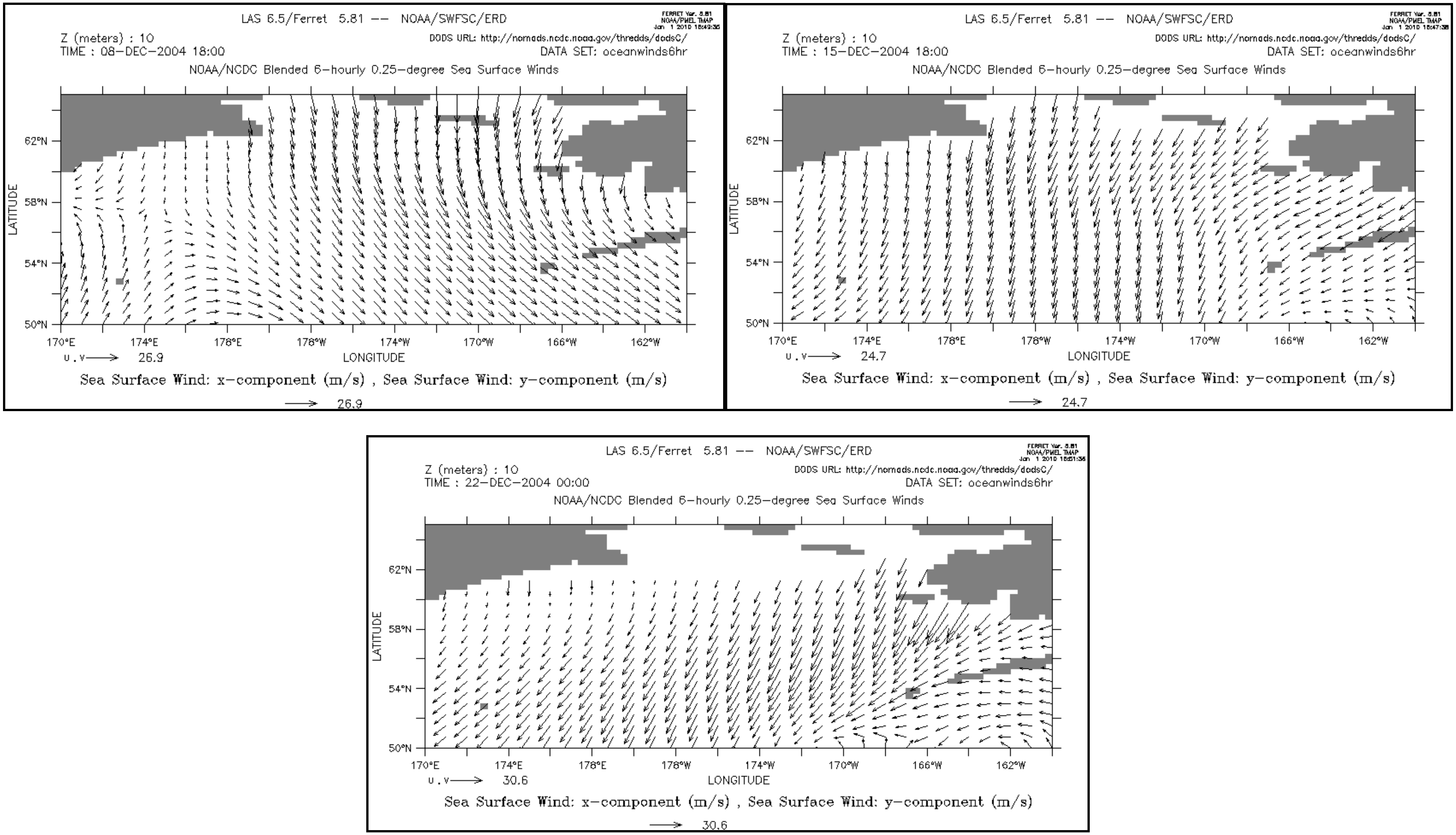
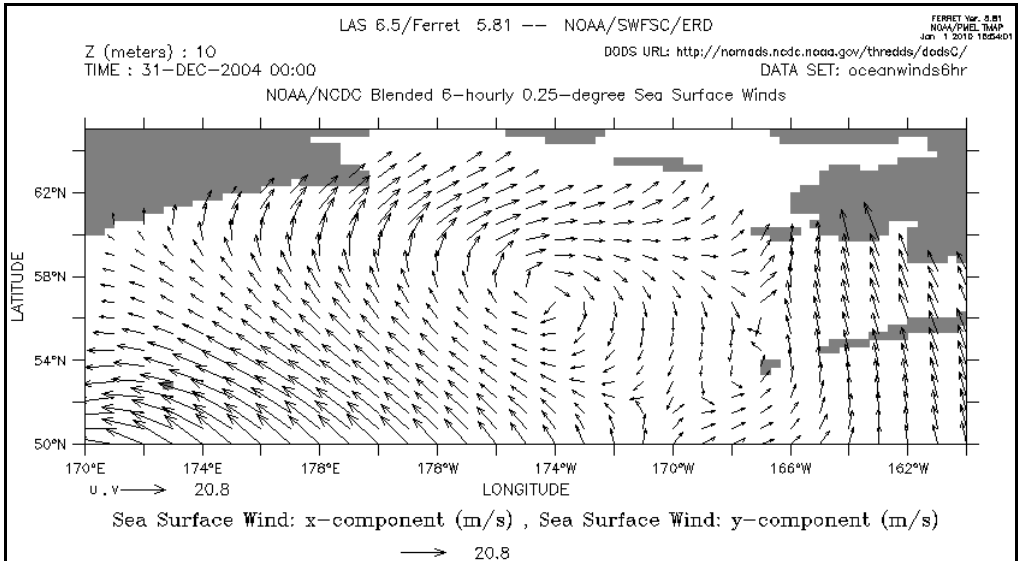


Figure 4-34 Wind patterns for 3 and 4 weeks after the occurrence of spill for Scenario 6



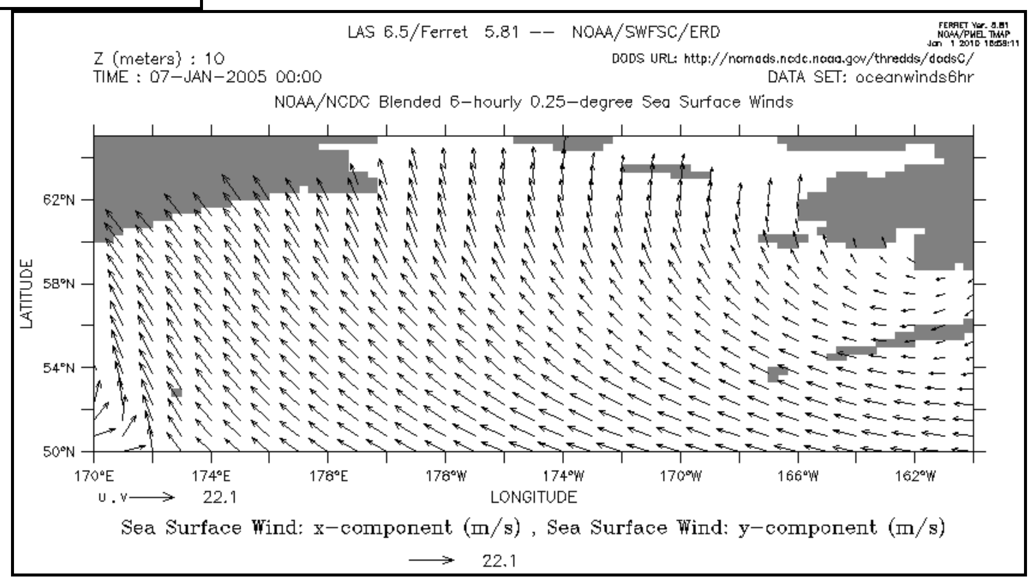


Figure 4-35 Wind rose diagram for winter season (January – March) used in Scenario 1

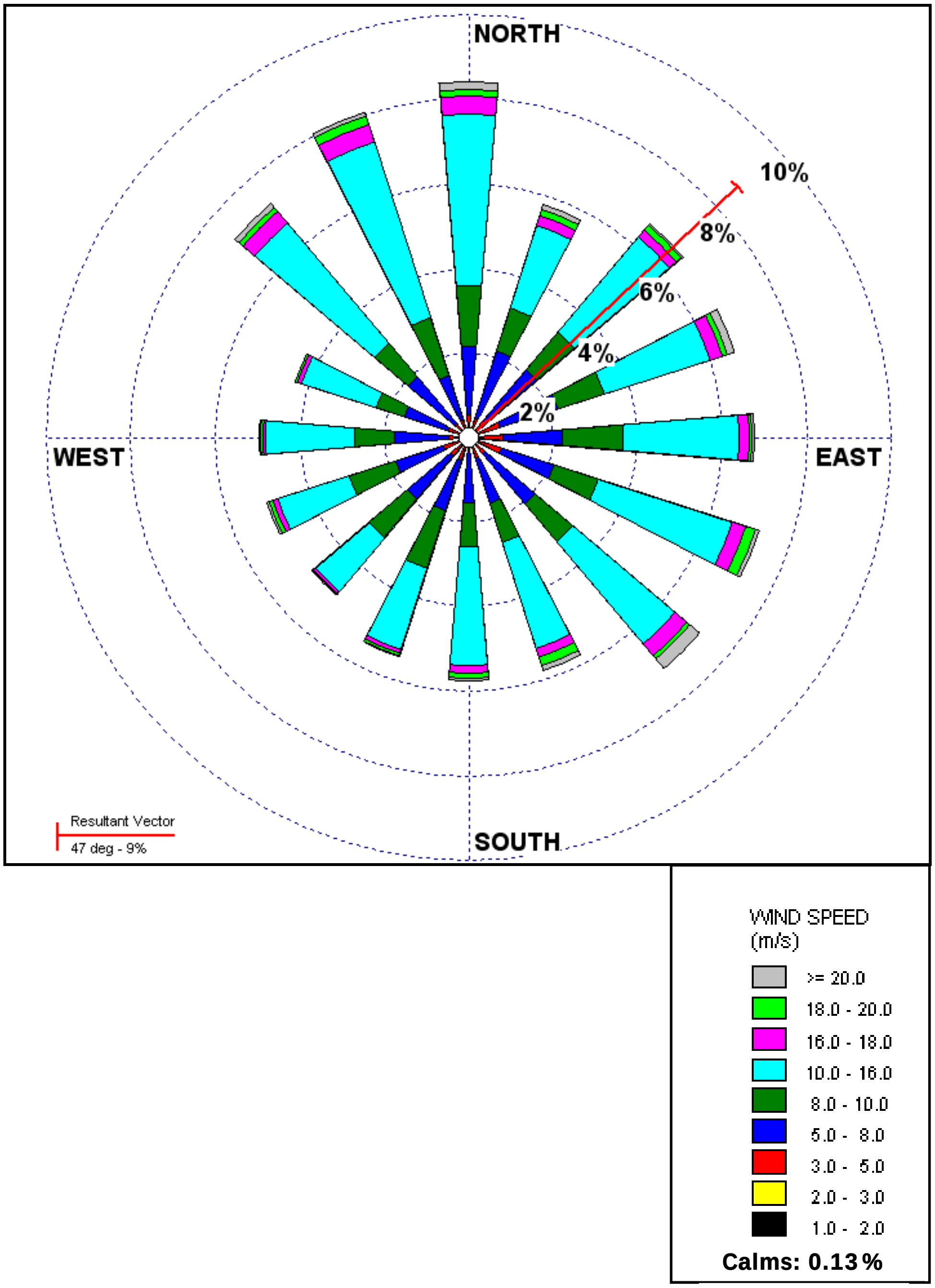


Figure 4-36 Wind rose diagram for summer season (June – September) used in Scenario 2

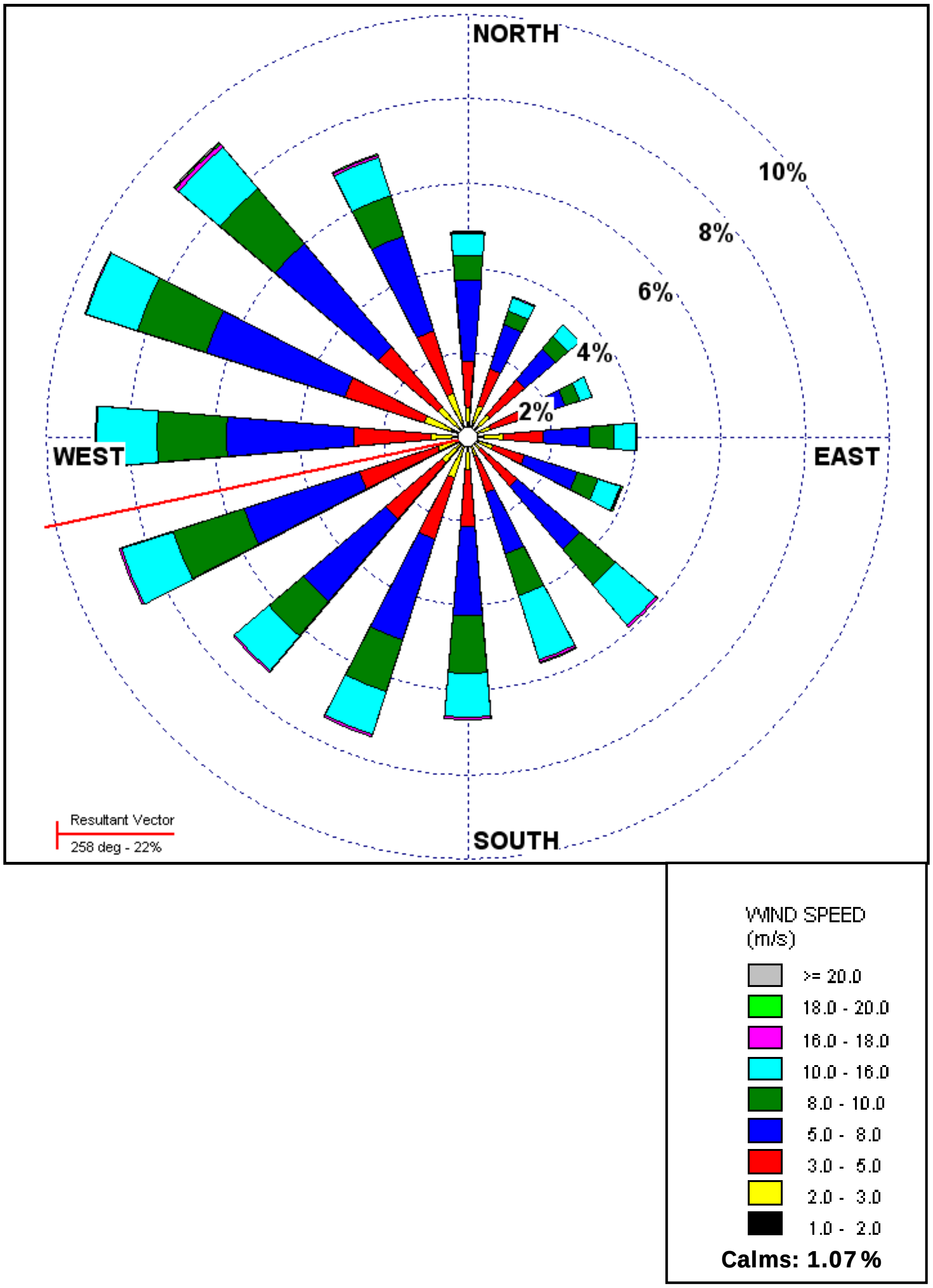


Figure 4-37 Wind rose diagram for summer season (June – September) used in Scenario 3

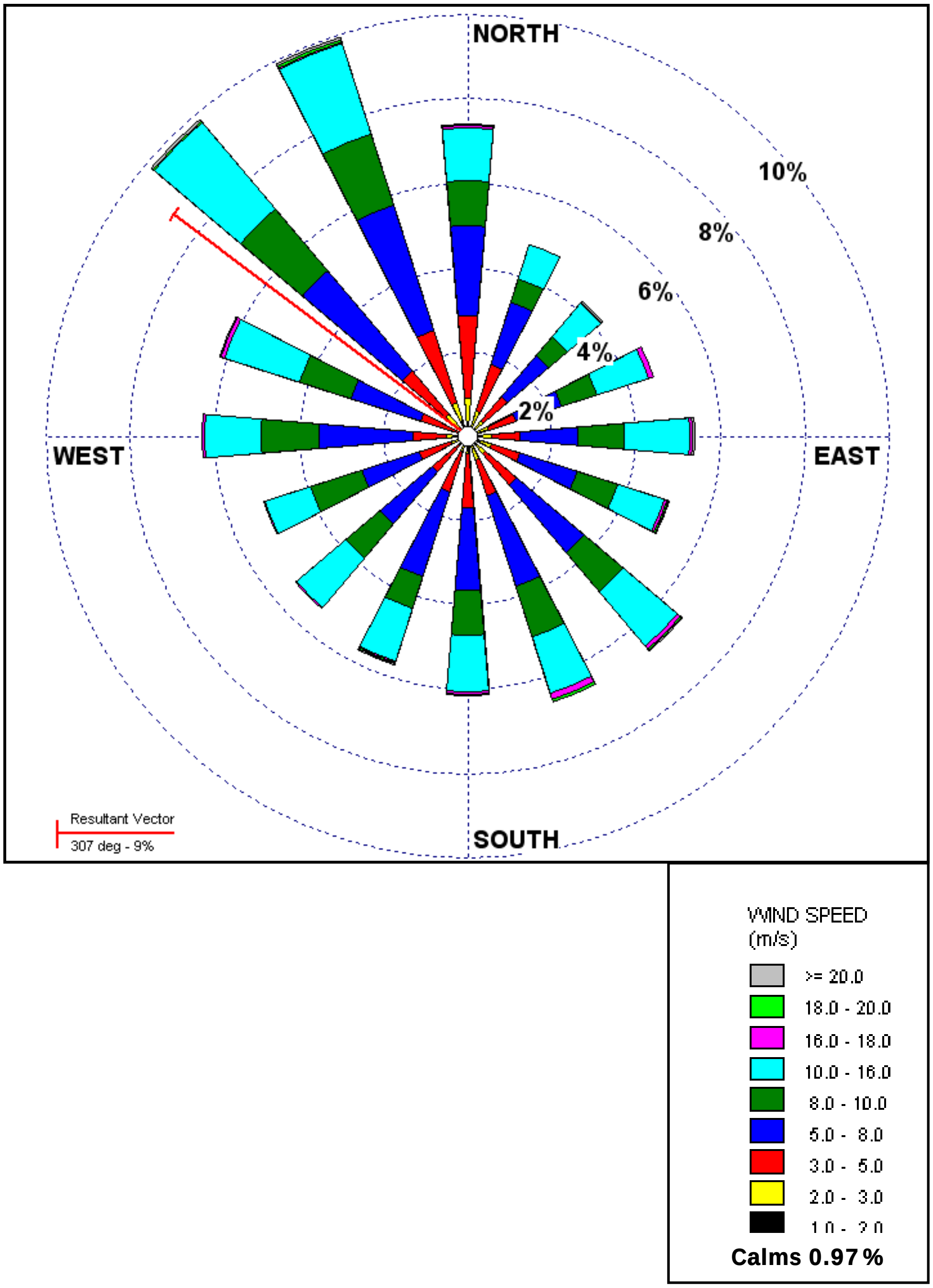


Figure 4-38 Wind rose diagram for spring season (April - June) used in Scenario 4

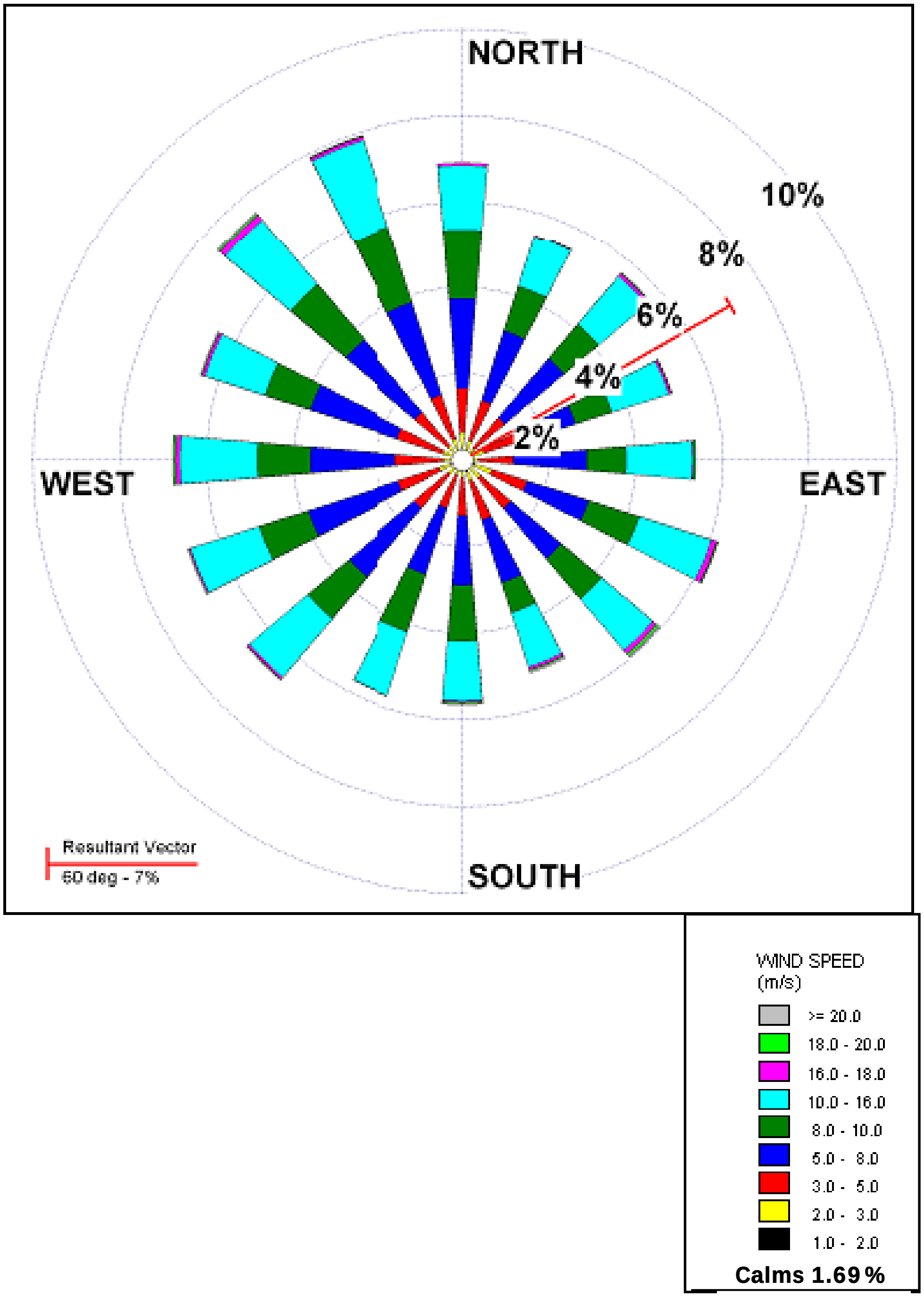


Figure 4-39 Wind rose diagram for fall season (October – December) used in Scenario 5

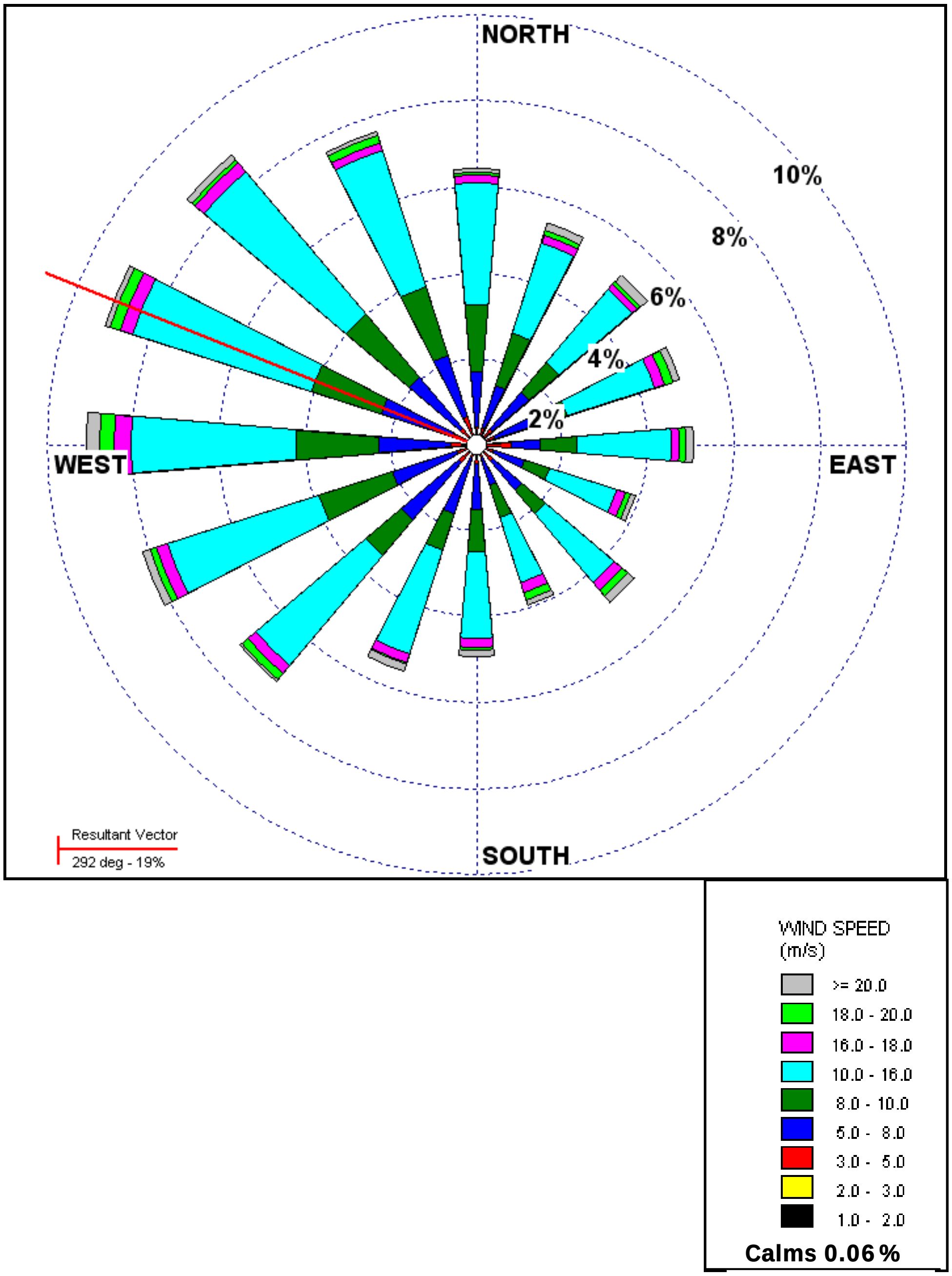
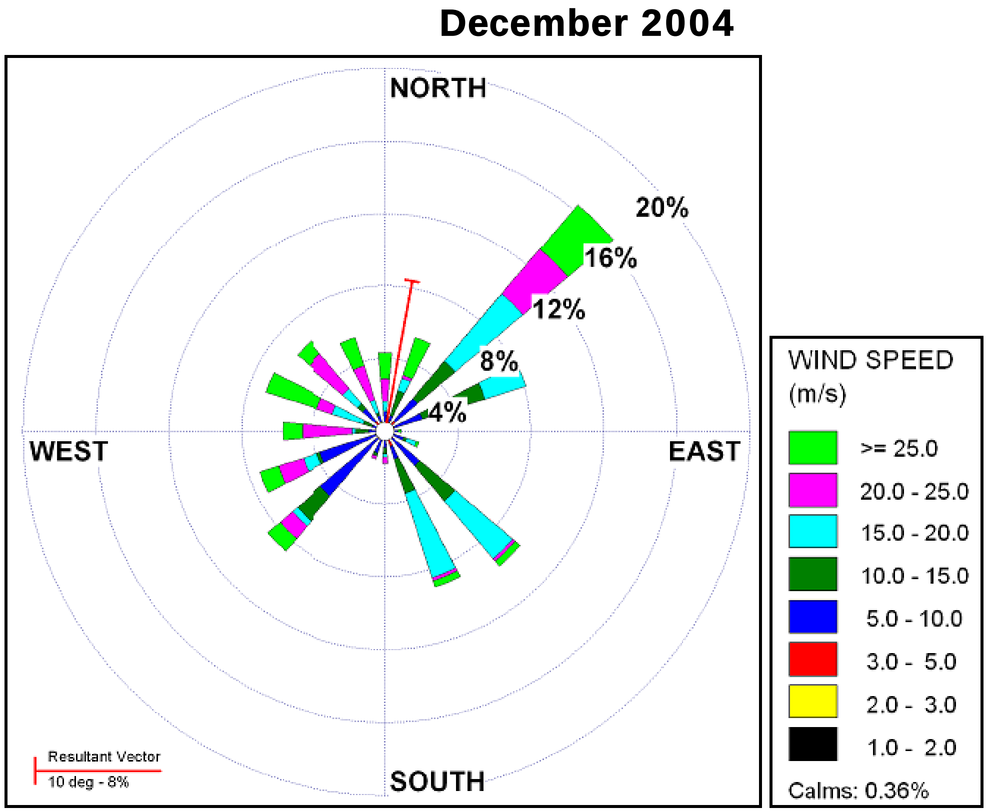


Figure 4-40 Wind rose diagram for December 2004 and for the first week of January 2005 for Scenario 6



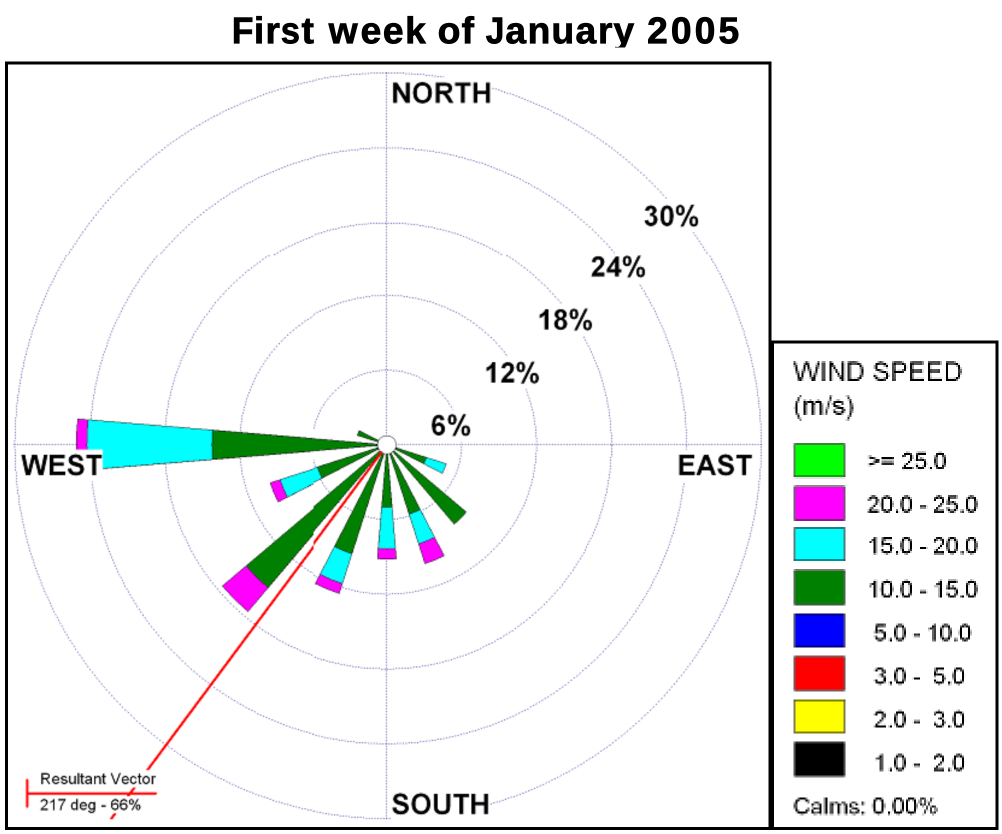


Figure 4-41 Schematic diagram for Markov wind regression analysis. Also shown is a sample Markov matrix

WIND SPEED

WIND DIRECTION

4	1	0	0	0	0
5	2	1	0	0	0
0	4	16	12	4	0
0	0	13	25	13	0
0	0	1	0	0	0

REPRESENTATIONS OF PHYSICAL DATA

NEXT WIND IS OUT OF ... AT SPEED ... IN PERCENT.

LAST FROM DIR	SPD	CALM	N 510152025	NE 510152025	E 510152025	SE 510152025	S 510152025	SW 510152025	W 510152025	NW 510152025
CALM	0	27	2 1 0 0 0	3 0 0 0 0	3* 3 0 0 0	4 0 0 0 0	1 0 0 0 0	1 0 0 0 0	6 4 1 0 0	7 3 1 0 0
N	5	28	1013 1 0 0	6 1 0 0 0	11 0 0 0 0	2 0 0 0 0	0 0 0 0 0	1 0 0 0 0	0 2 0 0 0	1211 4 0 0
N	10	10	1522 6 0 0	9 1 0 0 0	6 0 0 0 0	0 0 0 0 0	0 0 0 0 0	1 1 0 0 0	0 0 3 0 0	412 7 1 0
N	15	6	011 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	6 0 0 0 0	0 0 6 0 0	111144 6 0
N	20	50	050 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
N	25	0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
NE	5	26	6 1 0 0 0	9 1 0 0 0	16 4 0 0 0	8 1 0 0 0	0 0 0 0 0	1 0 0 0 0	8 4 1 0 0	3 5 6 0 0
NE	10	22	022 0 0 0	0 0 0 0 0	011 0 0 0	011 0 0 0	011 0 0 0	0 0 0 0 0	11 0 0 0 0	11 0 0 0 0
NE	15	0	0** 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
NE	20	0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
NE	25	0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
E	5	11	1 0 0 0 0	1 0 0 0 0	5011 0 0 0	4 1 0 0 0	0 1 0 0 0	1 0 0 0 0	8 5 0 0 0	2 2 0 0 0
E	10	7	0 0 0 0 0	2 0 0 0 0	4027 4 0 0	5 2 1 0 0	1 0 0 0 0	0 0 0 0 0	4 2 0 0 0	2 1 0 0 0
E	15	0	0 0 0 0 0	0 4 0 0 0	42824 0 0	0 41612 4	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	4 0 0 0 0
E	20	0	0 0 0 0 0	0 0 0 0 0	01325 013	0 0132513	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
E	25	0	0 0 0 0 0	0 0 0 0 0	0 0333333	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
SE	5	13	3 0 0 0 0	2 0 0 0 0	46 6 1 0 0	10 4 1 0 0	1 2 0 0 0	1 0 0 0 0	4 1 0 0 0	4 2 1 0 0
SE	10	2	0 0 0 0 0	0 0 0 0 0	9 7 2 0 0	112018 7 2	4 2 4 0 0	2 2 0 2 0	2 0 2 0 0	0 0 0 0 0
SE	15	0	0 0 0 0 0	3 0 0 0 0	10 3 8 8 0	0102618 3	0 3 8 0 0	0 3 0 0 0	0 0 0 0 0	0 0 0 0 0
SE	20	0	0 0 0 0 0	0 0 0 0 0	0 0 8 8 4	0 81923 8	0 0 412 0	0 0 0 4 0	0 0 0 4 0	0 0 0 0 0
SE	25	0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	014292914	014 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
S	5	26	3 0 0 0 0	3 0 0 0 0	24 0 0 0 0	3 0 3 0 0	15 6 0 3 0	9 6 0 0 0	0 0 0 0 0	0 0 0 0 0
S	10	9	0 0 0 0 0	0 0 0 0 0	3 0 0 0 0	9 3 3 0 0	121212 3 0	9 9 3 0 0	6 9 0 0 0	0 0 0 0 0
S	15	0	0 0 0 0 0	0 0 0 0 0	6 0 0 0 0	6 6 0 0 0	61919 0 0	01313 6 0	0 0 6 0 0	0 0 0 0 0
S	20	0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	014 029 0	0 0 029 0	0 0 0 0 0	01414 0 0	0 0 0 0 0
S	25	0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
SW	5	27	0 2 0 0 0	5 0 0 0 0	15 0 0 0 0	6 0 0 0 0	2 5 3 0 0	8 5 0 0 0	8 6 0 0 0	5 3 0 0 0
SW	10	20	3 0 0 0 0	0 0 0 0 0	10 0 0 0 0	0 0 0 0 0	7 7 0 0 0	23 7 0 0 0	313 0 0 0	3 0 3 0 0
SW	15	0	0 0 0 0 0	0 0 0 0 0	13 0 0 0 0	13 0 0 0 0	13 0 0 0 0	02513 0 0	1313 0 0 0	0 0 0 0 0
SW	20	0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	033 0 0 0	0 033 0 0	033 0 0 0	0 0 0 0 0
SW	25	0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0
W	5	33	1 0 0 0 0	0 0 0 0 0	9 0 0 0 0	3 0 0 0 0	1 0 0 0 0	2 1 0 0 0	23 7 1 0 0	10 7 2 1 0
W	10	15	0 1 1 0 0	1 0 0 0 0	3 0 0 0 0	1 0 0 0 0	1 0 0 0 0	3 1 1 0 0	2517 2 2 0	1513 3 1 0
W	15	0	0 0 0 0 0	3 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 3 0 0 0	013 8 3 0	11292111 0
W	20	7	0 0 7 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 714 7 7	7 72114 0
W	25	0	050 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 050 0	0 0 0 0 0
NW	5	27	6 1 1 0 0	2 0 0 0 0	10 0 0 0 0	1 0 0 0 0	0 0 0 0 0	1 0 0 0 0	8 4 1 0 0	1914 4 1 0
NW	10	7	4 2 1 0 0	1 0 0 0 0	2 0 0 0 0	0 0 0 0 0	0 0 0 0 0	2 0 0 0 0	7 4 1 0 0	203015 2 0
NW	15	2	5 2 1 0 0	1 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	2 0 2 0 0	11293110 0
NW	20	0	7 7 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 2 3 0	2133826 3
NW	25	0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 025 0	0 0 02550
OVERALL		16	2 2 0 0 0	2 0 0 0 0	24 5 1 0 0	3 1 1 1 0	1 1 0 0 0	1 1 0 0 0	8 5 1 0 0	8 8 5 1 0

* Indicates greater than 99 percent probability

Figure 4-42 Wave data for the study region

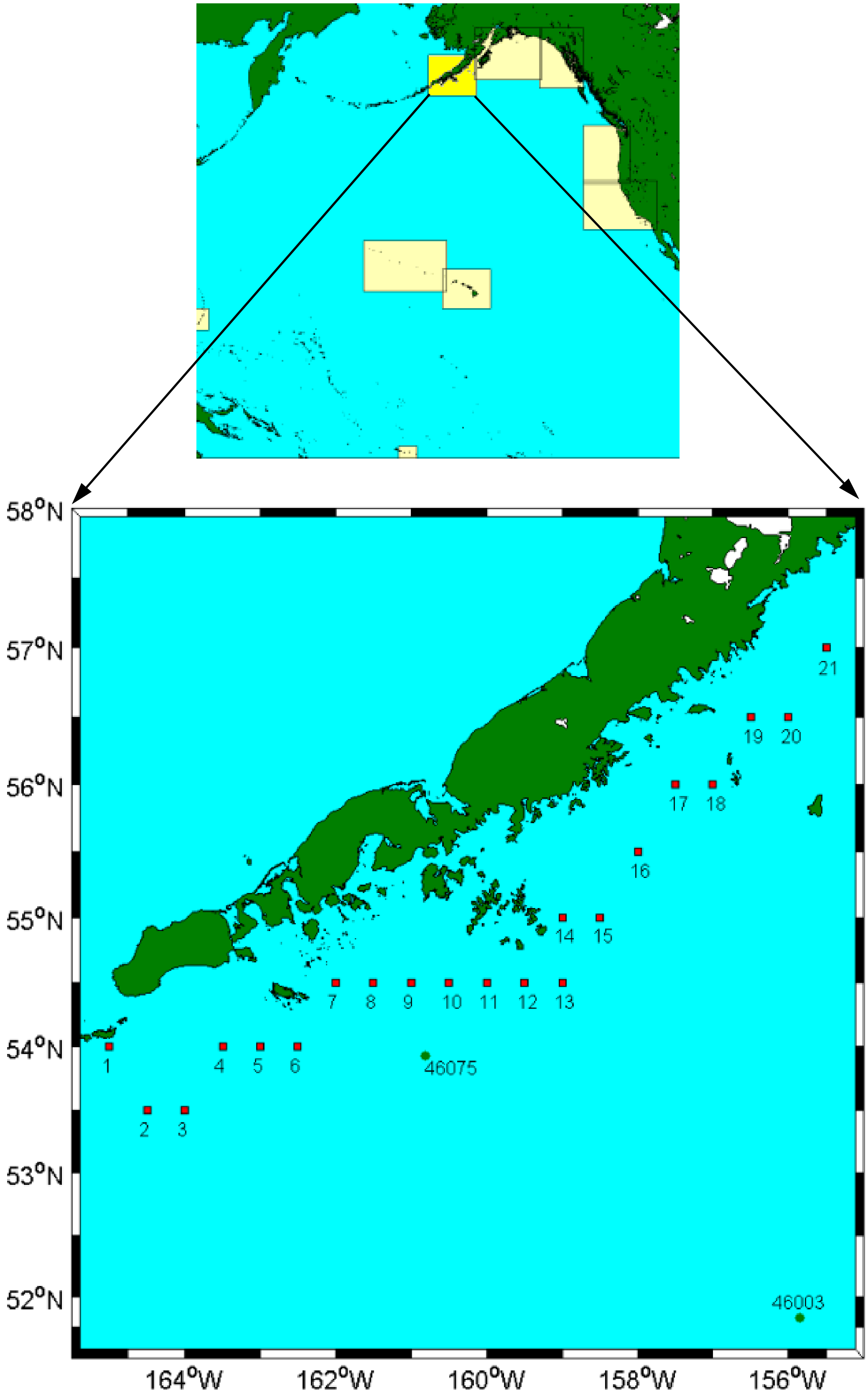
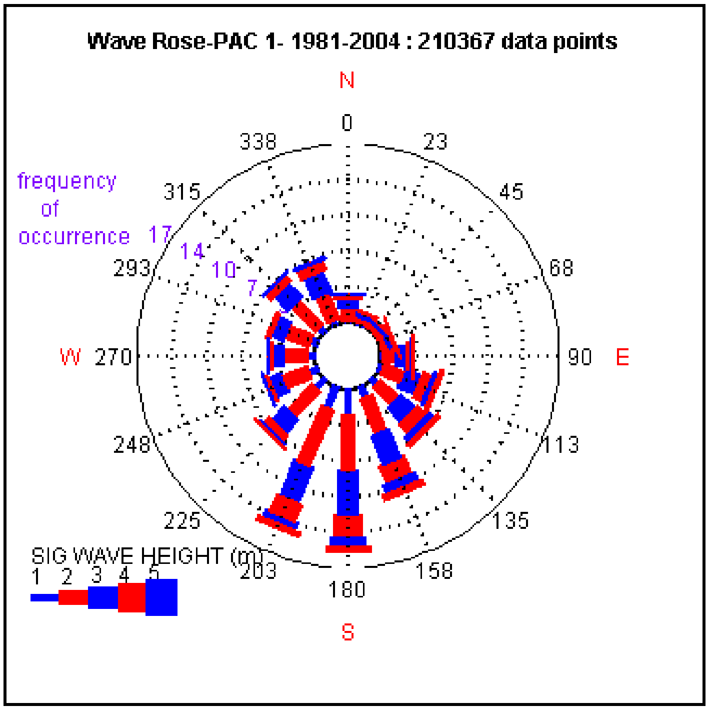


Figure 4-43 Wave rose diagrams for USCOE Stations 1 and 6



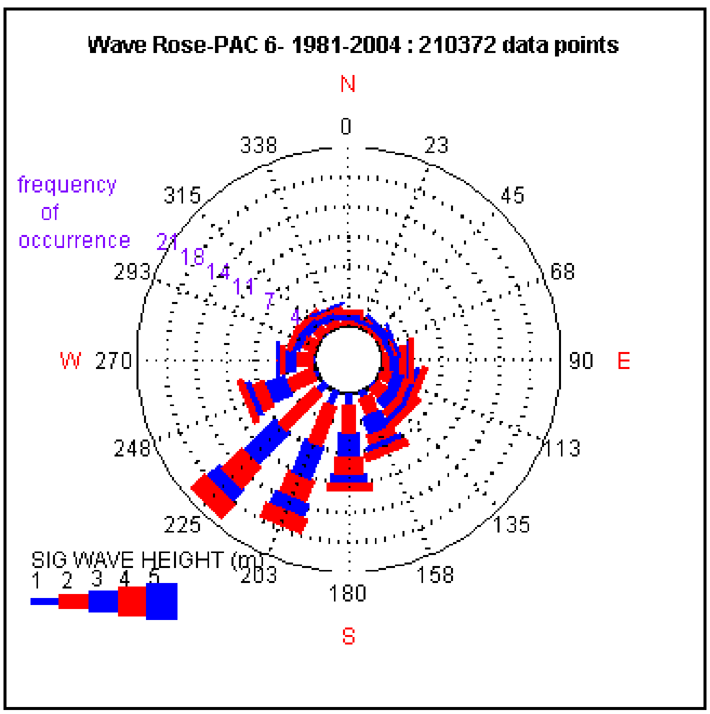
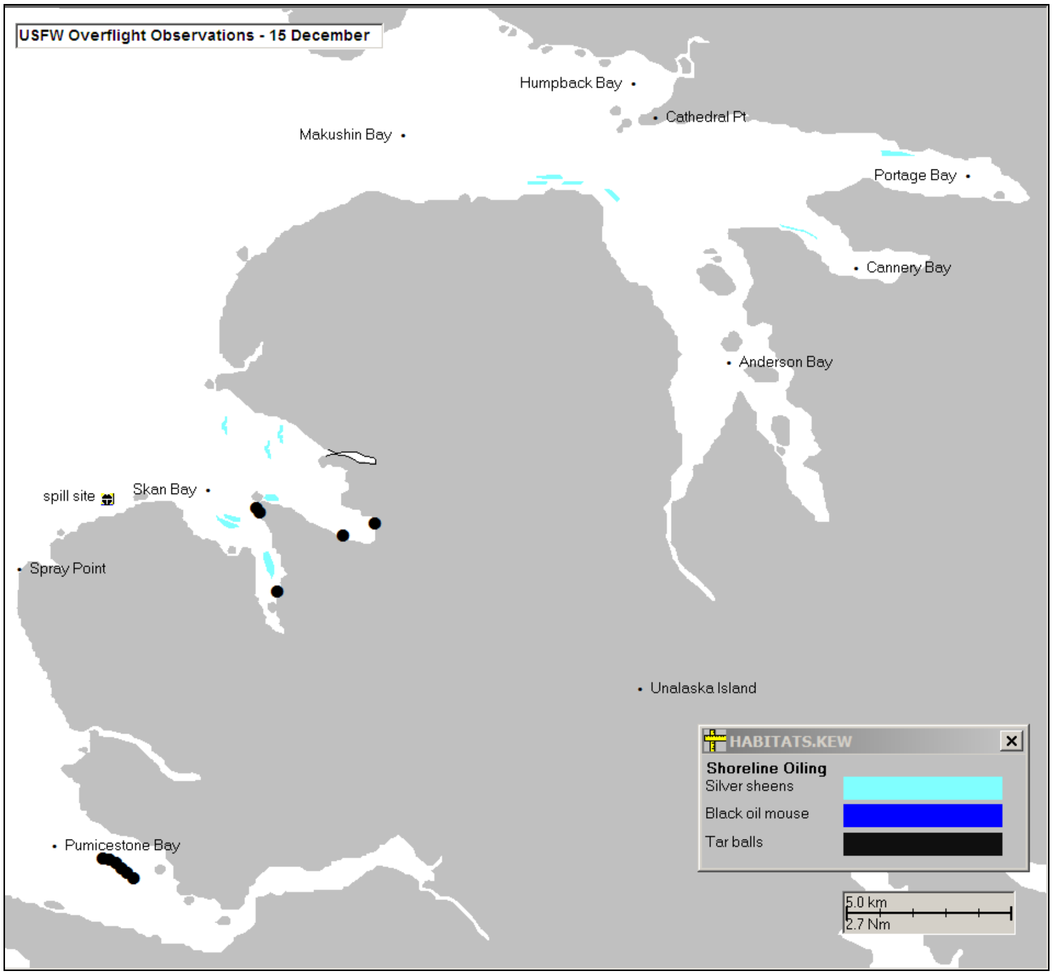
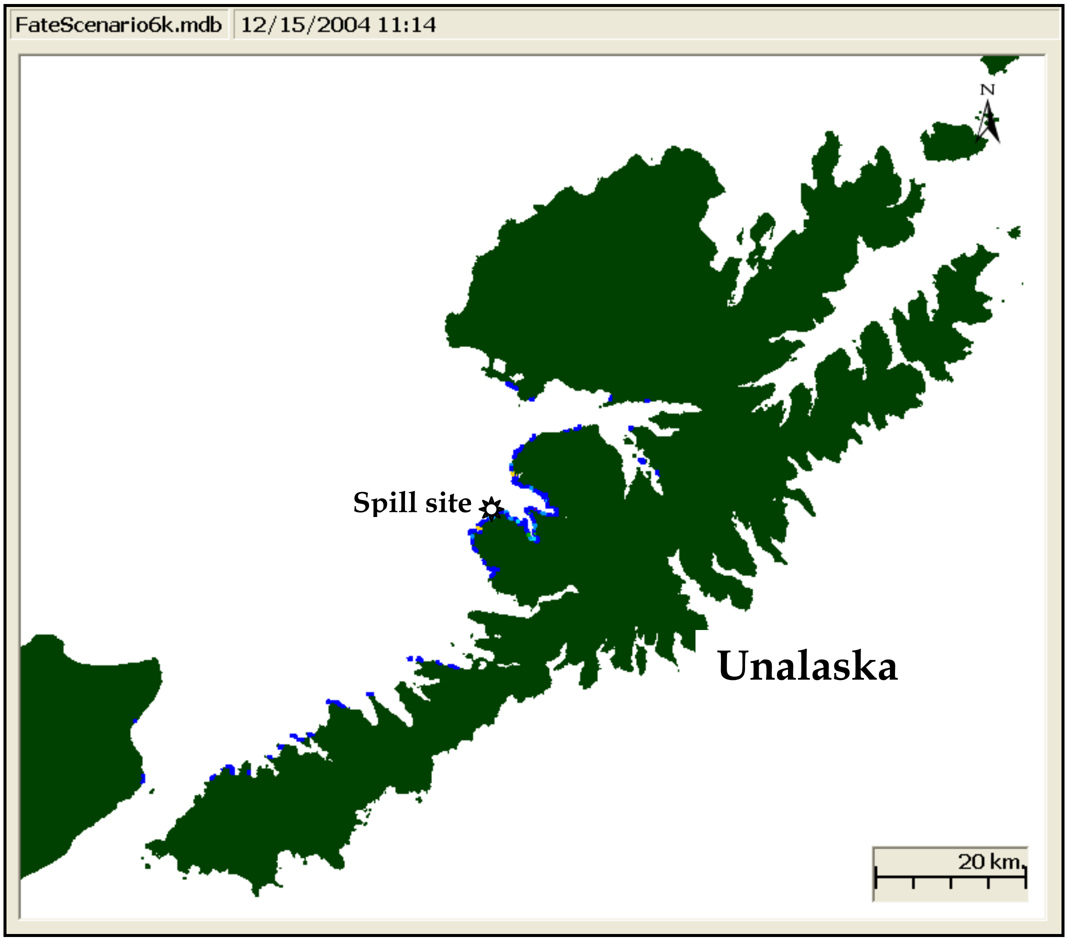


Figure 5-1 Over flight observations - 15 December 2004 from US Fish and Wildlife Service of the *M/V Selandang Ayu* Spill



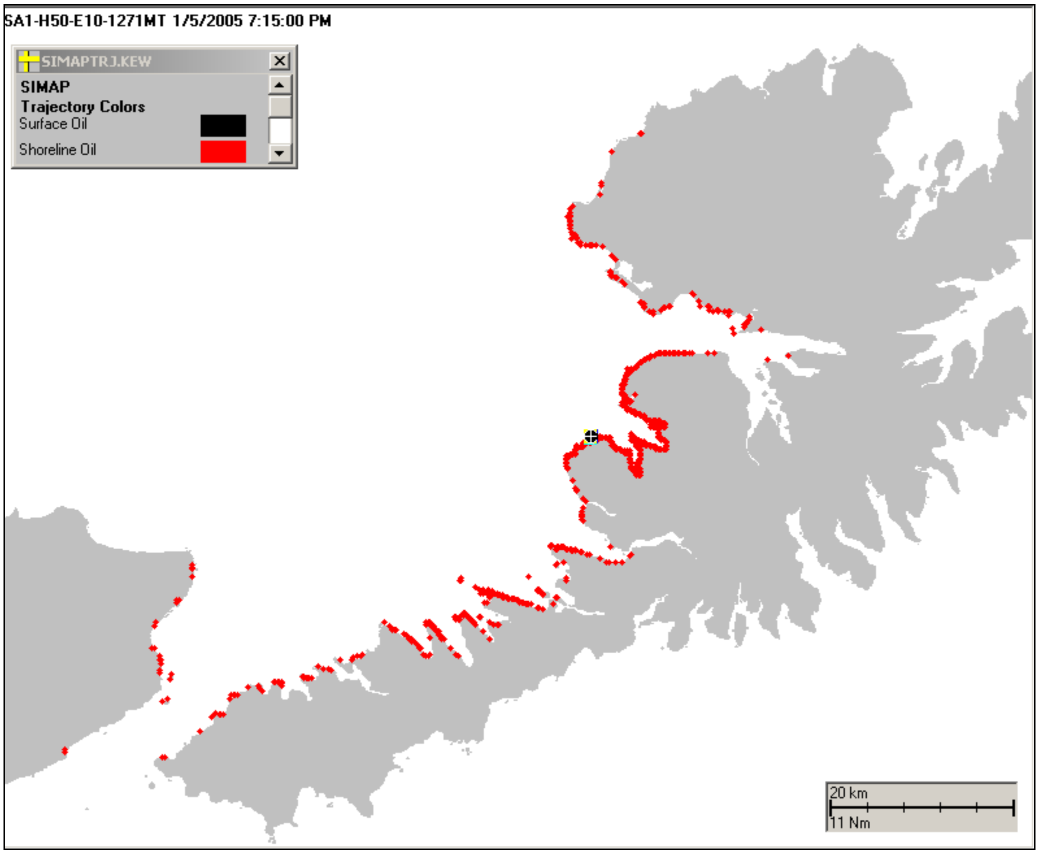
Notes: Time of observation not specified
Land mass is gray

Figure 5-2 COSIM predicted shoreline oiling on December 15, 2004 at 1100 hours of the *M/V Selandang Ayu* Spill



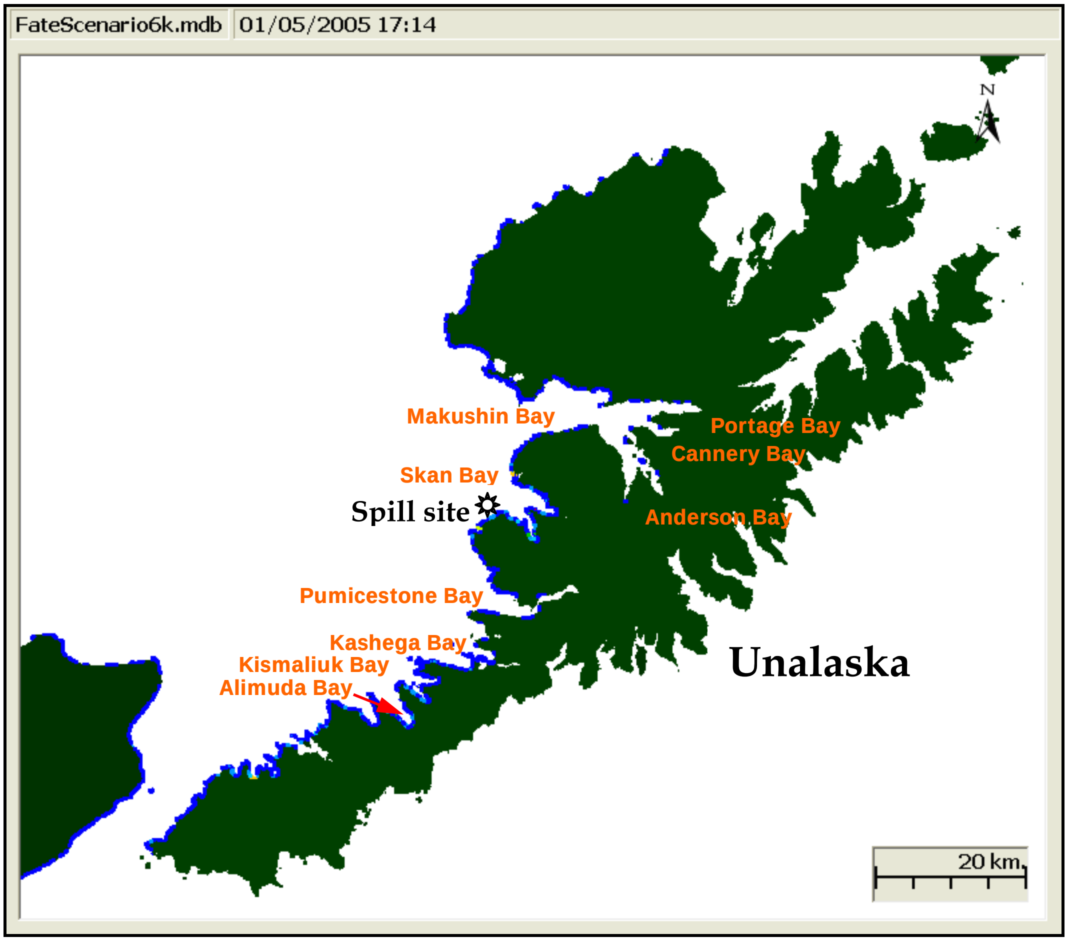
Note: Land mass is green/dark

Figure 5-3 SIMAP predicted shoreline oiling on 1/5/2005 at 19:15 hours



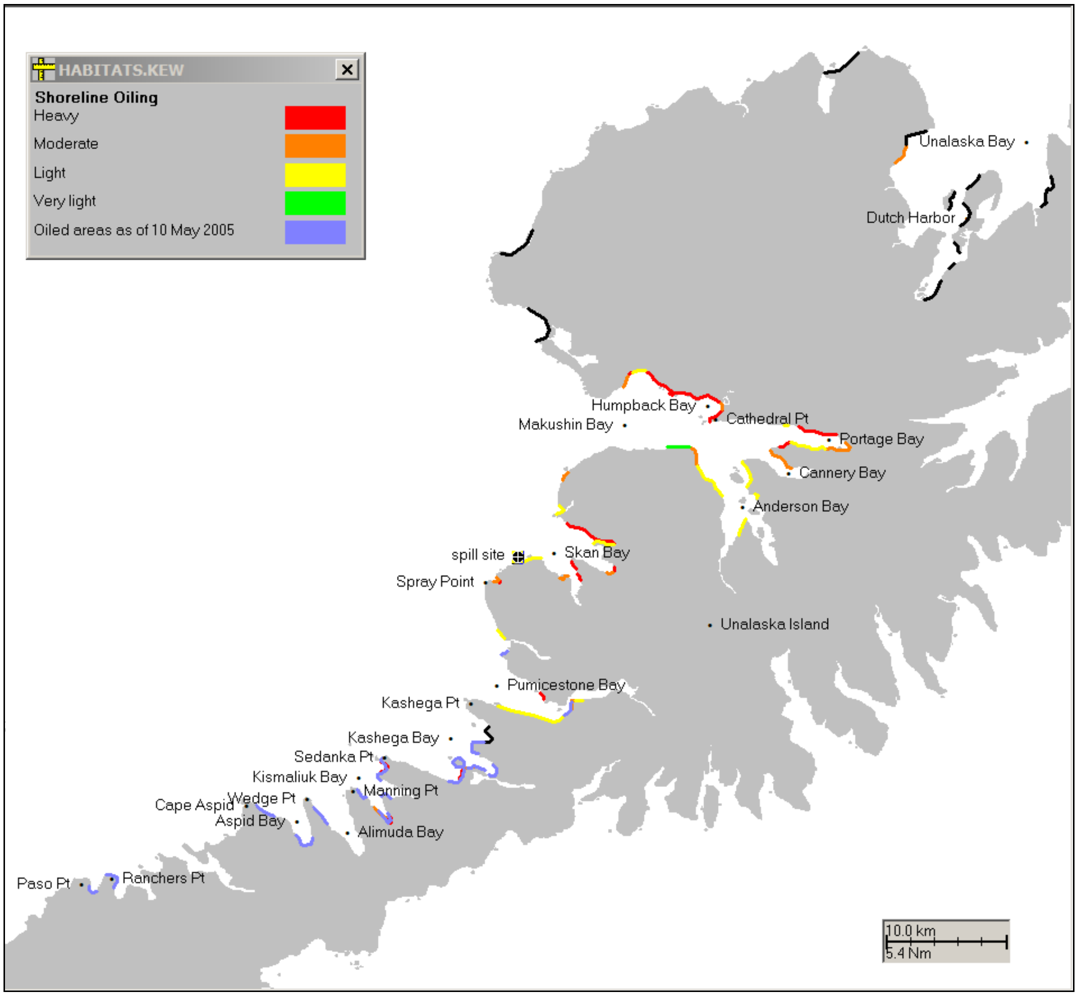
Notes: horizontal diffusion coefficient of 50 m^2/sec

Figure 5-4 COSIM predicted shoreline oiling on 1/5/2005 at 19:15 hours



Notes: horizontal diffusion coefficient of 50 m^2/sec

Figure 5-5 SCAT oiling observations



Notes: The heavy, moderate, light, very light and tar ball observations were from surveys completed between 27 December and 5 February (ASA, 2006)

Figure 5-6 COSIM predicted shoreline oiling after 4 weeks of simulation

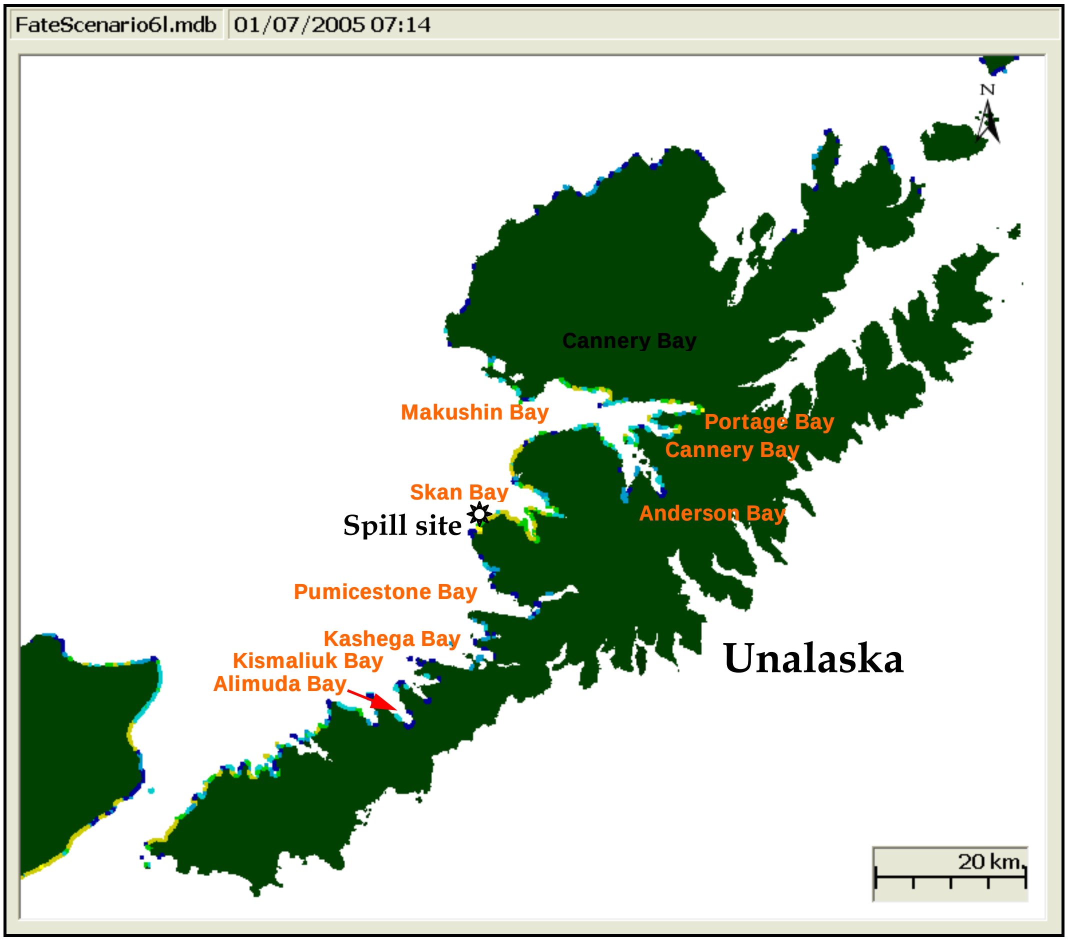


Figure 5-7 Comparison of model predicted shoreline oiling with field observations obtained from Alaska Department of Environmental Conservation

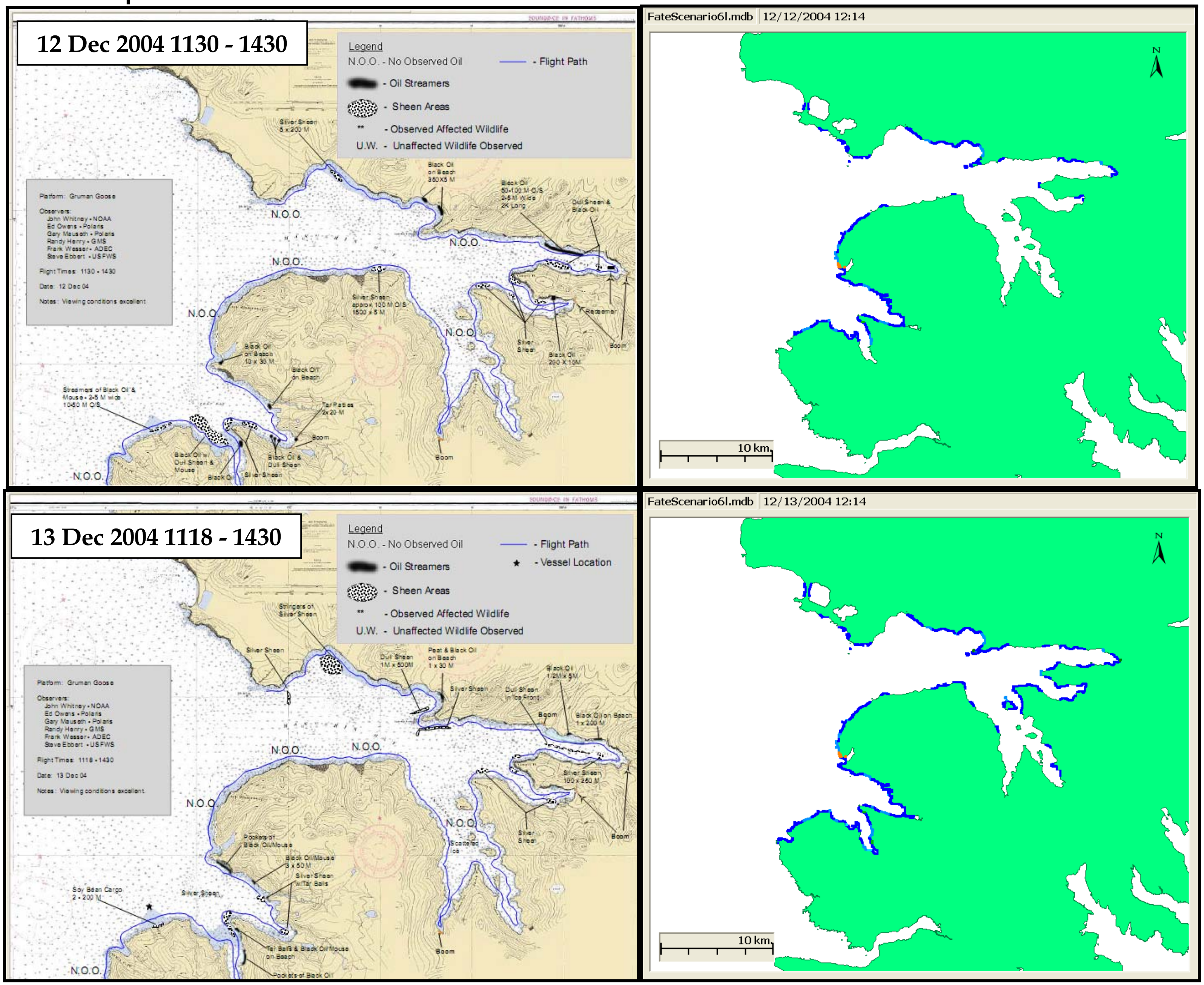


Figure 5-8 Comparison of model predicted shoreline oiling with field observations obtained from Alaska Department of Environmental Conservation

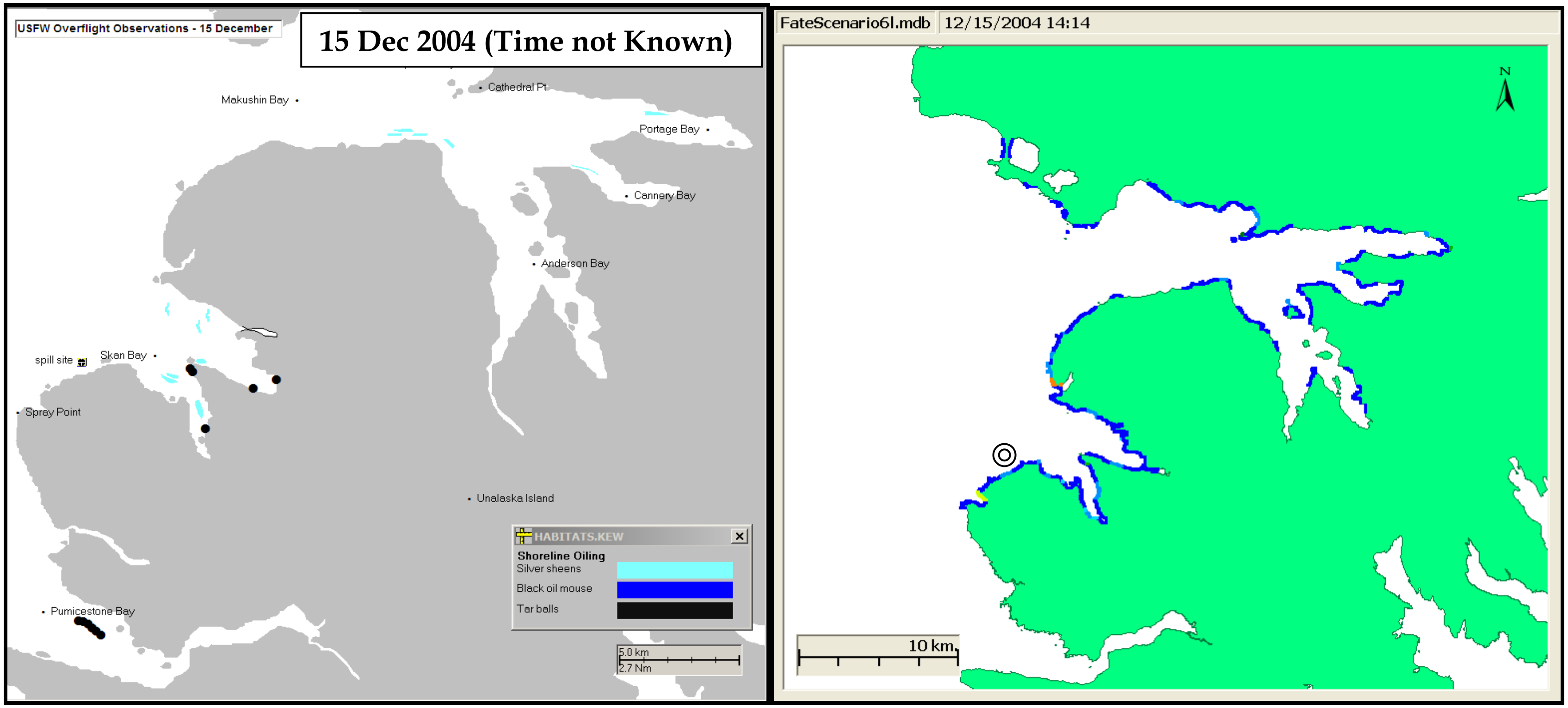
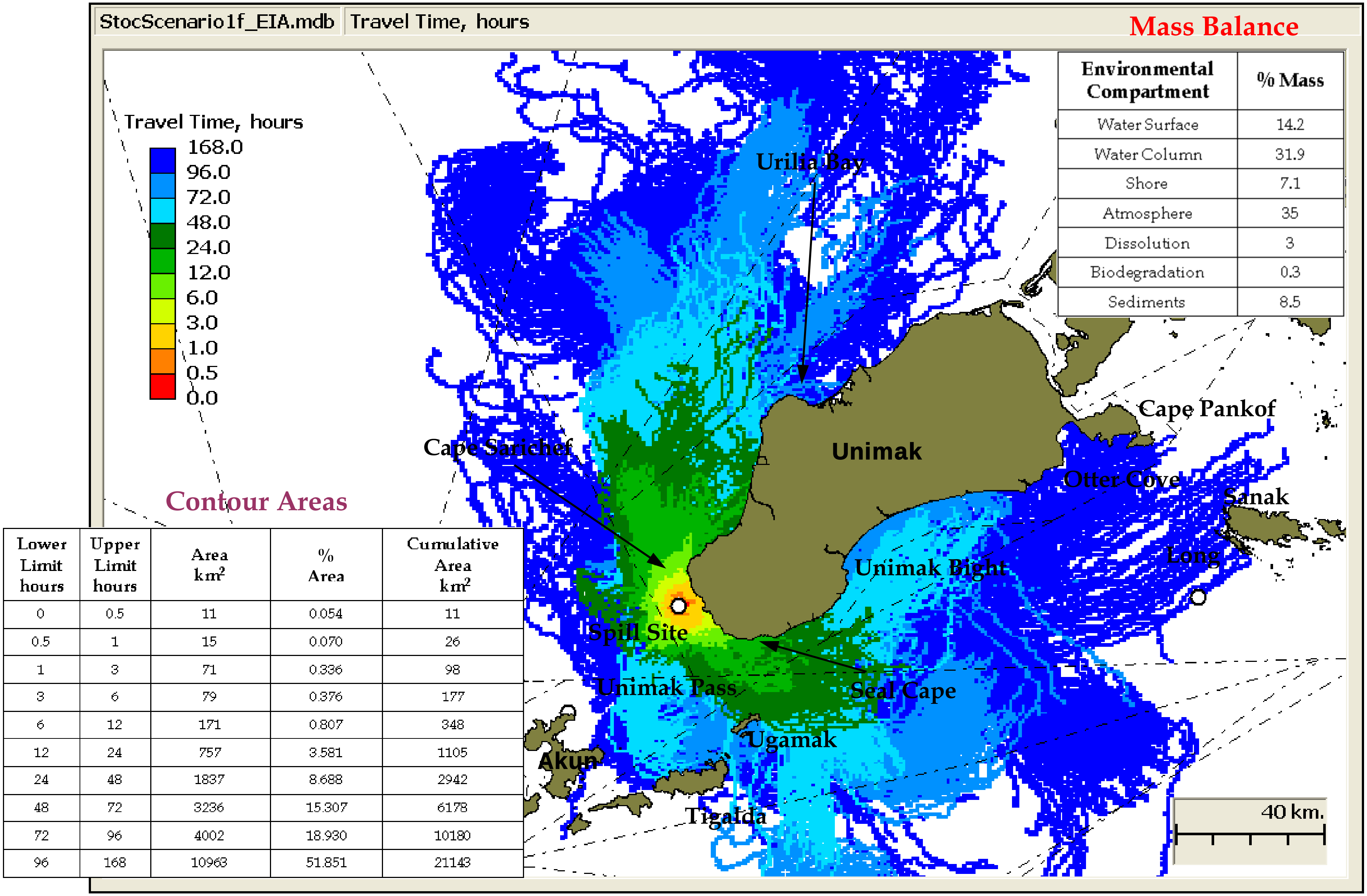


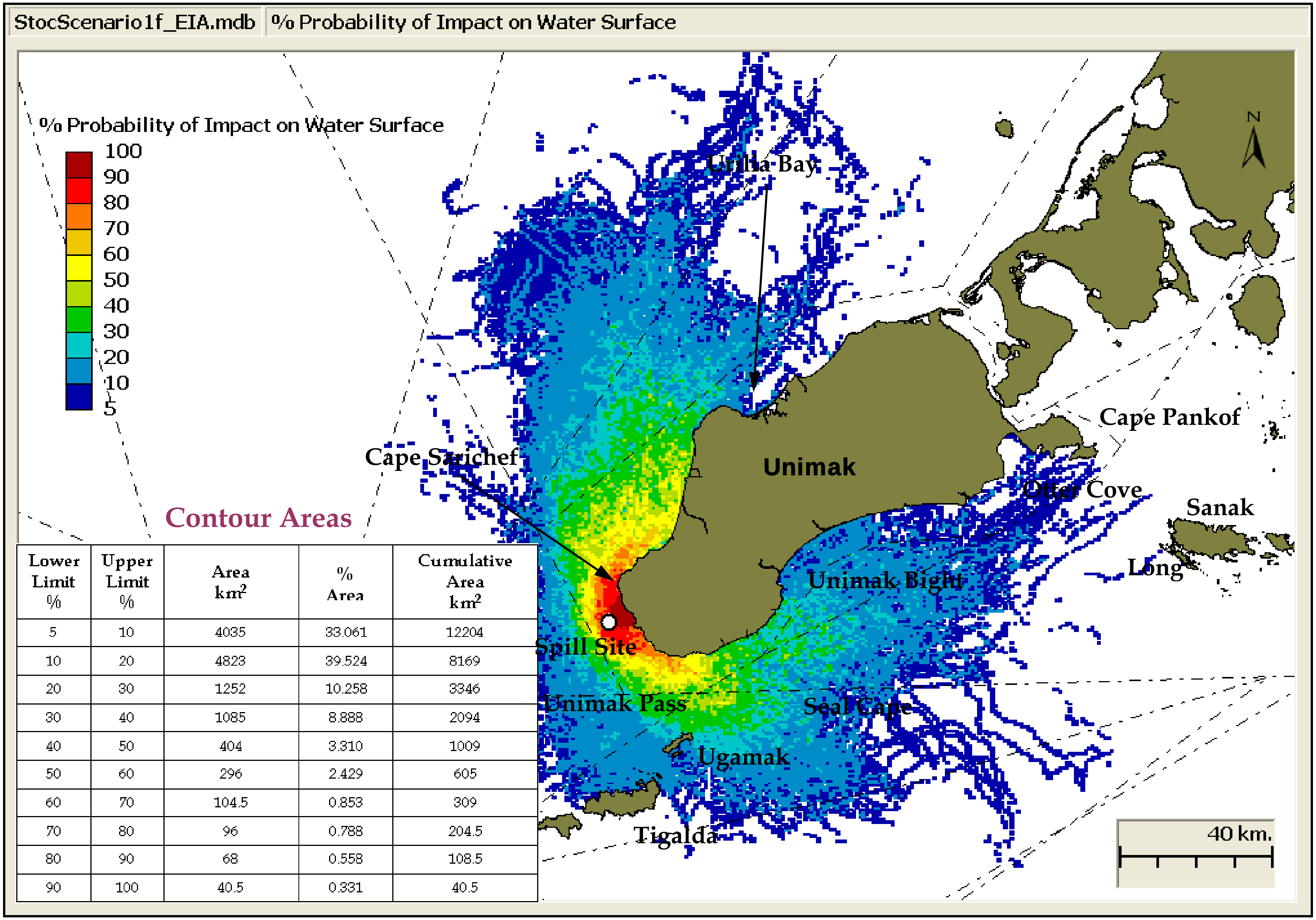
Figure 6-1 Travel time for Scenario 1 Bunker C fuel spill



Environmental Compartment	% Mass
Water Surface	14.2
Water Column	31.9
Shore	7.1
Atmosphere	35
Dissolution	3
Biodegradation	0.3
Sediments	8.5

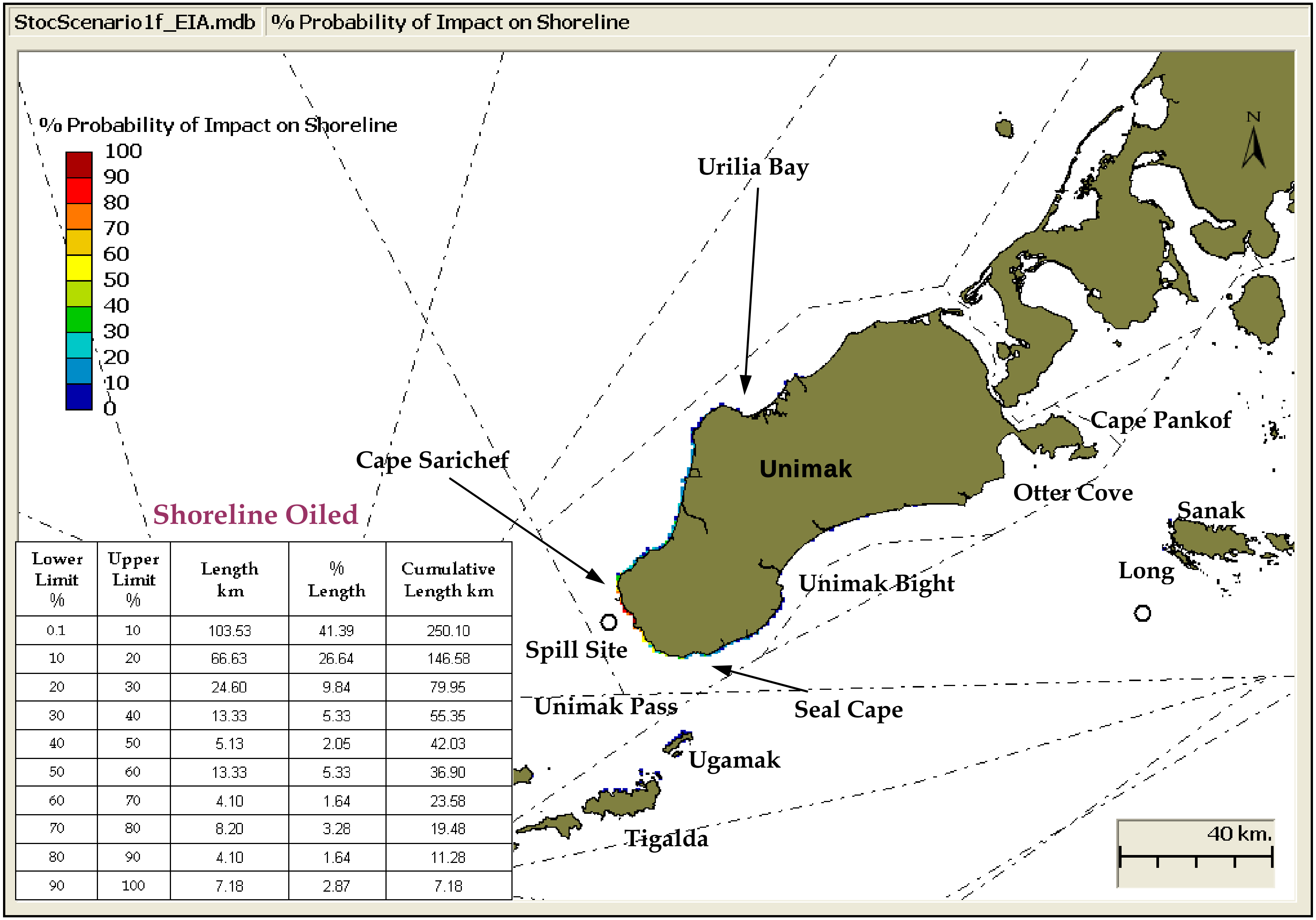
Lower Limit hours	Upper Limit hours	Area km²	% Area	Cumulative Area km²
0	0.5	11	0.054	11
0.5	1	15	0.070	26
1	3	71	0.336	98
3	6	79	0.376	177
6	12	171	0.807	348
12	24	757	3.581	1105
24	48	1837	8.688	2942
48	72	3236	15.307	6178
72	96	4002	18.930	10180
96	168	10963	51.851	21143

Figure 6-2 Probability of impact on water surface due to Scenario 1 Bunker C fuel spill



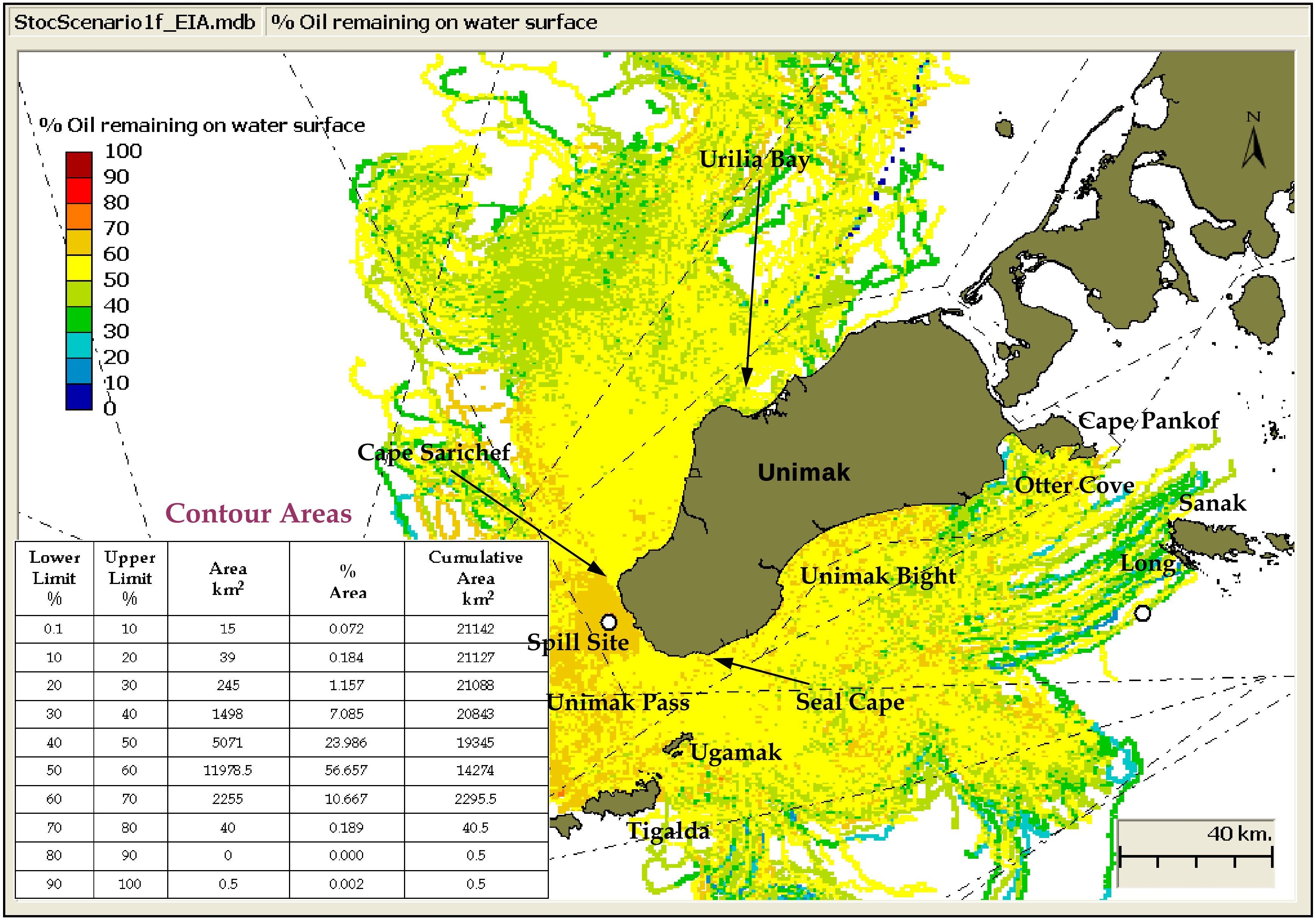
Lower Limit %	Upper Limit %	Area km²	% Area	Cumulative Area km²
5	10	4035	33.061	12204
10	20	4823	39.524	8169
20	30	1252	10.258	3346
30	40	1085	8.888	2094
40	50	404	3.310	1009
50	60	296	2.429	605
60	70	104.5	0.853	309
70	80	96	0.788	204.5
80	90	68	0.558	108.5
90	100	40.5	0.331	40.5

Figure 6-3 Probability of impact on shoreline due to Scenario 1 Bunker C fuel spill



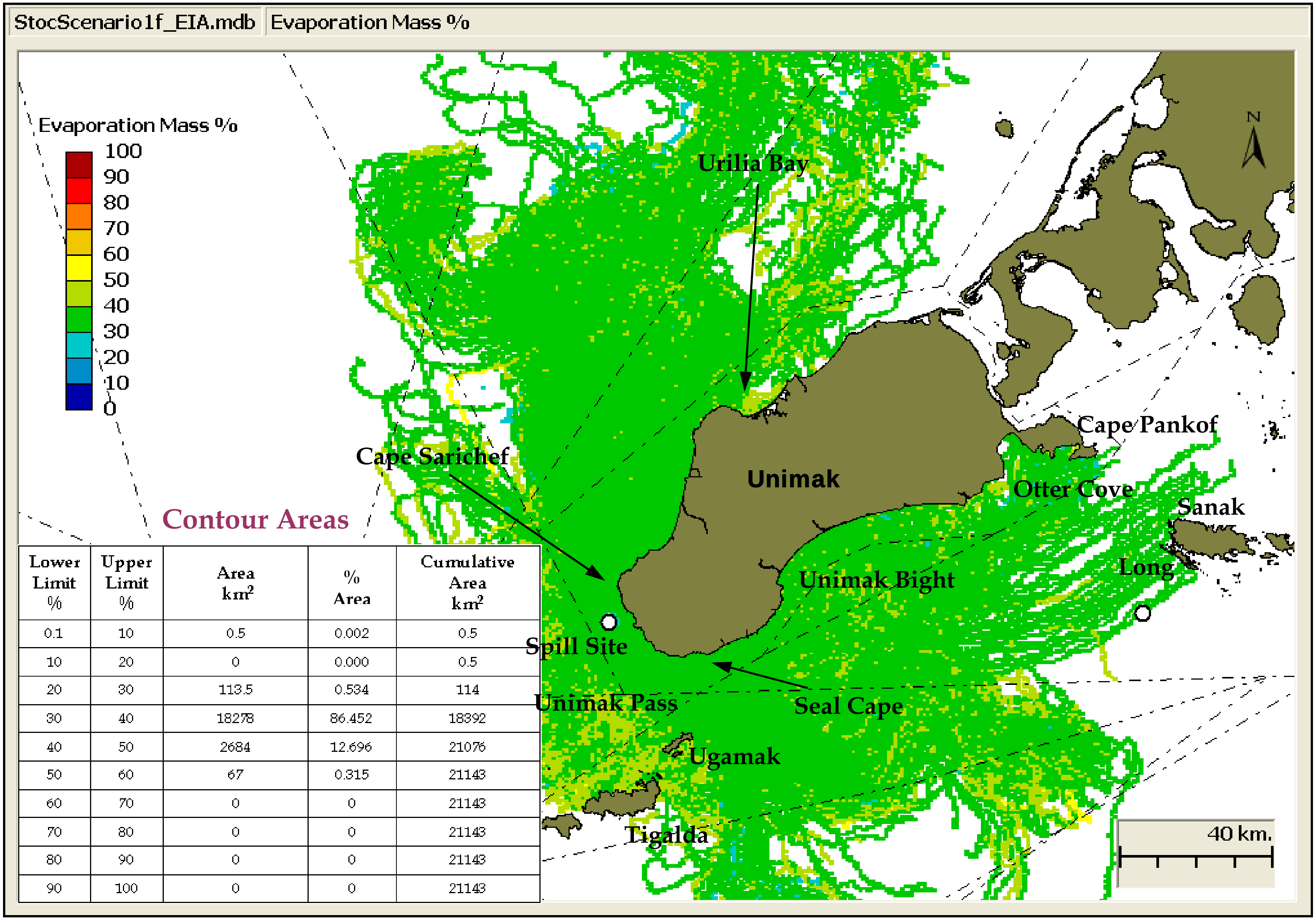
Lower Limit %	Upper Limit %	Length km	% Length	Cumulative Length km
0.1	10	103.53	41.39	250.10
10	20	66.63	26.64	146.58
20	30	24.60	9.84	79.95
30	40	13.33	5.33	55.35
40	50	5.13	2.05	42.03
50	60	13.33	5.33	36.90
60	70	4.10	1.64	23.58
70	80	8.20	3.28	19.48
80	90	4.10	1.64	11.28
90	100	7.18	2.87	7.18

Figure 6-4 Percent Bunker C fuel oil remaining on water surface for Scenario 1



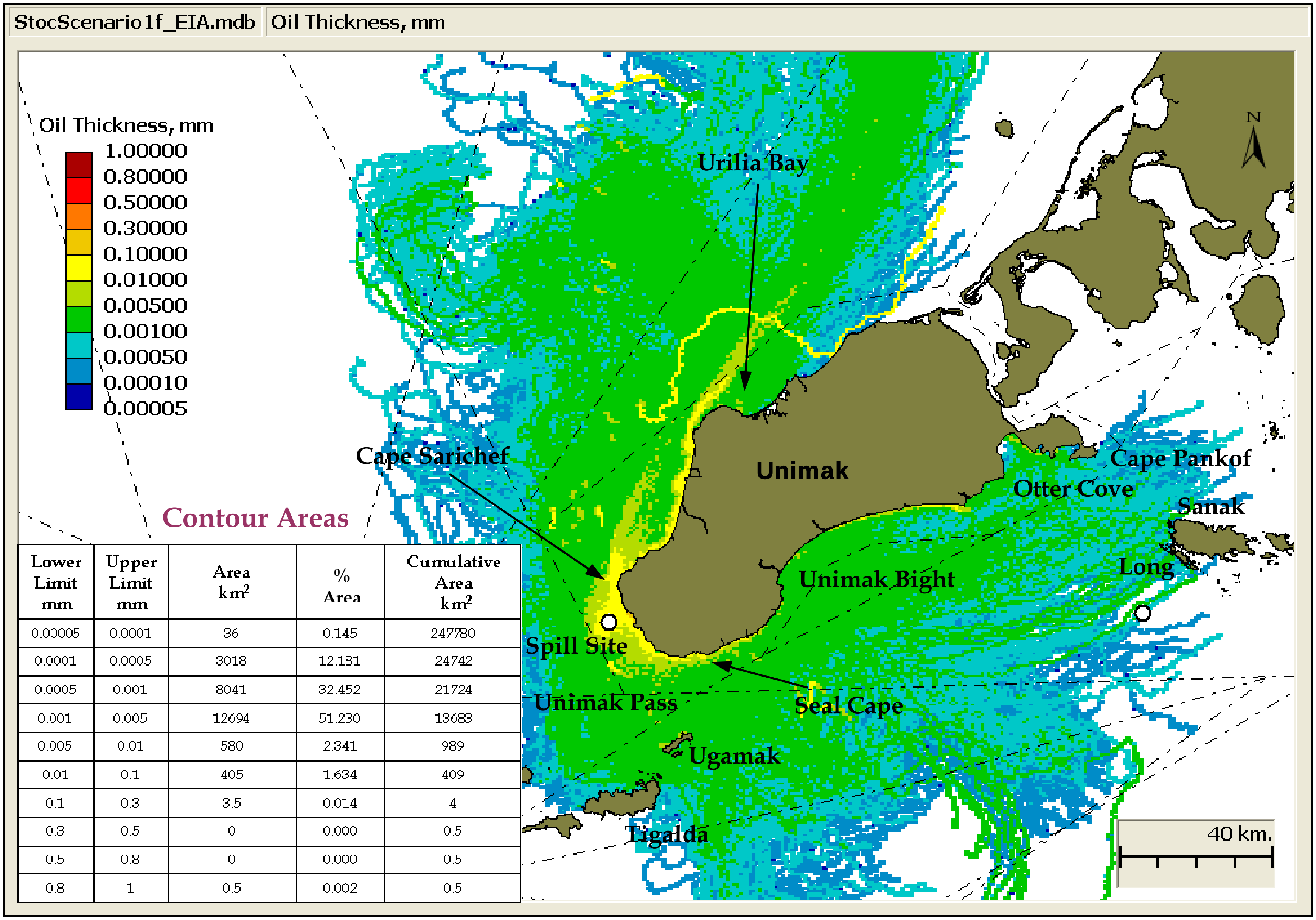
Lower Limit %	Upper Limit %	Area km²	% Area	Cumulative Area km²
0.1	10	15	0.072	21142
10	20	39	0.184	21127
20	30	245	1.157	21088
30	40	1498	7.085	20843
40	50	5071	23.986	19345
50	60	11978.5	56.657	14274
60	70	2255	10.667	2295.5
70	80	40	0.189	40.5
80	90	0	0.000	0.5
90	100	0.5	0.002	0.5

Figure 6-5 Percent Bunker C fuel oil lost due to evaporation for Scenario 1



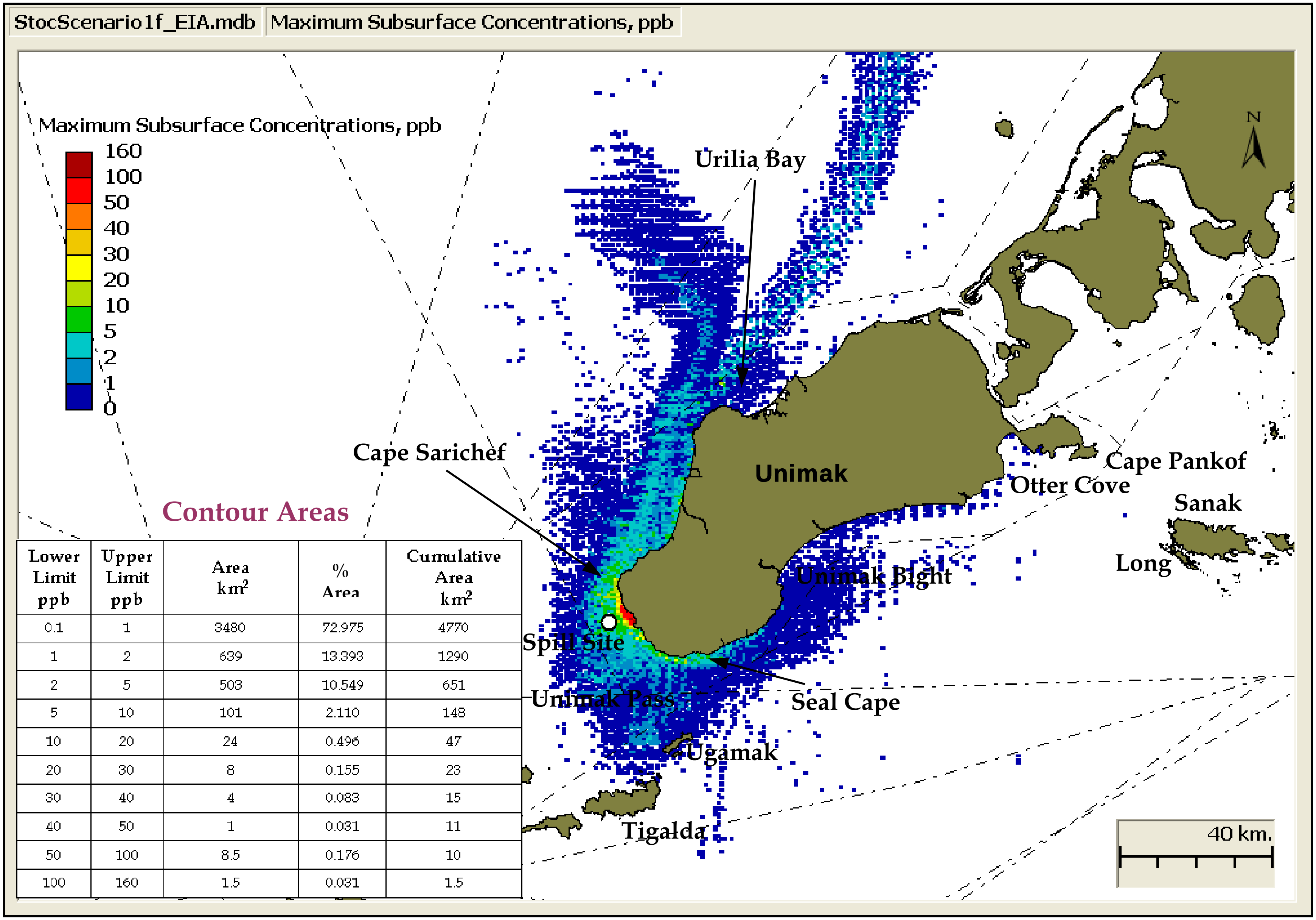
Lower Limit %	Upper Limit %	Area km^2	% Area	Cumulative Area km^2
0.1	10	0.5	0.002	0.5
10	20	0	0.000	0.5
20	30	113.5	0.534	114
30	40	18278	86.452	18392
40	50	2684	12.696	21076
50	60	67	0.315	21143
60	70	0	0	21143
70	80	0	0	21143
80	90	0	0	21143
90	100	0	0	21143

Figure 6-6 Maximum oil thickness of Bunker C fuel spill for Scenario 1



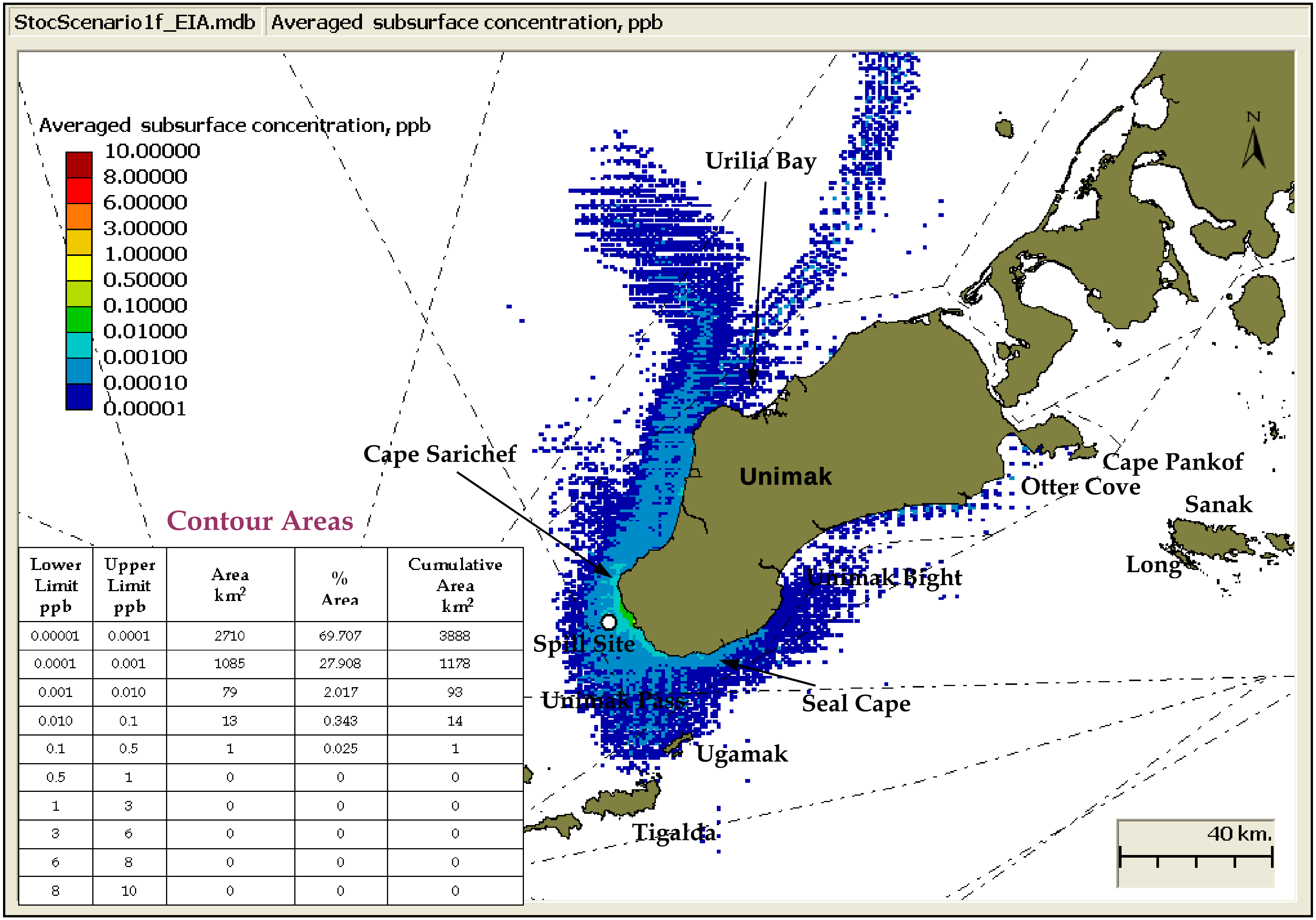
Lower Limit mm	Upper Limit mm	Area km²	% Area	Cumulative Area km²
0.00005	0.0001	36	0.145	247780
0.0001	0.0005	3018	12.181	24742
0.0005	0.001	8041	32.452	21724
0.001	0.005	12694	51.230	13683
0.005	0.01	580	2.341	989
0.01	0.1	405	1.634	409
0.1	0.3	3.5	0.014	4
0.3	0.5	0	0.000	0.5
0.5	0.8	0	0.000	0.5
0.8	1	0.5	0.002	0.5

Figure 6-7 Maximum water column concentration at any vertical location for Scenario 1 Bunker C fuel spill



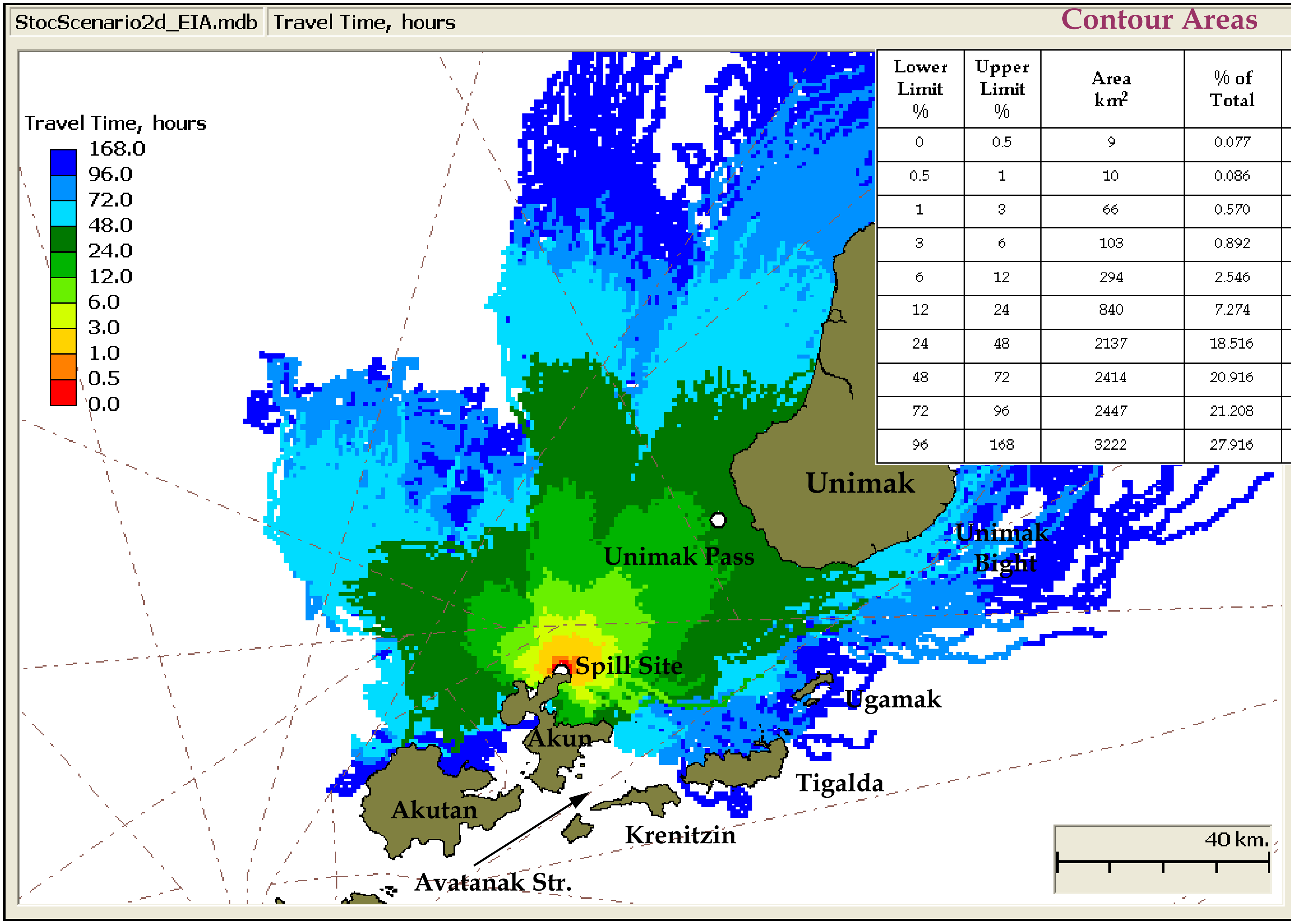
Lower Limit ppb	Upper Limit ppb	Area km²	% Area	Cumulative Area km²
0.1	1	3480	72.975	4770
1	2	639	13.393	1290
2	5	503	10.549	651
5	10	101	2.110	148
10	20	24	0.496	47
20	30	8	0.155	23
30	40	4	0.083	15
40	50	1	0.031	11
50	100	8.5	0.176	10
100	160	1.5	0.031	1.5

Figure 6-8 Maximum vertically averaged water column concentration for Scenario 1 Bunker C fuel spill



Lower Limit ppb	Upper Limit ppb	Area km²	% Area	Cumulative Area km²
0.00001	0.0001	2710	69.707	3888
0.0001	0.001	1085	27.908	1178
0.001	0.010	79	2.017	93
0.010	0.1	13	0.343	14
0.1	0.5	1	0.025	1
0.5	1	0	0	0
1	3	0	0	0
3	6	0	0	0
6	8	0	0	0
8	10	0	0	0

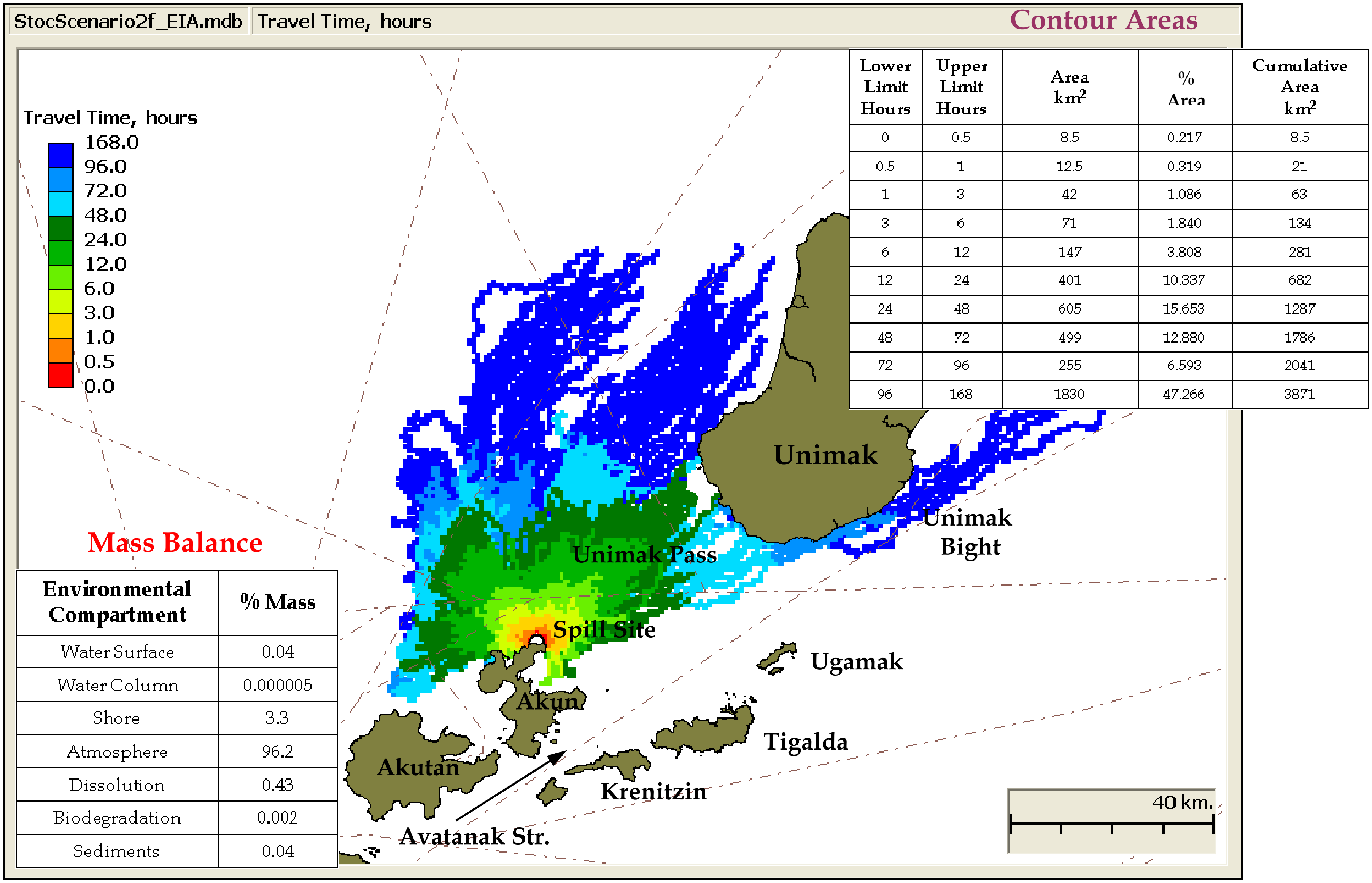
Figure 6-9 Travel times for Scenario 2 LNG spill assuming large persistence time



Contour Areas

Lower Limit %	Upper Limit %	Area km^2	% of Total	Cumulative Area km^2
0	0.5	9	0.077	9
0.5	1	10	0.086	19
1	3	66	0.570	85
3	6	103	0.892	188
6	12	294	2.546	482
12	24	840	7.274	1322
24	48	2137	18.516	3459
48	72	2414	20.916	5873
72	96	2447	21.208	8320
96	168	3222	27.916	11542

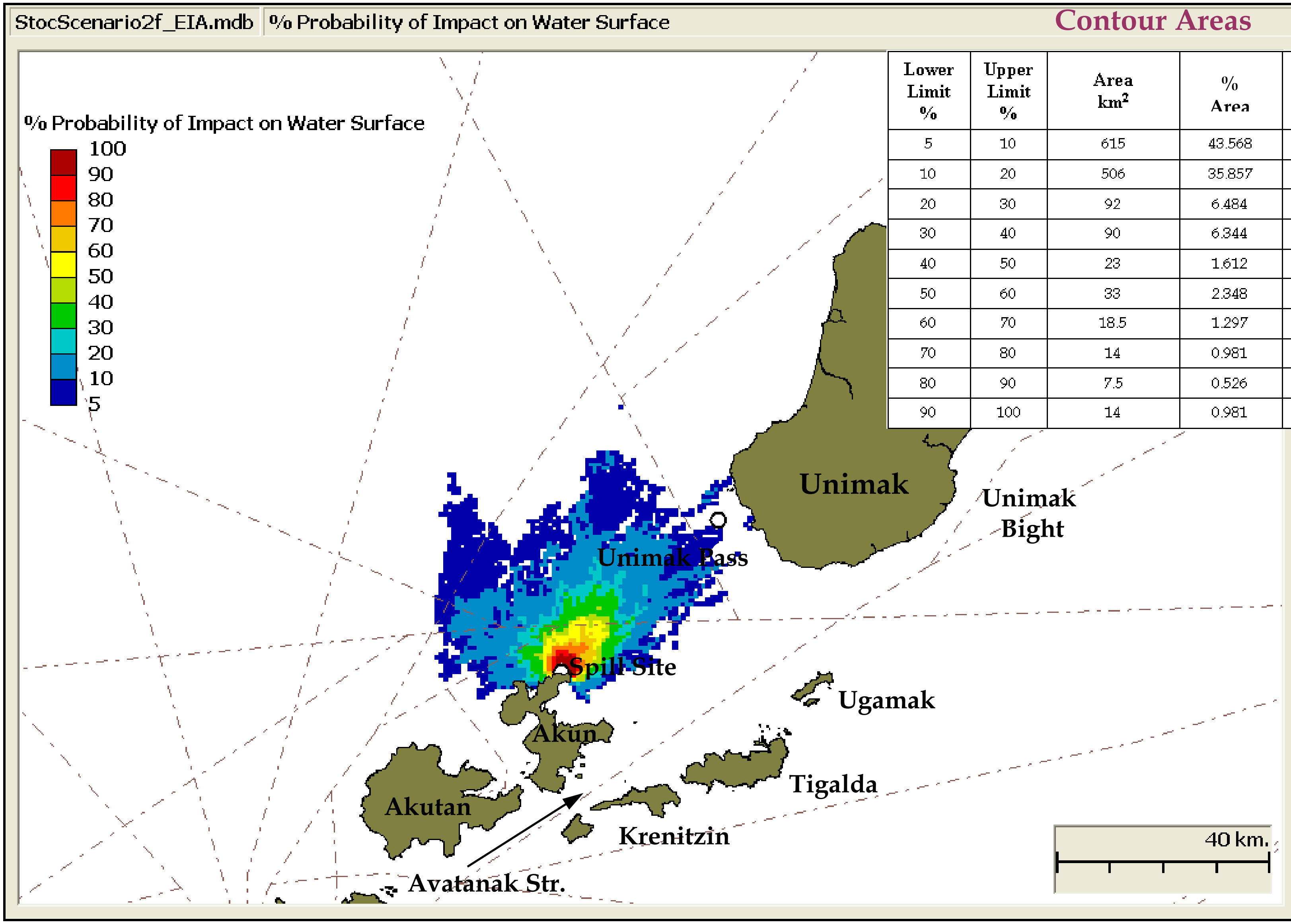
Figure 6-10 Travel times for Scenario 2 LNG spill assuming small persistence time



Lower Limit Hours	Upper Limit Hours	Area km²	% Area	Cumulative Area km²
0	0.5	8.5	0.217	8.5
0.5	1	12.5	0.319	21
1	3	42	1.086	63
3	6	71	1.840	134
6	12	147	3.808	281
12	24	401	10.337	682
24	48	605	15.653	1287
48	72	499	12.880	1786
72	96	255	6.593	2041
96	168	1830	47.266	3871

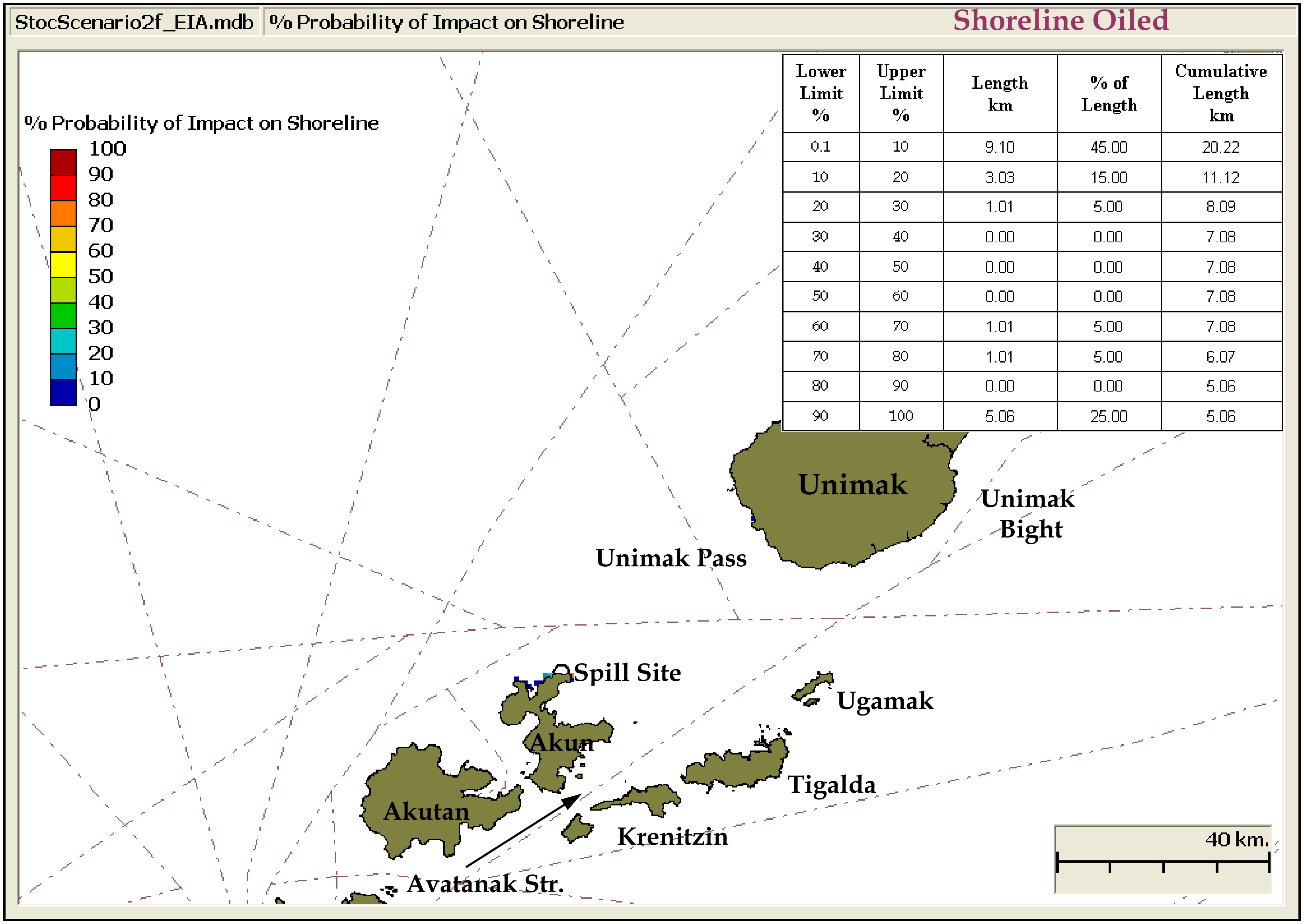
Environmental Compartment	% Mass
Water Surface	0.04
Water Column	0.000005
Shore	3.3
Atmosphere	96.2
Dissolution	0.43
Biodegradation	0.002
Sediments	0.04

Figure 6-11 Probability of impact on water surface due to Scenario 2 LNG spill



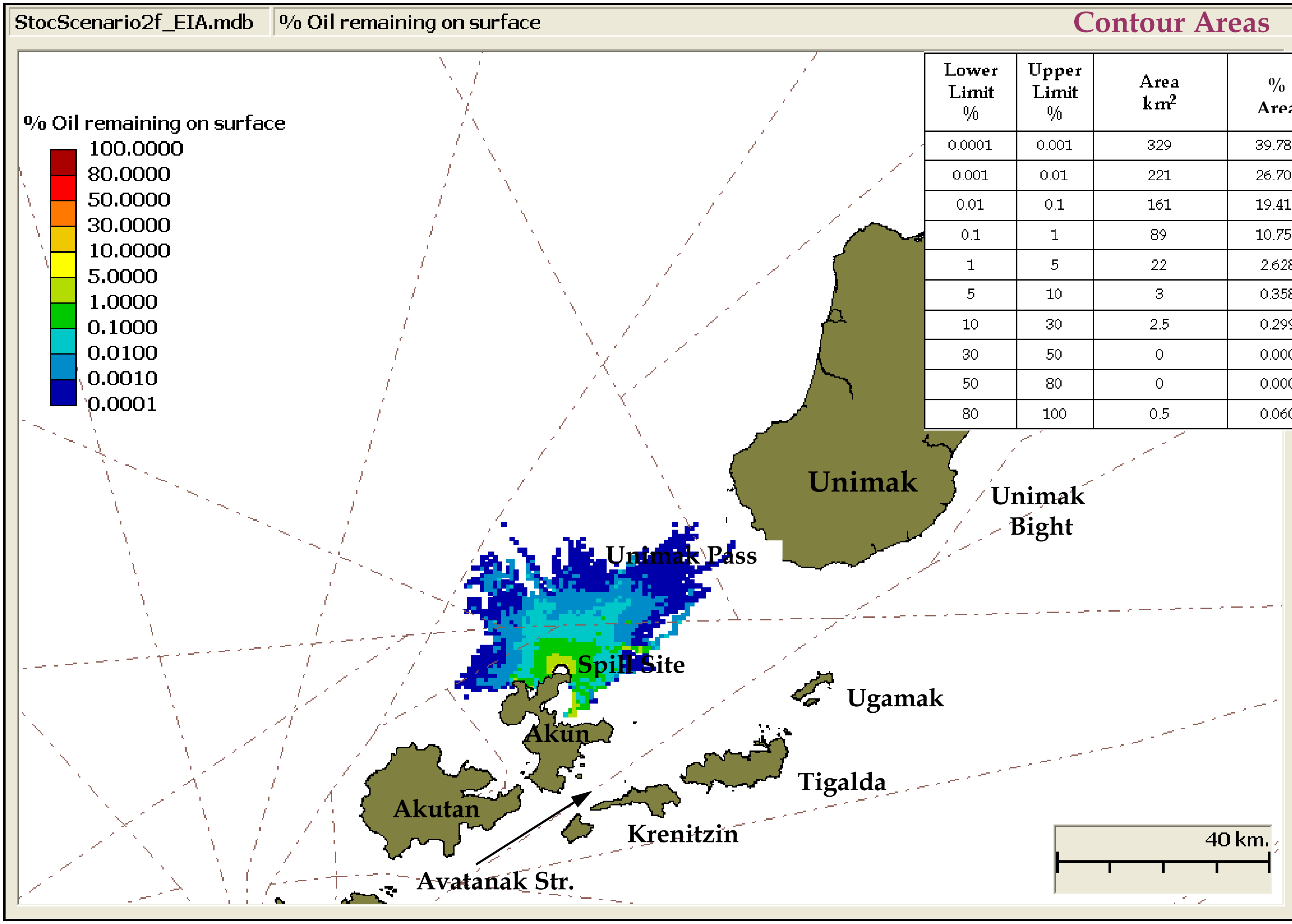
Lower Limit %	Upper Limit %	Area km^2	% Area	Cumulative Area km^2
5	10	615	43.568	1413
10	20	506	35.857	798
20	30	92	6.484	292
30	40	90	6.344	200
40	50	23	1.612	110
50	60	33	2.348	87
60	70	18.5	1.297	54
70	80	14	0.981	35.5
80	90	7.5	0.526	21.5
90	100	14	0.981	14

Figure 6-12 Percent probability of impact on shoreline due to Scenario 2 LNG spill



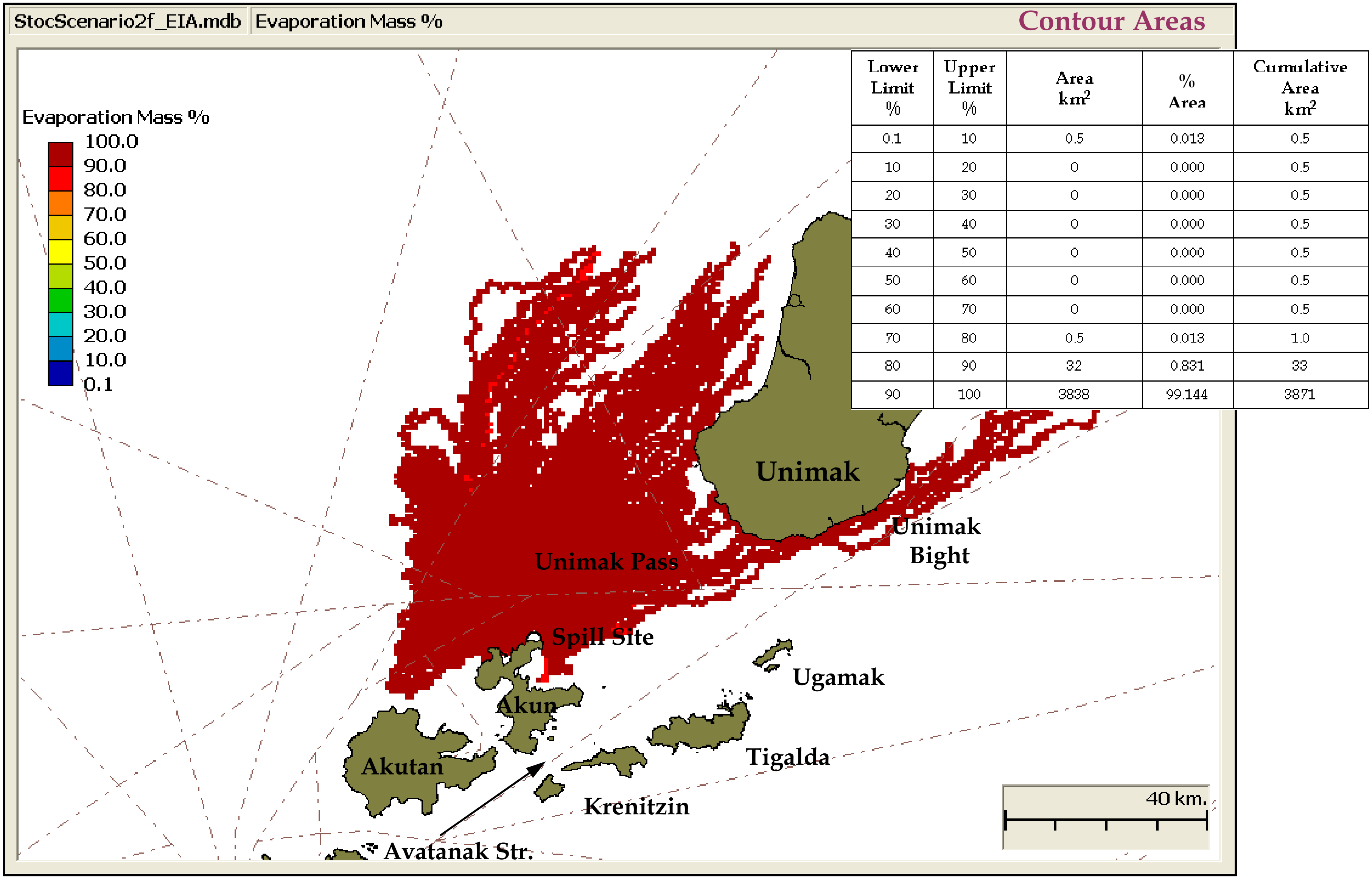
Lower Limit %	Upper Limit %	Length km	% of Length	Cumulative Length km
0.1	10	9.10	45.00	20.22
10	20	3.03	15.00	11.12
20	30	1.01	5.00	8.09
30	40	0.00	0.00	7.08
40	50	0.00	0.00	7.08
50	60	0.00	0.00	7.08
60	70	1.01	5.00	7.08
70	80	1.01	5.00	6.07
80	90	0.00	0.00	5.06
90	100	5.06	25.00	5.06

Figure 6-13 Percent LNG remaining on water surface for Scenario 2 spill



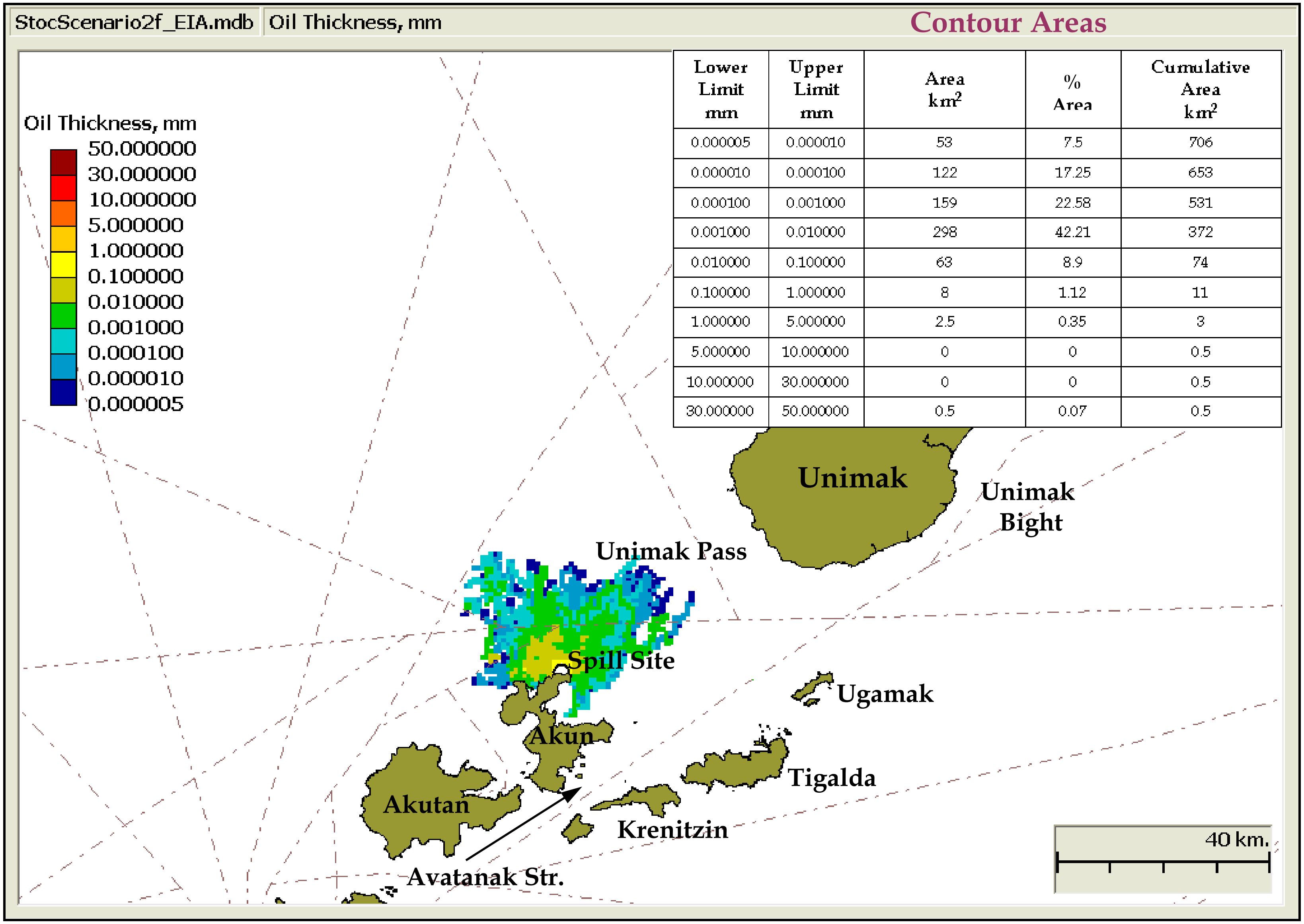
Lower Limit %	Upper Limit %	Area km²	% Area	Cumulative Area km²
0.0001	0.001	329	39.785	828
0.001	0.01	221	26.703	499
0.01	0.1	161	19.415	278
0.1	1	89	10.753	117
1	5	22	2.628	28
5	10	3	0.358	6
10	30	2.5	0.299	3
30	50	0	0.000	0
50	80	0	0.000	0
80	100	0.5	0.060	0.5

Figure 6-14 Percent LNG lost due to evaporation from water surface for Scenario 2 spill



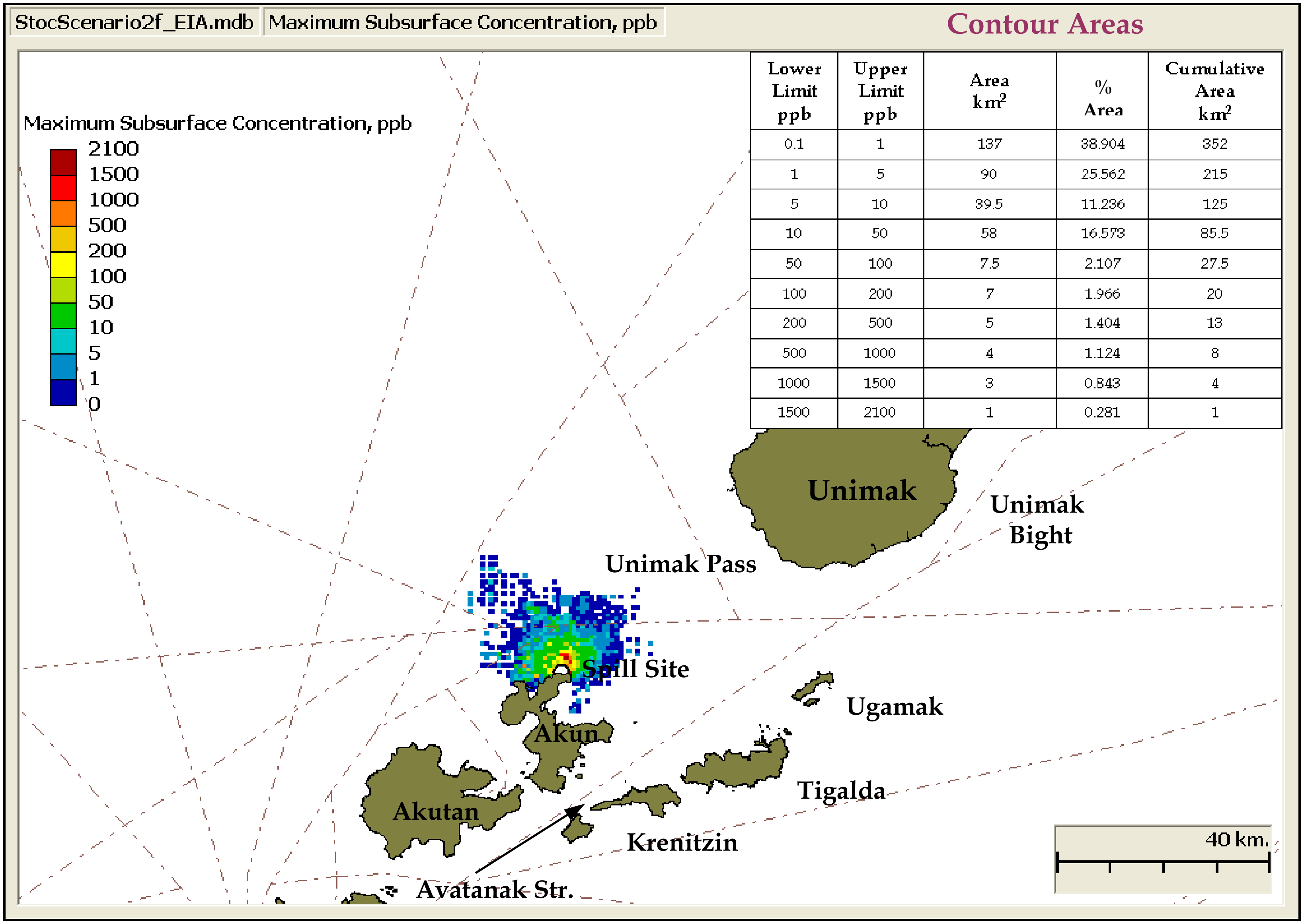
Lower Limit %	Upper Limit %	Area km²	% Area	Cumulative Area km²
0.1	10	0.5	0.013	0.5
10	20	0	0.000	0.5
20	30	0	0.000	0.5
30	40	0	0.000	0.5
40	50	0	0.000	0.5
50	60	0	0.000	0.5
60	70	0	0.000	0.5
70	80	0.5	0.013	1.0
80	90	32	0.831	33
90	100	3838	99.144	3871

Figure 6-15 Maximum LNG thickness for Scenario 2 LNG spill



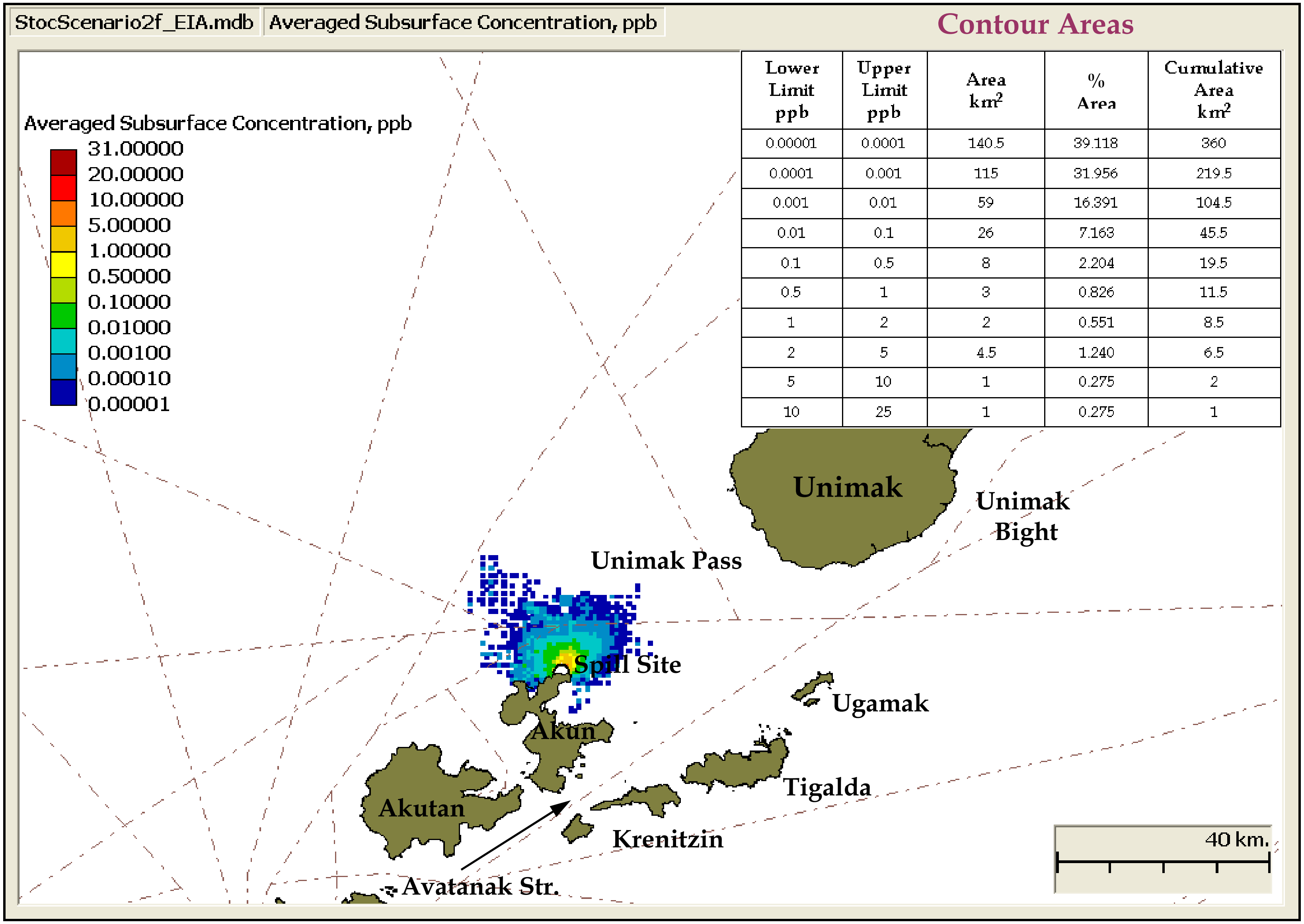
Lower Limit mm	Upper Limit mm	Area km^2	% Area	Cumulative Area km^2
0.000005	0.000010	53	7.5	706
0.000010	0.000100	122	17.25	653
0.000100	0.001000	159	22.58	531
0.001000	0.010000	298	42.21	372
0.010000	0.100000	63	8.9	74
0.100000	1.000000	8	1.12	11
1.000000	5.000000	2.5	0.35	3
5.000000	10.000000	0	0	0.5
10.000000	30.000000	0	0	0.5
30.000000	50.000000	0.5	0.07	0.5

Figure 6-16 Maximum water column concentration at any vertical location for Scenario 2 LNG spill



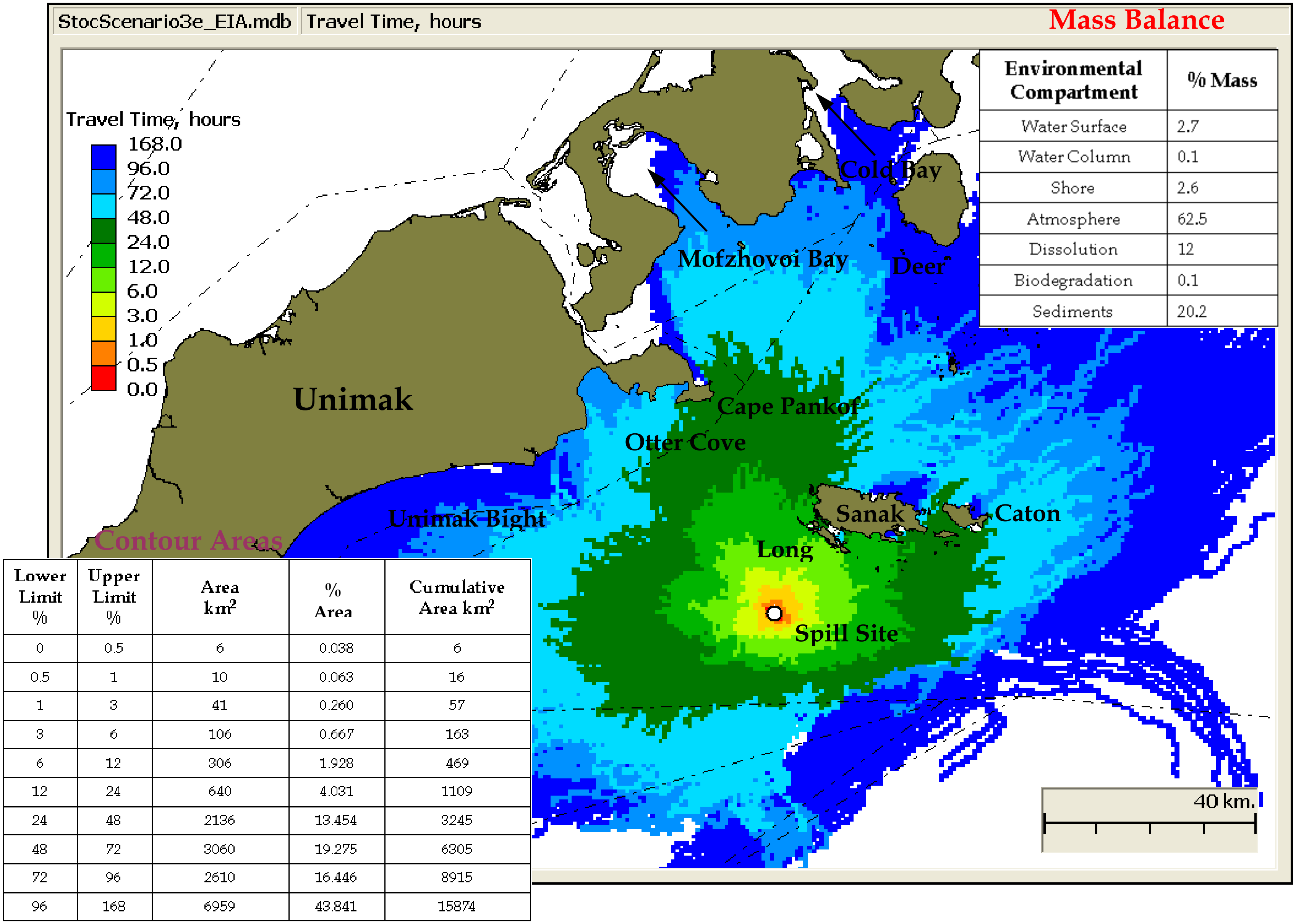
Lower Limit ppb	Upper Limit ppb	Area km²	% Area	Cumulative Area km²
0.1	1	137	38.904	352
1	5	90	25.562	215
5	10	39.5	11.236	125
10	50	58	16.573	85.5
50	100	7.5	2.107	27.5
100	200	7	1.966	20
200	500	5	1.404	13
500	1000	4	1.124	8
1000	1500	3	0.843	4
1500	2100	1	0.281	1

Figure 6-17 Maximum simulation averaged water column concentration at any vertical location for Scenario 2 LNG spill



Lower Limit ppb	Upper Limit ppb	Area km^2	% Area	Cumulative Area km^2
0.00001	0.0001	140.5	39.118	360
0.0001	0.001	115	31.956	219.5
0.001	0.01	59	16.391	104.5
0.01	0.1	26	7.163	45.5
0.1	0.5	8	2.204	19.5
0.5	1	3	0.826	11.5
1	2	2	0.551	8.5
2	5	4.5	1.240	6.5
5	10	1	0.275	2
10	25	1	0.275	1

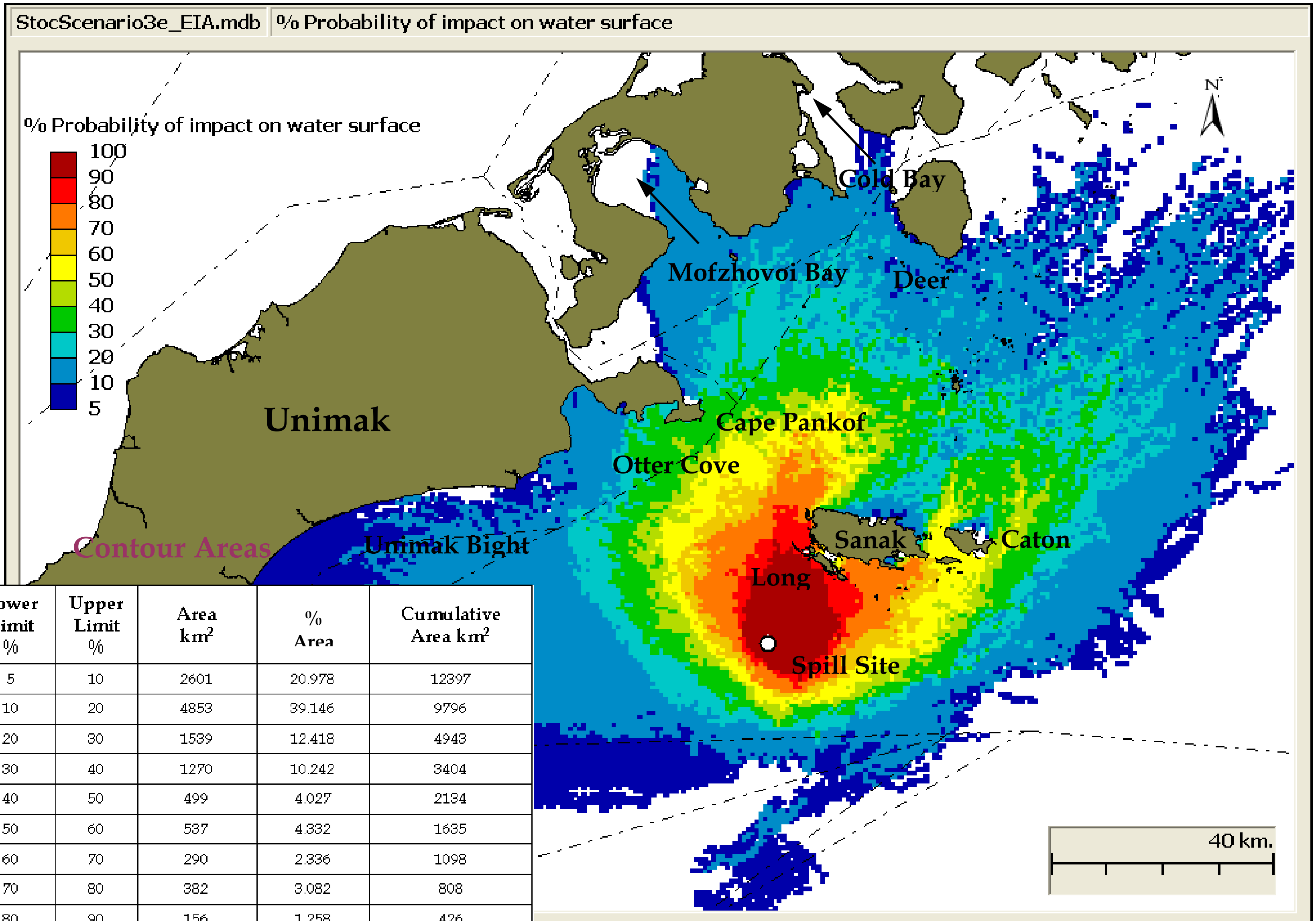
Figure 6-18 Travel time for Scenario 3 Diesel spill



Environmental Compartment	% Mass
Water Surface	2.7
Water Column	0.1
Shore	2.6
Atmosphere	62.5
Dissolution	12
Biodegradation	0.1
Sediments	20.2

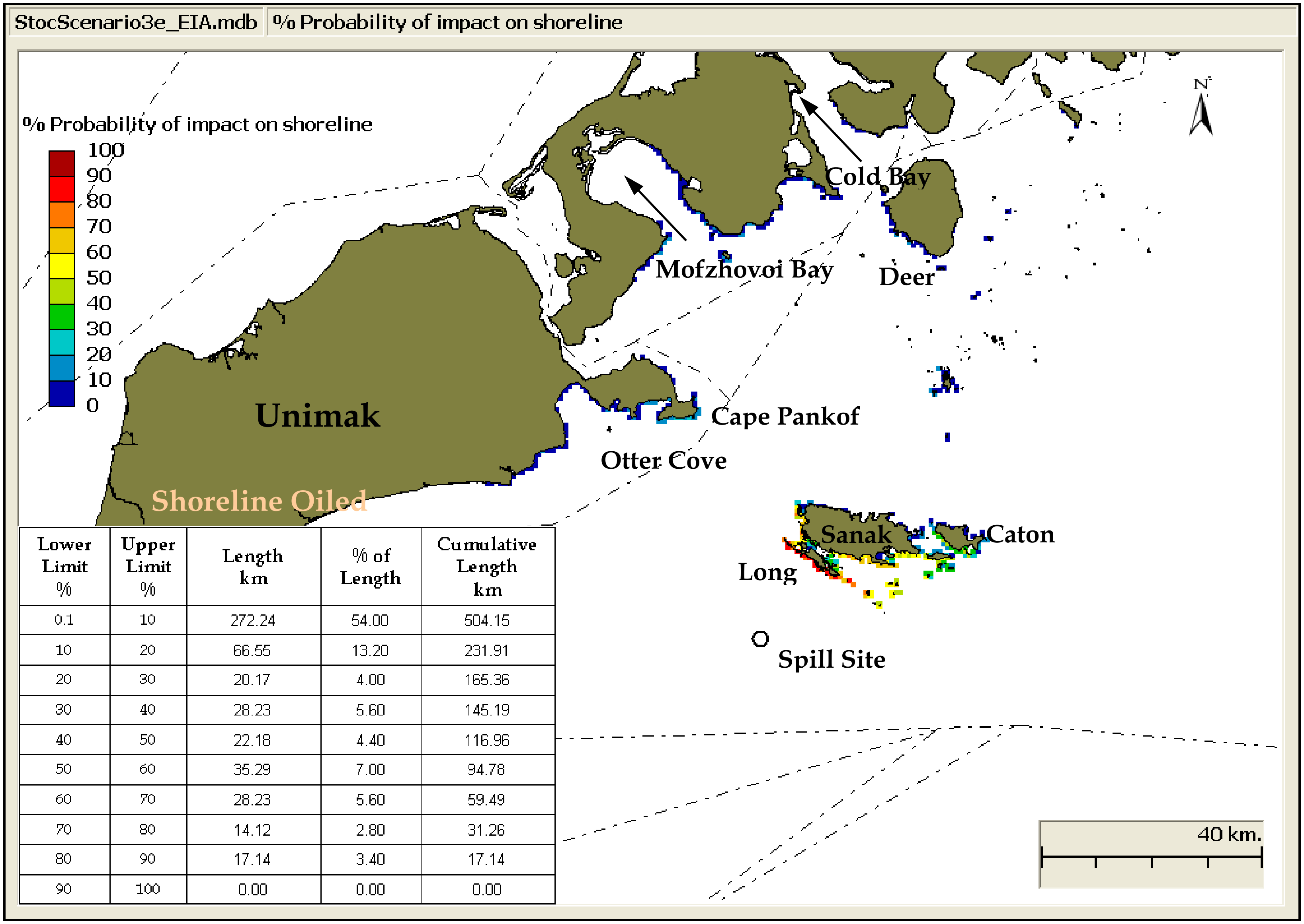
Lower Limit %	Upper Limit %	Area km²	% Area	Cumulative Area km²
0	0.5	6	0.038	6
0.5	1	10	0.063	16
1	3	41	0.260	57
3	6	106	0.667	163
6	12	306	1.928	469
12	24	640	4.031	1109
24	48	2136	13.454	3245
48	72	3060	19.275	6305
72	96	2610	16.446	8915
96	168	6959	43.841	15874

Figure 6-19 Probability of impact on water surface for Scenario 3 Diesel spill



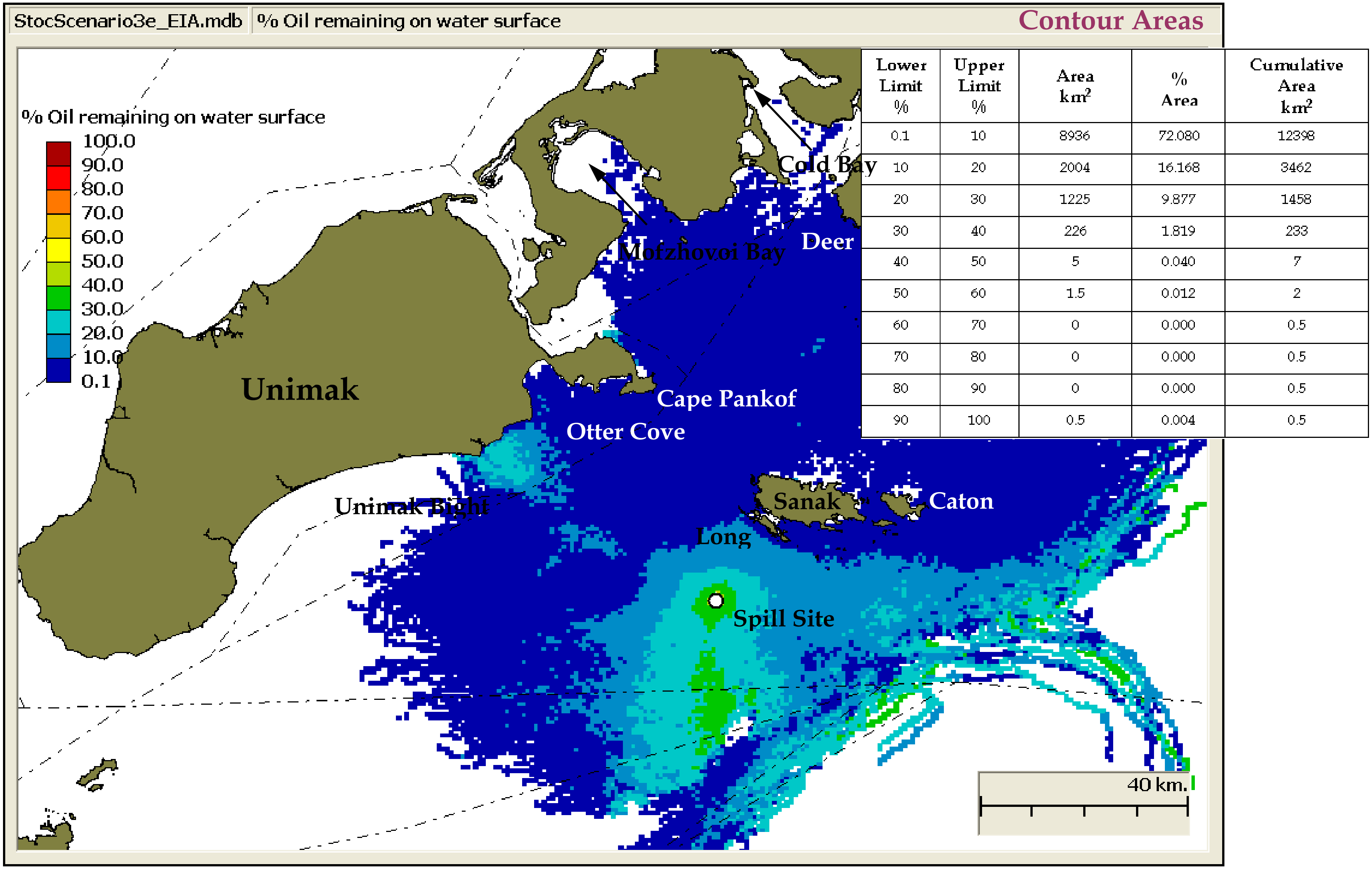
Lower Limit %	Upper Limit %	Area km²	% Area	Cumulative Area km²
5	10	2601	20.978	12397
10	20	4853	39.146	9796
20	30	1539	12.418	4943
30	40	1270	10.242	3404
40	50	499	4.027	2134
50	60	537	4.332	1635
60	70	290	2.336	1098
70	80	382	3.082	808
80	90	156	1.258	426
90	100	270	2.180	270

Figure 6-20 Probability of impact on shoreline for Scenario 3 Diesel spill



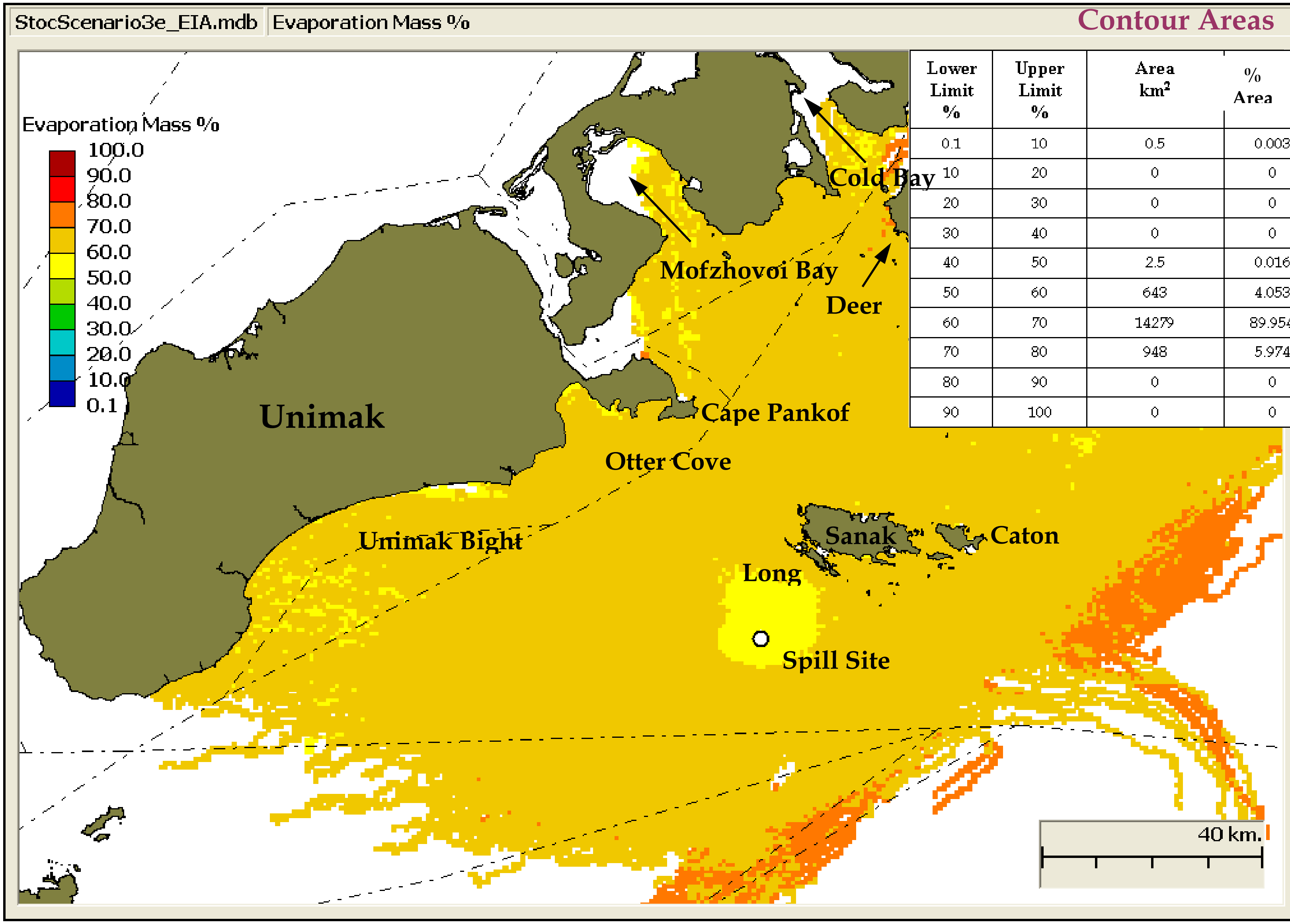
Lower Limit %	Upper Limit %	Length km	% of Length	Cumulative Length km
0.1	10	272.24	54.00	504.15
10	20	66.55	13.20	231.91
20	30	20.17	4.00	165.36
30	40	28.23	5.60	145.19
40	50	22.18	4.40	116.96
50	60	35.29	7.00	94.78
60	70	28.23	5.60	59.49
70	80	14.12	2.80	31.26
80	90	17.14	3.40	17.14
90	100	0.00	0.00	0.00

Figure 6-21 Percent oil remaining on water surface for Scenario 3 Diesel spill



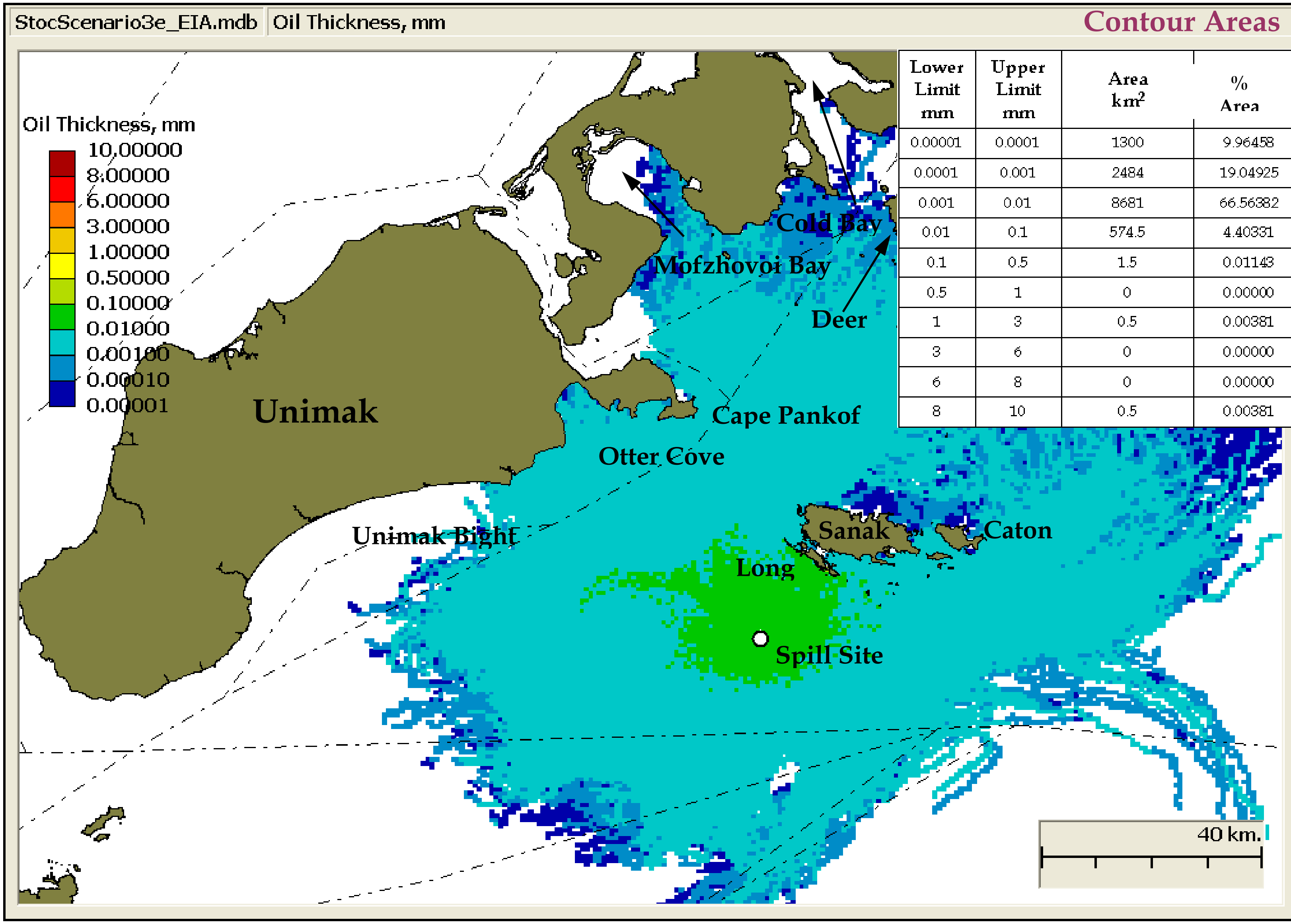
Lower Limit %	Upper Limit %	Area km²	% Area	Cumulative Area km²
0.1	10	8936	72.080	12398
10	20	2004	16.168	3462
20	30	1225	9.877	1458
30	40	226	1.819	233
40	50	5	0.040	7
50	60	1.5	0.012	2
60	70	0	0.000	0.5
70	80	0	0.000	0.5
80	90	0	0.000	0.5
90	100	0.5	0.004	0.5

Figure 6-22 Percent oil lost by evaporation for Scenario 3 Diesel spill



Lower Limit %	Upper Limit %	Area km²	% Area	Cumulative Area km²
0.1	10	0.5	0.003	0.5
10	20	0	0	0.5
20	30	0	0	0.5
30	40	0	0	0.5
40	50	2.5	0.016	3
50	60	643	4.053	646
60	70	14279	89.954	14925
70	80	948	5.974	15873
80	90	0	0	15873
90	100	0	0	15873

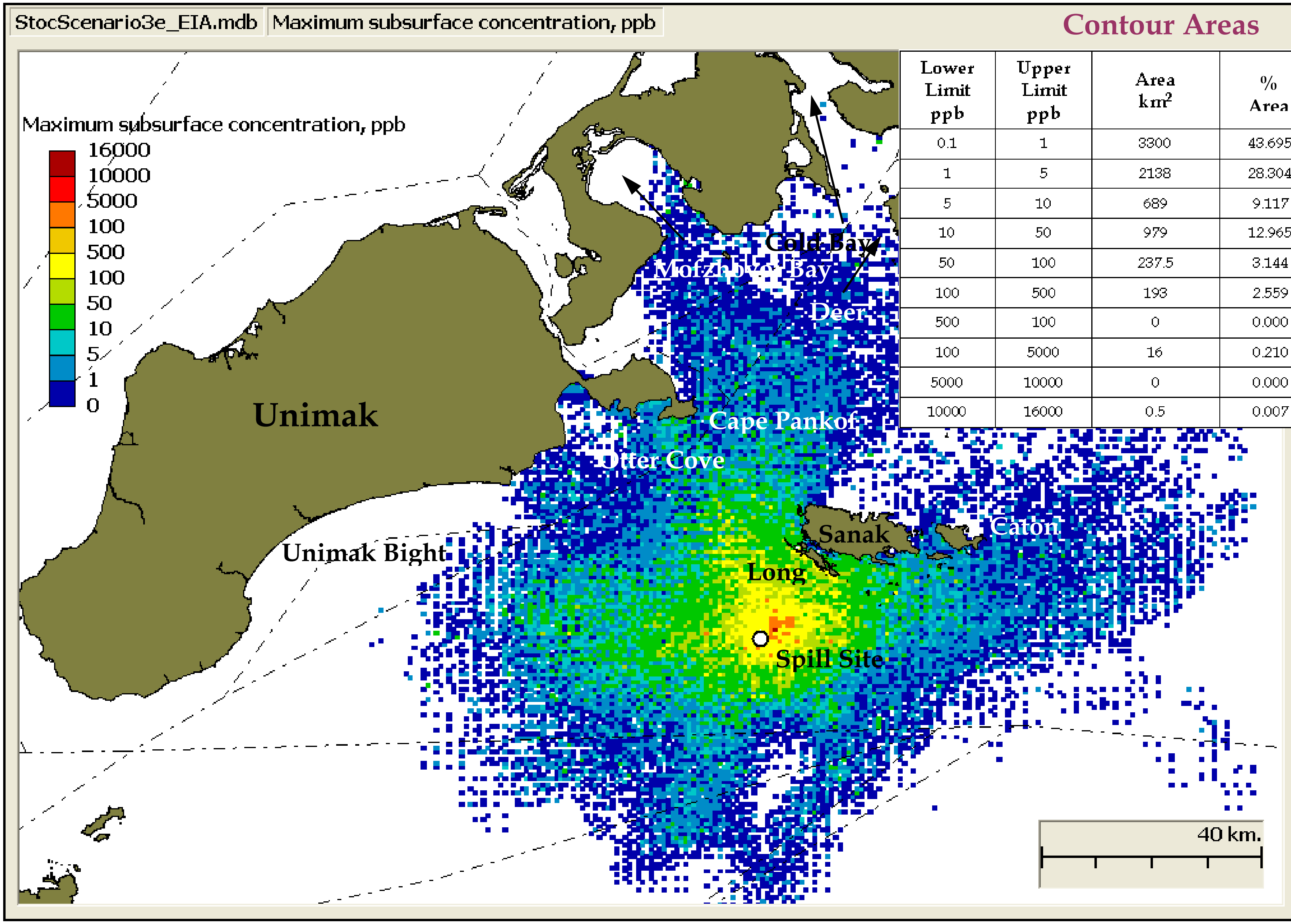
Figure 6-23 Maximum oil thickness for Scenario 3 Diesel spill



Contour Areas

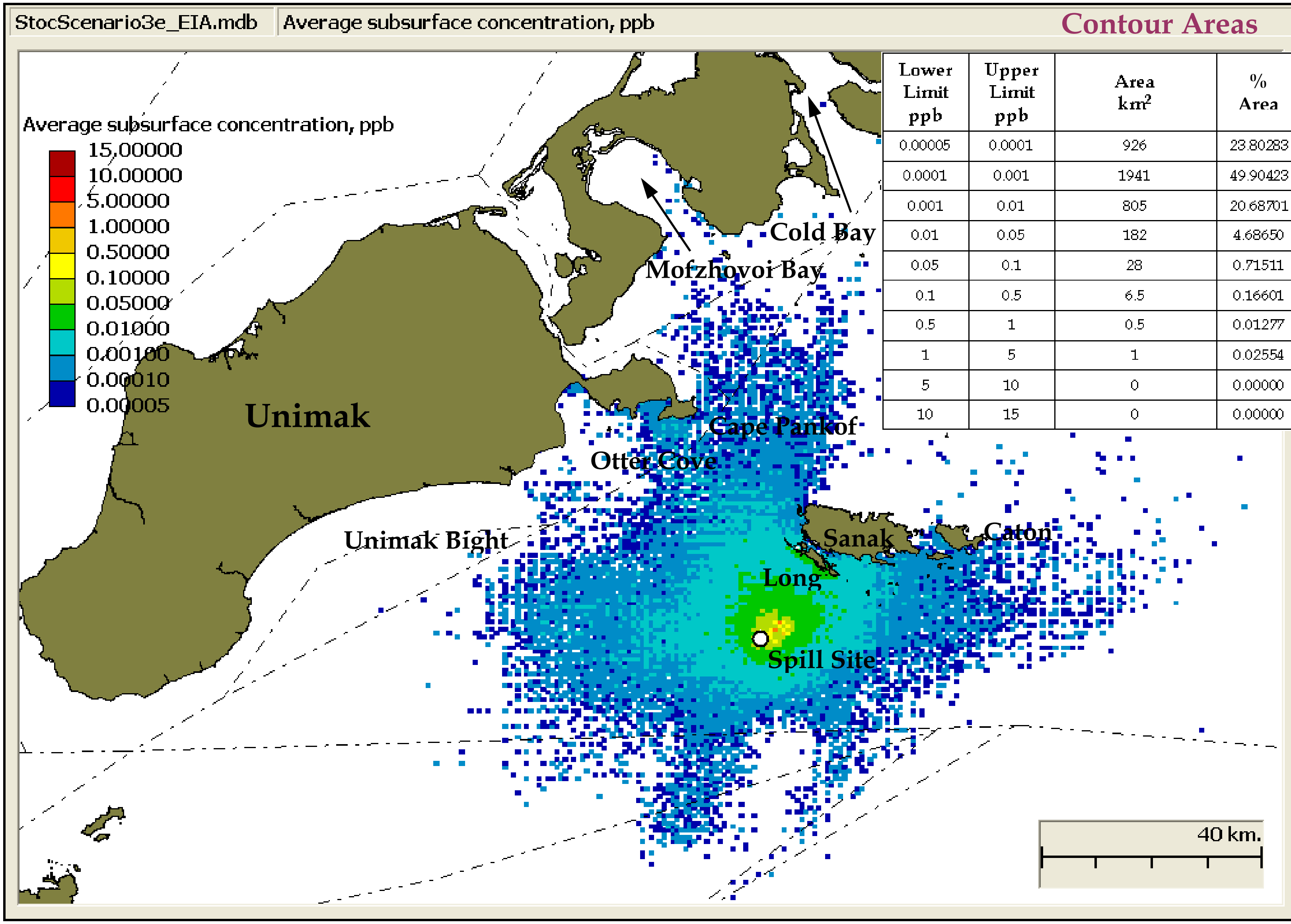
Lower Limit mm	Upper Limit mm	Area km²	% Area	Cumulative Area km²
0.00001	0.0001	1300	9.96458	13042
0.0001	0.001	2484	19.04925	11742
0.001	0.01	8681	66.56382	9258
0.01	0.1	574.5	4.40331	577
0.1	0.5	1.5	0.01143	2.5
0.5	1	0	0.00000	1
1	3	0.5	0.00381	1
3	6	0	0.00000	0.5
6	8	0	0.00000	0.5
8	10	0.5	0.00381	0.5

Figure 6-24 Maximum water column concentration at any vertical location for Scenario 3 Diesel spill



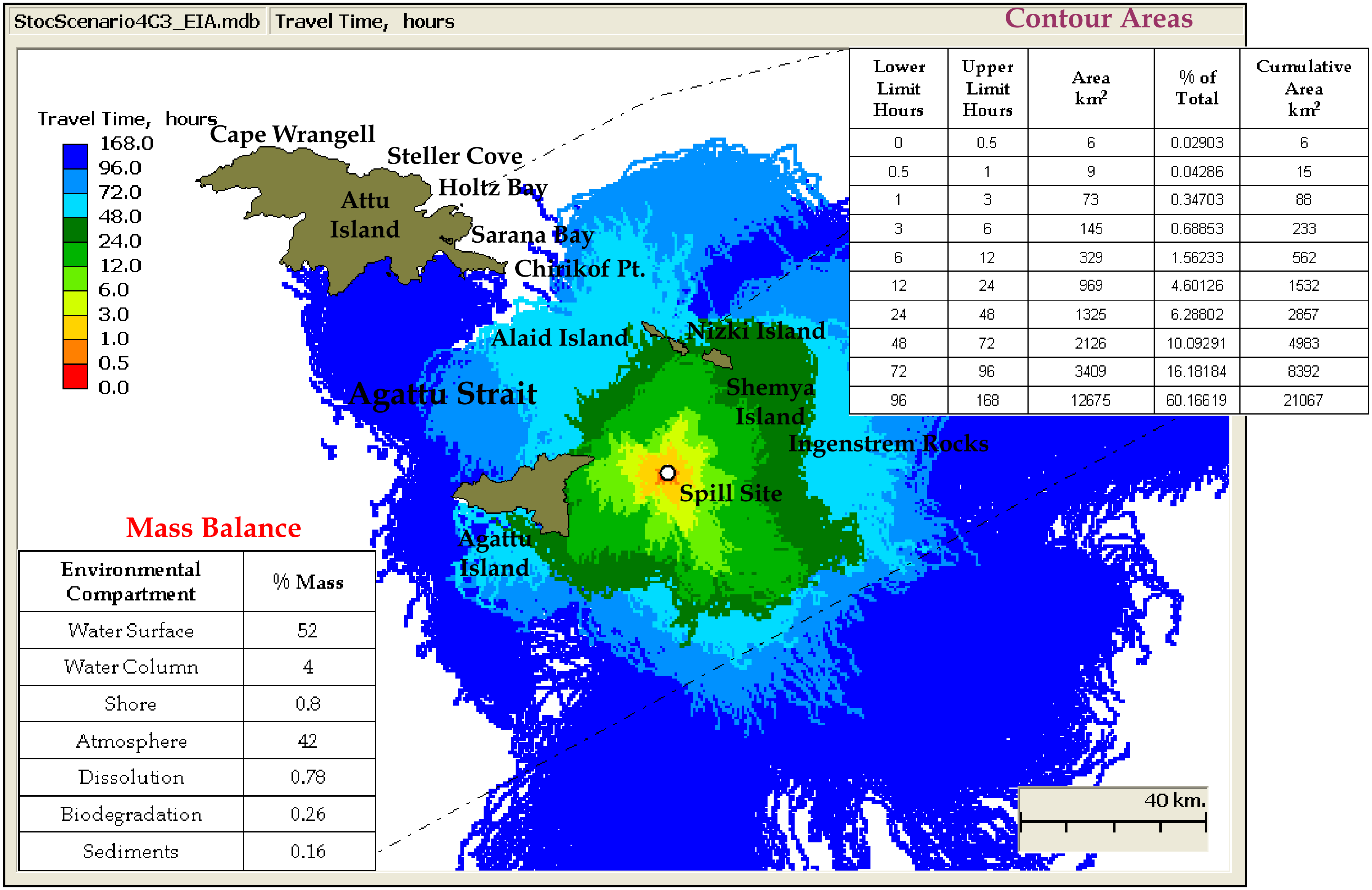
Lower Limit ppb	Upper Limit ppb	Area km^2	% Area	Cumulative Area km^2
0.1	1	3300	43.695	7553
1	5	2138	28.304	4253
5	10	689	9.117	2115
10	50	979	12.965	1426
50	100	237.5	3.144	447
100	500	193	2.559	209.5
500	100	0	0.000	16.5
100	5000	16	0.210	16.5
5000	10000	0	0.000	0.5
10000	16000	0.5	0.007	0.5

Figure 6-25 Maximum simulation averaged water column concentration at any vertical location for Scenario 3 Diesel spill



Lower Limit ppb	Upper Limit ppb	Area km^2	% Area	Cumulative Area km^2
0.00005	0.0001	926	23.80283	3890
0.0001	0.001	1941	49.90423	2964
0.001	0.01	805	20.68701	1023
0.01	0.05	182	4.68650	218
0.05	0.1	28	0.71511	36
0.1	0.5	6.5	0.16601	8
0.5	1	0.5	0.01277	1.5
1	5	1	0.02554	1
5	10	0	0.00000	0
10	15	0	0.00000	0

Figure 6-26 Travel time for Scenario 4 Crude oil spill



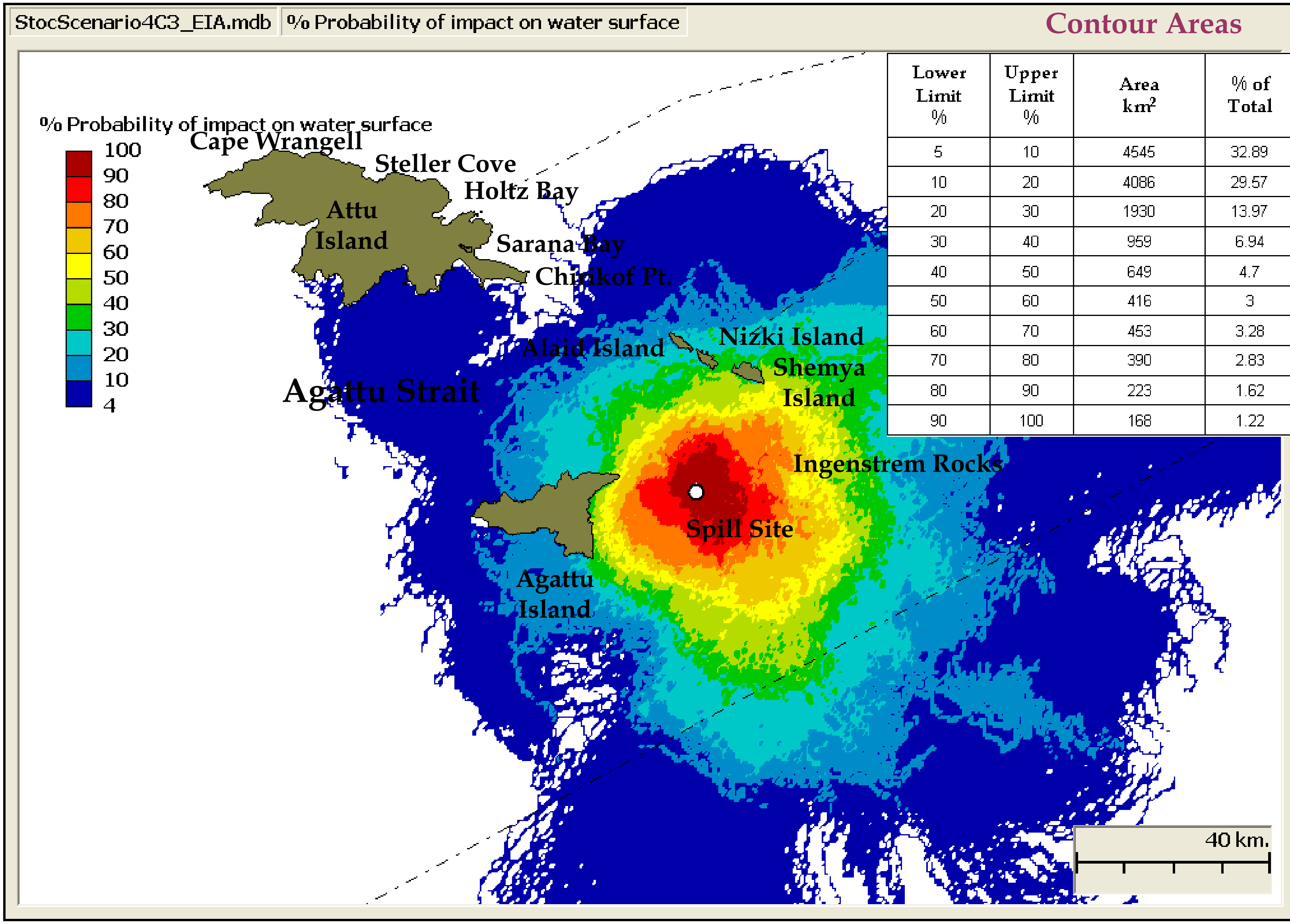
Contour Areas

Lower Limit Hours	Upper Limit Hours	Area km²	% of Total	Cumulative Area km²
0	0.5	6	0.02903	6
0.5	1	9	0.04286	15
1	3	73	0.34703	88
3	6	145	0.68853	233
6	12	329	1.56233	562
12	24	969	4.60126	1532
24	48	1325	6.28802	2857
48	72	2126	10.09291	4983
72	96	3409	16.18184	8392
96	168	12675	60.16619	21067

Mass Balance

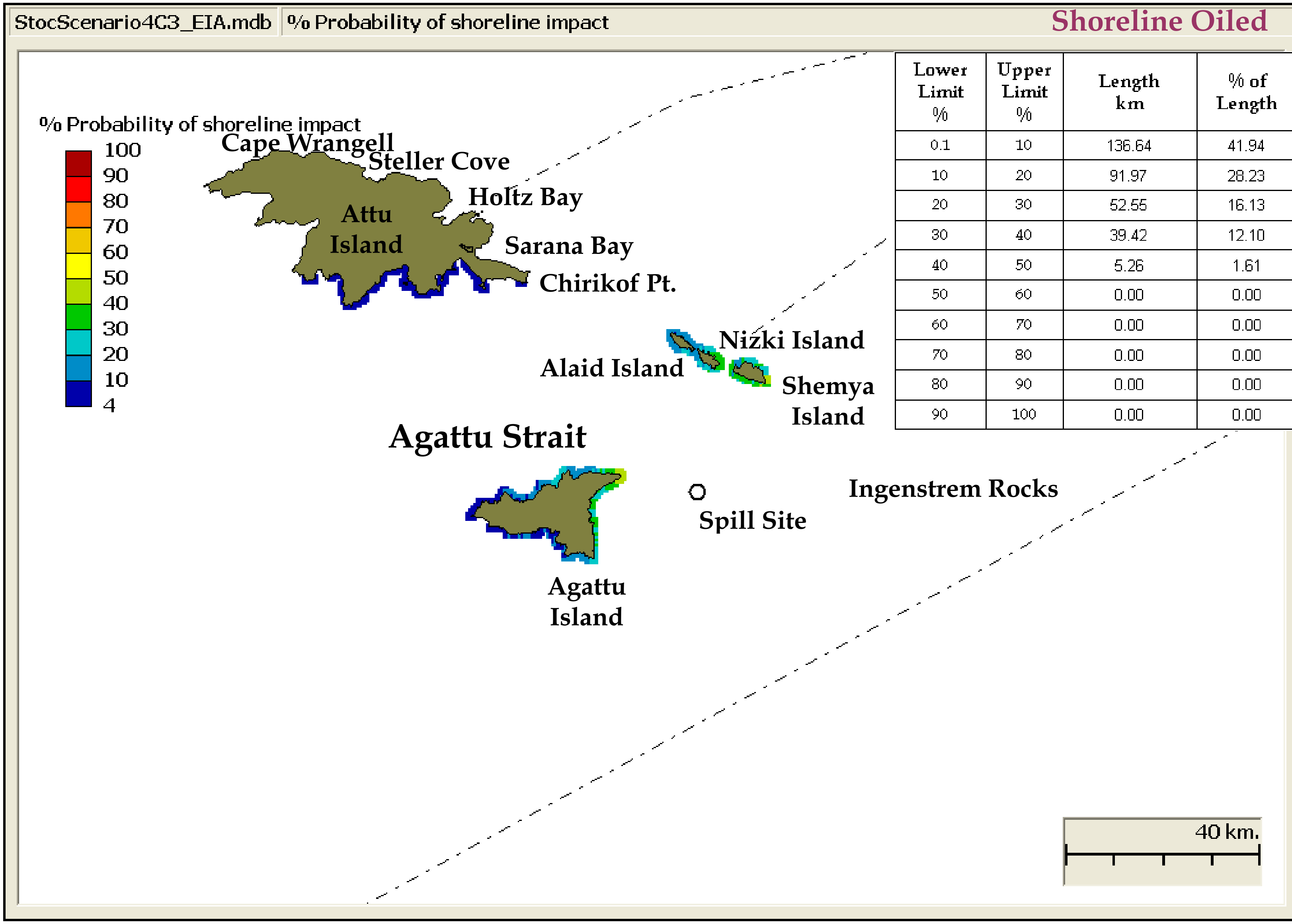
Environmental Compartment	% Mass
Water Surface	52
Water Column	4
Shore	0.8
Atmosphere	42
Dissolution	0.78
Biodegradation	0.26
Sediments	0.16

Figure 6-27 Probability of impact on water surface for Scenario 4 Crude oil spill



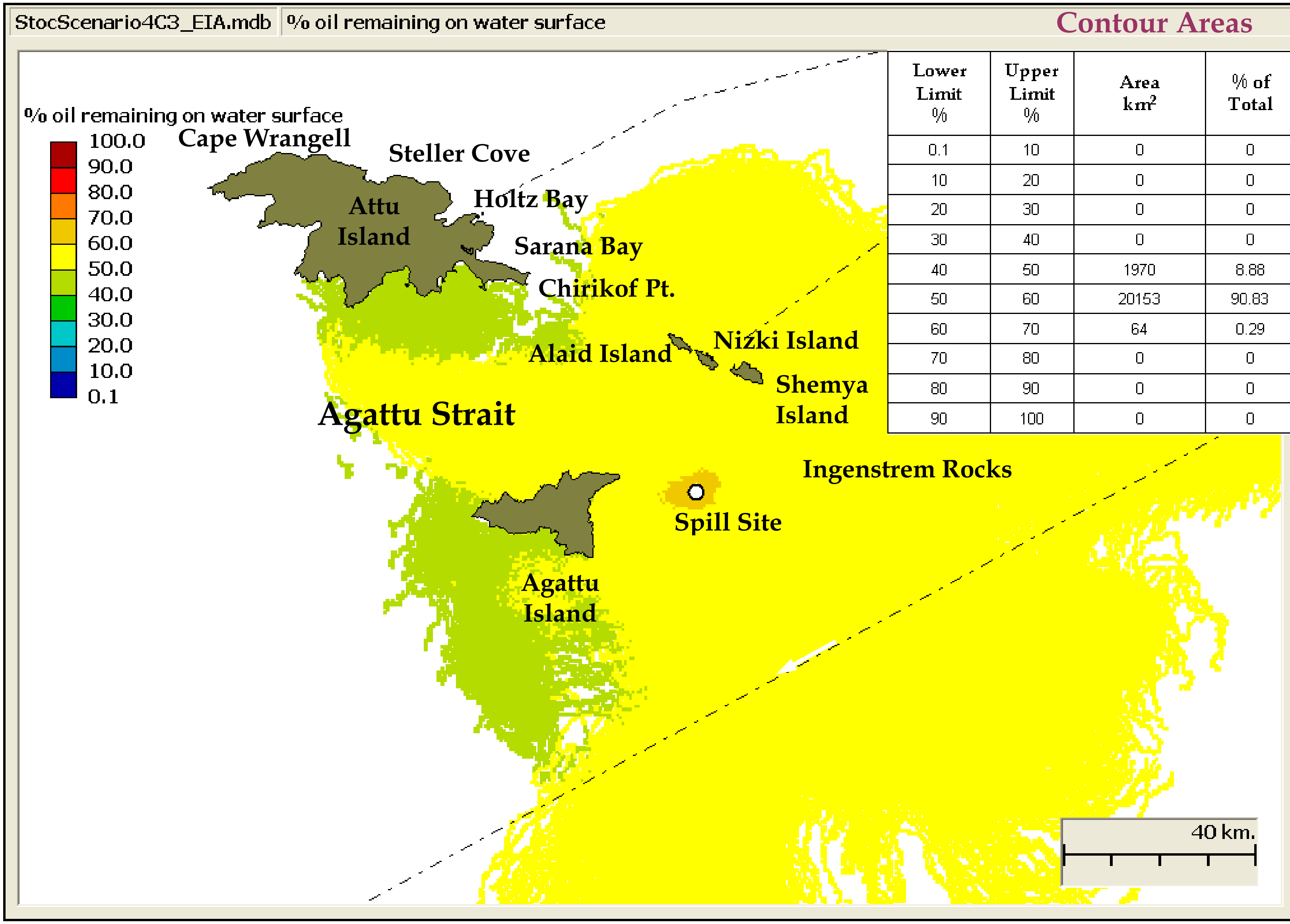
Lower Limit %	Upper Limit %	Area km^2	% of Total	Cumulative Area km^2
5	10	4545	32.89	13819
10	20	4086	29.57	9274
20	30	1930	13.97	5188
30	40	959	6.94	3258
40	50	649	4.7	2299
50	60	416	3	1650
60	70	453	3.28	1234
70	80	390	2.83	781
80	90	223	1.62	391
90	100	168	1.22	168

Figure 6-28 Probability of impact on shoreline for Scenario 4 Crude oil spill



Lower Limit %	Upper Limit %	Length km	% of Length	Cumulative Length km
0.1	10	136.64	41.94	325.84
10	20	91.97	28.23	189.19
20	30	52.55	16.13	97.23
30	40	39.42	12.10	44.67
40	50	5.26	1.61	5.26
50	60	0.00	0.00	0.00
60	70	0.00	0.00	0.00
70	80	0.00	0.00	0.00
80	90	0.00	0.00	0.00
90	100	0.00	0.00	0.00

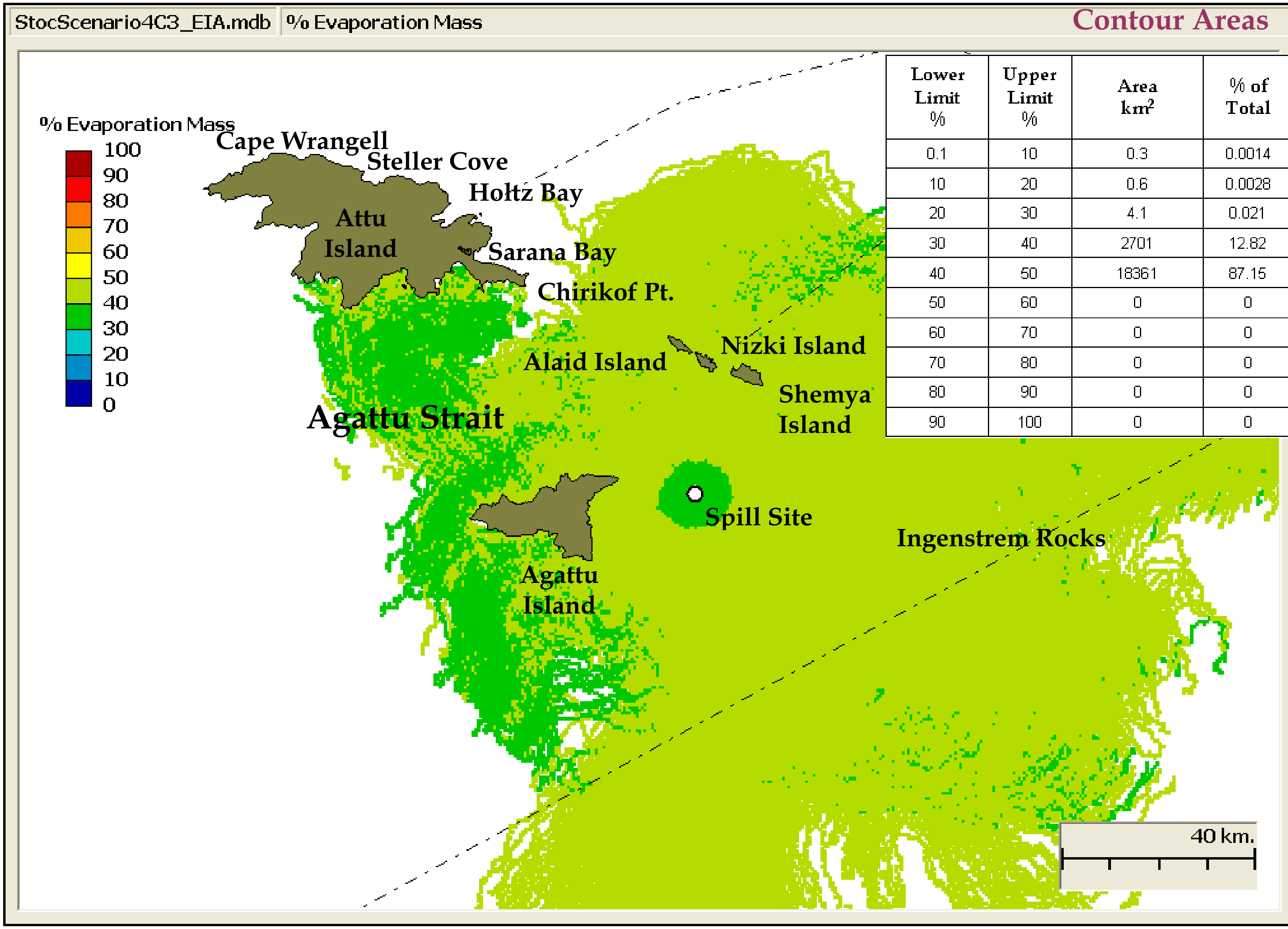
Figure 6-29 Percent oil remaining on water surface for Scenario 4 Crude Oil spill



Contour Areas

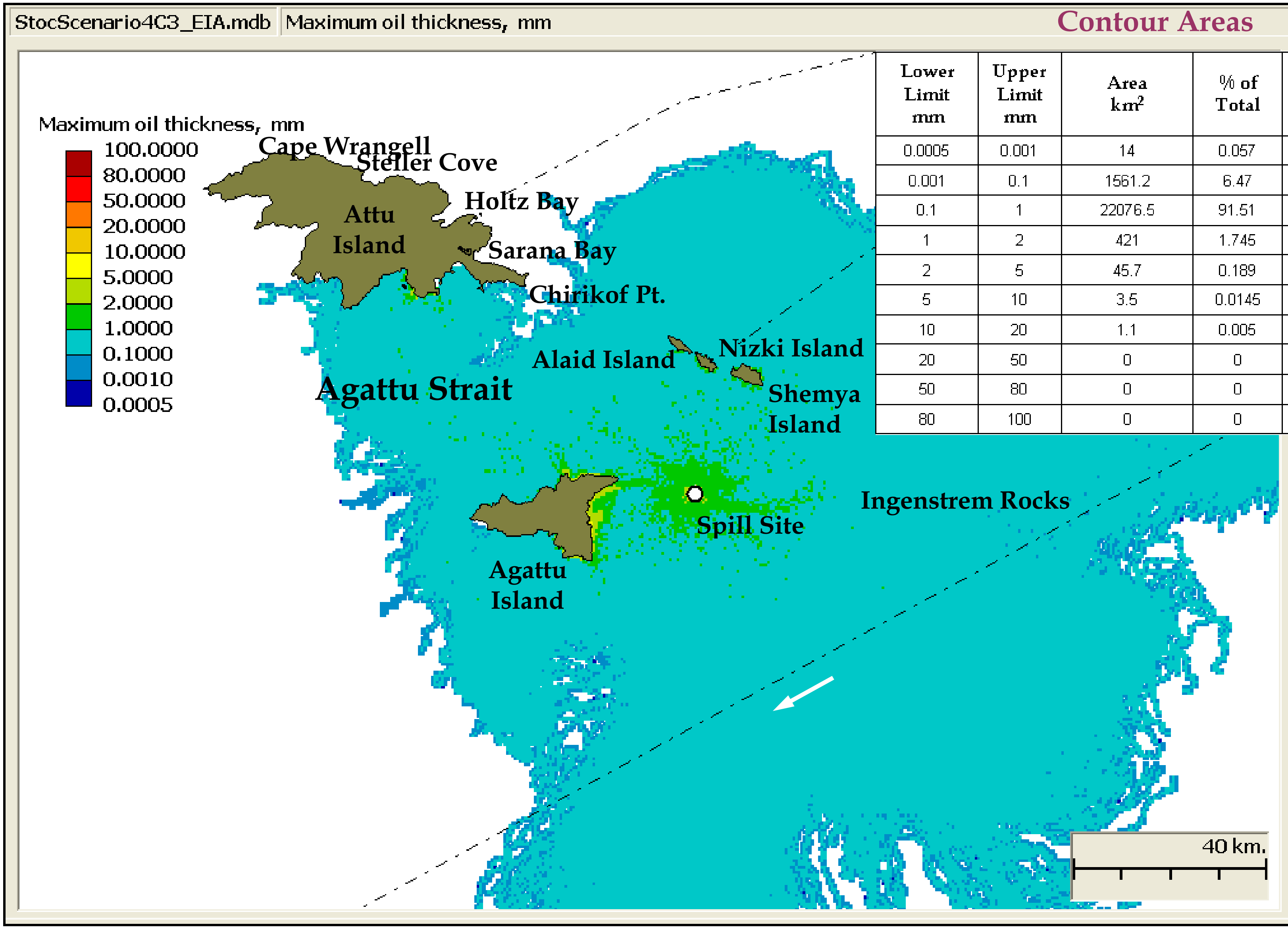
Lower Limit %	Upper Limit %	Area km²	% of Total	Cumulative Area km²
0.1	10	0	0	22187
10	20	0	0	22187
20	30	0	0	22187
30	40	0	0	22187
40	50	1970	8.88	22187
50	60	20153	90.83	20217
60	70	64	0.29	64
70	80	0	0	0
80	90	0	0	0
90	100	0	0	0

Figure 6-30 Percent oil lost by evaporation for Scenario 4 Crude Oil spill



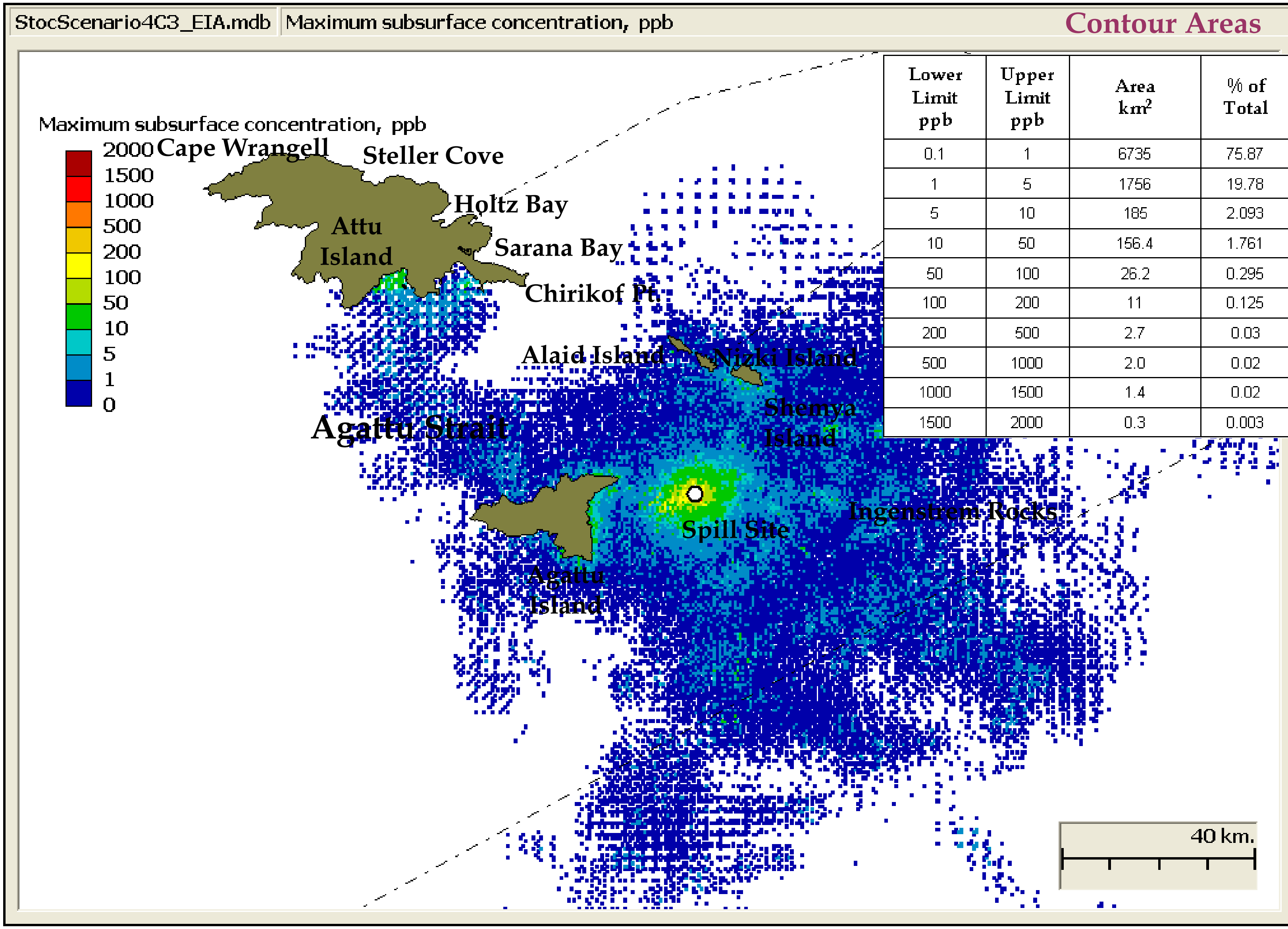
Lower Limit %	Upper Limit %	Area km²	% of Total	Cumulative Area km²
0.1	10	0.3	0.0014	21067
10	20	0.6	0.0028	21066.7
20	30	4.1	0.021	21066.1
30	40	2701	12.82	21062
40	50	18361	87.15	18361
50	60	0	0	0
60	70	0	0	0
70	80	0	0	0
80	90	0	0	0
90	100	0	0	0

Figure 6-31 Maximum oil thickness for Scenario 4 Crude Oil spill



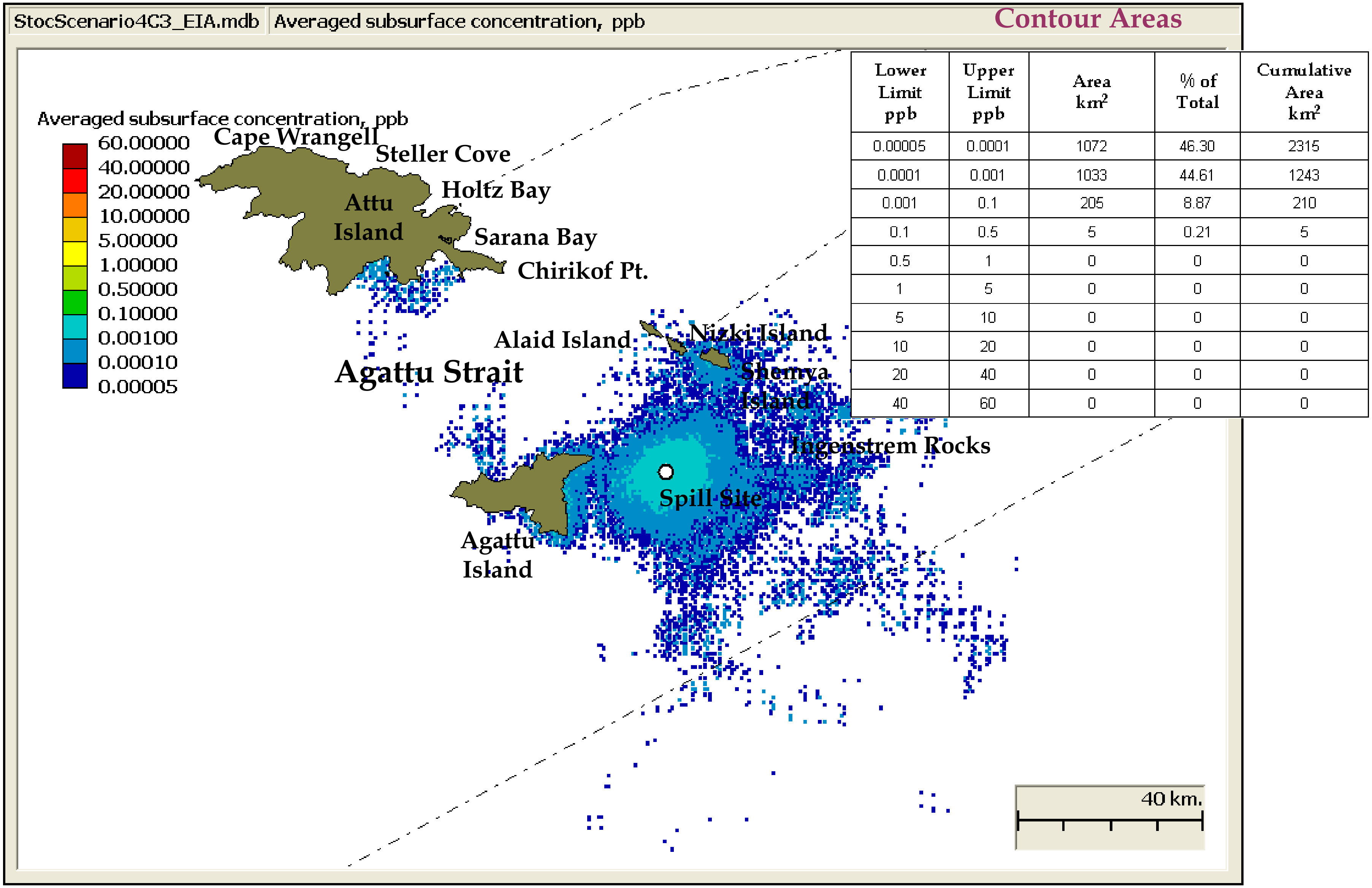
Lower Limit mm	Upper Limit mm	Area km^2	% of Total	Cumulative Area km^2
0.0005	0.001	14	0.057	24124
0.001	0.1	1561.2	6.47	24109
0.1	1	22076.5	91.51	22547.8
1	2	421	1.745	471.3
2	5	45.7	0.189	50.3
5	10	3.5	0.0145	4.6
10	20	1.1	0.005	1.1
20	50	0	0	0
50	80	0	0	0
80	100	0	0	0

Figure 6-32 Maximum water column concentration at any vertical location for Scenario 4 Crude Oil spill



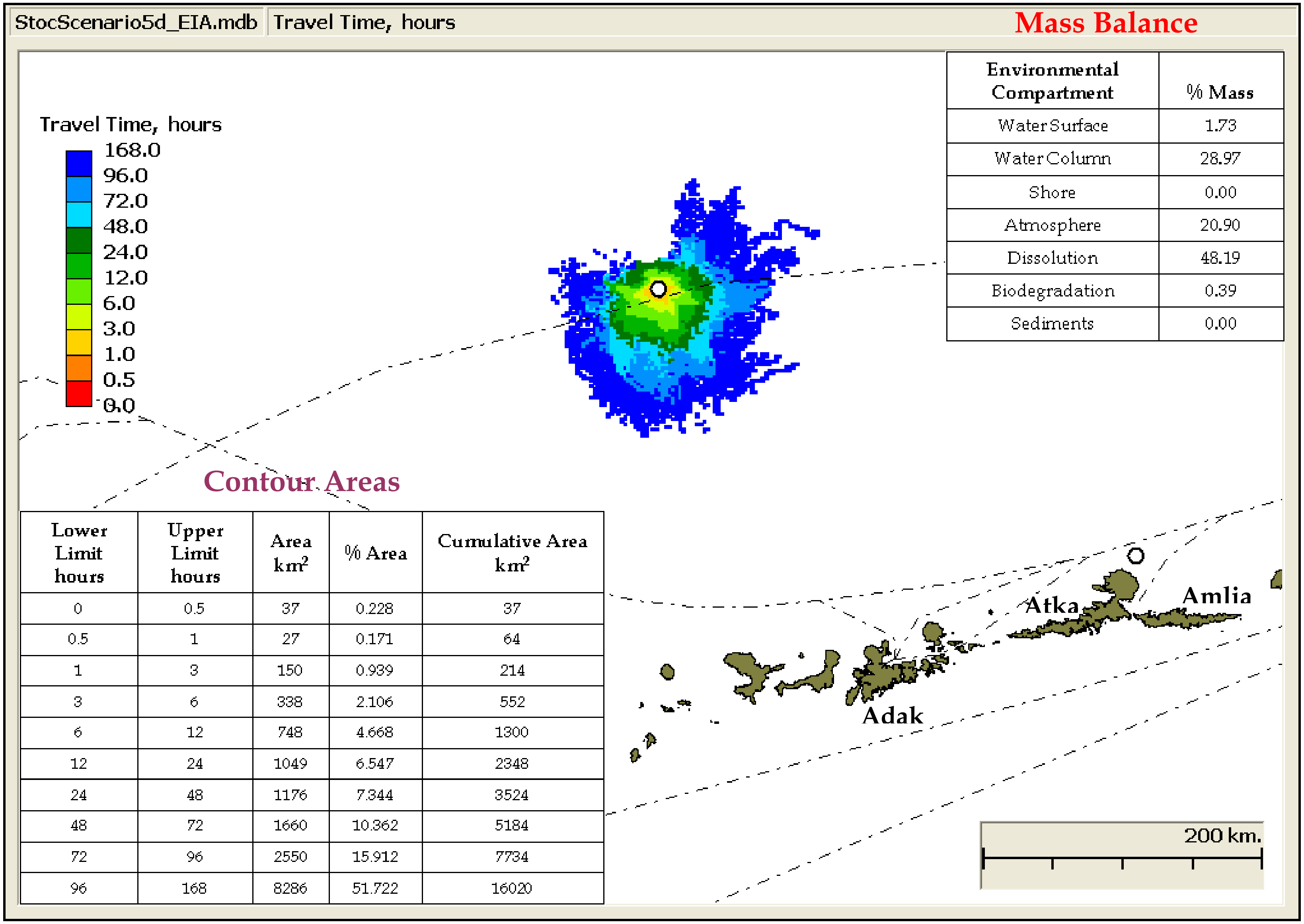
Lower Limit ppb	Upper Limit ppb	Area km^2	% of Total	Cumulative Area km^2
0.1	1	6735	75.87	8877
1	5	1756	19.78	2142
5	10	185	2.093	386
10	50	156.4	1.761	201
50	100	26.2	0.295	43.6
100	200	11	0.125	17.4
200	500	2.7	0.03	6.4
500	1000	2.0	0.02	3.7
1000	1500	1.4	0.02	1.7
1500	2000	0.3	0.003	0.3

Figure 6-33 Maximum simulation averaged water column concentration at any vertical location for Scenario 4 Crude Oil spill



Lower Limit ppb	Upper Limit ppb	Area km²	% of Total	Cumulative Area km²
0.00005	0.0001	1072	46.30	2315
0.0001	0.001	1033	44.61	1243
0.001	0.1	205	8.87	210
0.1	0.5	5	0.21	5
0.5	1	0	0	0
1	5	0	0	0
5	10	0	0	0
10	20	0	0	0
20	40	0	0	0
40	60	0	0	0

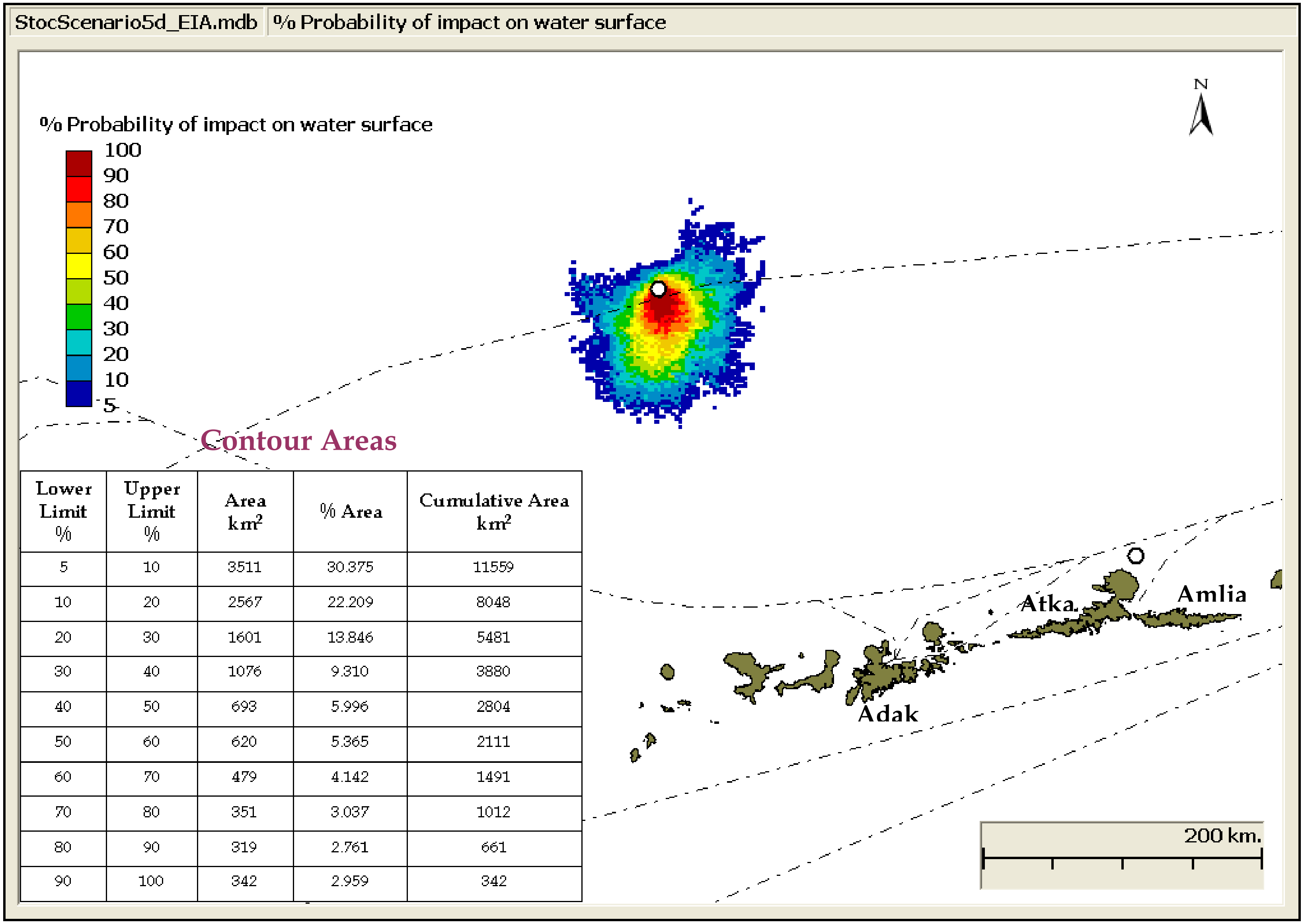
Figure 6-34 Travel time for Scenario 5 Bunker C fuel spill



Environmental Compartment	% Mass
Water Surface	1.73
Water Column	28.97
Shore	0.00
Atmosphere	20.90
Dissolution	48.19
Biodegradation	0.39
Sediments	0.00

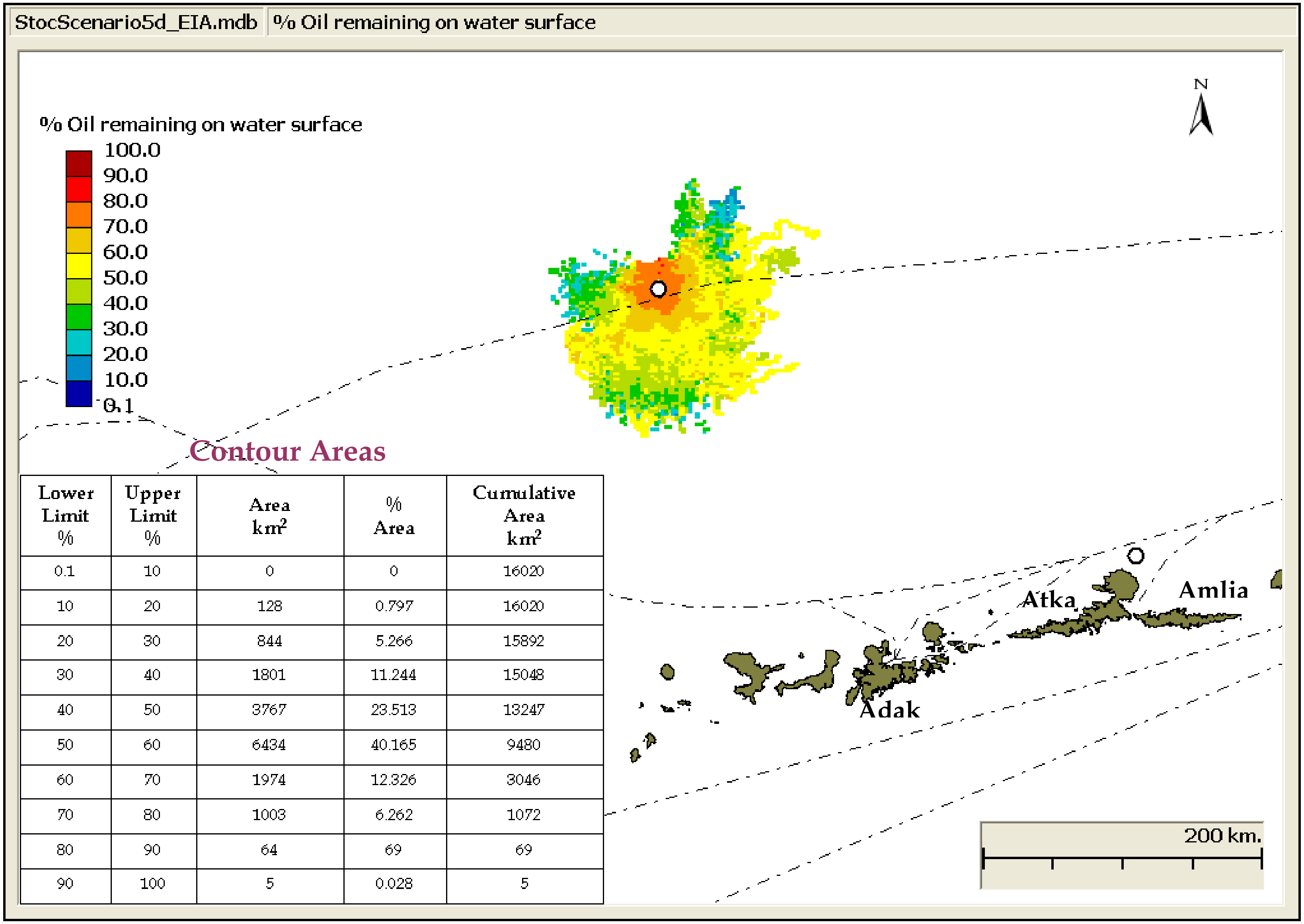
Lower Limit hours	Upper Limit hours	Area km²	% Area	Cumulative Area km²
0	0.5	37	0.228	37
0.5	1	27	0.171	64
1	3	150	0.939	214
3	6	338	2.106	552
6	12	748	4.668	1300
12	24	1049	6.547	2348
24	48	1176	7.344	3524
48	72	1660	10.362	5184
72	96	2550	15.912	7734
96	168	8286	51.722	16020

Figure 6-35 Percent probability of impact on water surface for Scenario 5 Bunker C fuel spill



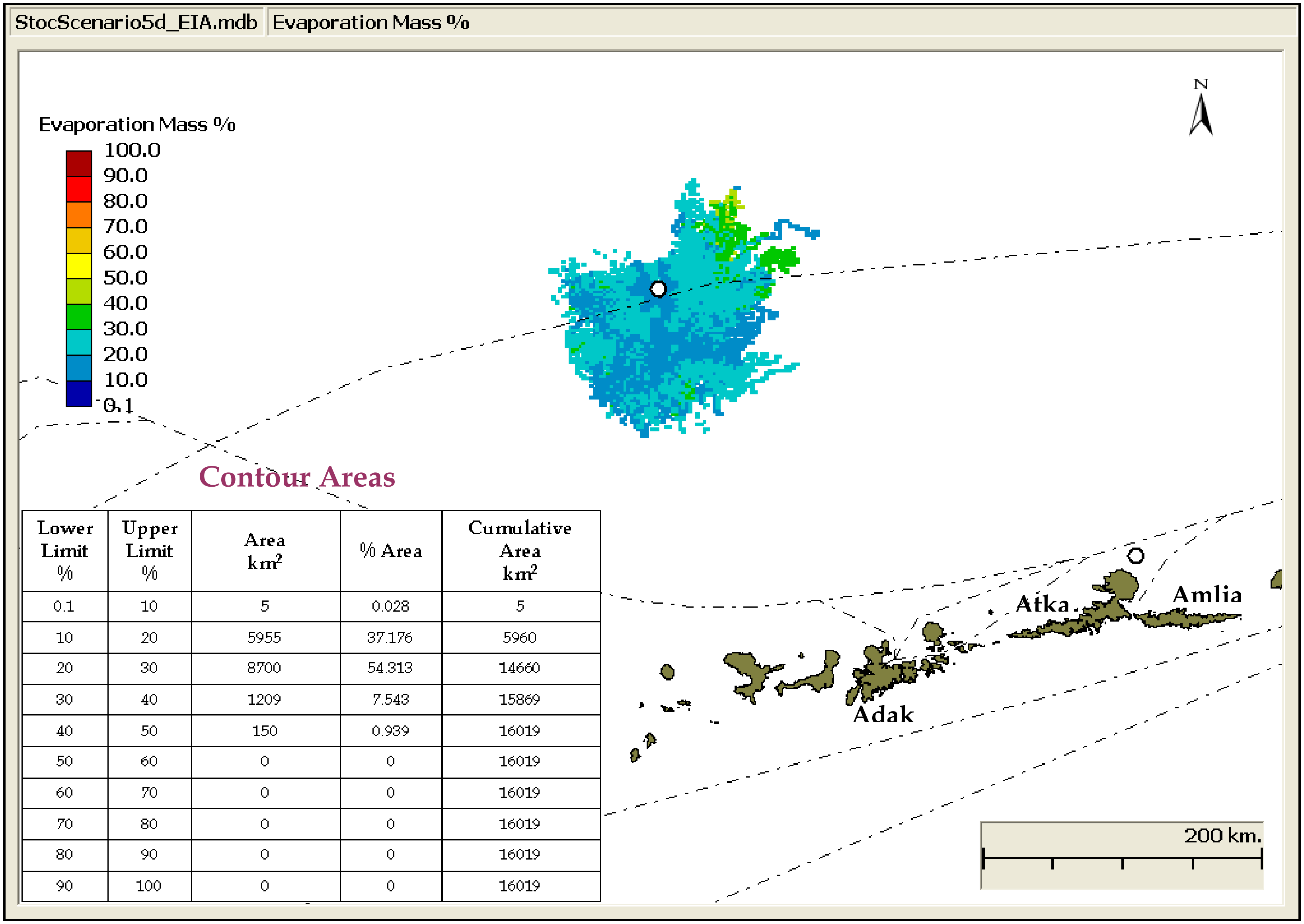
Lower Limit %	Upper Limit %	Area km²	% Area	Cumulative Area km²
5	10	3511	30.375	11559
10	20	2567	22.209	8048
20	30	1601	13.846	5481
30	40	1076	9.310	3880
40	50	693	5.996	2804
50	60	620	5.365	2111
60	70	479	4.142	1491
70	80	351	3.037	1012
80	90	319	2.761	661
90	100	342	2.959	342

Figure 6-36 Percent oil remaining on water surface for Scenario 5 Bunker C fuel spill



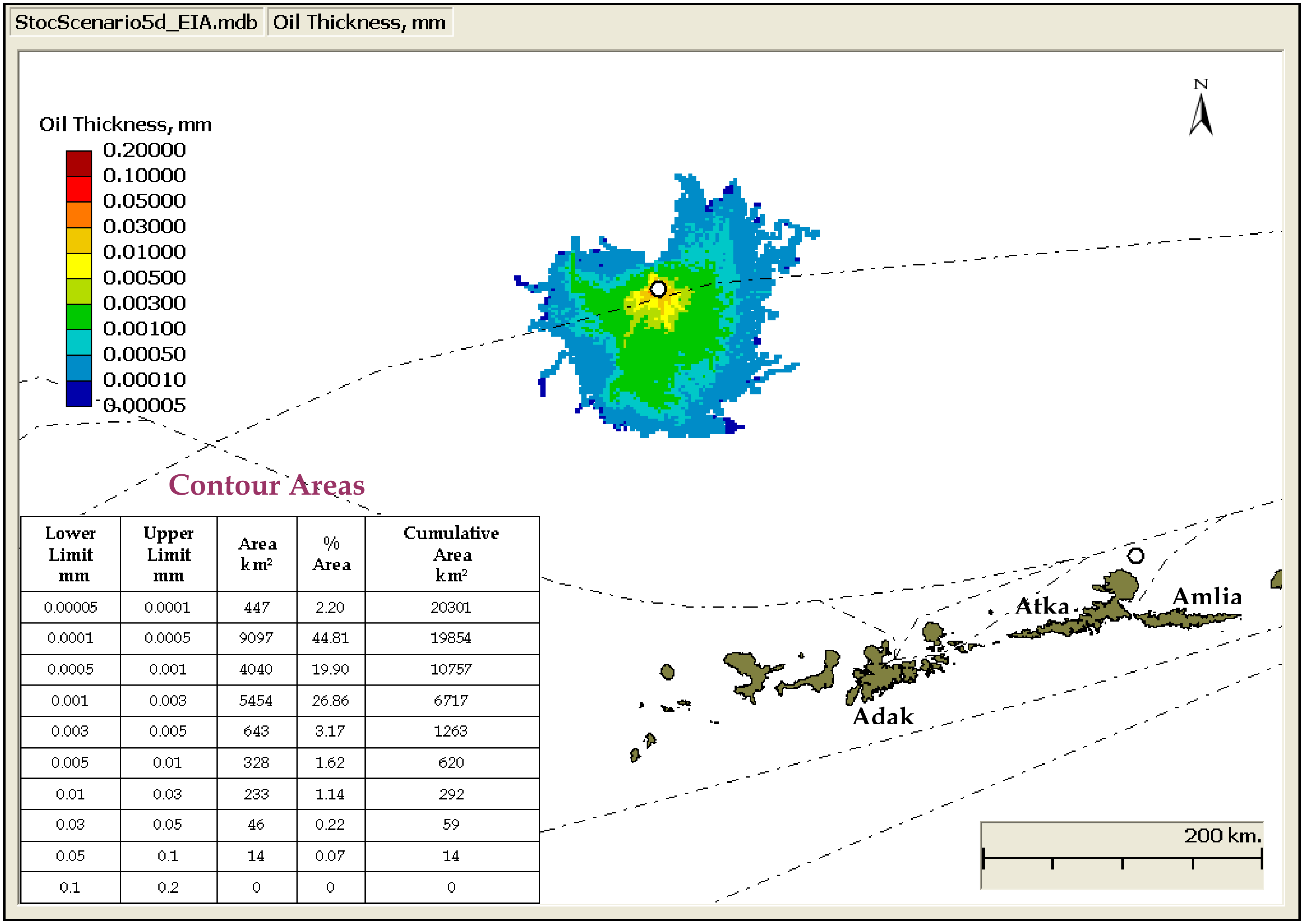
Lower Limit %	Upper Limit %	Area km²	% Area	Cumulative Area km²
0.1	10	0	0	16020
10	20	128	0.797	16020
20	30	844	5.266	15892
30	40	1801	11.244	15048
40	50	3767	23.513	13247
50	60	6434	40.165	9480
60	70	1974	12.326	3046
70	80	1003	6.262	1072
80	90	64	69	69
90	100	5	0.028	5

Figure 6-37 Percent oil lost by evaporation for Scenario 5 Bunker C fuel spill



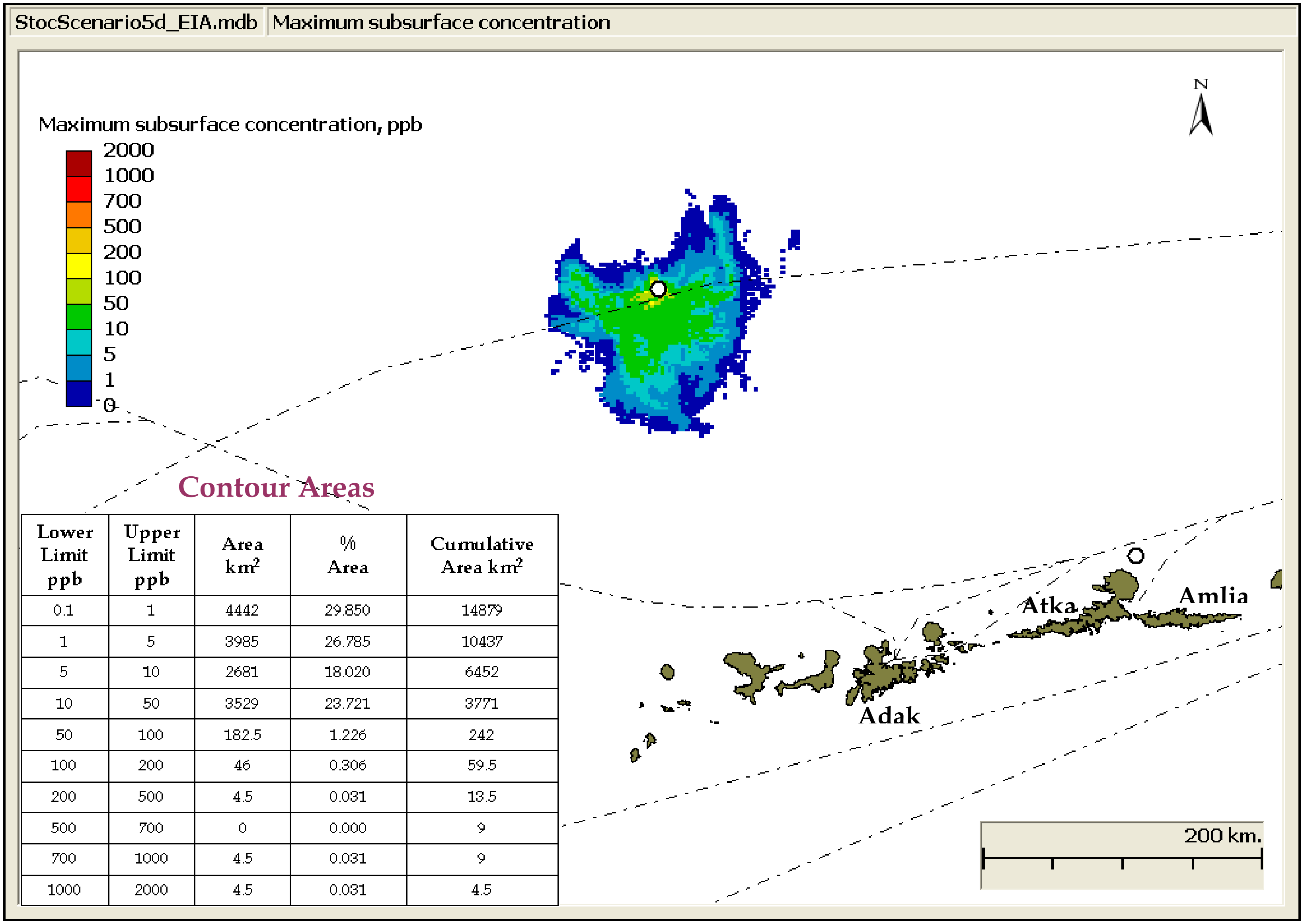
Lower Limit %	Upper Limit %	Area km²	% Area	Cumulative Area km²
0.1	10	5	0.028	5
10	20	5955	37.176	5960
20	30	8700	54.313	14660
30	40	1209	7.543	15869
40	50	150	0.939	16019
50	60	0	0	16019
60	70	0	0	16019
70	80	0	0	16019
80	90	0	0	16019
90	100	0	0	16019

Figure 6-38 Maximum oil thickness for Scenario 5 Bunker C fuel spill



Lower Limit mm	Upper Limit mm	Area km²	% Area	Cumulative Area km²
0.00005	0.0001	447	2.20	20301
0.0001	0.0005	9097	44.81	19854
0.0005	0.001	4040	19.90	10757
0.001	0.003	5454	26.86	6717
0.003	0.005	643	3.17	1263
0.005	0.01	328	1.62	620
0.01	0.03	233	1.14	292
0.03	0.05	46	0.22	59
0.05	0.1	14	0.07	14
0.1	0.2	0	0	0

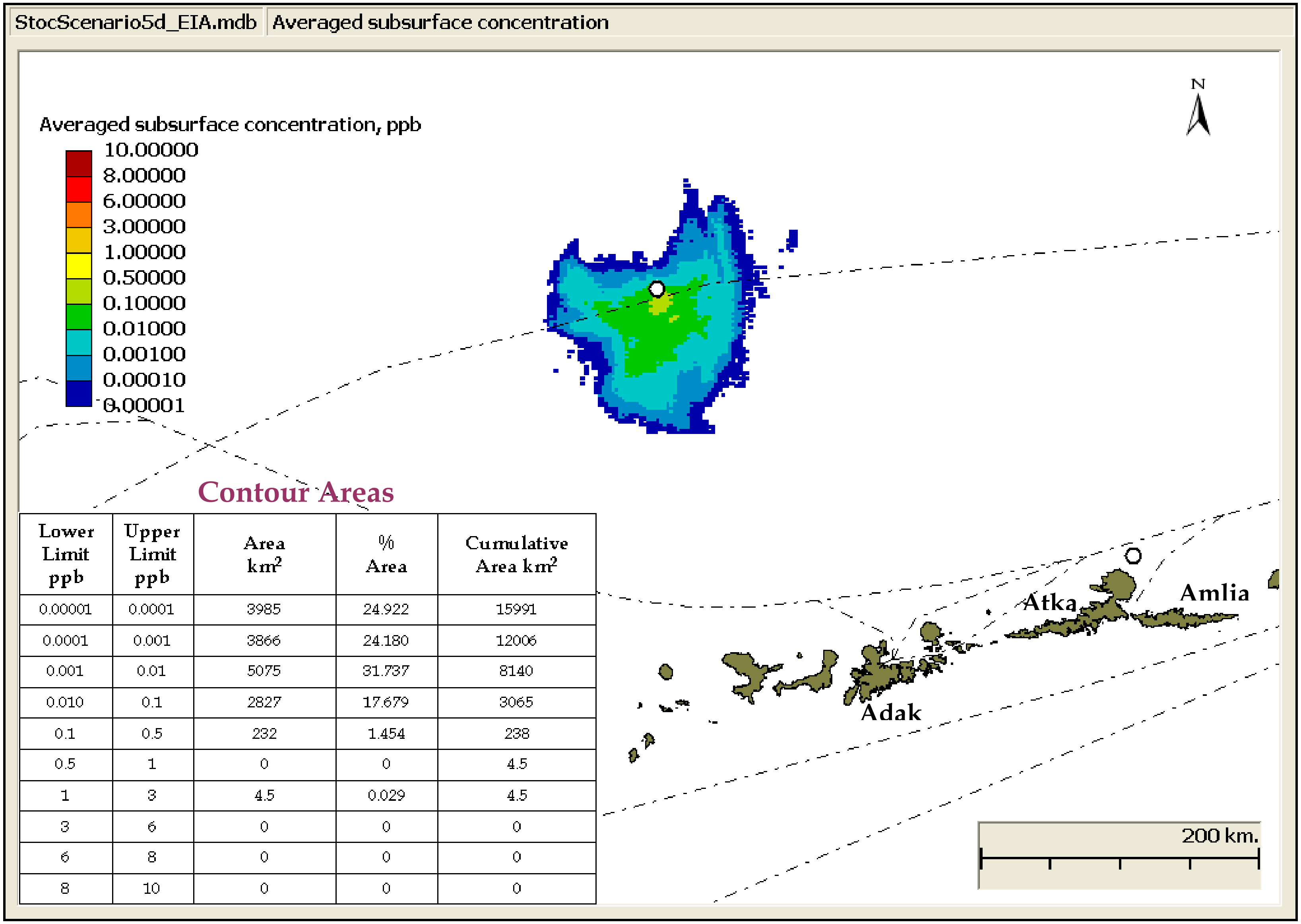
Figure 6-39 Maximum water column concentration at any vertical location for Scenario 5 Bunker C fuel spill



Contour Areas

Lower Limit ppb	Upper Limit ppb	Area km²	% Area	Cumulative Area km²
0.1	1	4442	29.850	14879
1	5	3985	26.785	10437
5	10	2681	18.020	6452
10	50	3529	23.721	3771
50	100	182.5	1.226	242
100	200	46	0.306	59.5
200	500	4.5	0.031	13.5
500	700	0	0.000	9
700	1000	4.5	0.031	9
1000	2000	4.5	0.031	4.5

Figure 6-40 Maximum simulation averaged water column concentration at any vertical location for Scenario 5 Bunker C fuel spill



Contour Areas

Lower Limit ppb	Upper Limit ppb	Area km²	% Area	Cumulative Area km²
0.00001	0.0001	3985	24.922	15991
0.0001	0.001	3866	24.180	12006
0.001	0.01	5075	31.737	8140
0.010	0.1	2827	17.679	3065
0.1	0.5	232	1.454	238
0.5	1	0	0	4.5
1	3	4.5	0.029	4.5
3	6	0	0	0
6	8	0	0	0
8	10	0	0	0

Figure 6-41 Travel time for Scenario 6 Phorate chemical spill

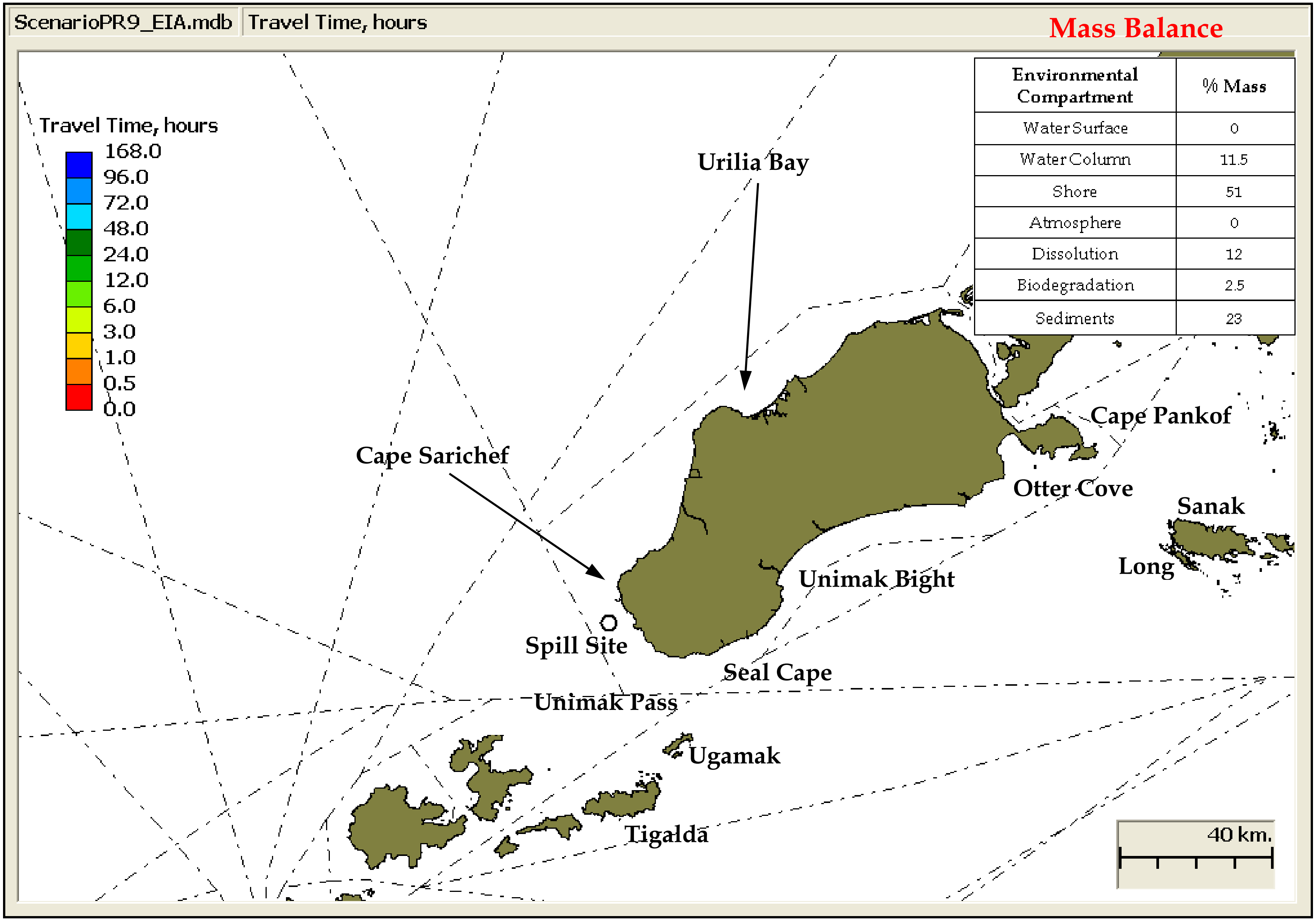
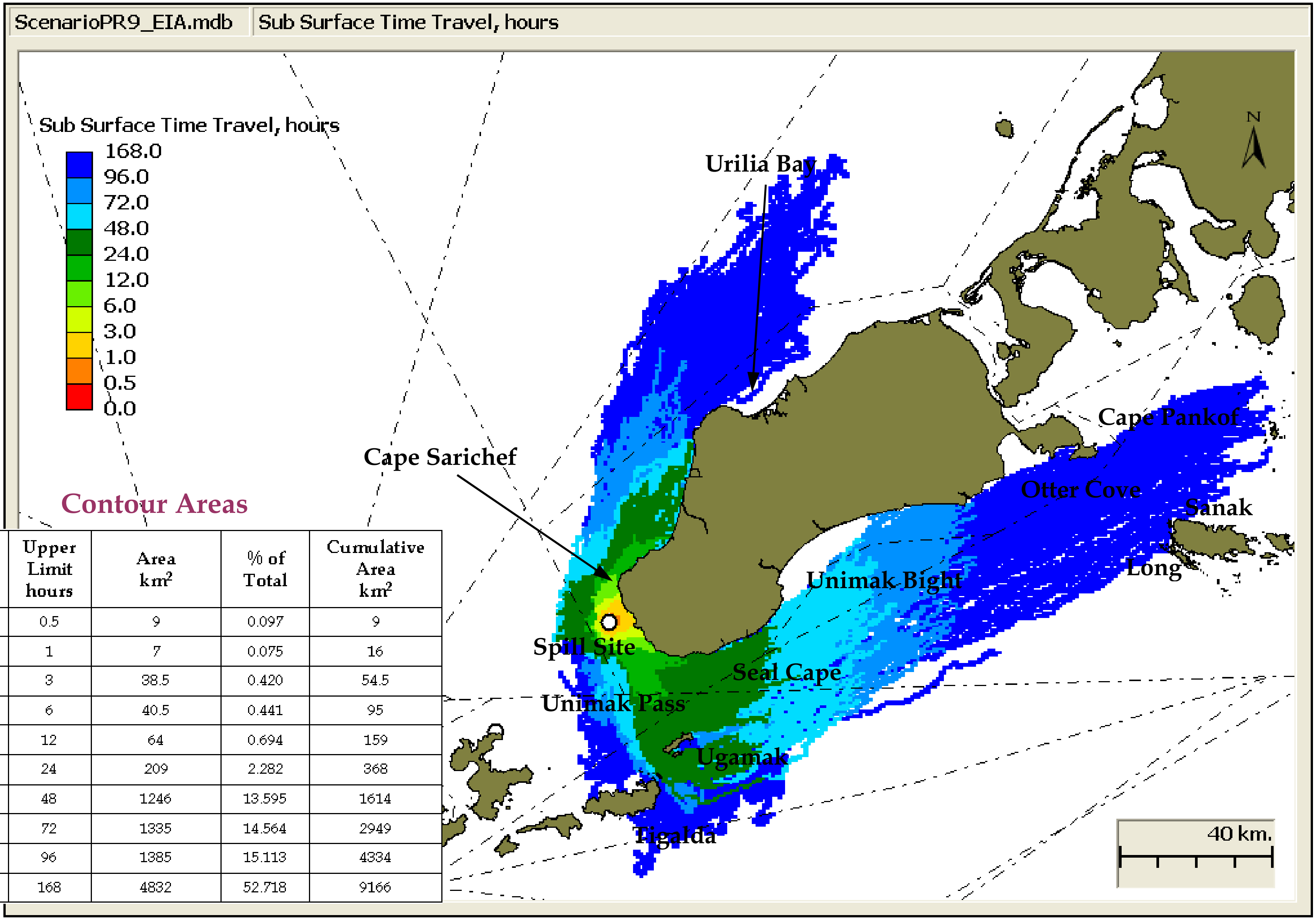


Figure 6-42 Travel time in water column for Scenario 6 Phorate chemical spill



Contour Areas

Lower Limit hours	Upper Limit hours	Area km^2	% of Total	Cumulative Area km^2
0	0.5	9	0.097	9
0.5	1	7	0.075	16
1	3	38.5	0.420	54.5
3	6	40.5	0.441	95
6	12	64	0.694	159
12	24	209	2.282	368
24	48	1246	13.595	1614
48	72	1335	14.564	2949
72	96	1385	15.113	4334
96	168	4832	52.718	9166

Figure 6-43 Probability of impact on water surface due to Scenario 6 Phorate chemical spill

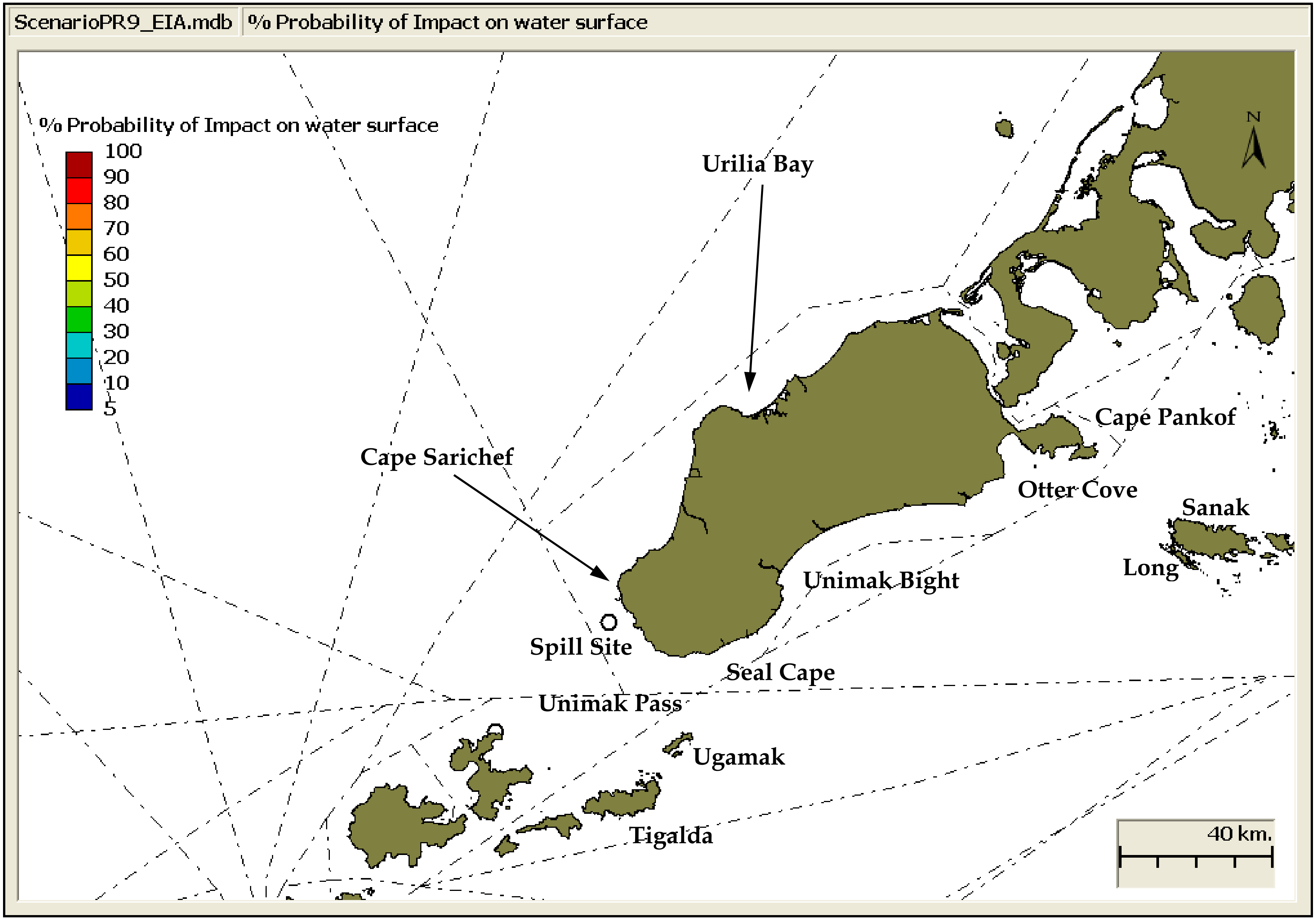
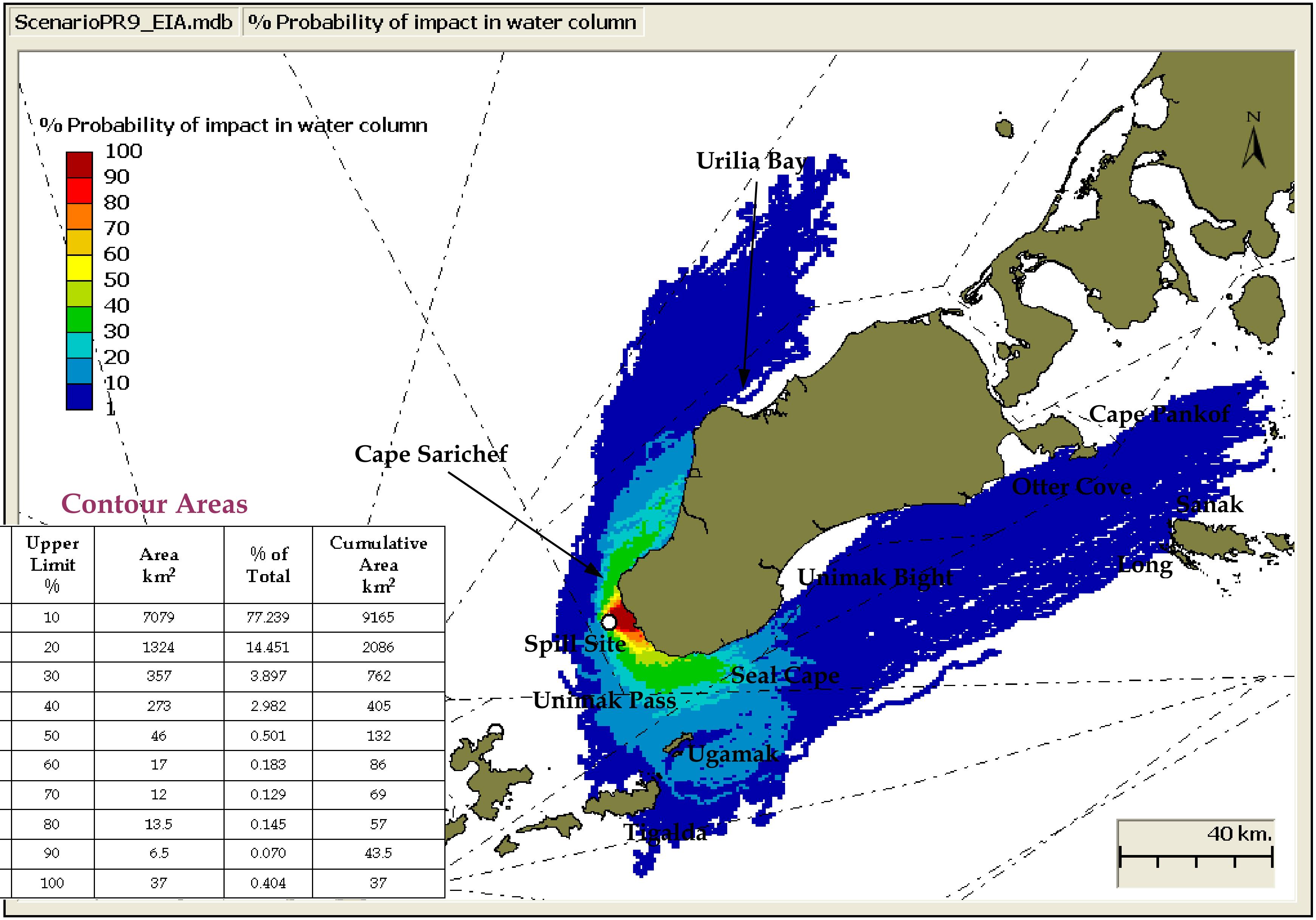
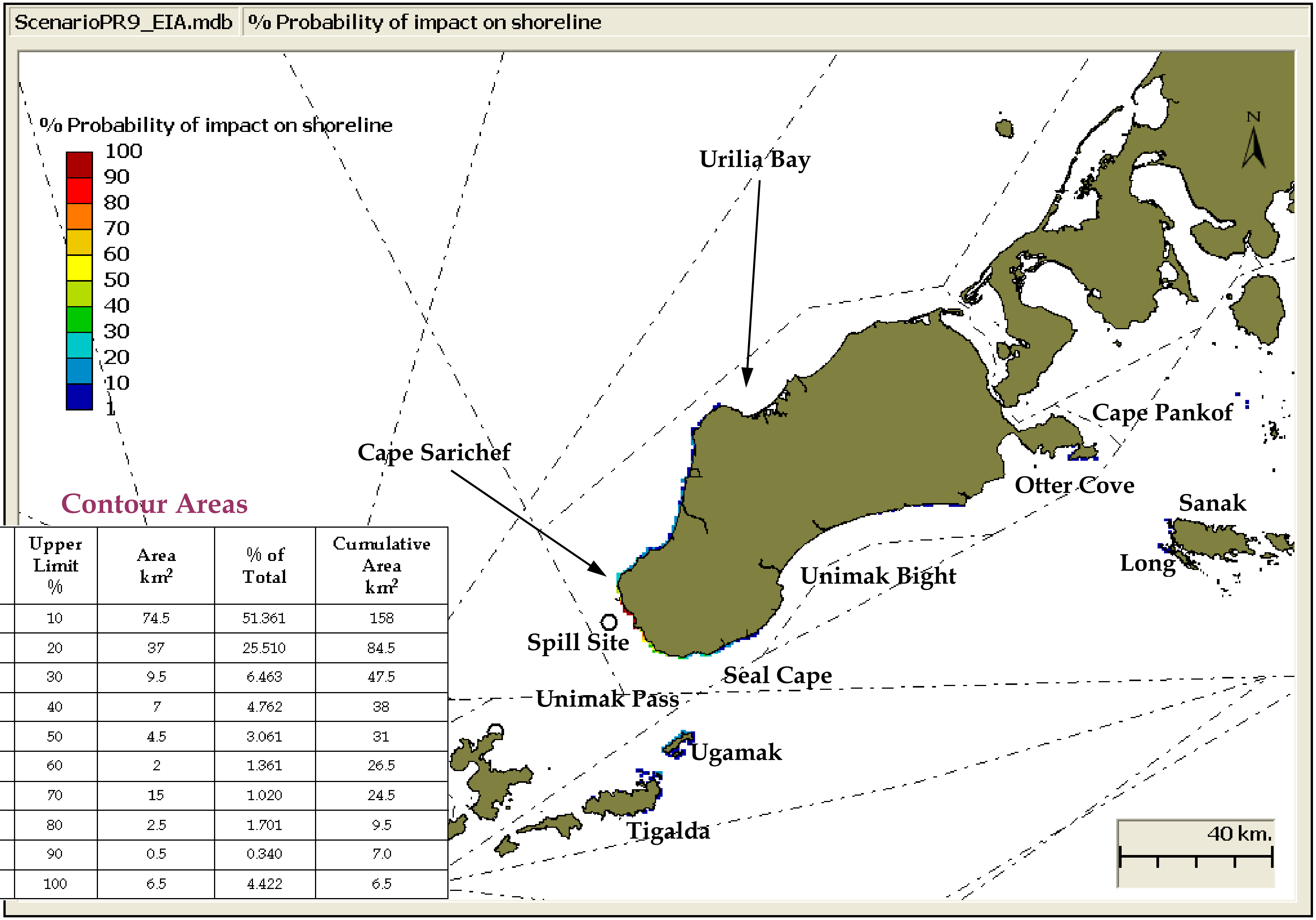


Figure 6-44 Probability of impact in water column due to Scenario 6 Phorate chemical spill



Lower Limit %	Upper Limit %	Area km²	% of Total	Cumulative Area km²
1	10	7079	77.239	9165
10	20	1324	14.451	2086
20	30	357	3.897	762
30	40	273	2.982	405
40	50	46	0.501	132
50	60	17	0.183	86
60	70	12	0.129	69
70	80	13.5	0.145	57
80	90	6.5	0.070	43.5
90	100	37	0.404	37

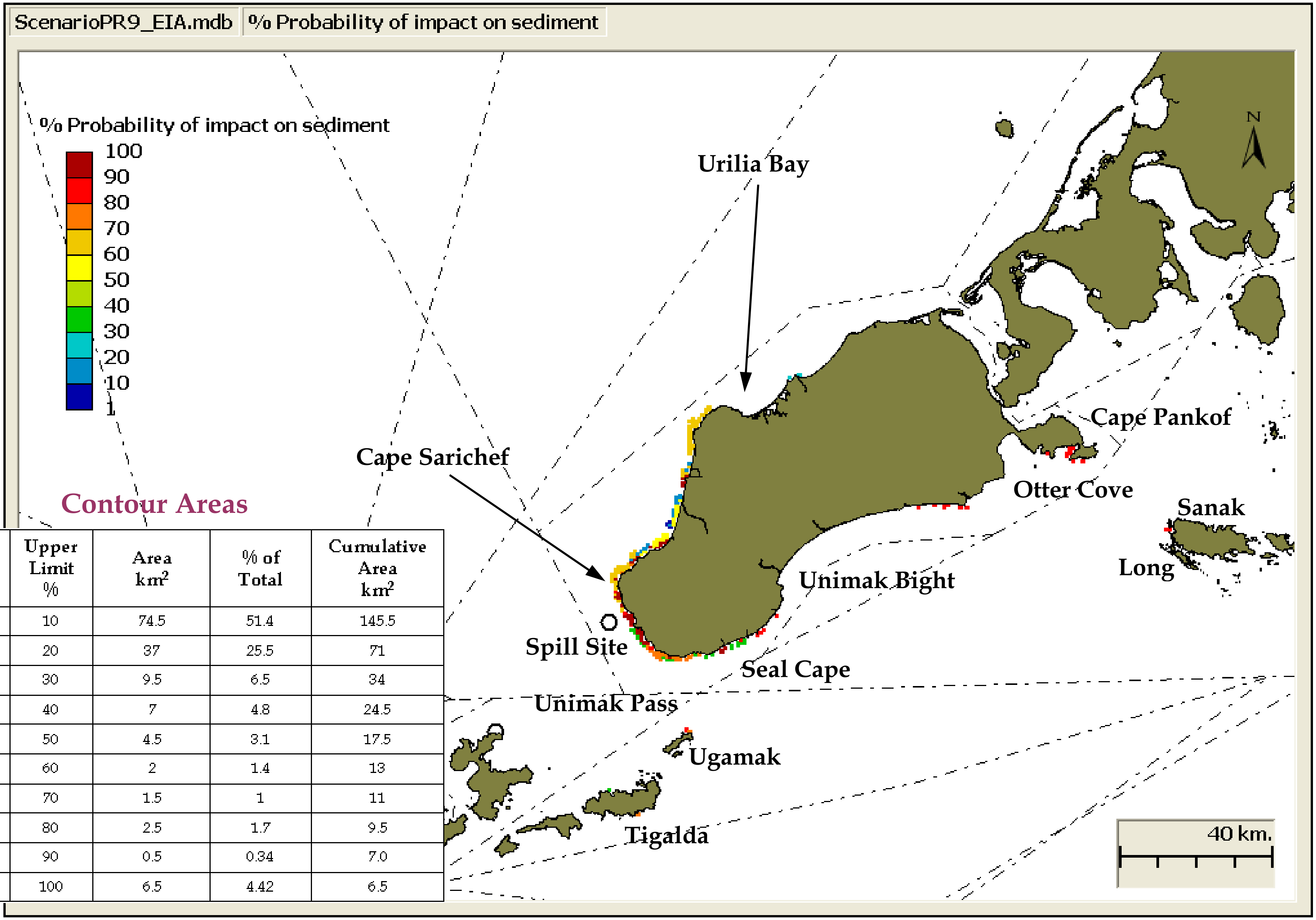
Figure 6-45 Probability of impact on shoreline due to Scenario 6 Phorate chemical spill



Contour Areas

Lower Limit %	Upper Limit %	Area km²	% of Total	Cumulative Area km²
1	10	74.5	51.361	158
10	20	37	25.510	84.5
20	30	9.5	6.463	47.5
30	40	7	4.762	38
40	50	4.5	3.061	31
50	60	2	1.361	26.5
60	70	15	1.020	24.5
70	80	2.5	1.701	9.5
80	90	0.5	0.340	7.0
90	100	6.5	4.422	6.5

Figure 6-46 Probability of impact on bottom sediments due to Scenario 6 Phorate chemical spill



Contour Areas

Lower Limit %	Upper Limit %	Area km²	% of Total	Cumulative Area km²
1	10	74.5	51.4	145.5
10	20	37	25.5	71
20	30	9.5	6.5	34
30	40	7	4.8	24.5
40	50	4.5	3.1	17.5
50	60	2	1.4	13
60	70	1.5	1	11
70	80	2.5	1.7	9.5
80	90	0.5	0.34	7.0
90	100	6.5	4.42	6.5

Figure 6-47 Percent Phorate chemical remaining on water surface for Scenario 6

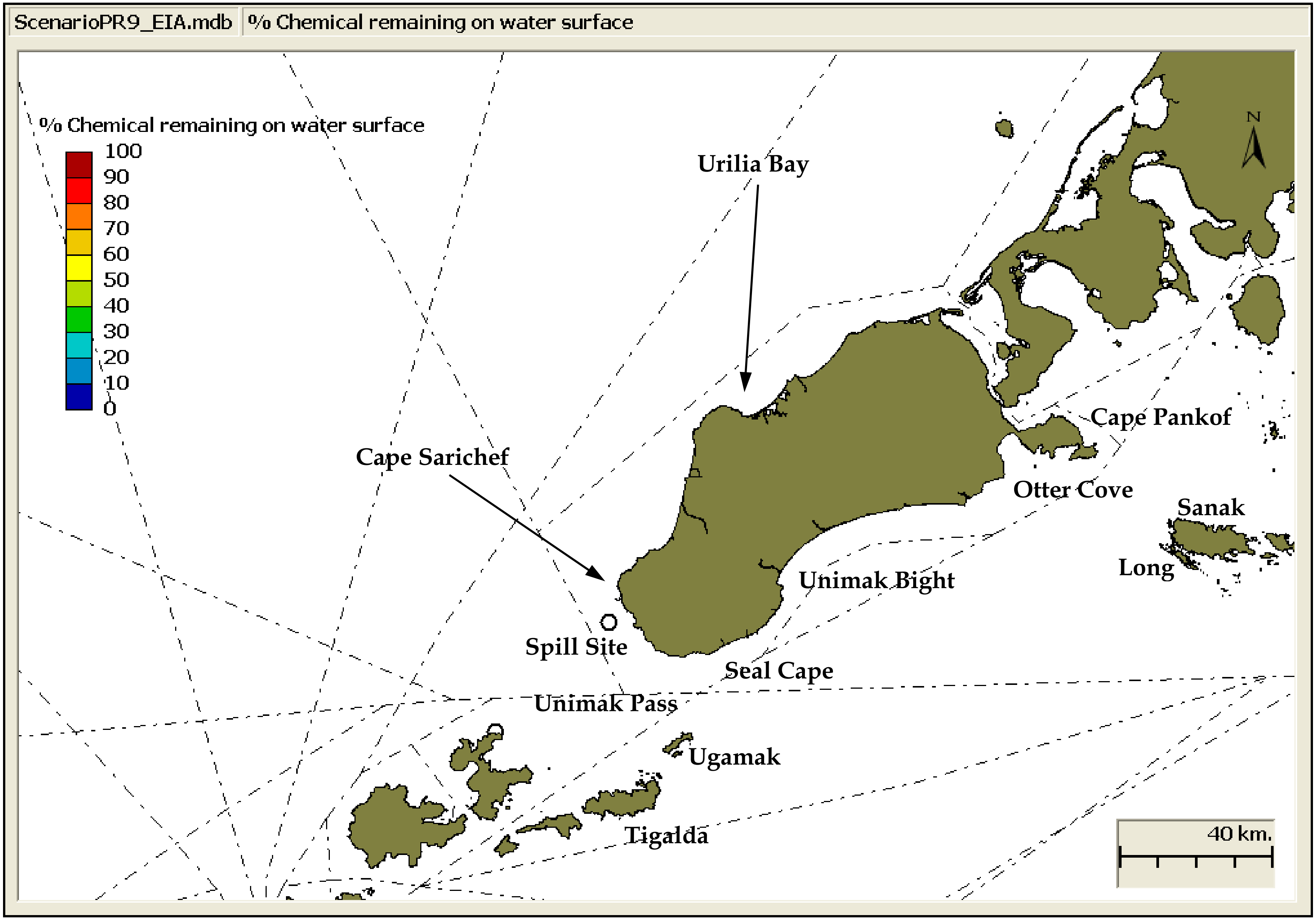


Figure 6-48 Percent Phorate chemical oil lost due to evaporation for Scenario 6

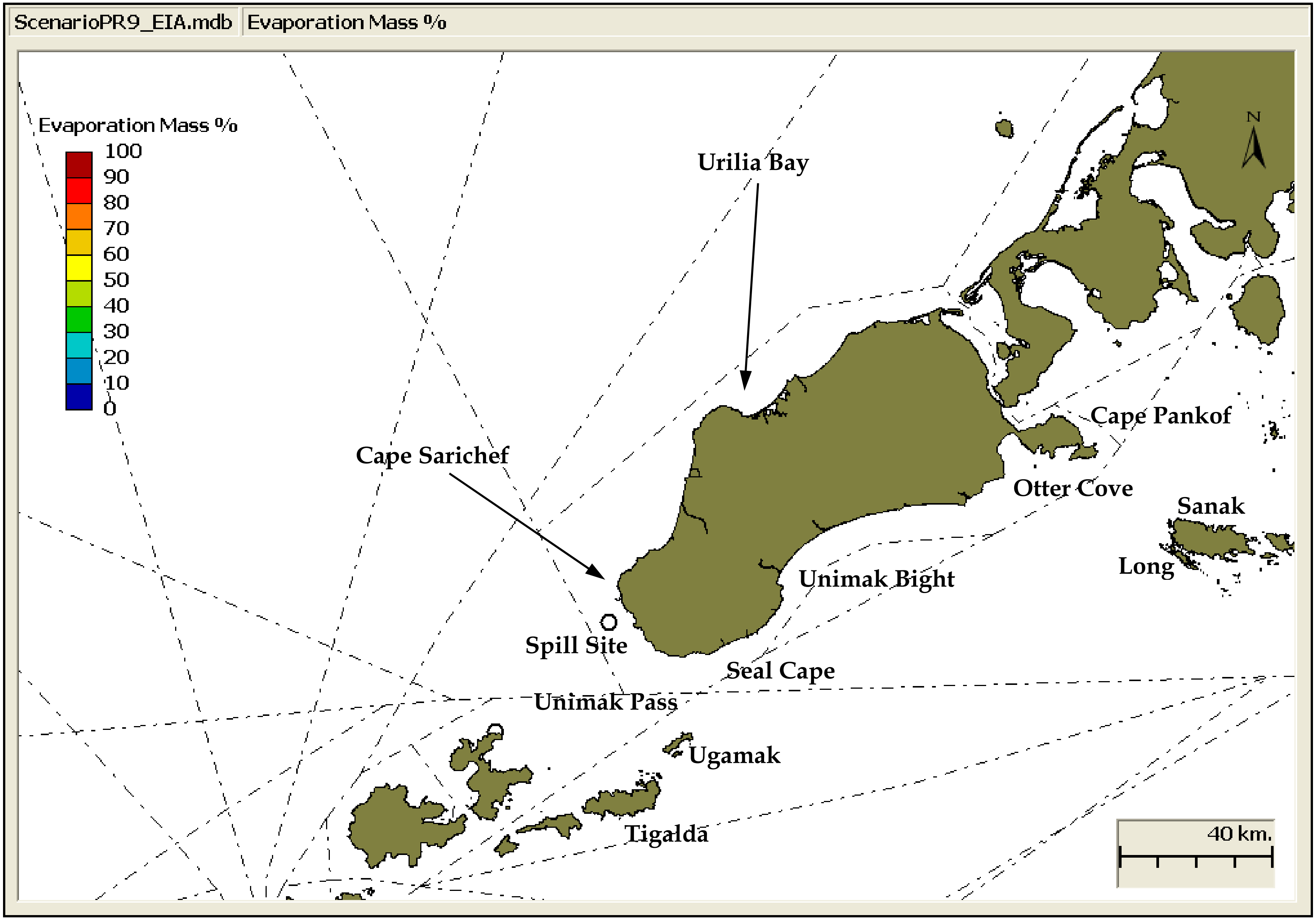
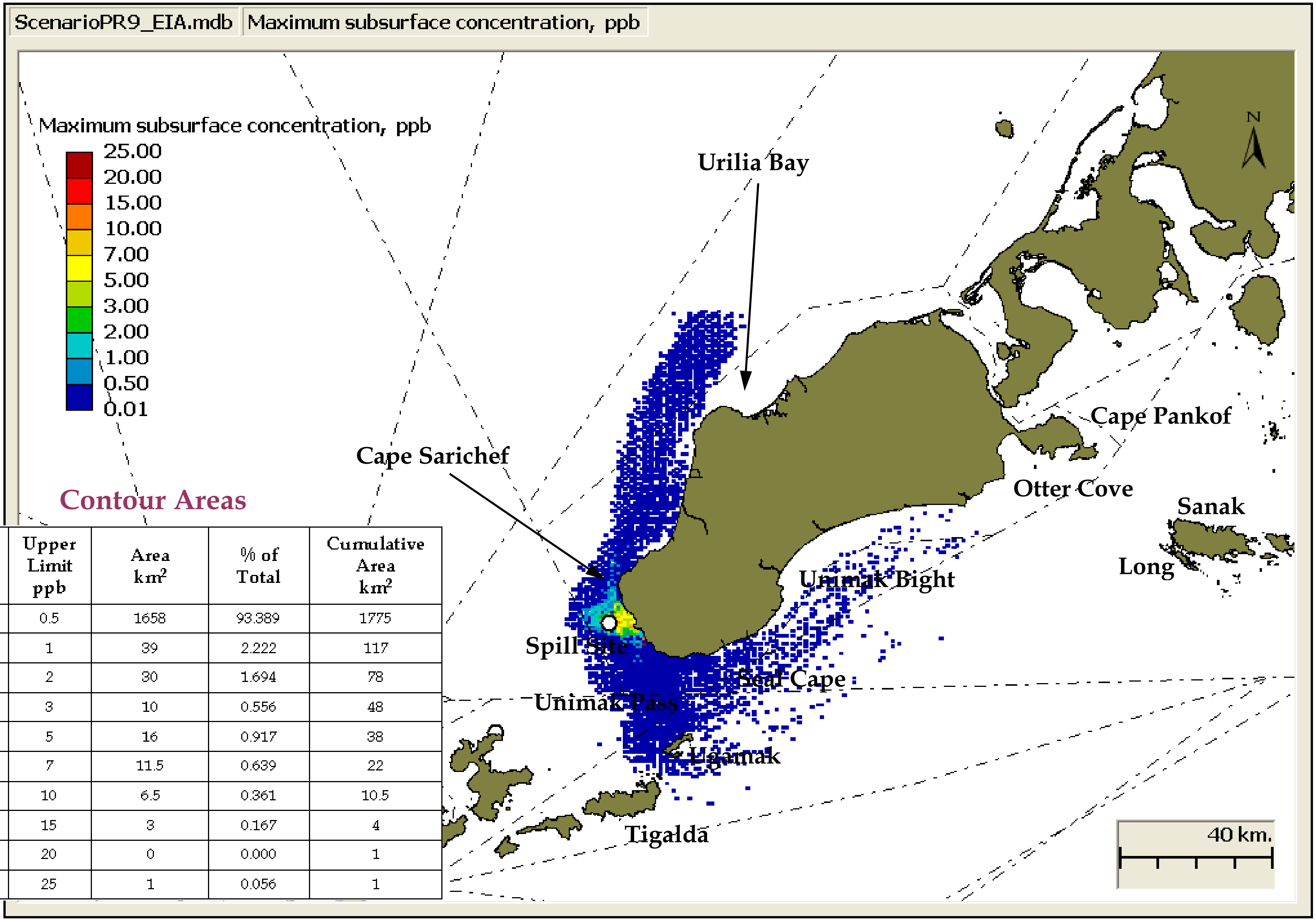


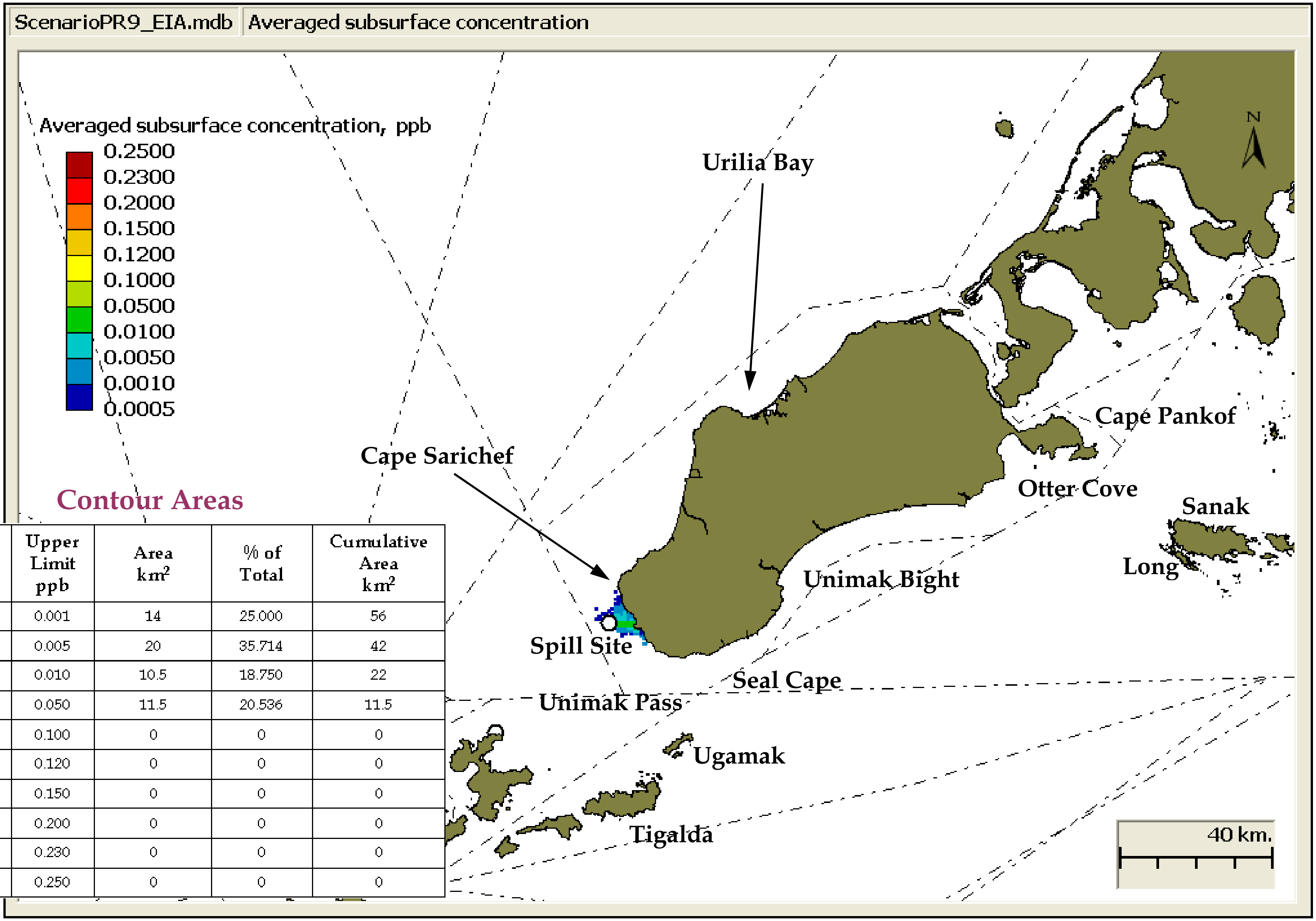
Figure 6-49 Maximum water column concentration at any vertical location for Scenario 6 Phorate chemical spill



Contour Areas

Lower Limit ppb	Upper Limit ppb	Area km²	% of Total	Cumulative Area km²
0.01	0.5	1658	93.389	1775
0.5	1	39	2.222	117
1	2	30	1.694	78
2	3	10	0.556	48
3	5	16	0.917	38
5	7	11.5	0.639	22
7	10	6.5	0.361	10.5
10	15	3	0.167	4
15	20	0	0.000	1
20	25	1	0.056	1

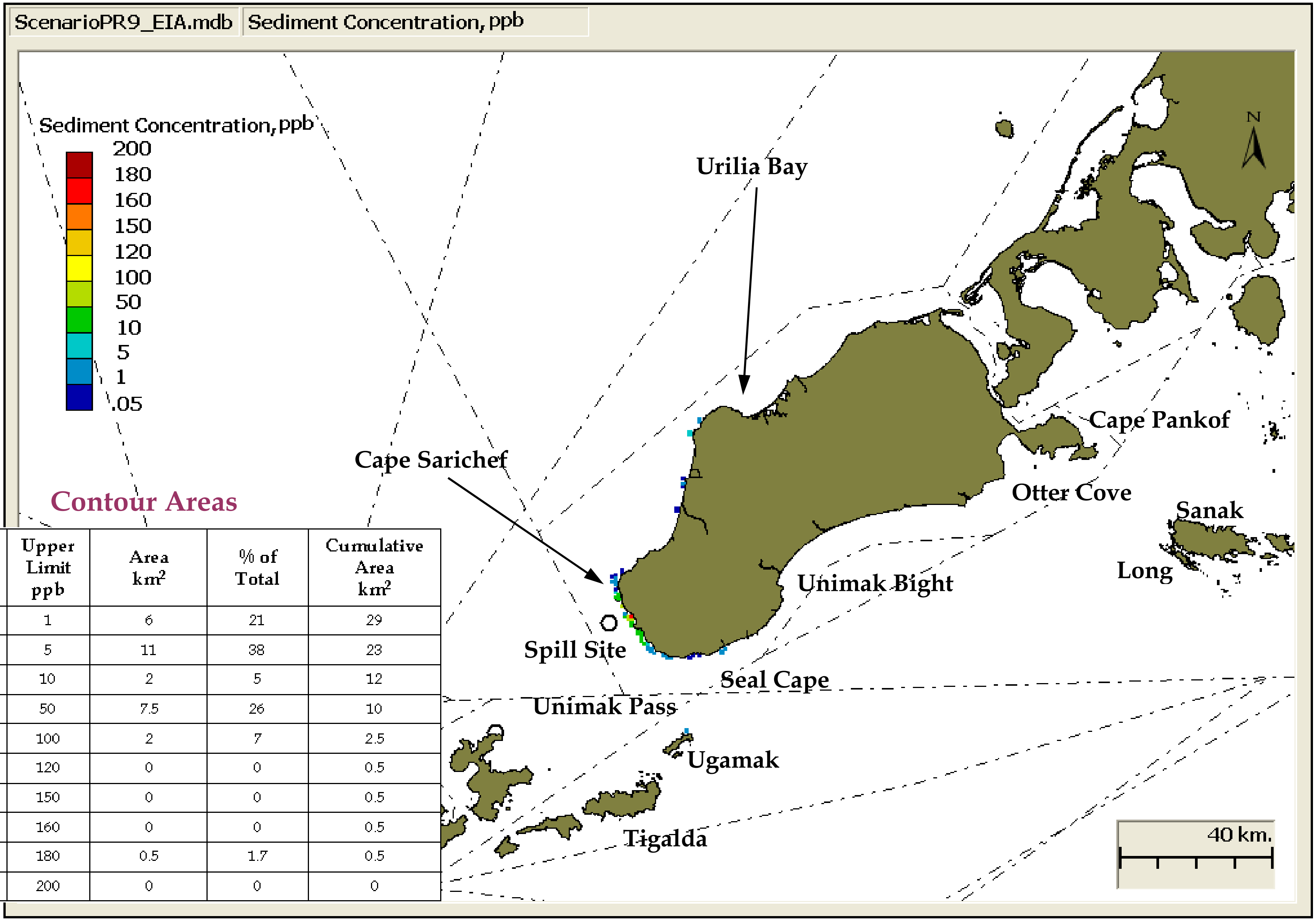
Figure 6-50 Maximum simulation averaged water column concentration for Scenario 6 Phorate chemical spill



Contour Areas

Lower Limit ppb	Upper Limit ppb	Area km²	% of Total	Cumulative Area km²
0.0005	0.001	14	25.000	56
0.001	0.005	20	35.714	42
0.005	0.010	10.5	18.750	22
0.010	0.050	11.5	20.536	11.5
0.050	0.100	0	0	0
0.100	0.120	0	0	0
0.120	0.150	0	0	0
0.150	0.200	0	0	0
0.200	0.230	0	0	0
0.230	0.250	0	0	0

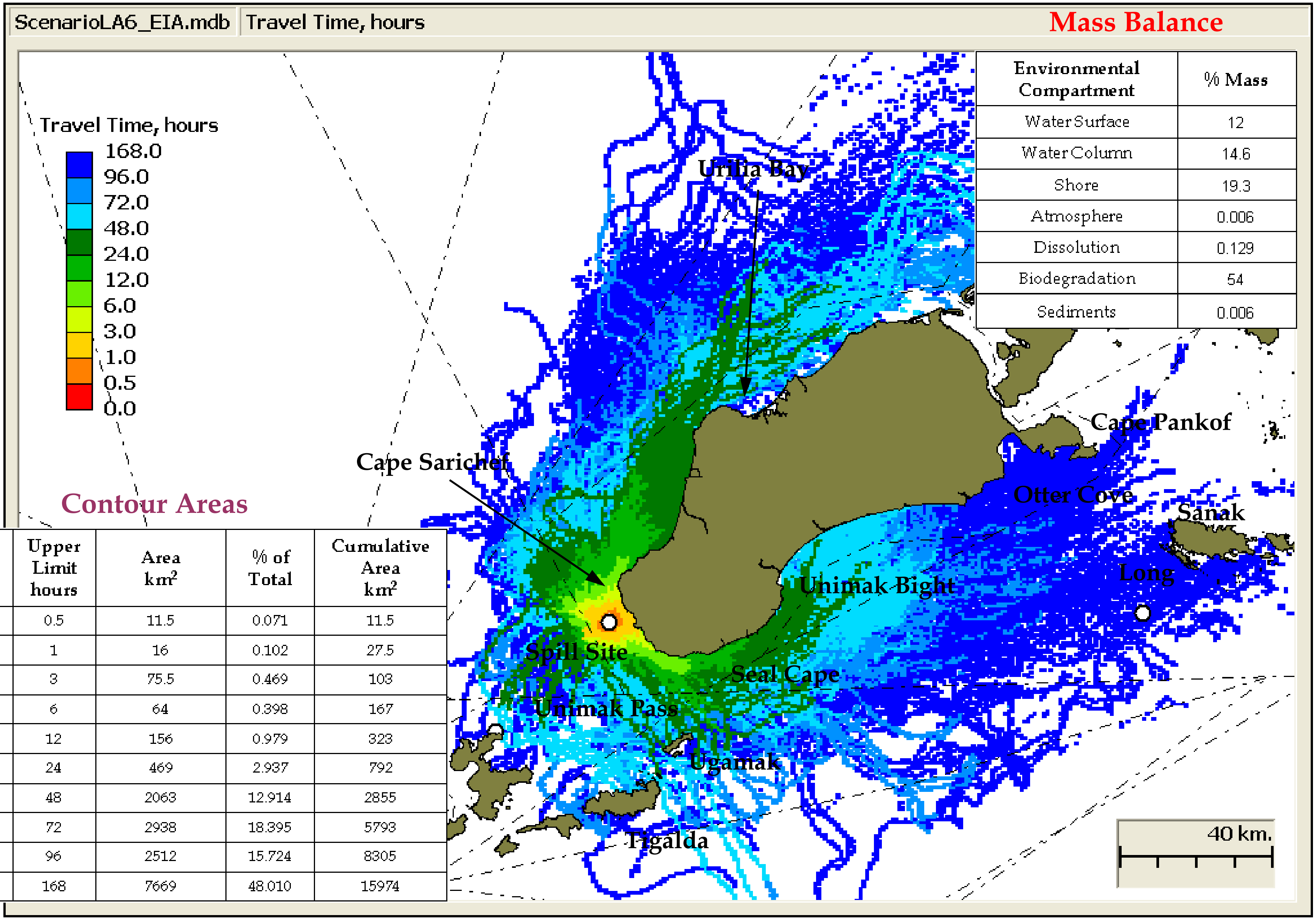
Figure 6-51 Maximum sediment concentration for Scenario 6 Phorate chemical spill



Contour Areas

Lower Limit ppb	Upper Limit ppb	Area km²	% of Total	Cumulative Area km²
0.5	1	6	21	29
1	5	11	38	23
5	10	2	5	12
10	50	7.5	26	10
50	100	2	7	2.5
100	120	0	0	0.5
120	150	0	0	0.5
150	160	0	0	0.5
160	180	0.5	1.7	0.5
180	200	0	0	0

Figure 6-52 Water surface travel time for Scenario 6 Linoleic Acid chemical spill



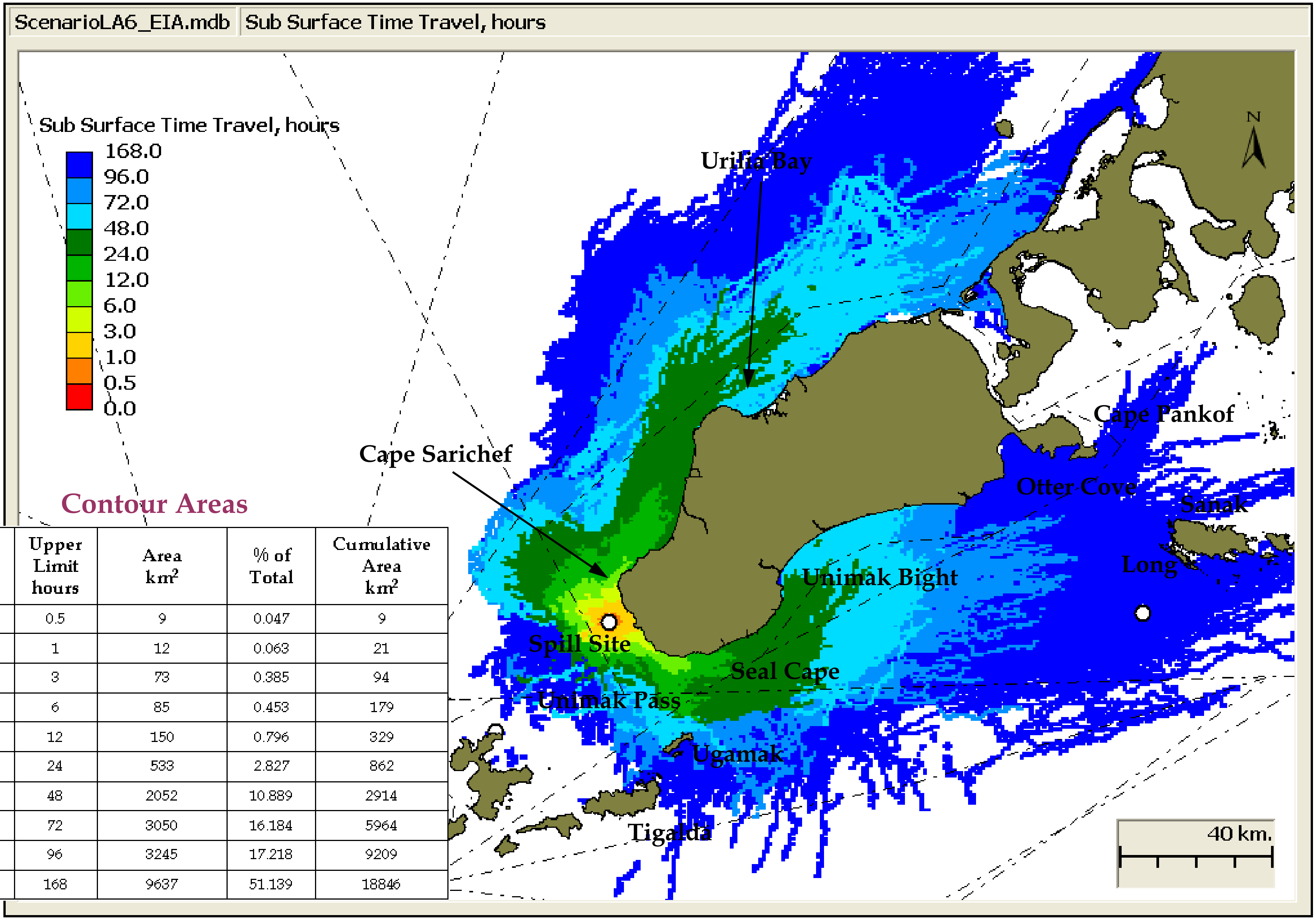
Mass Balance

Environmental Compartment	% Mass
Water Surface	12
Water Column	14.6
Shore	19.3
Atmosphere	0.006
Dissolution	0.129
Biodegradation	54
Sediments	0.006

Contour Areas

Lower Limit hours	Upper Limit hours	Area km^2	% of Total	Cumulative Area km^2
0	0.5	11.5	0.071	11.5
0.5	1	16	0.102	27.5
1	3	75.5	0.469	103
3	6	64	0.398	167
6	12	156	0.979	323
12	24	469	2.937	792
24	48	2063	12.914	2855
48	72	2938	18.395	5793
72	96	2512	15.724	8305
96	168	7669	48.010	15974

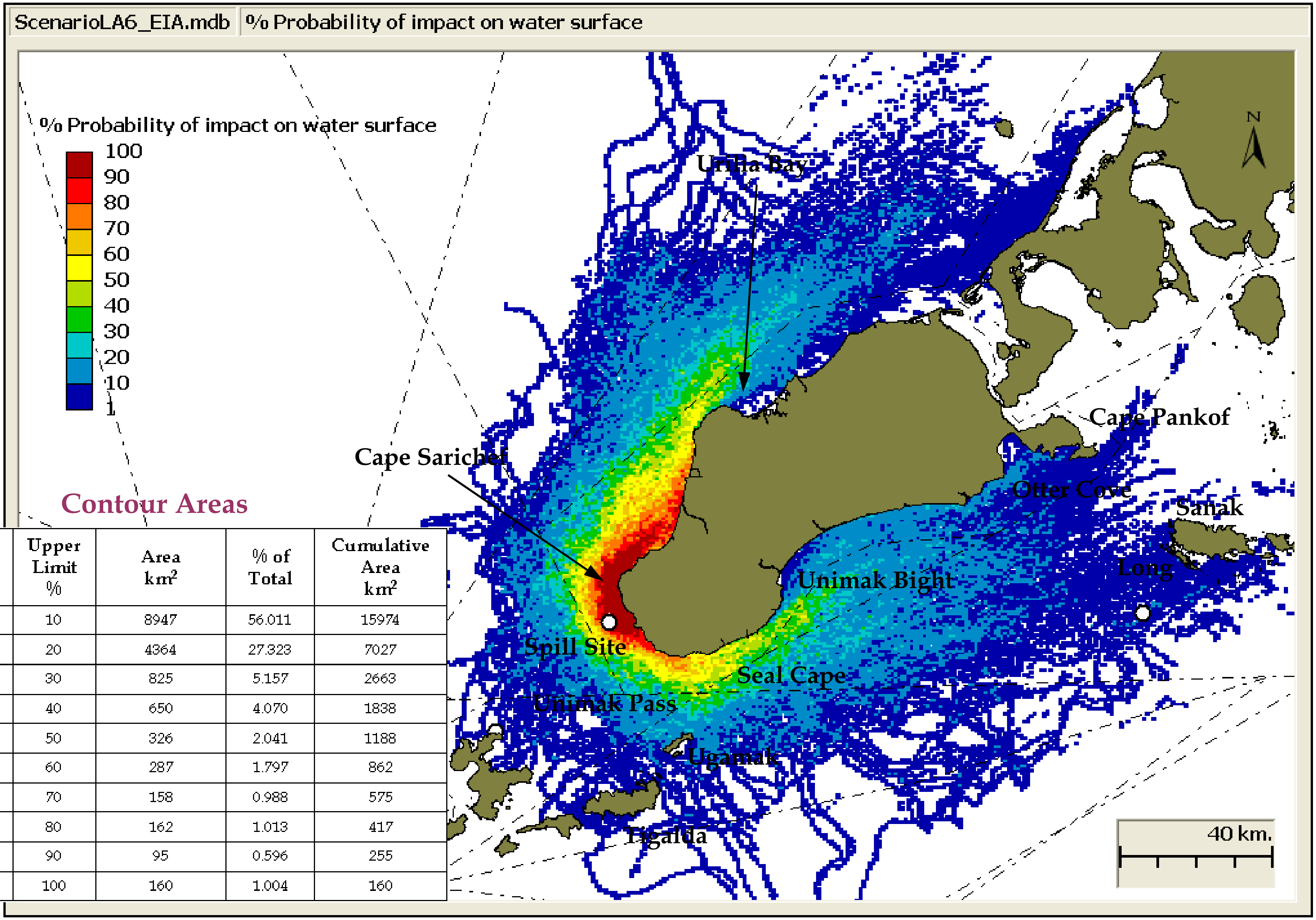
Figure 6-53 Water column travel time for Scenario 6 Linoleic Acid chemical spill



Contour Areas

Lower Limit hours	Upper Limit hours	Area km²	% of Total	Cumulative Area km²
0	0.5	9	0.047	9
0.5	1	12	0.063	21
1	3	73	0.385	94
3	6	85	0.453	179
6	12	150	0.796	329
12	24	533	2.827	862
24	48	2052	10.889	2914
48	72	3050	16.184	5964
72	96	3245	17.218	9209
96	168	9637	51.139	18846

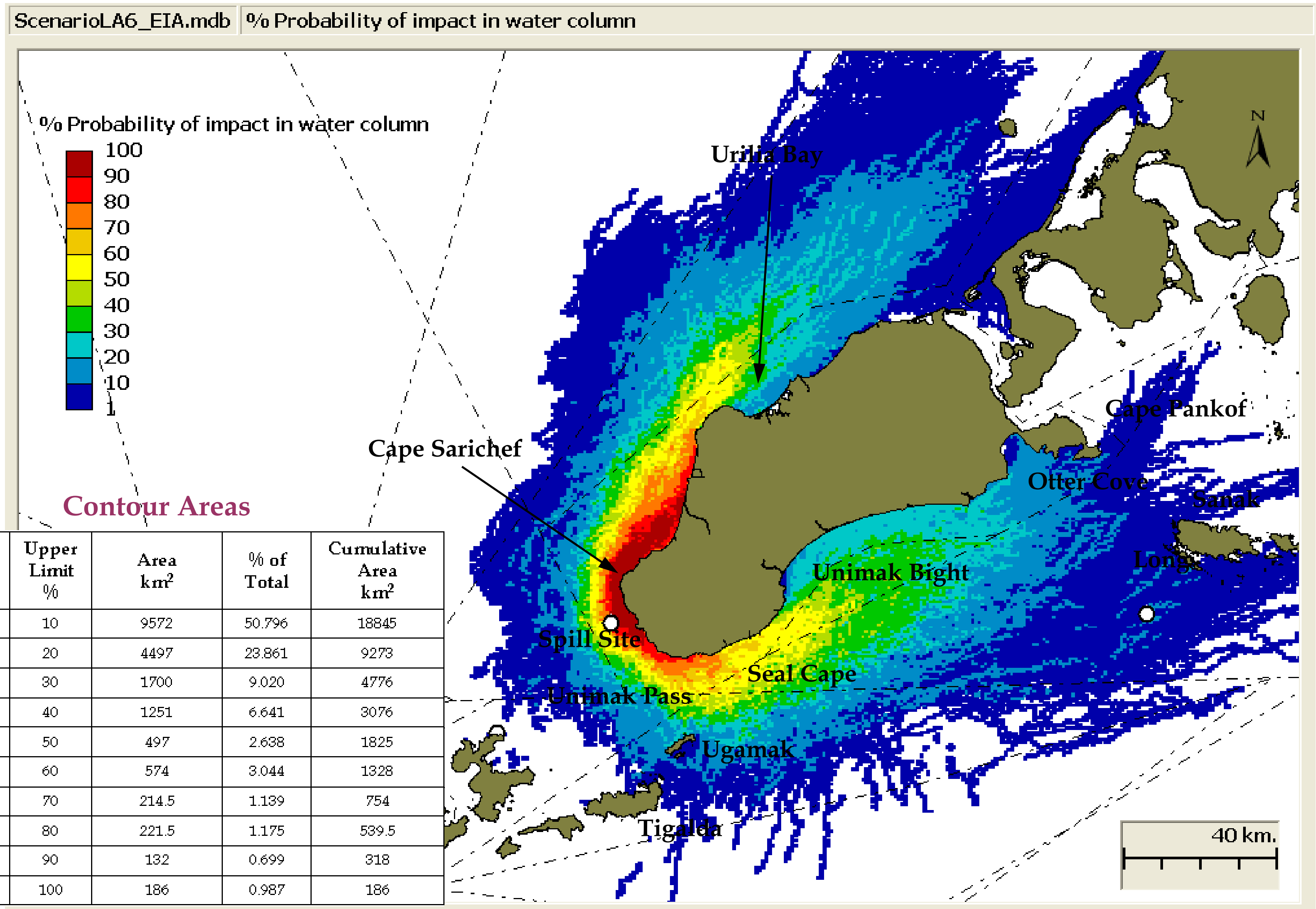
Figure 6-54 Percent probability of impact on water surface due to Scenario 6 Linoleic Acid chemical spill



Contour Areas

Lower Limit %	Upper Limit %	Area km²	% of Total	Cumulative Area km²
1	10	8947	56.011	15974
10	20	4364	27.323	7027
20	30	825	5.157	2663
30	40	650	4.070	1838
40	50	326	2.041	1188
50	60	287	1.797	862
60	70	158	0.988	575
70	80	162	1.013	417
80	90	95	0.596	255
90	100	160	1.004	160

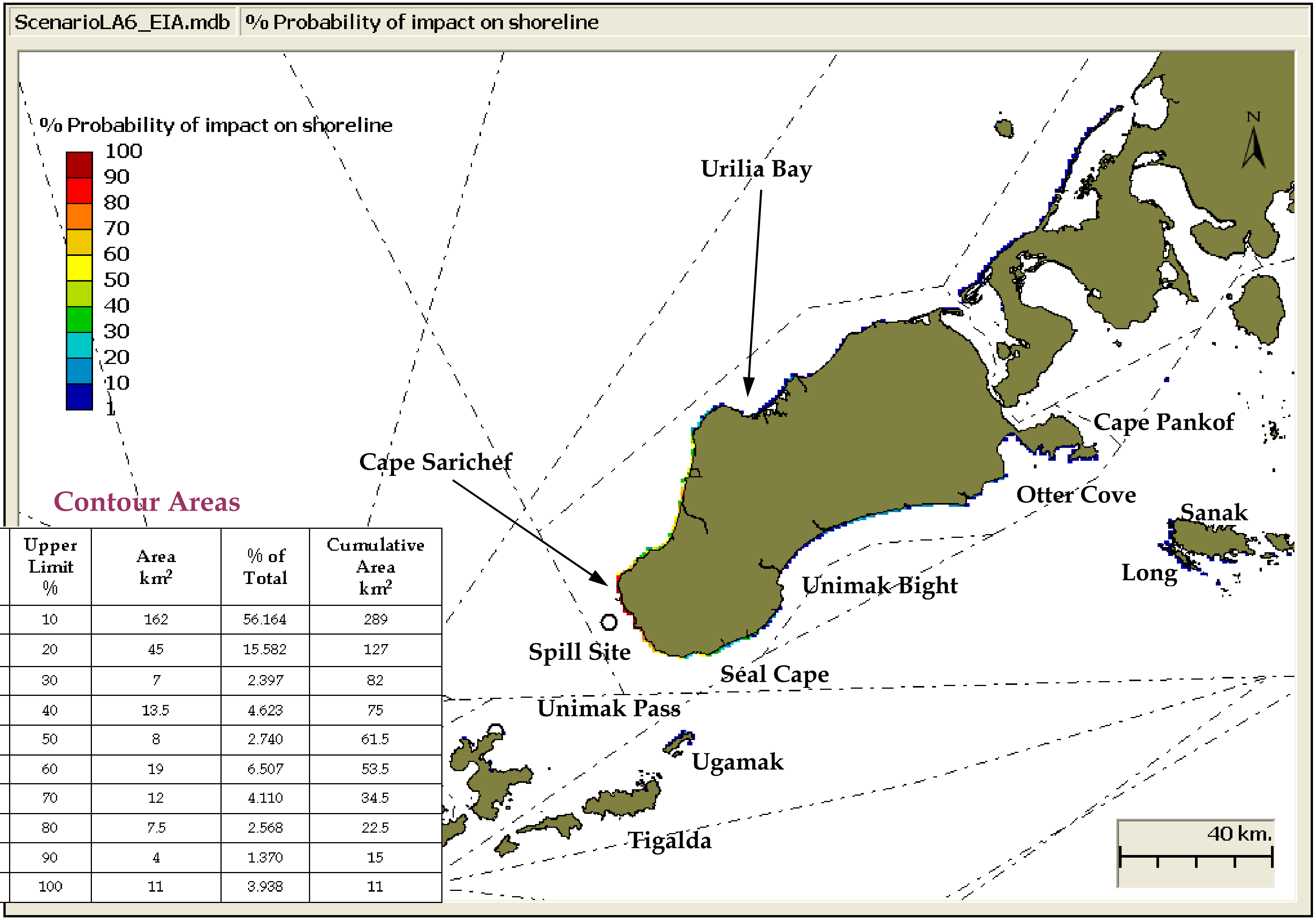
Figure 6-55 Percent probability of impact in water column due to Scenario 6 Linoleic Acid chemical spill



Contour Areas

Lower Limit %	Upper Limit %	Area km²	% of Total	Cumulative Area km²
1	10	9572	50.796	18845
10	20	4497	23.861	9273
20	30	1700	9.020	4776
30	40	1251	6.641	3076
40	50	497	2.638	1825
50	60	574	3.044	1328
60	70	214.5	1.139	754
70	80	221.5	1.175	539.5
80	90	132	0.699	318
90	100	186	0.987	186

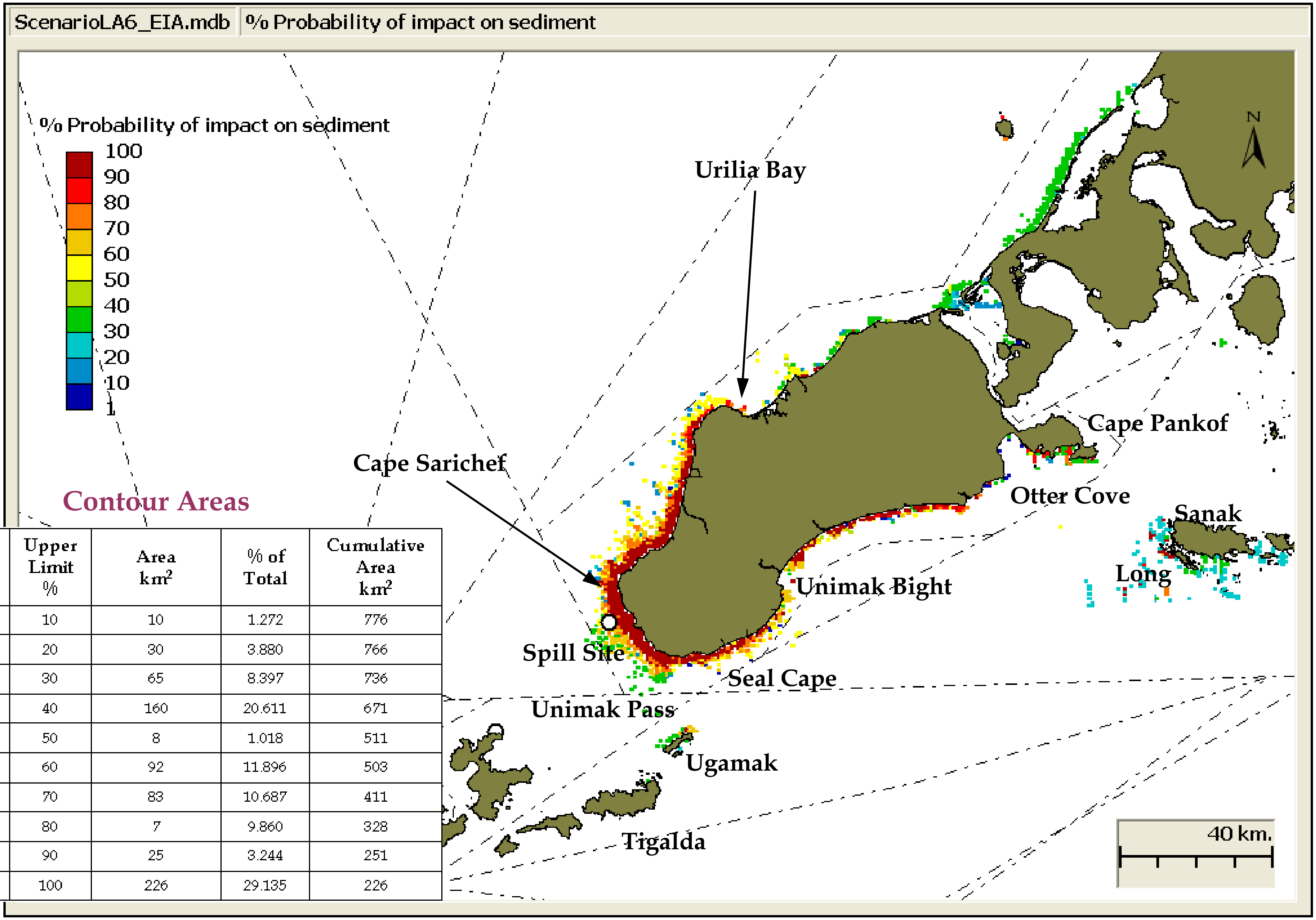
Figure 6-56 Percent probability of impact on shoreline due to Scenario 6 Linoleic Acid chemical spill



Contour Areas

Lower Limit %	Upper Limit %	Area km²	% of Total	Cumulative Area km²
1	10	162	56.164	289
10	20	45	15.582	127
20	30	7	2.397	82
30	40	13.5	4.623	75
40	50	8	2.740	61.5
50	60	19	6.507	53.5
60	70	12	4.110	34.5
70	80	7.5	2.568	22.5
80	90	4	1.370	15
90	100	11	3.938	11

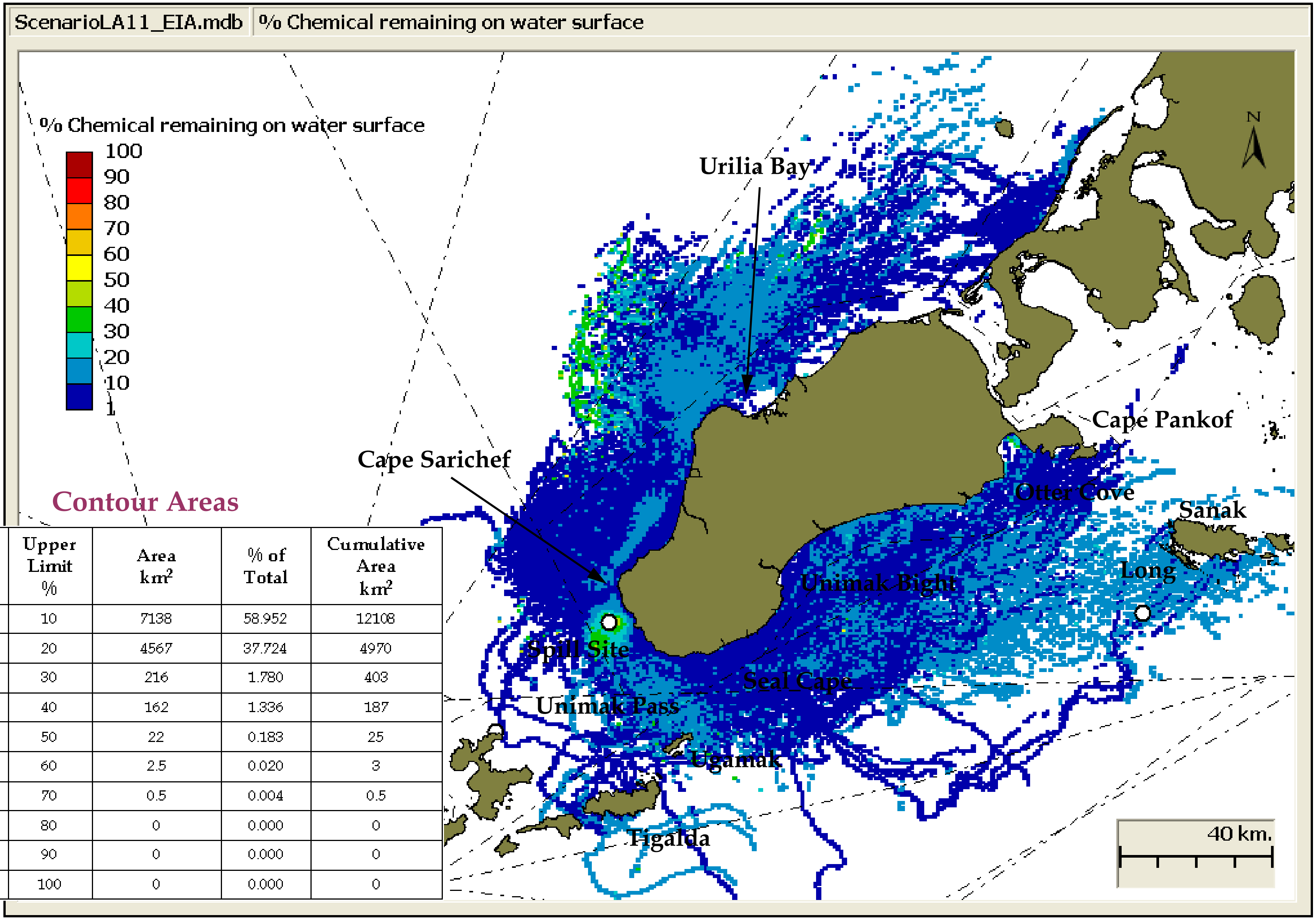
Figure 6-57 Percent probability of impact on bottom sediment due to Linoleic Acid chemical spill



Contour Areas

Lower Limit %	Upper Limit %	Area km²	% of Total	Cumulative Area km²
1	10	10	1.272	776
10	20	30	3.880	766
20	30	65	8.397	736
30	40	160	20.611	671
40	50	8	1.018	511
50	60	92	11.896	503
60	70	83	10.687	411
70	80	7	9.860	328
80	90	25	3.244	251
90	100	226	29.135	226

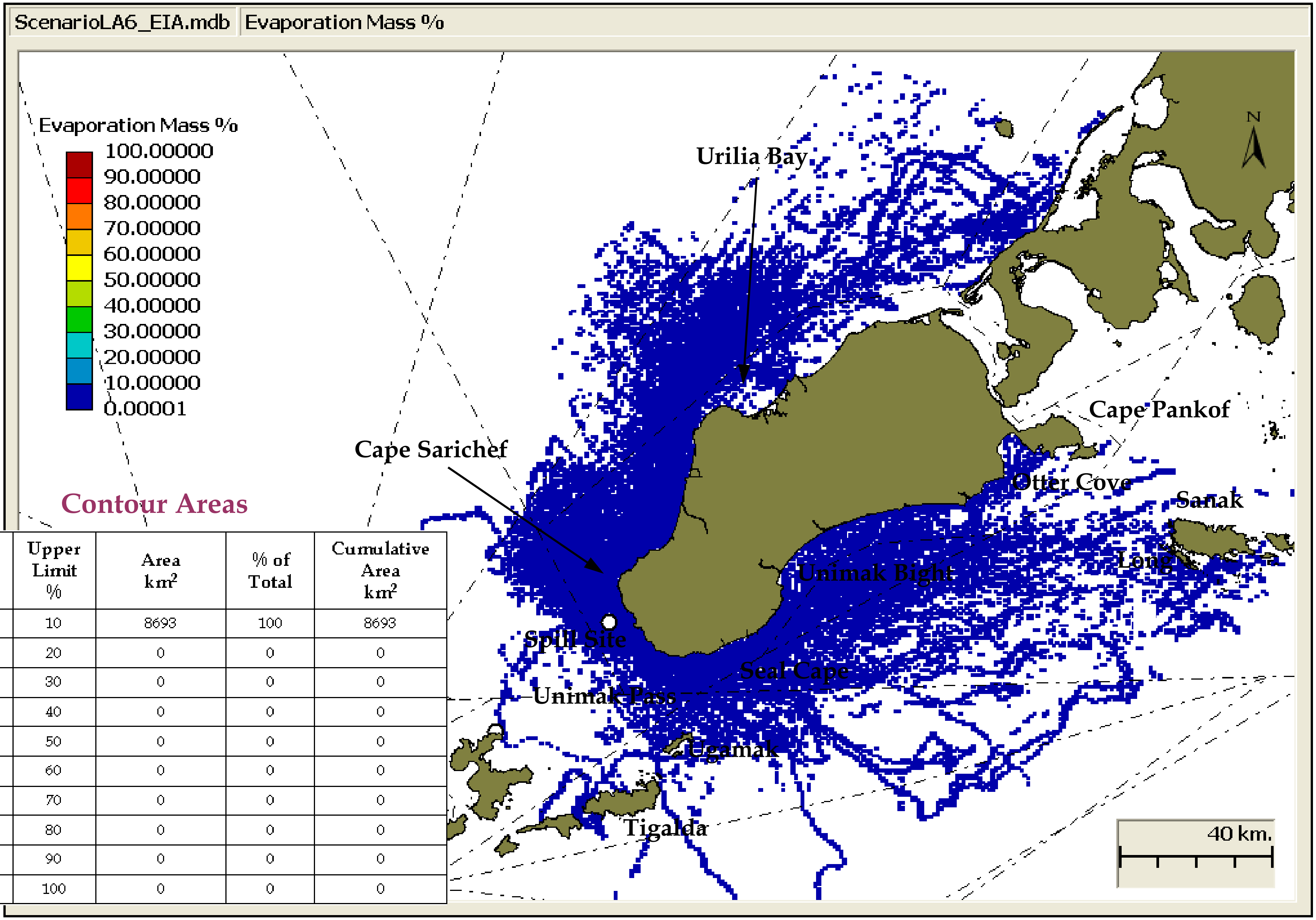
Figure 6-58 Percent probability of Linoleic Acid remaining on water surface for Scenario 6



Contour Areas

Lower Limit %	Upper Limit %	Area km²	% of Total	Cumulative Area km²
1	10	7138	58.952	12108
10	20	4567	37.724	4970
20	30	216	1.780	403
30	40	162	1.336	187
40	50	22	0.183	25
50	60	2.5	0.020	3
60	70	0.5	0.004	0.5
70	80	0	0.000	0
80	90	0	0.000	0
90	100	0	0.000	0

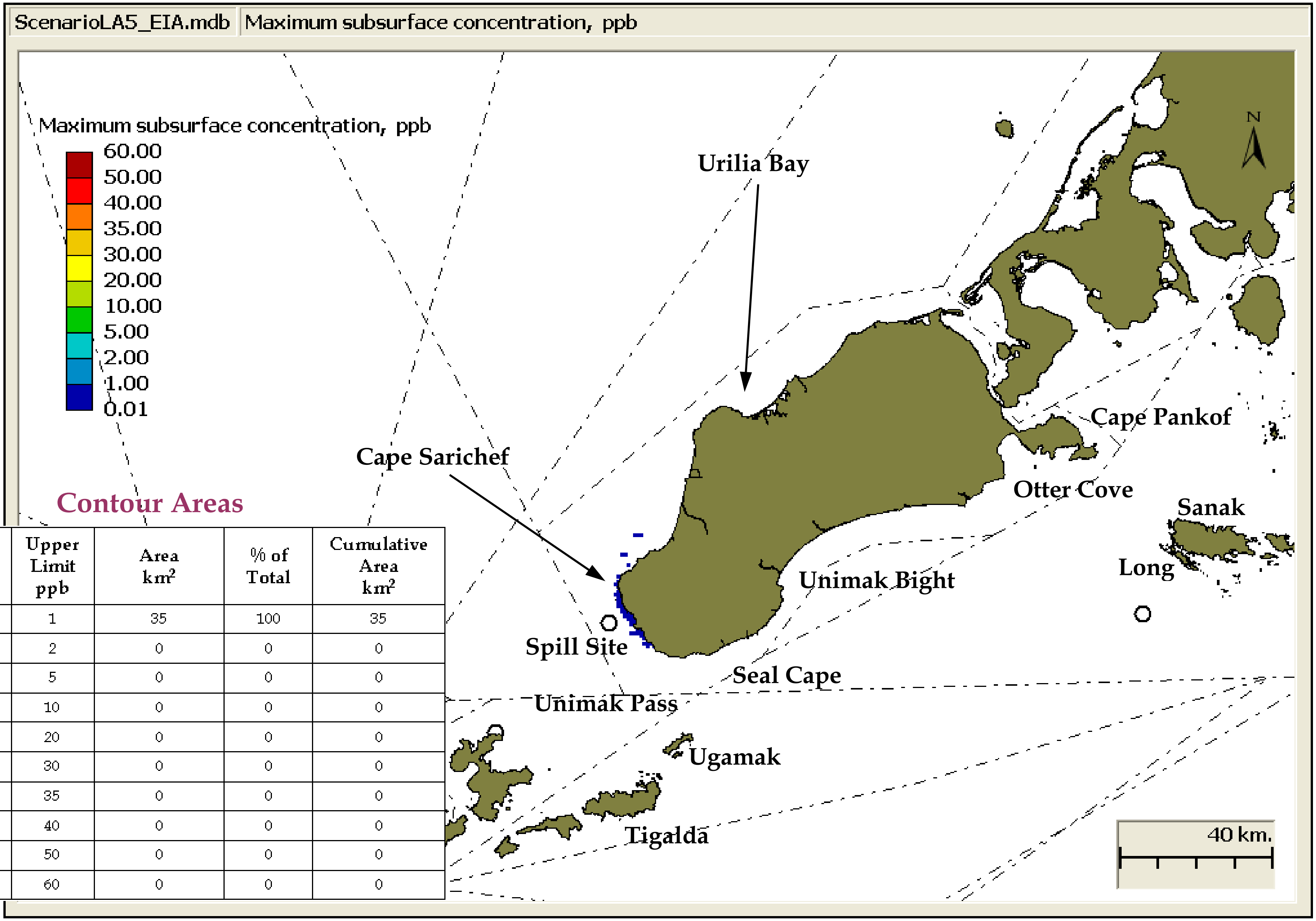
Figure 6-59 Percent Linoleic Acid lost due to evaporation for Scenario 6



Contour Areas

Lower Limit %	Upper Limit %	Area km²	% of Total	Cumulative Area km²
0.00001	10	8693	100	8693
10	20	0	0	0
20	30	0	0	0
30	40	0	0	0
40	50	0	0	0
50	60	0	0	0
60	70	0	0	0
70	80	0	0	0
80	90	0	0	0
90	100	0	0	0

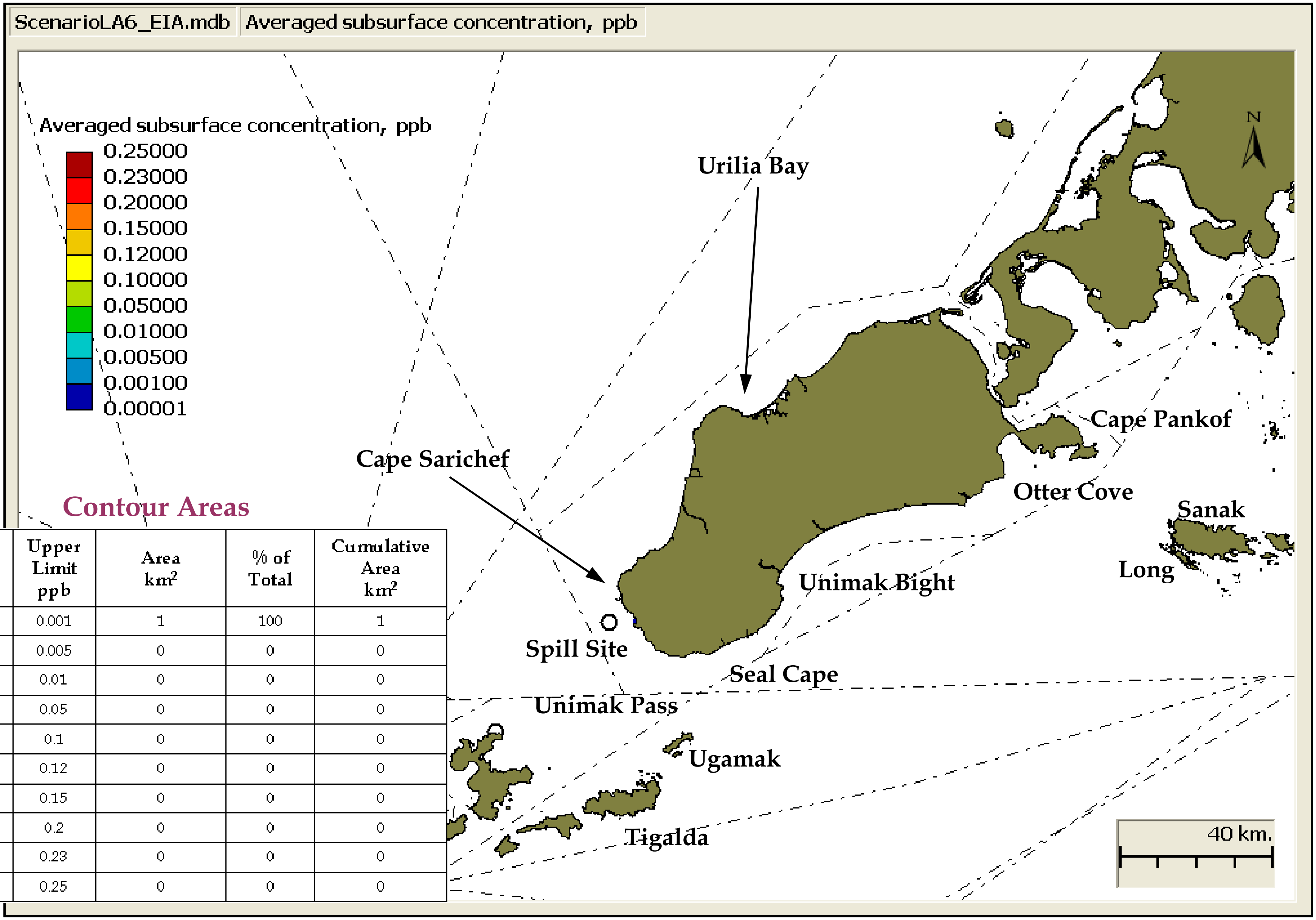
Figure 6-60 Maximum water column concentration at any vertical location for Scenario 6 Linoleic Acid chemical spill



Contour Areas

Lower Limit ppb	Upper Limit ppb	Area km²	% of Total	Cumulative Area km²
0.01	1	35	100	35
1	2	0	0	0
2	5	0	0	0
5	10	0	0	0
10	20	0	0	0
20	30	0	0	0
30	35	0	0	0
35	40	0	0	0
40	50	0	0	0
50	60	0	0	0

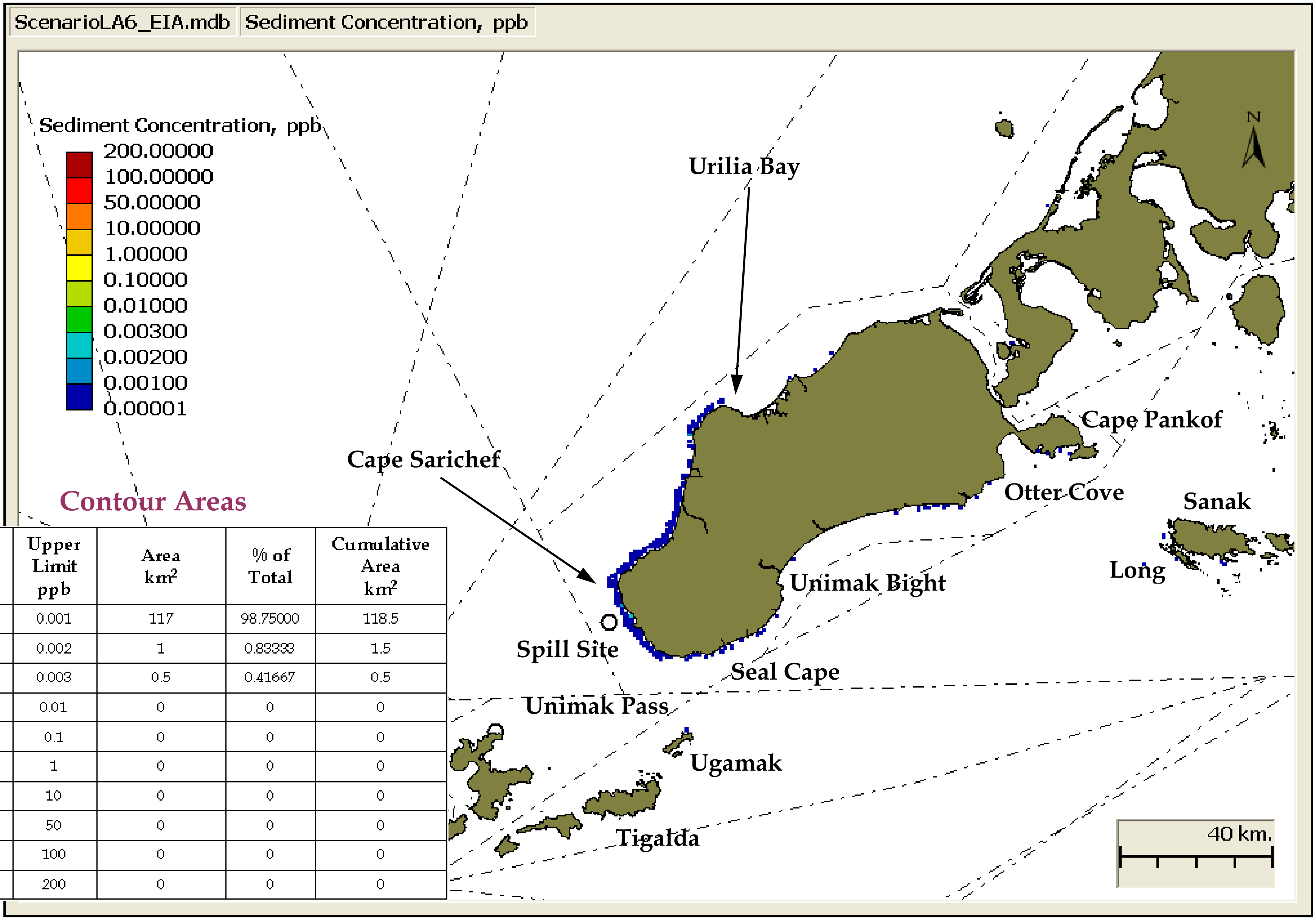
Figure 6-61 Maximum simulation averaged water column concentration for Scenario 6 Linoleic Acid chemical spill



Contour Areas

Lower Limit ppb	Upper Limit ppb	Area km^2	% of Total	Cumulative Area km^2
0.00001	0.001	1	100	1
0.001	0.005	0	0	0
0.005	0.01	0	0	0
0.01	0.05	0	0	0
0.05	0.1	0	0	0
0.1	0.12	0	0	0
0.12	0.15	0	0	0
0.15	0.2	0	0	0
0.2	0.23	0	0	0
0.23	0.25	0	0	0

Figure 6-62 Maximum bottom sediment concentration for Scenario 6 Linoleic Acid chemical spill



Contour Areas

Lower Limit ppb	Upper Limit ppb	Area km²	% of Total	Cumulative Area km²
0.00001	0.001	117	98.75000	118.5
0.001	0.002	1	0.83333	1.5
0.002	0.003	0.5	0.41667	0.5
0.003	0.01	0	0	0
0.01	0.1	0	0	0
0.1	1	0	0	0
1	10	0	0	0
10	50	0	0	0
50	100	0	0	0
100	200	0	0	0

Aleutian Islands Risk Assessment – Phase A
Risk Analysis Team