Draft Description of the Cost and Benefit Calculations in the Offshore Environmental Cost Model

(Posted as a Temporary Supplement to the Economic Analyses Summarized in the Decision Document for the Proposed 5-Year OCS Oil and Gas Program for 2012-2017)

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1 INTRODUCTION

Section 18 of the Outer Continental Shelf (OCS) Lands Act requires the Secretary of the Interior to develop and maintain a 5-year schedule of proposed lease sales prior to auctioning rights to oil and gas resources on the Federal OCS. Prior to the proposed program and the proposed final program (the second and third of three draft program decisions) in each new 5-year program development cycle, the Bureau of Ocean Energy Management (BOEM) conducts a benefit-cost analysis by program area.[1] The analysis examines the benefits to society from the production of oil and natural gas as well as the net environmental and social costs associated with the anticipated exploration, development, and production of those resources.

This document is a temporary supplement to the descriptions of the net benefits analysis for the Proposed OCS Program for 2012-2017 and focuses on the Offshore Environmental Cost Model (OECM),[2] which is used to estimate net environmental and social costs for the net benefits analysis. The OECM is in the final stages of a major revision to update the data and model approach and, because the final documentation for the new version of the model is not yet available, this document provides a description of the methodology, data sources, etc., used to update the OECM. The overall methodology for the benefit-cost analysis is summarized in part IV of the proposed program decision document. Additional information on the methodology and economic assumptions can be found in the *Economic Analysis for the OCS 5-Year Program 2012-2017: Theory and Methodology* (BOEM 2011-050).

Note that with the exception of publications whose title includes the agency name or as otherwise noted, all references to BOEM in this draft document include its predecessor agencies, the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE) and the Minerals Management Service (MMS).

5-Year Program Net Benefits Analysis

Producing energy domestically provides benefits to society. The net benefits analysis considers the net economic value of production of OCS oil and gas anticipated from the program options, the associated economic and societal costs, and the consumer surplus[3] created by the additional supply of energy.

[1] See Map A and Map B in the proposed program decision document for the proposed program areas for the 5 years beginning in the second half of 2012.

[2] Upon completion of all revisions to the OECM, prior to development of the proposed final program decision document, a full report will be published and posted.

[3] As explained under the Net Benefits heading in part IV of the proposed program decision document, consumer surplus, a standard term in economics, represents the difference between the price actually charged for a service or product and the higher price consumers would be willing to pay for a service or product if they had to. In this context, an action or event that lowers the price of a good or service will increase consumer surplus by the change in price times the quantity purchased at that lower price (which would be all oil and gas purchased in the United States).

Environmental and Social Costs of the Program Options

The exploration, development, production, and transportation of OCS oil and gas resources also impose environmental and social costs on society that are not accounted for market costs. (These are sometimes referred to as external costs or spillover costs.) Among these are negative health effects caused by reduced air quality from construction and routine operations, harm to plants and animals from oil spills, possible effects on property values, and effects on commercial, recreational, and subsistence fishing. This document describes the methodology for estimating these costs.

Environmental and Social Costs of the Energy Market Substitutions (No Sale Options)

However, in the absence of the proposed new lease sales (auctions) in the next the 5-year program (the result of a No Sale decision for one or more program areas), energy markets would substitute other energy sources to replace the foregone OCS production, and these energy substitutes would also impose environmental and social costs on society. Many of these environmental and social costs are of the same type as those that result from OCS oil and gas activities. However, they stem from the increased levels of tanker traffic needed to transport imported oil to our shores, as well as increased domestic onshore oil and natural gas activities, domestic coal production, etc., that would be needed without new OCS production from the program areas.

The BOEM uses its *Market Simulation Model* (MarketSim) to estimate the amount and percentage of sources of energy the economy would adopt in the absence of lease sales for one or more of the program areas under consideration. Increases in imports and domestic onshore production as well as fuel switching would be necessary to meet continuing domestic demand for oil and gas resources. Although the model provides estimates specific to the anticipated production from each program area, on average it indicates overall that most of the anticipated production would be replaced by increased oil imports, but with the remainder replaced by increased onshore gas production, gas imports, domestic coal production, electricity, onshore oil production, and other energy sources. In an environment of increasing world demand for oil and gas, a supply cut equivalent to the production anticipated to result from a new 5-year program would contribute to rising prices in the absence of additional production somewhere else. This would lead to a small reduction in oil and gas consumed in the United States, and the MarketSim estimates that reduction in energy use would be another “energy substitute.”

Costs from the energy substitutions would be the result of the added risk of oil spills and additional air emissions from increased tanker imports as well as from increased air emissions as a result of increased onshore production of oil, gas, coal, and other energy sources. Because this is a national analysis, only the costs imposed within the United States and its waters are estimated; i.e., the environmental and social costs of exploration, development, production, and transportation of U.S.-destined oil (or gas) in Canada, Saudi Arabia, Venezuela, Mexico, Nigeria, and other exporting countries are not included in the costs of the energy substitutions in the net benefits analysis.[4]

A more detailed discussion of the model and substitute sources of energy in the context of the proposed program for 2012-2017 is given in *Energy Alternatives and the Environment, 2012-2017* (BOEM 2011-051), which can be found with other 5-year program documents at www.boem.gov.

Offshore Environmental Cost Model

The OECM provides estimates of the environmental and social costs for both the program options and the energy market substitutions (implied by the No Sale Option for the relevant program area), and these are used in the net benefits analysis. (See Tables 13, 15, and 16 in the proposed program decision document.). The OECM uses the levels of OCS activity from the exploration and development (E&D) scenarios employed in the net economic value (NEV) and the environmental impact statement (EIS) as well as the energy market substitutions from the MarketSim to calculate environmental and social costs. In order to get an accurate value of the net environmental and social costs of each program option, the No Sale (energy substitutes') costs are subtracted from the environmental and social costs anticipated from OCS oil and gas activities anticipated under that option.

The BOEM has been updating the OECM over the past 3 years. This update is in the final stages and the new version was used for the estimates in the proposed program and the draft programmatic EIS.

The new version of the OECM is based on Microsoft (MS) Access and is driven by the same E&D scenarios used for other analyses supporting the 5-year program. This document describes the model's cost calculation methodologies as well as descriptions of each calculation driver, including the sources of underlying data and any necessary assumptions.

The model currently addresses six cost categories:

- Recreation: The loss of consumer surplus that results when oil spills interfere with recreational offshore fishing and beach visitation.
- Air quality: Emissions—by pollutant, year, and planning area—and the monetary value of the human health and environmental damage caused by these emissions.
- Property values: Impacts of the visual disamenity caused by offshore oil and gas platforms and losses in the economic rent of residential properties caused by oil spills.
- Subsistence harvests: The estimated replacement cost for marine subsistence organisms killed by oil spills.

[4] The BOEM staff is working on a supplemental methodology that would consider all sources, regardless of location, to the extent feasible. However, estimates would be only for greenhouse gas (GHG) emissions. GHG emissions from anywhere in the world would be relevant, given the global nature of likely effects. The estimates would be for emissions resulting from both the program and the energy substitutions but would not include monetization. Any costs of GHG emissions from the production quantities anticipated from program-area-specific options would be speculative, and the uncertainty would overwhelm the estimates.

- Commercial fishing: The costs of fishing area preemption caused by the placement of oil and gas infrastructure (platforms and pipelines).
- Ecological: Restoration costs for habitats and biota injured by oil spills.

Note that the model is not intended to address the broader, often regional economic impacts of oil and gas exploration and development activity (e.g., the employment this activity supports and the indirect effects that result when employment-related income enters a local economy).

The OECM is designed to model the social and environmental impact of activities associated with OCS oil and gas activities, as well as with typical oil spills[5] occurring on the OCS, and the effects of activities necessary to bring energy substitutes to market. The model is not designed to represent impacts from catastrophic events or impacts on unique resources such as endangered species. Information on the range of factors that could influence the impacts of a catastrophic event and the resources that could be harmed are included in Appendix B of the proposed program decision document.

Commenting on the Data and Methodology Described in This Document

Given that the *net* environmental and social costs for most or all program options are positive (i.e., costs are greater for the energy substitutes than for OCS oil and gas activities) for the first time, BOEM is temporarily posting the following draft description of the model and its calculations to provide insight on the model to interested parties. The public may comment on the methodology or supporting data. Comments can be submitted via the procedures described in the notice of availability published in the *Federal Register* on November 10, 2011 (Vol. 76, No. 218). The same procedures are posted at on the BOEM web site at www.boem.gov (http://www.boem.gov/Oil-and-Gas-Energy-Program/Leasing/Five-Year-Program/2012-2017/PP.aspx).

Once the OECM revisions and model documentation is complete, the report will be posted on the BOEM Environmental Studies Program Information System (ESPIS) web pages (go to www.boem.gov and search on ESPIS). This document will be removed from the 5-year web site once the report is posted but no sooner than the end of the comment period.

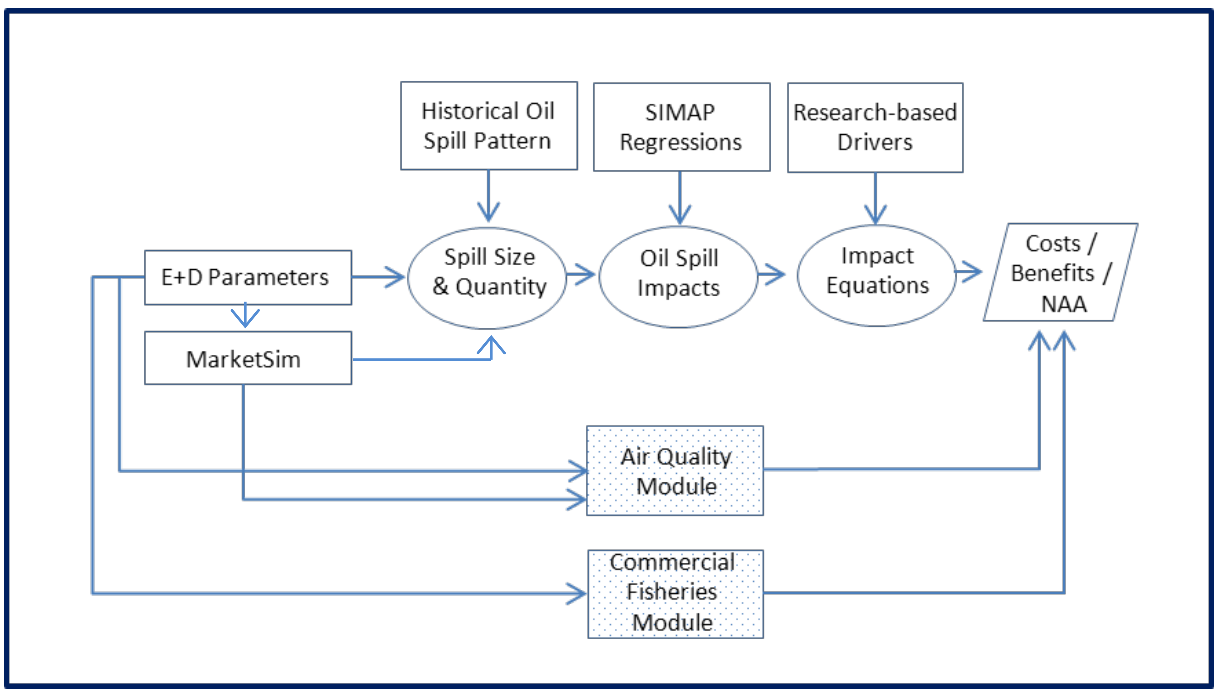
[5] "Typical" oil spills are those that occur with enough frequency to provide analytically supportable estimates of their likely frequency and effects.

2 MODEL DESCRIPTION

The OECM is built on a MS Access 2003 platform and is compatible with MS Access 2010. As defined in the E&D worksheet, the OCS platform groups serve as the fundamental unit for estimating costs and benefits. Currently, the model estimates costs for six sectors:

- Recreation;
- Air quality;
- Property values;
- Subsistence use;
- Commercial fishing; and
- Ecological effects.

For the recreation, property value, subsistence use, and ecological sectors, the OECM uses the parameters set forth in the E&D scenario worksheet to estimate annual oil production and the location of potential spills associated with each platform group. This is represented by the Spill Size & Quantity portion of the diagram below.[6]



[6] The E&D scenario worksheet includes information on several variables for platforms, including depth and distance from shore. Platforms in a given planning area that share the same values across these variables are combined into platform groups.

The OECM feeds this information into SIMAP-generated regressions to estimate the physical impacts of oiling, as represented by the Oil Spill impacts node in the diagram below. Then, using impact equations developed for each sector, the OECM employs the SIMAP regression outputs and impact-specific data elements to estimate monetized estimates of costs and benefits. The OECM then uses this information in its estimation of the total environmental and social costs associated with an E&D scenario. The model provides additional flexibility for BOEM to add additional cost sector and impacts as information becomes available. Due to the unique characteristics of the air quality and commercial fishing sectors, the OECM employs the output from external modules to estimate impacts associated with OCS production in these sectors.

The description below walks through the series of model steps and calculation used in the general cost and benefit calculations that occur within the OECM. A discussion of the calculations associated with the No Action Alternative (NAA) is also provided.

2.1 GENERAL COST AND BENEFIT CALCULATIONS

The following describes OECM's general methods for estimating costs and benefits. These methods apply to the first four sectors presented above and would apply to additional sectors added through the OECM interface. As stated above, the OECM performs calculations at the platform group level as provided in the E&D scenario worksheet. For each platform group, the OECM completes the following steps:[7]

Step 1. Annualize and distribute oil production across potential spill sources

The OECM estimates annual oil production based on each platform group's anticipated total oil production adjusted by the Activity and Production Schedule from the E&D scenario. Annualized oil production is then distributed across production and transportation modes (i.e., platform, pipeline, barge, and tanker) based on the percentages held in the OECM (see the Oil Transport Assumptions under Manage Data).[8] The OECM assumes all oil originates at the platform, and therefore attributes 100 percent of oil production to platforms.

Step 2. Classify mean spill sizes by oil source and type

Based on historic oil spill information, the OECM applies the mean spill size per barrel (bbl) of oil production or transport for four spill sources: platforms, pipelines, OCS supply vessels, and tankers; and three oil types: crude and condensate; heavy fuel oil; and diesel. The OECM classifies mean spill sizes into five or six size classes ranging from very small (1 to 10 bbl) to extra-large (10,001 to 100,000 bbl). The default OECM size classes and mean spill rates can be found and edited on the Oil Spill Data page within the model.

Step 3. Estimate number of spills for each size class, oil type, and oil source.

For each combination of size class, oil type, and oil source, the OECM estimates the annual number of individual spills that correspond to the mean spill size for each class. To accomplish this, the model applies the following equation:

$$\frac{\left(P_a \times R_s \times C_s \times 1{,}000{,}000{,}000\right)}{X_s}$$

[7] Note that those impacts that do not depend on oil spill impact drivers (e.g., visual disamenity from platforms) skip directly to Step 7 using the research-based drivers relevant to the specific impact equation.

[8] Little information is available on spills from barges, and the percentage of oil moved through barges is believed to be minimal; therefore, the OECM combines barge spills with pipeline spills.

where:

P_a = Annual oil production adjusted for source of spill (billion barrels of oil (BBO))

R_s = Mean spill rate per size class (bbl/bbl produced or transported)

C_s = Spill class as a percentage of total spills (%)

X_s= Mean spill size per spill class (bbl)

Step 4. Employ SIMAP-generated regressions based on oil type and spill location.

As discussed in detail in Appendix A, Oil Spill Modeling for the Offshore Environmental Cost Model, the OECM applies regressions developed using SIMAP to estimate the impacts of oil spills based on a volume of oil spilled and distance from shore.[9] SIMAP-generated impacts include:

- Length of oiled shoreline ~ rock and gravel in meters (m)
- Length of oiled shoreline ~ sand (m)
- Length of oiled shoreline ~ mudflat and wetland (m)
- Length of oiled shoreline ~ artificial (m)
- Water surface area exposed to oil (m^2)
- Surface area of shoreline oiled ~ rock and gravel (m^2)
- Surface area of shoreline oiled ~ sand (m^2)
- Surface area of shoreline oiled ~ mudflat and wetland (m^2)
- Surface area of shoreline oiled ~ artificial (m^2)
- Water surface area ~ impacts to shorebirds and waders (km^2)
- Water surface area ~ impacts to birds mammals and sea turtles (km^2)
- Volume of oil water exposed ~ impacts to water column organisms (m^3)

For each spill size class, oil type, and oil source, the mean spill size is applied to the SIMAP regression to generate measures of the above impacts. For spills originating from platforms, pipelines, and OCS supply vessels, the OECM assumes that the spill occurs at the location of the platform. For tanker spills, we assume that one-half of the spills occur in the planning area where production occurs and one-half of the spills occur in the planning area where oil is brought to shore. In an effort to avoid significantly over- or under-estimating the spill-related costs, the model assumes that tanker spills would occur at the distance specified as the boundary between the nearshore and offshore areas.

[9] For most planning areas, the OECM applies a different set of regressions for nearshore areas and offshore areas. The boundary line between inshore and offshore differs by planning area.

Step 5. Multiply regression outputs by the number spills per size class

For the combination of spill size class, oil type, and oil source, the OECM multiplies each regression output by the number of spills estimated in Step 3.

Step 6. Sum regression outputs to develop oil spill-related drivers

The OECM sums the resulting impacts (corresponding to those in Step 4) across spill size classes, oil sources, and oil types to develop the final oil spill-related drivers for the relevant platform group.

Step 7. Apply relevant oil spill-related drivers and research drivers in the impact equations

The OECM loops through each sector and impact and applies the relevant oil-spill-related and research-based drivers to estimate annual costs and benefits associated with the platform group.

Step 8. Calculate present value based on user assumptions

Finally, the OECM converts the annual impacts to present values based on the analysis year and discount rate assumptions entered in the E&D Scenario and the Update OECM page.

National versus regional allocations

The OECM allows the user to choose between national allocation and regional allocation schemes. Under the national allocation, the OECM attributes all of the impacts associated with an E&D scenario to the planning area of production. For the NAA, the OECM allocates (avoided) impacts to planning areas in proportion to their combined oil and gas production under the E&D scenario. For example, if 35 percent of oil and gas production under an E&D scenario occurs in the Western Gulf of Mexico, the OECM assigns 35 percent of No Action Alternative impacts to this planning area.

For the regional allocation, the OECM uses two allocation approaches—one for oil-spill related impacts and one for air pollution impacts. For the former, the regional allocation assigns one-half of the impacts from tankers spills to the planning area where oil is brought to shore, and the remainder (platforms, pipelines, OCS vessels, and one-half of tanker spills) are attributed to the planning area of production. This approach acknowledges the uncertainty regarding the location oil spills, as spills could occur anywhere between the loading and offloading locations. For air pollution impacts, the regional allocation distributes emissions to the location where they are expected to occur, including the domestic onshore environment (e.g., for onshore oil and gas production).

2.2 COST CALCULATIONS FOR THE NO ACTION ALTERNATIVE

An assessment of net environmental and social costs depends on monetization of anticipated costs (and benefits) in the absence of 5-year program activity (i.e., if no leases are anticipated during the 5-year period of analysis. The absence of program activity is referred to as the NAA. The process for calculating these costs begins with the application of the MarketSim to an E&D scenario. MarketSim produces an estimate of the energy markets' response to the foregone production that would have occurred as a result of the five-year program. The MarketSim results may show an overall reduction in energy demand due to conservation, but will also show substitution responses across various segments of the energy sector. Three specific responses are considered important to evaluate in the absence of the program production forecasted in the E&D

scenario: an increase in the quantity of oil delivered into the U.S. market via overseas tanker; the quantity of natural gas imported into the U.S. via tanker; and an increase in the onshore production of oil, gas, and coal within the United States.[10] These responses are assumed to be the most significant in terms of potential environmental costs, namely (1) the impact of oil spills from incoming oil tankers; (2) the air quality impacts associated with emissions from incoming tankers (oil and liquid natural gas); and (3) the incremental emissions associated with onshore oil, gas, and coal production. Other potential costs may also be relevant (for example, potential impacts associated with the waste water generated through onshore oil and gas production) but are not included in this version of the model due to the lack of credible bases for describing them as functions of specific model inputs.

2.2.1 Oil spill costs under the No Action Alternative

The methodology for modeling oil-spill related costs under the NAA is as follows:

- The OECM imports the MarketSim estimate of imported crude oil in the absence of the oil production assumed to result from the five-year leasing program. Note that the relevant MarketSim output is exclusive to tankers, and thus does not need to be expressed net of imports that might arrive via pipeline.
- In order to assign potential costs to individual planning areas, the model must make assumptions about the geographic distribution of the volume of imported oil. The model user can view and adjust this distribution by selecting the No Action Alternative Page under Manage Data. The default values correspond to the average annual fraction of total crude oil tanker trips that arrive at ports in each of the planning areas, assuming that per tanker quantities do not vary significantly between ports.[11]
- To calculate spill-related costs under the NAA, the model uses the same spill probability and spill size distribution factors to determine the volume of spilled oil in each of the applicable planning areas, and then applies this volume to each of the cost calculations that have a spill component in the same way it would calculate costs associated with a program scenario.
- Since the OECM distinguishes between nearshore and offshore locations for its assessment of oil spill impacts, an assumption is required regarding the location of potential spills. In an effort to avoid significantly over- or under-estimating the spill-related costs, the model assumes that spills would occur at the distance specified as the boundary between the nearshore and offshore areas. This boundary ranges from approximately 29 to 87 miles offshore.

2.2.2 Air quality costs under the No Action Alternative

The OECM uses two separate approaches to estimate the air quality costs of the No Action Alternative: one approach for tanker imports of oil and natural gas and a second methodology for increased onshore production of oil, natural gas, and coal.

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[10] The OECM does not estimate impacts associated with pipeline imports because pipeline transportation is unlikely to result in significant environmental impacts relative to tankers. Thus, while pipeline oil and gas imports from Canada may change under the NAA, no impacts are estimated for these specific changes in imports.

[11] Based on data for the years 2004 - 2008 collected by Environmental Research Consulting.

- For oil and gas tanker imports, the model applies emissions factors from the literature to various tanker activities, including (1) tanker cruising, (2) unloading, (3) volatile organic compounds (VOC) losses in transit (oil tankers only), and (4) ballasting (oil tankers only). For emissions that occur in transit (i.e., tanker cruising and VOC losses), we assume that emissions are distributed across an entire planning area. In contrast, emissions released at port (unloading and ballasting emissions) are uniformly distributed across the coastal portion of each planning area. Similar to the OECM's assessment of oil spill costs for tanker imports, the model allows users to specify the distribution of imports across planning areas.
- To estimate the air quality costs related to increased onshore production of oil, natural gas, and coal, the model follows a two-step process:
    - First, the OECM estimates the emissions associated with onshore production by applying the change in onshore production projected by MarketSim to a series of emission factors specific to each fuel (i.e., onshore oil, natural gas, and coal). This yields the change in emissions associated with onshore production.
    - Second, the model multiplies emissions resulting from oil, gas, and coal production by a series of dollar per ton values that represent the monetized costs of onshore emissions. These values were derived from outputs of the Air Pollution Emission Experiments and Policy analysis model (APEEP, see Appendix C).

3 RECREATION

3.1 OVERVIEW

The model assesses the impact of OCS oil and gas activities by estimating the loss of consumer surplus that results when oil spills interfere with two activities that occur in the coastal and marine environment: recreational offshore fishing and beach visitation. The model is limited to these two general use categories because (1) they capture the primary recreational uses of coastal and marine resources that would be affected by OCS activity, and (2) they are the uses for which relevant data are generally available on a consistent, national basis. Recreational boating (non-fishing) is a use that would also realize an impact. However, the lack of geographically organized activity data (i.e., trips or days per year by state or region) precludes, at this time, the ability to model this potential cost.

The model estimates and values changes in recreational offshore fishing activity for the planning areas on the Atlantic and Pacific coasts and in the Gulf of Mexico, as well as three planning areas in Alaska (Gulf of Alaska, Cook Inlet, and Kodiak, which are assumed to account for nearly all recreational saltwater angling activity in the state). The model estimates and values changes in beach use only for the planning areas in the Atlantic, Pacific, and Gulf of Mexico regions.

As described below, the methods for estimating the costs associated with changes in recreational activity are essentially the same as those employed in the previous version of the OECM. Specifically, the costs are attributable to presumed closures of offshore fishing areas or beaches resulting from oil spills.

Note that the model does not take into account a recreational user's ability to move to another location in response to a spill-related closure, in which case some proportion of the value realized by the user would be retained. Note as well the difference between the model's measure of consumer surplus losses (a welfare-based measure of economic value) and the assessment of the regional economic impact of an oil spill on recreational activity. Expenditures (as captured in a regional economic impact analysis) provide a measure of the relative importance of different industries or sectors, such as recreation, within a local or regional economy. However, expenditures do not reveal the underlying value of those activities to participants, and when aggregated across all participants, to society as a whole. Value, more specifically net economic value or consumer surplus, is measured by what individuals are willing to pay for something above and beyond what they are required to spend. This concept of value is recognized as the appropriate measure to compare the costs and benefits of policy alternatives.

3.2 BASIC CALCULATION – RECREATIONAL FISHING

The model develops an estimate of costs for each Planning Area in which OCS activity is projected to occur using the equation

$$(T \div A \div 365) \times O \times C \times V$$

where:

T = Number of recreational fishing trips per year

A = Area within which recreational fishing activity occurs (assumed to be within 30 miles of the planning area coastline) (m^2)

O = Area of recreational fishing closure resulting from an oil spill (m^2)

C = Duration of recreational fishing closure (days)

V = Economic value of a recreational fishing trip ($/trip)

For the purpose of the model, the annual number of recreational fishing trips is assumed to be distributed evenly across the area within which this activity is assumed to occur.

3.3 CALCULATION DRIVERS – RECREATIONAL FISHING

3.3.1 Recreational fishing trips per year

Estimates of the baseline annual level of recreational fishing trips in each planning area are drawn from the most recent National Survey of Fishing, Hunting, and Wildlife-Associated Recreation produced by the U.S. Fish and Wildlife Service in cooperation with the U.S. Census Bureau (FWS 2006). This report provides consistent, state-level estimates of saltwater fishing trips and days for resident and nonresident populations aged 16 and older. The total for each planning area is the sum of the state-level estimates for states associated with that planning area, with the following exceptions:

- The Florida total is assumed to be distributed as follows: 50 percent – Eastern Gulf of Mexico; 25 percent – South Atlantic; 25 percent – Straits of Florida.
- The California total is assumed to be distributed equally among the Southern California, Central California, and Northern California Planning Areas.
- The allocation of the Alaska total is based on the relative proportions documented in the 2001 OECM, but only accounts for 90 percent of the total to reflect a concentration of activity in three planning areas (Gulf of Alaska – 45 percent; Cook Inlet – 40 percent; Kodiak – 5 percent). The remaining 10 percent is assumed to be distributed across the other Alaska planning areas, but at very low levels of activity in each which are not included in the model based on an assumption that activity at this scale cannot be reasonably distinguished from subsistence activity.

3.3.2 Area of recreational fishing activity

The model adopts the previous version of the OECM's general assumption that recreational fishing activity occurs within 30 miles of the coast (Roach et al. 2001). Using a geographic information system (GIS), an estimate of the relevant area offshore each state was generated by creating a buffer at the 30 mile mark. Planning area totals are the sum of the measured areas across the states (or partial states) that correspond to the planning areas.

3.3.3 Area of recreational fishing closure

The SIMAP model quantifies areas swept by floating oil of varying thicknesses and the fates and concentrations of subsurface oil components (dissolved and particulate). Regressions on the results of multiple SIMAP iterations in representative regions, simulating a range of oil types, volumes, spill distance from shore, and environmental conditions, produce equations that generally relate spill volume to water area exposed to oil above an impact threshold. For recreational fishing, the threshold is specified as a surface sheen produced by an oil concentration of 1 gram (g)/m^2.

3.3.4 Duration of recreational fishing closure

Lacking a sound basis for altering the assumption included in the 2001 OECM, the duration of saltwater recreational fishing closures associated with oil spills is set at 60 days for all planning areas (Roach et al. 2001).

3.3.5 Economic value of a recreational fishing trip

Based on a review of recreational valuation literature available at that time, the 2001 OECM model employed a range of consumer surplus estimates of $11 to $57 per trip for saltwater fishing. To identify relevant studies published since the previous update, we conducted searches of the economics and social science literature. Specifically, our goal was to determine if additional information was available to 1) refine and/or narrow the ranges of values, and 2) support assignment of region-specific values (e.g., east, west and gulf coasts). We restricted our review to studies of recent vintage that apply current best-practices in recreational demand modeling (i.e., random utility travel cost models). While several additional studies were identified, reported values generally fell within the existing ranges. In addition, no consistent patterns across regions could be discerned. It is likely that differences in model specification and estimation procedures obscure any underlying regional variation in value estimates. As such, we have retained the existing range of values, inflated the high and low to current dollars, and have assigned the resulting average value of $42 as the oil spill-related per-trip loss for recreational fishing.

3.4 BASIC CALCULATION – BEACH USE

The model develops an estimate of costs for each planning area in which OCS activity is projected to occur using the equation

$$\left[T \div B \div 365\right] \times O \times C \times V$$

where:

T = Number of beach use days per year

B = Total length of public beach in the planning area (m)

O = Length of beach closure resulting from an oil spill (m)

C = Duration of beach closure (days)

V = Economic value of a beach use day ($/day)

As with recreational fishing trips, the annual number of beach use days is assumed to be distributed evenly across the cumulative length of beach within each planning area.

3.5 CALCULATION DRIVERS – BEACH USE

3.5.1 Beach use days per year

Lacking newer or more refined data that are consistent and complete across all states/planning aeas, the model uses the annual beach use data included in the 2001 OECM (Roach et al. 2001). These data describe typical “sandy beach” use in the lower 48 states; data describing the use of Alaskan beach types (e.g., kayak haul-outs on rocky beaches) are not included in the available sources of information. Though the relative use levels in Alaska are assumed to be low, this omission is a limitation of the model in its current form.

3.5.2 Total length of public beach

The length of public beach in each state was determined in GIS using a shapefile associated with a dataset maintained by the U.S. Environmental Protection Agency. This dataset does not include beach length information for Alaska. The dataset contains information on Beaches Environmental Assessment and Coastal Health (BEACH) Program events indexed to the National Hydrography Dataset (NHD) Reach Addressing Database (RAD). The total length of public beach in each planning area is the sum of state-level beach lengths across the states (or partial states) that correspond to the planning areas.

3.5.3 Length of beach closure

The SIMAP models the fate and transport of oil spilled in the ocean to quantify lengths of oiled shoreline, using regional data to separate those impacts by shore type (specifically, rock and gravel; sand; mudflat and wetland; and artificial). Regressions on the results of multiple SIMAP iterations in representative regions, simulating a range of oil types, volumes, spill distance from shore, and environmental conditions, produce equations that generally relate spill volume to the length of shoreline exposed to oil above an impact threshold. For beach use, the model uses the regression result for the sand shoreline type. The impact threshold is specified as a surface sheen produced by an oil concentration of 1 g/m^2.

3.5.4 Duration of beach closure

Lacking a sound basis for altering the assumption included in the 2001 OECM, the duration of beach closures associated with oil spills is set at 21 days for all planning areas. This generalized estimate of closure duration does not capture possible variation in spill impacts across different beach types.

3.5.5 Economic value of a beach use day

Based on a review of recreational valuation literature available at that time, the 2001 OECM model employed a range of consumer surplus estimates of $4 to $19 per person per day for beach use. As with recreational fishing, we conducted searches of the economics and social science literature to identify relevant studies published since the previous update, again restricting our review to studies of recent vintage and that apply current best-practices in recreational demand modeling. While several additional studies were identified, reported beach use values also generally fell within the existing ranges and no consistent patterns across regions could be discerned. As such, we have retained the existing range of values, inflated the high and low to current dollars, and have assigned the resulting average value of $14 as the oil spill-related per-day loss for beach use.

3.6 REFERENCES - RECREATION

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4 AIR QUALITY

4.1 OVERVIEW

Exploration and development of the OCS will lead to emissions of sulfur dioxide (SO^2), oxides of nitrogen (NOx), volatile organic compounds (VOC), particulate matter (PM), and other air pollutants that may adversely affect human populations and the environment. To account for these effects, the revised OECM includes an air quality module that estimates (1) the emissions—by pollutant, year, and planning area—associated with a given E&D scenario and, (2) the monetary value of the environmental damage caused by these emissions (estimated on a dollar-per-ton basis). The model estimates emissions based on a series of emissions factors derived from BOEM data and, for planning areas along the coast of the contiguous U.S., converts these values to monetized damages using a modified version of the Air Pollution Emission Experiments and Policy analysis model (APEEP) developed by Muller and Mendelsohn (2006). The model monetizes damages associated with emissions in Alaska planning areas using scaled estimates of the monetized damages by scaling the APEEP estimates of damages per ton of emissions for the Oregon-Washington Planning Area. The geographic unit of analysis within the air quality module is a series of offshore grid cells approximately 2,500 km^2 in size, as illustrated in Figure 1.

The specific air pollution impacts that the OECM examines include:

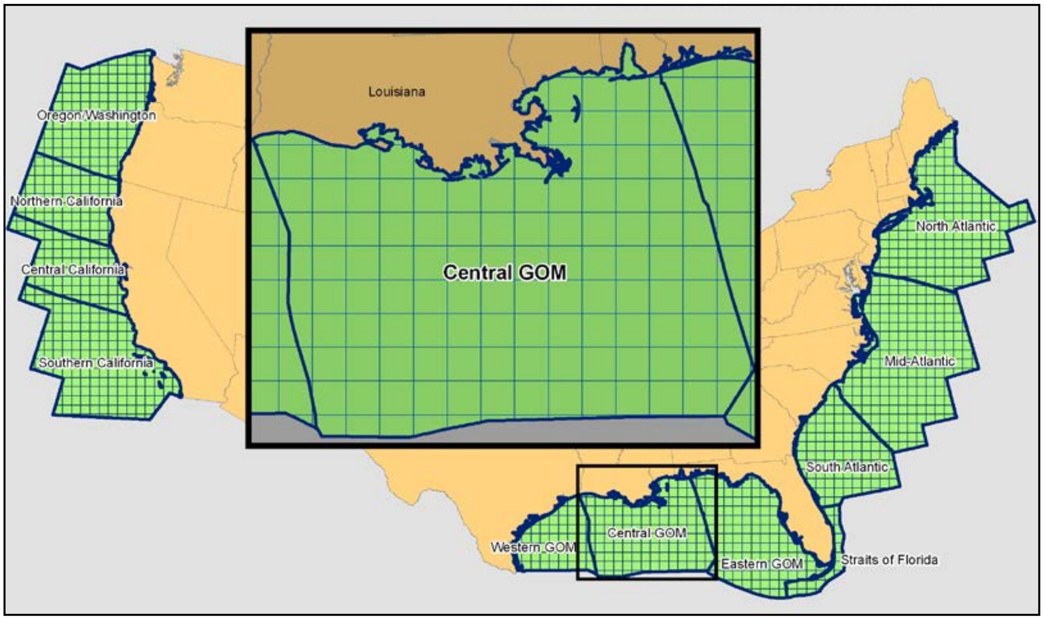
- Adverse human health effects associated with increases in ambient $PM_{2.5}$ and ozone concentrations;
- Changes in agricultural productivity caused by changes in ambient ozone concentrations; and
- Damage to physical structures associated with increases in SO_2.

Emissions from OCS development may also affect visibility, forest productivity, and recreational activity (e.g., visits to National Parks). The OECM does not include these effects, however, as the limited data on these impacts in the peer-reviewed literature are not amenable to the streamlined air quality modeling framework included in APEEP. Because human health effects generally dominate the results of more detailed air pollution impact analyses,[12] excluding emissions-related changes in visibility, forest productivity, and recreational activity from the OECM is unlikely to have a significant impact on the model's results.

The revised OECM uses a similar methodology as the 2001 OECM for estimating the emissions associated with E&D activity, but applies a more detailed approach for monetizing the impact of these emissions. For example, the revised model relies upon a more systematic framework for assessing the onshore air quality impacts of offshore emissions. The model also includes a greater degree of geographic specificity in its estimation of the damages caused by offshore emissions. Whereas the 2001 model applied the same dollar-per-ton value to an entire planning area, the current model uses values specific to individual offshore grid cells approximately 2,500 km^2 square in size, as shown in Figure 1 for the Atlantic, Pacific, and Gulf of Mexico planning areas. The dollar-per-ton estimates for each offshore grid cell also reflect recent developments in the epidemiological literature on the physical impacts of air pollution and advances in the economics literature on society's willingness to pay to avoid these impacts.

[12] See U.S. EPA (2010a).

Figure 1 Offshore Grid for the OCS Adjacent to the Contiguous United States



4.2 BASIC CALCULATION

To estimate air quality impacts, the OECM first estimates the emissions for a given E&D scenario and then estimates the damages associated with these emissions. Equation 1 illustrates the OECM's estimation of emissions:

(1) $E_{P,A,Y,G} = L_{A,Y,G} \times F_{P,A}$

where

$E_{P,A,Y,G}$ = Emissions of pollutant P from emissions-generating activity A (*e.g.*, number of platforms operating) in year Y and offshore grid cell G;

$L_{A,Y,G}$ = Level of emissions-generating activity A in year Y and offshore grid cell G;

$F_{P,A}$ = Emission factor (*e.g.*, tons per platform operating) for pollutant P and emissions-generating activity A.

The timing of emissions in the OECM depends on the specified schedule for various E&D activities (i.e., exploration and development, platform construction, platform operations, oil and gas extraction, and platform removal). The model also uses a series of activity-specific assumptions to specify the location of OCS emissions. For example, the E&D scenarios specified by BOEM specify the average distance from shore for each platform group within a planning area. Using this information, the model distributes platform emissions to those offshore grid cells that are located a similar distance from shore.

To estimate the economic damages associated with the emissions estimates generated from Equation 1, the OECM applies pollutant-specific dollar-per-ton values, as shown in Equation 2.

(2) $I_{P,Y,G} = \sum_{G}\sum_{A} E_{P,Y} \times D_{P,Y,G}$

where

$I_{P,Y}$ = Monetized impacts from emissions of pollutant *P* in year Y;

$\sum_{G}\sum_{A} E_{P,Y}$ = Emissions of pollutant *P* in year *Y*, summed across all emissions-generating activities and offshore grid cells.

$D_{P,Y,G}$ = Damages per ton of pollutant *P* emitted in year *Y* and offshore grid cell *G*.

As indicated by Equation 2, the value of the damages caused by a ton of air emissions varies by year. This reflects growth in population and income per capita over time.

4.3 CALCULATION DRIVERS

4.3.1 Level of emissions generating activity

The OECM estimates the level of emissions generating activity for any given year based on the E&D scenarios and schedules developed by model users. The specific activities used by the air quality module to assess emissions associated with OCS exploration and development activities include:

- Exploration/Delineation wells drilled, by year
- Development and production wells drilled, by year
- Production platforms installed, by year
- Production platforms in operation, by year
- Transport of oil produced on the OCS, by year[13]
- Miles of pipeline laid, by year
- Production platforms decommissioned, by year
- For the NAA, changes in onshore energy production and tanker imports of oil and gas, by year.

4.3.2 Emission factors

The OECM applies a series of emission factors to the annual estimates of emission-generating activity to estimate emissions associated with the following OCS activities: (1) oil and gas platform operations, (2) exploration and delineation well activity, (3) development and production well activity, (4) helicopter trips, (5) pipe-laying vessels, (6) platform installation and removal, (7) support vessels, (8) survey vessels, and (9) tankers and/or barges/tugs transporting oil produced on the OCS (with separate emission factors for oil produced in Alaska planning areas versus all other planning areas).[14] Table 1 summarizes the

[13] All natural gas is assumed to be shipped via pipeline, with no emissions.

[14] We note that the model allows users to specify how oil is distributed across three modes of transportation to shore in non-Alaska OCS regions: pipeline (assumed to cause emissions), tanker, and tug/barge. The OECM estimates emissions related to tanker and tug/barge transport. Emissions associated with pipeline transportation are assumed to be zero. The only pipeline-related emissions estimated by the OECM are emissions associated with the laying of pipelines.

emission factors for each of these activities. With the exception of tankers transporting oil produced in the Alaska OCS region, the values in the figure for OCS exploration and development activities are based upon emissions data provided by BOEM staff for oil and gas operations in the GOM. We apply the non-tanker emission factors to all OCS regions under the assumption that oil and gas operations in these areas would not differ significantly from operations in the GOM.[15]

Table 1 also presents the emission factors for activities associated with the NAA. These include (1) onshore oil production in the contiguous United States, (2) onshore gas production in the contiguous United States, (3) coal production in the contiguous United States, (4) importation of oil by tanker, and (5) importation of LNG by tanker. The data sources for these emission factors are as follows:

- *Onshore oil and gas production:* We estimated emission factors for onshore oil and gas production for the contiguous United States based on the Western Regional Air Partnership's (WRAP) 2002 emissions inventory for oil and gas activities in ten western states. These states include Alaska, Arizona, California, Colorado, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, and Wyoming (WRAP 2009).[16] Excluding oil and gas operations in coastal states included in the WRAP inventory (Alaska and California), we developed emission factors for onshore oil and gas production by dividing the emissions estimates from the WRAP inventory (with some adjustments) by the Department of Energy (DOE) estimates of onshore oil and gas production in the eight states analyzed. These states accounted for approximately 14 percent of onshore crude oil production in 2002 and approximately 30 percent of onshore natural gas production. More detailed information on the derivation of the onshore oil and gas emission factors is available in Appendix B.

  The WRAP states include areas of conventional gas production as well as areas of shale gas and coal bed methane production. The documentation for the WRAP dataset, however, does not indicate the extent to which emissions documented by the WRAP are associated with each of these production methods. Despite this uncertainty, the WRAP dataset represents the best available information on emissions from onshore gas production, and we therefore include the WRAP data in the OECM.

- *Onshore coal production:* Emissions per unit production of coal were obtained from Franklin (1998) data reported in version 7.1 of the SimaPro lifecycle assessment software.

- *Imports of oil by tanker:* For tankers carrying oil imported into the United States, we used the same emission factors used for tankers transporting crude oil from Alaska to the west coast of the contiguous 48 states.

As indicated in Table 1, the OECM estimates emissions for each emissions category (e.g., helicopter trips) based on the emission factors for that category and an emissions driver that represents the amount of emissions-generating activity. For reference, Table 2 provides a crosswalk between the various emissions categories and the emissions drivers employed in the OECM.

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[15] Model users wishing to obtain emissions estimates that reflect emissions factors specific to individual planning areas can run the model separately with emissions factors and E&D data tailored to a specific planning area.

[16] The WRAP also includes the states of Washington and Idaho, but they did not produce crude oil or natural gas in 2002, so we did not consider them in this analysis.

Table 1 Emission Factors for the Gulf of Mexico, Atlantic, and Pacific OCS regions

EMISSIONS FACTORS:		NO_X	SO_X	PM_{10}	$PM_{2.5}$	CO	VOC	CO_2	CH_4	N_2O
Oil and Gas Platform Operations (tons/platform/yr)[1]		53.1	1.3	0.494	0.49	59.5	33.9	5,860	142.1	0.086
Exploration and Delineation Wells (tons/well/yr, by water depth)[1]	0-60 m	103	13	1.83	1.8	27.3	2.6	5,314	0.3	NA
	60-800 m	238	30	4.24	4.16	63.2	5.9	12,270	0.6	NA
	800-1600 m	161.6	20.7	2.83	2.79	35.3	3.7	8,452	0.3	0.1
	>1600 m	222.5	28.8	3.85	3.81	42.1	4.7	11,742	0.3	0.3
Development and Production Wells (tons/well/yr, by water depth)[1]	0-60 m	103	13	1.83	1.8	27.3	2.6	5,314	0.3	0
	60-800 m	238	30	4.24	4.16	63.2	5.9	12,270	0.6	0
	800-1600 m	161.6	20.7	2.83	2.79	35.3	3.7	8,452	0.3	0.1
	>1600 m	222.5	28.8	3.85	3.81	42.1	4.7	11,742	0.3	0.3
Helicopters (tons/platform/yr)[1]		0.8	0.2	1.7	1.7	9.6	1.9	971.4	NA	NA
Pipe-laying Vessels (tons/mile of pipe)[1]		13.3	2.3	0.5	0.5	2.8	0.5	896	NA	NA
Platform Construction/Removal (tons/platform, by water depth)[1]	<300 ft	6.8	0.9	0.15	0.15	0.8	0.1	424	NA	NA
	300-600 ft	19.3	2.7	0.37	0.37	2	0.4	1,079	0	0.1
	>600 ft	212.6	31.2	5.17	5.17	28.4	5.2	12,578	0.1	0.6
Support Vessels (tons/platform/year)[1]		95.6	12.9	1.7	1.7	9.1	1.7	5,247	0	0.2
Survey Vessels (tons/platform/year)[1]		1.1952	0.1443	0.0184	0.0184	0.0997	0.0184	59.1	0.0007	0.0028
Tugs pulling barges, non-Alaska OCS regions (tons per bbl per mile)[1,2]	Cruising emissions	183.5	22.2	2.8	2.8	15.3	21.1	9,063	3.3	0.4
Oil Tankers, non-Alaska OCS regions [1,2]	Cruising emissions (tons per bbl per mile)	62.8	7.6	1	1	5.2	19.3	3,100.6	3.3	0.1
	Idling emissions during loading & unloading (tons per bbl)[3]	1,740.3	295.5	65.7	65.7	361.2	9,660	117,717	1,694.4	5.1
Oil Tankers (Alaska OCS region)[1,2]	Cruising emissions (tons per bbl per mile)	19.2	3.3	0.7	0.7	4	4	1298.2	0.8	0.1
	Idling emissions during	662.5	112.5	25	25	137.5	12,306	44,815	3,085.3	1.9

EMISSIONS FACTORS:		NO_X	SO_X	PM_{10}	$PM_{2.5}$	CO	VOC	CO_2	CH_4	N_2O
	loading (tons per bbl)									
	Idling emissions during unloading (tons per bbl)	662.5	112.5	25	25	137.5	6,194	44,815	1,542.9	1.9
LNG Tankers[4]	Cruising emissions (tons per trillion ft^3 per mile)	235.52	578.10	40.68	27.83	66.37	4.18	NA	NA	NA
	Unloading emissions (tons per trillion ft^3)	33,457	82,121	5,779	3,954	9,429	593	NA	NA	NA
Onshore Oil Production – contiguous US (tons per thousand barrels)[5]		0.00496	0.0150	3.22×10^{-6}	8.81×10^{-7}	0.00447	0.210	NA	NA	NA
Onshore Gas Production – contiguous US (tons per million cubic feet)[5]		0.0391	0.00727	1.31×10^{-4}	3.08×10^{-4}	0.0188	0.103	NA	NA	NA
Onshore Coal Production – contiguous US (tons per thousand short tons)[6]		0.230	0.230	2.56	NA	0.180	0.085	41.00	NA	NA

Sources/Notes:

1. Derived from emissions data provided by Dirk Herkhof of BOEM, September 13, 2011 and September 26, 2011.
2. The OECM uses the emission factors for “Tugs pulling barges, non-Alaska OCS regions” and “Oil Tankers, non-Alaska OCS regions” to estimate emissions associated with transporting oil from the OCS to shore in the Atlantic, Pacific, and Gulf of Mexico OCS regions. The model uses the emissions factors for “Oil Tankers (Alaska OCS region)” to estimate emissions associated with transporting oil from the Port of Valdez to ports on the west coast of the contiguous United States .
3. Emissions factors for loading and unloading apply separately to both loading and unloading. For example, idling results in 1,740 tons of NO_x emissions per bbl when loading tankers from regions other than Alaska and 1,740 tons of NO_x emissions per bbl when unloading.
4. Derived from Jaramillo et al. (2007) and Afon and Ervin (2008).
5. Derived from WRAP (2009).
6. Franklin (1998) as obtained from SimaPro version 7.1.

Table 2 Crosswalk Between Emissions Drivers and Emissions Category

EMISSIONS DRIVERS	EMISSIONS CATEGORIES
Number of operational platforms	Platform operations Helicopters Support vessels Survey vessels
Number of platforms over the life of the 5-year program	Platform construction Platform removal
Number of exploration & delineation wells	Exploration & delineation wells
Number of development & production wells	Development & production wells
Pipeline miles installed	Pipe-laying vessel emissions
Number of barrel miles traveled (e.g., 3 million barrels traveling 10 miles is 30 million barrel miles)	Cruising emissions – tugs pulling barges, non-Alaska OCS regions Cruising emissions – oil tankers non-Alaska OCS regions Cruising emissions – oil tankers Alaska OCS region
Barrels of oil shipped	Idling emissions – oil tankers non-Alaska OCS regions Loading emissions – oil tankers Alaska OCS region Unloading emissions – oil tankers Alaska OCS region
TCF miles traveled for imported natural gas (e.g., 2 TCF of gas traveling 100 miles is 200 TCF miles traveled)	LNG tanker cruising emissions
TCF of natural gas imported	LNG tanker unloading emissions
Barrels of onshore oil production	Emissions from onshore oil production
TCF of onshore natural gas production	Emissions from onshore gas production
Tons of onshore coal production	Emissions from onshore coal production

- *Imports of natural gas by tanker:* We developed emission factors for LNG tankers (expressed as emissions per trillion cubic feet) based on LNG tanker emission information (e.g., power rating, average speed, etc.) obtained from Jaramillo et al. (2007) and Afon and Ervin (2008).

A critical element of modeling the impact of emissions in the OECM is developing assumptions about where these emissions will occur. The E&D scenarios specified by OECM users provide some insight in this regard, as they specify the distance from shore for platform groups within individual planning areas. Even with this information, however, the location of various exploration and development activities is uncertain. The location of emissions associated with the NAA is similarly uncertain. For example, if domestic onshore gas production increases under the NAA relative to a given E&D scenario, the air impacts associated with this increased gas production depend on where production increases (e.g., Wyoming, Pennsylvania, etc.).

To address uncertainty related to the location of emissions, we employ the following approaches for allocating emissions geographically:

- *Offshore Band:* For a given platform group with an average distance from shore specified in the E&D scenario, some E&D activities are likely to be concentrated near platform locations. Among the activities listed in Table 1, this includes (1) platform operations, (2) exploration and delineation wells, (3) platform installation and removal, (4) and survey vessel activity. For these E&D activities, we allocate emissions for a given platform group to the band of offshore grid cells in the planning area with a distance from shore equal to the distance from shore specified for the platform group. Within the offshore band, we allocate emissions to grid cells in proportion to their surface area.

- *Offshore Array of Grid Cells:* While some E&D activities are likely to be concentrated offshore near platforms, others are likely to occur over a larger geographic range between platform groups and shore. For example, crew boats are likely to log several miles between platforms and port facilities. Helicopters, support vessels, and pipe-laying vessels are also likely to operate over the full distance between platform groups and shore. To account for this wider geographic scope of activity, we allocate emissions for these activities to the array of grid cells whose distance from shore is less than or equal to the distance from shore for the corresponding platform group.

- *Tankers*: Our assumptions about the location of tanker emissions vary by tanker type (e.g., tankers delivering imports versus tankers delivering oil from Alaska) and tanker activity (i.e., loading, cruising, and unloading). Table 3 summarizes these assumptions.

- *Onshore Energy Production:* The model does not allocate onshore energy production to specific locations within the United States. Instead, it applies the same dollar-per-ton values to all onshore production of a given fuel (e.g., oil). These dollar-per-ton values reflect the geographic distribution of onshore oil, gas, and coal production across the contiguous United States as derived from DOE production data. Thus, we implicitly assume that the geographic distribution of onshore energy production under the NAA is the same as for current onshore production.

Table 3 Assumptions Regarding Location of Tanker Emissions

TANKER TYPE	TANKER ACTIVITY	SPATIAL ASSUMPTIONS
Tankers delivering oil from Alaska	Loading	All emissions from loading assumed to originate from the offshore grid cell adjacent to the Port of Valdez.
	Cruising	Cruising emissions (including VOC losses) assumed to be released in the OCS grid cells intersected by the shipping routes between Valdez and three ports on the West Coast: Port Angeles, Washington; San Francisco, California; and Long Beach, California.
	Unloading and Ballasting	All emissions from unloading and ballasting assumed to occur in the grid cell of the destination port.
Tankers and Tugs/Barges in the Atlantic, Pacific, and Gulf of Mexico	Loading	Location uncertain due to uncertainty regarding the location of offshore platforms. E&D scenarios specified by model users indicate the distance from shore for each platform group. Loading emissions for each platform group are therefore distributed across the band of offshore grid cells whose distance from shore is equal to that of the platform group.
	Cruising	Cruising emissions are distributed to those offshore grid cells between shore and the band of cells identified for loading. All cruising emissions are assumed to occur in the grid cell where oil is produced.
	Unloading and Ballasting	Given the uncertainty regarding where unloading would occur in each planning area, unloading and ballasting emissions are assumed to occur in the grid cells along the coast in the planning area where oil is produced.
Tankers – Oil Imports	Cruising	For a given planning area receiving oil imports, emissions from tanker cruising are distributed to all of the grid cells in the planning area, given the uncertainty about where oil tankers may travel within each planning area.
	Unloading and Ballasting	Given the uncertainty regarding where unloading would occur in each planning area, unloading and ballasting emissions are assumed to occur in the grid cells along the coast in the planning area where oil is delivered.
Tankers – LNG Imports	Cruising	For a given planning area receiving oil imports, emissions from tanker cruising are distributed to all of the grid cells in the planning area, given the uncertainty about where oil tankers may travel within each planning area. Based on the current LNG port infrastructure, the model assumes that LNG tankers may deliver natural gas to eight LNG terminals in five planning areas (North Atlantic, Mid-Atlantic, South Atlantic, Central Gulf of Mexico, and Western Gulf of Mexico).
	Unloading and Ballasting	Unloading and ballasting assumed to occur only in existing LNG terminals.

4.3.3 Damages per ton

As noted above, the OECM uses two approaches for monetizing the damages associated with emissions from OCS activities: one approach for planning areas in the Atlantic, Pacific, and Gulf of Mexico OCS regions and a second approach for planning areas in the Alaska region. We first discuss the approach for the former and subsequently outline the methods employed for monetizing emissions off the coast of Alaska.

The dollar-per-ton values included in the revised OECM for the non-Alaska planning areas are derived from a modified version of APEEP. APEEP is a reduced-form integrated air quality assessment model designed to estimate county-level dollar-per-ton estimates of the damages associated with $PM_{2.5}$, VOC, NO_x, and SO_2 emissions. To generate dollar-per-ton values for the OECM, APEEP follows a three-step analytic chain consistent with the methods employed in U.S. Environmental Protection Agency (EPA) regulatory impact analyses of air pollution impacts:

1. *Air Quality:* First APEEP estimates the extent to which one ton of emissions of a given pollutant affects ambient pollutant concentrations in different locations.
2. *Physical Effects:* Based on the change in air quality estimated for each location, APEEP employs a series of peer-reviewed dose-response functions to estimate changes in the incidence of various adverse physical effects (*e.g.*, premature mortality).
3. *Valuation:* APEEP estimates the monetized value of the change in physical effects based on information from the economics literature and other published sources.

Based on these steps, APEEP generates dollar-per-ton impact estimates for emissions of NO_x, SO_x, $PM_{2.5}$, and VOCs. Each of these steps is described in more detail below.

<u>Air quality</u>

The air quality modeling module within APEEP was originally designed to estimate the extent to which changes in *onshore* emissions affect air quality in individual (onshore) counties. Developing the dollar-per-ton values for the OECM therefore required modifying APEEP to assess how *offshore* emissions affect onshore air quality. Our approach for estimating the onshore air quality impacts for each of the offshore grid cells shown in Figure 1 is as follows:

1. *Statistical assessment of emissions-air quality transfer coefficients.* For onshore emissions, APEEP includes a series of emissions-air quality parameters (*i.e.*, transfer coefficients) that represent the relationship between emissions in one county and ambient air quality in another county. Using these data, we conducted a regression analysis that estimates the value of transfer coefficients as a function of both the distance and directional relationship (measured in degrees) between an emissions source and a receptor county.
2. *Estimate transfer coefficients for each offshore location.* Based on the statistical relationships estimated in Step 1, we estimated the emissions-air quality transfer coefficients for each offshore grid cell. To develop these estimates, we entered the distance and directional relationship between each offshore grid cell and each (onshore) county in the contiguous United States into the regression equations developed under Step 1. The values generated by these equations represent the relationship between emissions in each offshore grid cell and ambient air quality in each county of the contiguous United States.

Using the transfer coefficients developed from this methodology, we assessed the changes in onshore pollutant concentrations associated with changes in offshore emissions. Additional information on the air quality modeling approach is presented in Appendix B.

Physical Effects

The county-level changes in air quality derived from the methods outlined above serve as inputs into the assessment of pollution-related physical effects in APEEP. As outlined in Table 4, these effects include adverse health impacts, changes in agricultural productivity, and damage to manmade materials. To quantify these physical effects, APEEP (1) estimates the number of receptors exposed to changes in air pollution and (2) employs a series of peer-reviewed dose-response functions to estimate impacts for exposed receptors. Appendix D presents additional information on the assumptions employed in the modeling of physical effects.

Table 4 Summary of Air Pollution Physical Effects Included in APEEP for the Revised OECM

IMPACT CATEGORY	POLLUTANT(S)	PHYSICAL EFFECT	STUDIES USED FOR DOSE-RESPONSE
Human Health	PM	Premature mortality (adults aged 29 and older)	Pope *et al*. (2002) and Laden *et al*. (2006)
		Infant mortality (<1 year of age)	Woodruff *et al.* (1997)
		Chronic bronchitis (all ages)	All ages: Abbey *et al.* (1995)
	Ozone	Premature mortality (all ages)	Ito et al. (2005) and Bell *et al.* (2004)
		Respiratory hospital admissions (adults aged 65 and older)	Schwartz (1995)
		Respiratory hospital admissions (age <2 years)	Burnett *et al.* (2001)
		Asthma-related emergency room visits (all ages)	Peel *et al*. (2005) and Wilson *et al.* (2005)
		Minor restricted activity days (ages 18-64)	Ostro and Rothschild (1989)
		School loss days (ages 5 to 17)	Chen *et al.* (2000)
Agriculture	Ozone	Change in yield for corn, cotton, peanuts, wheat, grain sorghum, soybeans, kidney beans, and tobacco	Lesser, et al. (1990)
Material Damage	SO_2	Damage to galvanized steel, painted surfaces, and carbonate stone surfaces	Atteraas (1982), Haynie (1986), and ICP (1998)

Valuation

To estimate the value of the health, agricultural, and materials impacts outlined above, APEEP uses a combination of market price data, willingness to pay (WTP) values estimated in the peer-reviewed literature, and (for certain health impacts) cost of illness (COI) estimates derived from studies of treatment costs. Tables 5 and 6 summarize these values.

In economic terms, WTP is the more appropriate measure of the value of avoiding an adverse effect, as it reflects the dollar amount necessary such that a person would be indifferent between avoiding the effect and receiving the compensation. Where possible, APEEP therefore uses WTP values derived from the peer-reviewed literature to estimate the value of avoiding adverse health effects associated with changes in ambient pollutant concentrations. For some health effects, however, (*e.g.*, hospital admissions), WTP estimates are not available from the peer-reviewed literature. In these cases, APEEP uses the cost of treating or mitigating the illness (COI) as a primary estimate.

The data in Table 5 also show that valuation estimates expressed as WTP values increase over time. This reflects projected increases in income. Economic theory maintains that individuals' WTP for goods, including the avoidance of an adverse health effect, increases as real income increases. Given that incomes are likely to increase during the 50-year analytic time horizon of the OECM, APEEP (where possible) uses income-adjusted valuation estimates to assess the value of adverse health effects. More detailed valuation estimates for each year in the OECM's time horizon are available in Appendix D.

Table 5 Unit Values for Economic Valuation of Health Endpoints (2006$)

HEALTH ENDPOINT	CENTRAL ESTIMATE OF VALUE PER STATISTICAL INCIDENCE (ADJUSTED FOR INCOME)		WTP OR COI	NOTES
	2015 INCOME	2065 INCOME		
Premature mortality	$8,600,000	$12,000,000	WTP	• Mean Value of Statistical Life (VSL), adjusted for income, based on 26 wage-risk and contingent valuation studies. A Weibull distribution provided the best fit to the 26 estimates. Note that VSL represents the value of a small change in mortality risk aggregated over the affected population. This is consistent with the VSL approach used in U.S. EPA (2010b).
Chronic bronchitis (CB)	$470,000	$680,000	WTP	• The WTP to avoid a case of pollution-related CB is calculated as $WTP_x = WTP_{13} \cdot e^{-\beta(13-x)}$, where x is the severity of an average CB case; WTP_{13} is the WTP for a severe case of CB; and β is the parameter relating WTP to severity, based on the regression results reported in Krupnick and Cropper (1992). This valuation function and the rationale behind it are described in detail in U.S. EPA (1999).
Respiratory hospital admissions (age 65+)	$25,000	$25,000	COI	• These COI point estimates (lost earnings plus direct medical costs) are based on ICD-9 code level information (*e.g.*, average hospital care costs and average length of hospital stay) reported in Agency for Healthcare Research and Quality (2000). As noted in the text, no adjustments are made to cost of illness values for income growth.
Respiratory hospital admissions (age <2)	$10,000	$10,000		
Asthma-related emergency room visits	$370	$370	COI	• Simple average, adjusted for income, of estimates from Smith *et al.* (1997) and Stanford *et al.* (1999).
Minor restricted activity days	$62	$70	WTP	• Median WTP estimate to avoid one minor restricted activity day from Tolley *et al.* (1986).
School loss days	$89	$89	COI	• Point estimate is based on (1) the probability that, if a school child stays home from school, a parent will have to stay

HEALTH ENDPOINT	CENTRAL ESTIMATE OF VALUE PER STATISTICAL INCIDENCE (ADJUSTED FOR INCOME)		WTP OR COI	NOTES
	2015 INCOME	2065 INCOME		
				home from work to care for the child, and (2) the value of the parent's lost productivity. Additional information on the derivation of this valuation estimate is available in Abt Associates (2008).

Table 6 Summary of Crop and Materials Prices (2006$)

	CROP	PRICE
Agriculture	Corn	$4.08 per bushel
	Cotton	$0.59 per pound
	Peanut	$0.20 per pound
	Grain Sorghum	$7.08 per hundredweight
	Soybeans	$9.82 per bushel
	Spring Wheat	$7.31 per bushel
	Tobacco	$1.65 per pound
Materials	Galvanized Steel	$750 per ton.
	Carbonate Stone	$115 per square meter
	Paint	$35 per gal
Sources: Agriculture - USDA/NASS (2009) Materials – Morici (2005) Stone - Masonry Advisory Council, 2009-2010 Masonry Cost Guide, http://www.maconline.org/tech/estimating/cost/cost.html		

Damages per Ton in Alaska Planning Areas

As outlined above, the air quality analysis for the Atlantic, Pacific, and GOM OCS regions relies on an existing modeling framework (APEEP) to monetize the air quality impact of offshore emissions. A similar model for Alaska, however, is not readily available. Moreover, we identified no studies in the literature that could be adapted to estimate the economic damage of emissions in the Alaska OCS region. In the absence of Alaska-specific models or literature, we derived dollar-per-ton values for grid cells off the coast of Alaska by scaling values generated by APEEP for the Washington and Oregon Planning Area. This scaling approach accounts for a given grid cell's distance from shore, as well as the population located near each grid cell, as outlined below:

1. *Distance to Shore*: As shown in the APEEP results presented in Appendix C for the Atlantic, Pacific, and GOM OCS regions, a grid cell's distance from shore has a significant effect on the extent to which emissions from the grid cell affect onshore air quality. To incorporate this relationship into our scaling procedure, we grouped the Alaska and Washington/Oregon grid cells into a series of 50-kilometer (km) bands. The cells in the band nearest shore have an average distance from shore of between 0 and 50 km; the next nearest band is located between 50 and 100 km offshore, etc.

2. *Develop dollar-per-ton values for each 50-km band*: After developing the offshore bands, we then developed average dollar-per-ton values, by pollutant and year, for each band of grid cells in the Washington and Oregon Planning Area. These band-specific values form

the basis of our scaled dollar-per-ton values for Alaska.

3. *Scale band-specific dollar-per-ton values:* Based on the distance from shore for each grid cell in the Alaska OCS region, we identified the corresponding 50-km band of grid cells in the Washington and Oregon Planning Area. To develop dollar-per-ton estimates for a given Alaska grid cell, we multiplied the dollar-per-ton values for the corresponding Washington/Oregon distance band by the ratio of (1) the population within 750 miles of the Alaska grid cell and (2) the average population within 750 miles for the grid cells in the Washington/Oregon band. We chose 750 miles as the cutoff around each grid cell based on the APEEP results presented in Appendix C. As noted in the appendix, the effect of distance on air quality, as modeled by APEEP, levels off at approximately 750 miles.

4.4 OFFSHORE DOLLAR PER TON VALUES

Figure 2 displays the damages ($/ton) due to emissions of $PM_{2.5}$ corresponding to all of the nearly 1,500 offshore source locations for the lower 48 states. The figure shows several patterns that are important in determining damages. First, in any region, sources that are closer to land cause greater damage per ton than sources farther offshore. Second, sources located nearby to large cities tend to cause greater damage than sources offshore from rural areas. Third, the importance of prevailing winds is clearly evident. For example, sources off the northeast coast of the United States are located very close to large population centers. As such, one would expect these sources to have very high damages per ton. While this basically holds, it is interesting to note that the sources with damages between $12,500 and $20,525 (shown in crimson) do not extend far off of the east coast.

In contrast, examine sources in the GOM. This top damage class encompasses sources that extend far out into the Gulf. Yet, the nearby populations that would be exposed to emissions from sources in the Gulf must be smaller than the populations nearby to offshore sources in the northeast. This difference is due to the prevailing wind direction; in the Gulf emissions are pushed to the northeast over land and the cities in the southeastern United States. Similarly, sources off of the east coast also have their emissions directed to the northeast. However, in marked contrast, the major population centers lie to the west of these sources. A small fraction of emissions are projected to reach onshore given the direction of prevailing winds. This reduces the estimated damage per ton of emissions from sources in the Atlantic Ocean. Hence, sources that produce the highest damage are concentrated in a narrow band along the eastern seaboard.

Figure 2 Damages Due to $PM_{2.5}$ Emissions

[redacted]

4.5 ONSHORE ENERGY PRODUCTION DOLLAR-PER-TON VALUES

A key element of impacts realized under the NAA is the economic value of the air quality effects associated with onshore production of oil, gas, and coal. Emissions associated with onshore energy production may be estimated based on the fuel-specific emission factors presented in Table 1. To monetize the resulting emissions estimates, the OECM relies upon dollar-per-ton impact values, by pollutant and year, derived from the APEEP model. APEEP produces these values at the county level, but the change in onshore energy production for the NAA is specified only at the national level. We therefore developed two sets of weighted average dollar-per-ton values: one for oil and gas and a second set of estimates applied to emissions from onshore coal production. For oil and gas, we developed weighted average values based on county-level employment data for the oil and gas sector from the U.S. Census Bureau's County Business Pattern data. To develop weighted average dollar-per-ton values for coal production, we used county-level coal production published in the DOE's Annual Coal Report 2009.

We note that our assessment of air quality impacts related to onshore oil production does not capture the effects of increased onshore oil and gas production in Alaska. Because DOE's baseline oil and gas projections do not distinguish between onshore and offshore production in Alaska, the outputs generated by the MarketSim model do not differentiate between changes in onshore and offshore production in Alaska under a given E&D scenario.

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5 PROPERTY VALUES – VISUAL DISAMENITIES

5.1 OVERVIEW

The model estimates the annual losses in economic rent of residential properties due to the visual impact of offshore oil and gas platforms than can be seen from shore (a "visual disamenity"). Estimates of the value of property in the affected area and of the effects of distance of the proposed platforms are calculated for each planning area that is within visible distance from land (i.e., 23 of the 26 planning areas). Due to the size of the planning areas, parameters must be generalized over coastlines with varying levels of visibility and development. Parameters and effects are determined using literature and data from previous studies.

The model makes the following simplifying assumptions:

- Property values decrease when a platform is visible from a home;
- Property value impacts decline with the distance from a visual disamenity (Bishop and Miller 2007, Des Rosiers 2002, Hoen et al. 2010); and
- No impacts occur beyond a fixed distance from shore, which varies regionally based on visibility information (Ladenburg 2009).

This model differs from the 2001 OECM's assessment of the impact of the visual aesthetics of platforms in that: (1) it uses a logarithmic decay in damages with the distance an oil platform is implemented from shore, and (2) the negative effect is considered prominent over longer distances. Importantly, this modeling framework is relevant only as a generalized analysis of property value impacts at the planning area-level. The approach is therefore not appropriate for application to smaller geographic regions (e.g., a 10-mile segment of densely populated coastline).

5.2 BASIC CALCULATION

The model develops an estimate of damage to residential property values using the equation below. Damage in this context represents an annual loss in the economic rent of residential properties from the year oil exploration begins through the final year of decommissioning. Note that unlike other impacts estimated by the OECM model, impacts due to visual disamenities do not follow the level of construction or production activity. Instead, the undiscounted annual impacts to property values are constant between the start and finish of platform activities.

$$Damage_p = A_p * i_{atp} * \sqrt{r_p{}^2 - d^2} * m \ * d^{-c_p}$$

where:

A_p = Annualized total residential property value (USD) over the lifetime of a platform per mile coastline from the shore to one-eighth mile inland

r_p = Regional visibility (*miles*)

d = Shortest distance from shore to the platform to a maximum of r (*miles*)

m = Maximum percent reduction in property value due to disturbance in visual surroundings

c_p = Constant of decay, dependent on region

i_{atp} = $(i_{ptp} - (i_{ptp}*(t_f+t_{sp}*(1- t_f))))$, where:

  i_{atp} = after-tax discount rate in each planning area

i_{ptp} = pre-tax discount rate in each planning area
t_f = marginal federal tax rate (28 percent for individual)
t_{sp} = marginal state tax rate in each planning area

This equation is used to determine annual monetary damage to residential property values due to the visual disamenity created by offshore oil platforms. Damage is measured in 2010 U.S. dollars. The variables and parameters are described below.

5.3 CALCULATION DRIVERS

5.3.1 Total residential property value along the coast

The parameter A is the total residential property value per mile of coastline from the shore to one-eighth mile inland annualized over the lifetime of a platform. This parameter varies across the 23 planning areas that are adjacent to the coastline in the lower 48 states and Alaska, and includes residential property values from assessor and census data at the census block group level (DataQuick 2007-2009, U.S. Census 2000). The coastline is split into the 23 planning areas using a BOEM shape file, then is further split by census block group using a census shape file (U.S. Census 2000). Length of coastline and area of each block group are measured with GIS.

To determine total residential property value within each block group, assessor data are used when available in the lower 48 states (DataQuick 2007-2009); otherwise, data from the 2000 census are used (U.S. Census 2000). Figure 8 provides an overview of the total residential property value per one-eighth mile by one mile area of coastline within each planning area based on assessor and census data. From both sources, the total residential housing values per block group are employed, and values are converted to 2010 U.S. dollars using an implicit Gross Domestic Product (GDP) price deflator (BEA 2010). The model assumes that property values will be affected to one-eighth mile back from shore, so total housing value divided by eight times the total area in each block group yields the average residential property value of one linear mile of shoreline that will be adversely affected by offshore visual disamenities. When the calculated coastal residential property value is greater than the total value of residential properties in the block group reported by assessors or the census (i.e., due to a highly detailed coastline), the total value of residential properties in the block group is used. Next, the coastal property value per mile of coastline is summed within each planning area and divided by the total miles of coastline to determine the weighted average of a one eighth by one mile section in each planning area.

The following assumptions are made in determining residential property value impacts by planning area:

- Residential property value impacts occur up to one-eighth mile from the coast. This assumption was retained from the previous version of the OECM (as described in Kearney 1991) given a lack of data or other information upon which to base an alternative assumption.
- Coastal block groups extend at least one eighth mile inland;
- Coastal property values are equivalent to average property values over the extent of a coastal block group;

- The prior existence of one or more platforms in the region in which new platforms may be installed does not affect the property value impact. While this may result in an overestimate of the impact in areas of existing activity, such as the GOM, we make the assumption that new platforms would be located in different "viewsheds."
- The density of residential properties near the coast is the same as the density over the entire block group; and
- Overlapping areas within Planning Areas are assigned to a single planning area.

Table 7 Total Residential Property Value per Mile of Coastline from the Coast to One Eighth Mile Inland

REGION	PLANNING AREA	TOTAL RESIDENTIAL PROPERTY VALUE PER MILE COASTLINE FROM THE COAST TO 1/8 MILE INLAND (PARAMETER *A* IN 2010 USD)
Atlantic and Gulf	North Atlantic	$32,100,000
	Mid-Atlantic	$8,350,000
	South Atlantic	$16,900,000
	Straits of Florida	$56,900,000
	Eastern Gulf of Mexico	$25,000,000
	Central Gulf of Mexico	$1,560,000
	Western Gulf of Mexico	$2,470,000
Pacific	Oregon/Washington	$2,980,000
	Northern California	$1,120,000
	Central California	$24,900,000
	Southern California	$36,200,000
Alaska	Beaufort Sea	$0.00420
	Chukchi Sea	$331
	Hope Basin	$355,000
	Norton Basin	$122,000
	St. Matthew Hall	$0.373
	St. George Basin	$31.7
	Aleutian Arc	$5.55
	North Aleutian Basin	$770
	Shumagin	$9.24
	Cook Inlet	$263,000
	Kodiak	$329,000
	Gulf of Alaska	$305,000

5.3.2 After tax discount rate

To calculate the annual losses in economic rent (i.e., property value impacts), this analysis applies, in each year of the analysis, a discount rate in each of the planning areas of between 4.20

and 4.45 percent. This value is the adjusted after tax current residential mortgage rate (i.e., cost of capital) for the average national 30-year fixed interest loan rate between 2005 and 2009. The average national 30-year fixed interest loan rate is 5.94 percent (Freddie Mac 2010), the federal tax rate at the median household income of $50,300 is 25 percent (Census 2009a; Tax Foundation 2010), and average state taxes weighted by coastline in each planning area vary between 0 and 5.58 percent (Federation of Tax Administrators 2010).

As noted above, the after-tax discount rate is determined using the following formula: (Pre-Tax Rate) – (Pre-Tax Rate)*[(Federal Tax Rate) + (State Tax Rate)*(1 – Federal Tax Rate)]. For example, for the North Atlantic Planning Area: 5.94 – 5.94*[0.25 + (0.0558)*(1 – 0.25)] = 4.20.

5.3.3 Visibility and Distance

The parameter r represents the maximum visibility by region measured in miles. In prior research, the maximum visibility of an offshore wind turbine was estimated to be approximately 31 miles (Ladenburg 2009). Due to the absence of studies on the maximum visibility distance to oil platforms, 31 miles is assumed to represent the maximum distance an offshore platform can be seen under good visibility conditions. Visibility by region is known to vary due to haze; based on visibility data from National Parks and Wilderness areas in the United States from 1992 through 2004, visibility on the Pacific coast is generally superior (IMPROVE 2007). As such, visibility (the parameter r) is assumed to be 31 miles on the Pacific coast and in Alaska. Based on a ratio of visibility in eastern to western parks and wilderness areas drawn from the above dataset, visibility (r) is assumed to be 16 miles on the Atlantic coast and the Gulf of Mexico (IMPROVE 2007).

The variable d is the distance of the platform to the closest point on shore measured in miles. A constraint is placed on d based on visibility; where d must be less than 16 miles in the Atlantic and Gulf regions and 31 miles in the Pacific and Alaska regions. To analyze the value of property across the total area affected, the length of shoreline from which the platform can be seen must be determined. The length of affected coastline based on the maximum visibility and distance from shore is $2\sqrt{r^2 - d^2}$, based on simple geometry. The total value of properties in the affected region per year is the product of A and the distance along the shoreline.

5.3.4 Percent Damage

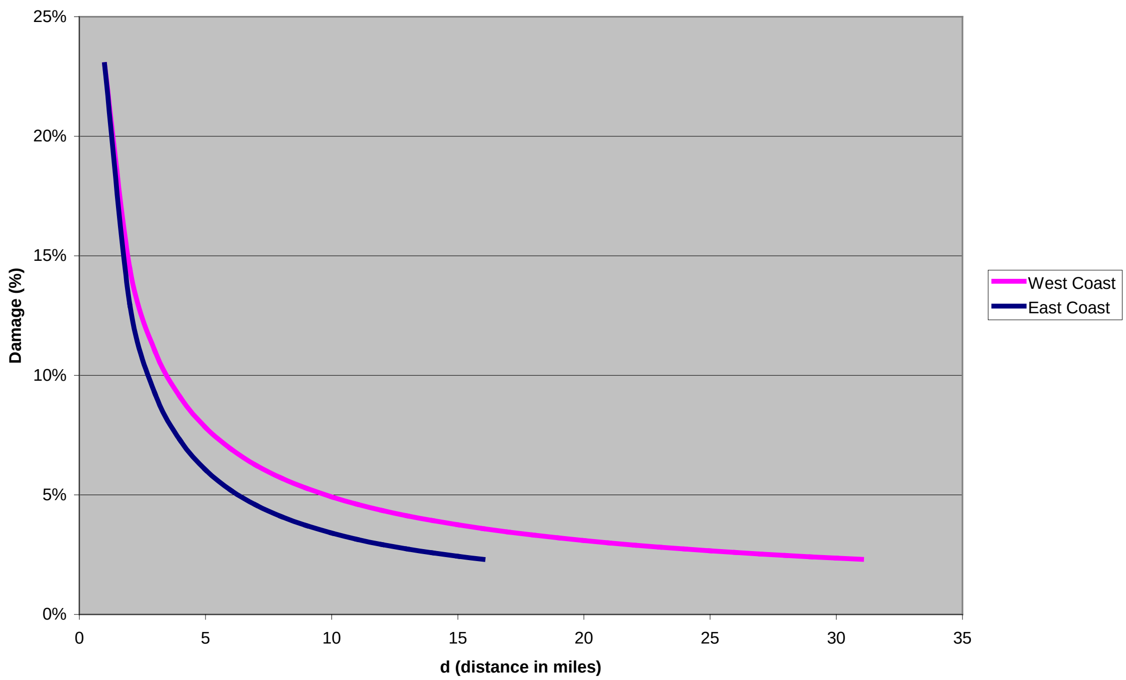
The parameter m is the maximum percentage impact of a visual disturbance on residential property values. Based on previous studies, the maximum loss in property values resulting from a visual disturbance ranges from 21 to 25 percent, so an estimate of 23 percent is used here (Hoen et al. 2010, Des Rosiers 2002, Sims and Dent 2005).

Previous studies have indicated that the impact on property values tends to attenuate with distance of households from the visual disturbance. Following a study of the effect of an electrical power plant on housing values (Blomquist 1974), the model assumes that there is a constant negative elasticity between distance to platforms and effect on housing values; that is, for a one percent decrease in distance, there is some constant percentage increase in property value impacts. In the damage formula, the effect of distance on damage is d^{-c}, where c is a constant value. Because property value impacts will never fall to zero in this formulation, the value of c is scaled such that damage is assumed to be 100 percent of the maximum impact (i.e., 23 percent) when d is one mile, and less than 10 percent when d is r miles (16 miles in the East and 31 miles in the West).

This leads to a decay equation where c = 0.83 in the East and c = 0.67 in the West. Figure 3 provides a graph of the assumed relationship between distance from shore and property value impacts for the east and west coasts. Note that this assumes the relationship between distance and economic impact has the same functional form for onshore and offshore structures. If this is not the case – for example if the impact of offshore structures is constant as long as the structures are visible – then economic impacts would vary from those reported here.

Additionally, the visual impact will decrease with distance along the shore from the closest point to the platform (i.e., at the outer edge of the affected segment of shoreline, distance to the platform would be r and the platform(s) would just be visible). To incorporate this effect, the impact on economic rents is multiplied by one-half, which cancels the '2' in the $2\sqrt{r^2 - d^2}$ term described above.

Figure 3 Relationship between Percent Reduction in Economic Rent from Properties and Distance from Shore to Platforms



5.4 References – Property Value: Visual Disamenity

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6 PROPERTY VALUES – OIL SPILLS

6.1 OVERVIEW

The model estimates the annual losses in the economic rent of residential properties caused by oil spills in each of the planning areas.

6.2 BASIC CALCULATION – OIL SPILLS

The model develops an estimate of damage to residential property values using the equation below. In the equation, impact is defined as the annual loss in economic rent from residential properties that results from oil spill events. This is calculated as the product of the property value per linear meter of beach, the after tax discount rate, the fraction of year taken up by the event, and the length of oiled shore in meters.

$Impact_p = Value_p * i_{atp} *(d_p/365)*l_p$

where:

$Value_p$ = total coastal property value per meter in each planning area

d_p = duration of event (in days)

l_p = length of beach oiled in meters

i_{atp} = $(i_{ptp} – (i_{ptp}*(t_f+t_{sp}*(1- t_f))))$, where:

- i_{atp} = after-tax discount rate in each planning area
- i_{ptp} = pre-tax discount rate in each planning area
- t_f = marginal federal tax rate (28 percent for individual)
- t_{sp} = marginal state tax rate in each planning area

6.3 CALCULATION DRIVERS

6.3.1 Residential property value along the coast

The parameter *Value* is the total residential property value per meter of coastline from the shore to one house width inland. This parameter varies across the 23 planning areas that are adjacent to the coastline in the lower 48 states and Alaska. In order to solve for this parameter, residential property values from assessor and census data are used at the census block group level (DataQuick 2007-09; U.S. Census 2000). The coastline is split into the 23 planning areas using a BOEM shape file, then is further split by census block group using a census shape file (U.S. Census 2000). The length of coastline and area of each block group are measured with GIS.

To determine total residential property value within each block group, assessor data are used when available in the 48 mainland states (DataQuick 2007-2009). Otherwise, data from the 2000 census are used (U.S. Census 2000). Table 8 provides an overview of the total residential property value per one meter wide by 242-foot (the length of an average property) area of coastline within each planning area based on assessor and census data.[17] From both sources, the total residential housing values per block group were employed, and values were converted to 2010 U.S. dollars using an implicit GDP price deflator (BEA 2010). Total housing value divided by the total area in each block group yielded the average residential values for a one meter by 242-foot area. The model assumes that this is the average residential property value of one linear meter of shoreline that will be adversely affected by oil spills. When the calculated coastal residential property value was greater than the total value of residential properties in the block group reported by assessors or the census (i.e., due to a highly detailed coastline), the total value of residential properties in the block group was used. Weighted averaging is used to aggregate census block group data to the planning area level.

Table 8 Total Residential Property Value Per Meter of Coastline to an Average Property Width Inland

REGION	PLANNING AREA	*VALUE* (2010 USD)
Atlantic and Gulf	North Atlantic	$7,620
	Mid-Atlantic	$1,980
	South Atlantic	$4,010
	Straits of Florida	$13,500
	Eastern Gulf of Mexico	$5,930
	Central Gulf of Mexico	$369
	Western Gulf of Mexico	$587
Pacific	Oregon/Washington	$707
	Northern California	$266
	Central California	$5,910
	Southern California	$8,590
Alaska	Beaufort Sea	$9.96E-07
	Chukchi Sea	$0.0785
	Hope Basin	$84
	Norton Basin	$29
	St. Matthew Hall	$8.85E-05
	St. George Basin	$0.00752
	Aleutian Arc	$0.00132
	North Aleutian Basin	$0.183
	Shumagin	$0.002
	Cook Inlet	$62
	Kodiak	$78
	Gulf of Alaska	$72

[17] Note that this method makes the simplifying assumption that only those properties immediately adjacent to the shore, and thus directly affected by an oil spill, would experience a property value effect. Other, near-coast properties could potentially see an affect if those properties' value is in part derived from proximity to the shoreline.

6.3.2 After tax discount rate

To calculate the annual losses in economic rent from residential property, this analysis applies a discount rate in each of the planning areas of between 4.20 and 4.45 percent. This value is the adjusted after tax current residential mortgage rate (i.e., cost of capital) for the average national 30-year fixed interest loan rate between 2005 and 2009. The average national 30-year fixed interest loan rate is 5.94 percent (Freddie Mac 2010), the federal tax rate at the median household income of $50,300 is 25 percent (Census 2009a; Tax Foundation 2010), and average state taxes weighted by coastline in each planning area vary between 0 and 5.58 percent (Federation of Tax Administrators 2010).

As noted above, the after-tax discount rate is determined using the following formula: (Pre-Tax Rate) – (Pre-Tax Rate)*[(Federal Tax Rate) + (State Tax Rate)*(1 – Federal Tax Rate)]. For example, for the North Atlantic Planning Area: 5.94 – 5.94*[0.25 + (0.0558)*(1 – 0.25)] = 4.20.

6.3.3 Duration of event

Property values are assumed to be lost entirely for the duration of the spill event. Consistent with the assumed duration of a beach closure resulting from an oil spill, the duration of shoreline oiling is set at 21 days for all planning areas.

6.3.4 Length of oiled shore

SIMAP models the fate and transport of oil spilled in the ocean to quantify lengths of oiled shoreline, using regional data to separate those impacts by shore type (specifically, rock and gravel; sand; mudflat and wetland; and artificial). Regressions on the results of multiple SIMAP iterations in representative regions, simulating a range of oil types, volumes, spill distance from shore, and environmental conditions, produce equations that generally relate spill volume to the length of shoreline exposed to oil above an impact threshold. For property value impacts, the model uses the regression result for all four shoreline types. The impact threshold is specified as a surface sheen produced by an oil concentration of 1 g/m^2.

6.4 ASSUMPTIONS

Several assumptions are made in determining the driver values for each BOEM planning area. These assumptions include:

- Coastal property values are equivalent to average property values over the extent of a coastal block group;
- The density of residential properties near the coast is the same as the density over the entire block group;
- Residential properties from the coast to 242 feet inland are negatively affected by oil spills. This value is based on the width of an average parcel size of the United States, assuming that this average parcel is square (ERS 2002, Census 2009b);
- Overlapping areas within planning areas are assigned to a single planning area;
- Property values are lost entirely for the duration of the spill event; and
- Property values along all types of shoreline are affected equally.

6.5 REFERENCES – PROPERTY VALUE: OIL SPILLS

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7 SUBSISTENCE HARVESTS

7.1 OVERVIEW

The model assesses the impact of OCS oil and gas activities on subsistence harvests by estimating oil spill-related mortality effects among general subsistence species groups, assuming that all organisms killed by oil spills would have been harvested for commercial or subsistence purposes, estimating the subsistence component of this lost harvest, and calculating an estimated replacement cost.

The model does not currently assess three potential subsistence harvest-related costs that might be attributed to OCS oil and gas activities:

- *Resource "Tainting."* An oil spill can create a situation in which potentially exposed subsistence resources, while unharmed by the spill, would be considered unfit for hunting. Depending on the magnitude of the spill, this perception could remain across multiple hunting seasons. While this potential cost is important to acknowledge, a method for credibly quantifying a change in behavior, as a function of a specific model input, has not been identified.
- *Seismic Impacts.* In the offshore environment, seismic testing and other physical disturbance such as drilling during exploration and development might alter the behavioral patterns of whales or other marine species valued by subsistence hunters, and thus might interfere with traditional harvesting activities. Anecdotal information, cited in the 2007-2012 program EIS, strongly suggests that seismic and drilling activities do have an effect on the subsistence harvest of whales and other marine mammals, but, as the EIS also indicates, thresholds above which specific changes can be expected to occur, and that could potentially serve as the basis for modeling an adverse change in subsistence harvest success rates, do not exist in the literature.
- *Onshore Infrastructure.* The development of coastal infrastructure to support OCS activity (e.g., oil and gas processing facilities, water treatment plants, pipelines) might alter or otherwise impair habitats upon which subsistence harvests depend. Furthermore, development might impede the movement on land of harvesters or target species. Additional research is necessary to establish a credible relationship between terrestrial impacts and adverse effects on the subsistence harvest of terrestrial species.

The model is also limited to the impact of OCS oil and gas activities on subsistence harvests in Alaskan planning areas, reflecting the significance of this issue in Alaska relative to other regions and the availability of Alaskan subsistence harvest data. Planning areas that do not include an Alaskan coastal component (Navarin Bay, Aleutian Basin, and Bowers Basin) are excluded from the analysis. While subsistence harvests do occur in other regions of the coastal United States, they are not readily characterized. As data that describe the scope and value of these harvests become available, the OECM can be easily updated to incorporate assessments of any impact OCS oil and gas exploration and production activity might have.

While similar in approach to the assessment of spill-related subsistence costs in the 2001 OECM, the methodology in the model is somewhat simplified in comparison to the previous model due to the availability of relationships describing mortality as a function of spill volume for four distinct harvest categories (whales, other marine mammals, marine invertebrates, and fish), as described below. The previous model assumed that mortality among all marine subsistence species occurs in the same proportion as the mortality rate assumed for marine mammals.

7.2 BASIC CALCULATION

The model develops an estimate of costs for each planning area in which OCS activity is projected to occur using the equation

$$A_i \times B_i \times C_i \times D_i$$

where:

A_i = Subsistence harvest as a percentage of total harvest of biological group *i* (specifically whales, other marine mammals, marine invertebrates, and fish)

B_i = Area or volume of water in which spill impact occurs (km^2 of oiled surface area above an impact threshold for whales and other marine mammals; m^3 for marine invertebrates and fish)

C_i = Mortality factor for biological group *i* (*kg killed/*km^2 for whales and other marine mammals, kg/m^3 for marine invertebrates and fish)

D_i = Replacement cost for biological group *i* (*$/kg*)

For each platform/well group within each planning area, the model calculates a replacement cost for the spill-related loss in each biological group. The planning area result is the sum across platform/well groups.

7.3 CALCULATION DRIVERS

7.3.1 Subsistence harvest as percentage of total harvest

The Alaska Department of Fish and Game (ADFG), Division of Subsistence reports that subsistence harvests, in the aggregate, account for two percent of the annual harvest of all fish and game in the state (Wolfe 2000, Fall et al. 2009). Information describing this relationship at the level of specific harvests or sub-harvests (e.g., fish or salmon) is not readily available. Therefore, with the exception of whales (for which the subsistence harvest is equal to the total harvest), calculation driver A_i, is specified in the model as two percent.

7.3.2 Area or volume of water in which spill impact occurs

The SIMAP model quantifies areas swept by floating oil of varying thicknesses and the fates and concentrations of subsurface oil components (dissolved and particulate). Regressions on the results of multiple SIMAP iterations in representative regions, simulating a range of oil types, volumes, spill distance from shore, and environmental conditions, produce equations that generally relate spill volume to water area or water column volume exposed to oil above impact thresholds specified in the SIMAP model.

7.3.3 Mortality factors

SIMAP calculates the oil/hydrocarbon exposure, dose, and resulting percent mortality for organisms in the contaminated exposure areas (wildlife) and water volumes (fish, invertebrates). SIMAP applies these results to region-specific biological databases, which describe population densities for each of several organism types, to arrive at mortality factors per unit water area or water volume. For the model, species-level data are aggregated into four biological groups.

- *Whales:* baleen and piscivorous
- *Other marine mammals:* polar bears, pinnipeds, and sea otters
- *Marine invertebrates:* crustaceans and mollusks
- *Fish:* small pelagic fish, large pelagic fish, demersal fish

An analysis of the ADFG Community Profile Database (ADFG 2001), which provides the most current accounting of subsistence harvests by type, indicates that this taxonomy is consistent with observed activity. Figure 4 provides marine harvest profiles, drawn from the ADFG database, for each of the Alaska planning areas where subsistence activity is presumed to occur. To avoid overstating costs associated with whale harvests, the model includes whale mortality factors only for the planning areas that in the aggregate account for more than 99 percent of the total whale harvest, according to the information contained in the ADFG database.[18]

7.3.4 Replacement cost

Subsistence use of natural resources includes a cultural element that is not well-addressed in the economics literature. The standard methods for deriving estimates of economic value are limited in their ability to capture the full value associated with subsistence use activities, as it is very difficult to include cultural and other intangible values that would necessarily be part of a "total" value measure. Replacement cost is the common substitute measure of value, though here too data are limited. The model currently utilizes a single per kilogram (kg) replacement cost derived from the BP Exploration Good Neighbor Policy for its Northstar Project (Sharpe 2001). This policy called for the creation of a financial instrument in the amount of $20 million to serve as a fund for specific expenditures required to mitigate the impact of an oil spill on an Alaska native community's subsistence harvests. The bowhead whale is the most significant element of this harvest, with an estimated annual harvested quantity of 336,000 lbs. To account for other marine subsistence resources that would be affected by a spill, BP and the local community agreed on a scaling factor of 1.5, resulting in a total estimated annual harvest, subject to replacement, of 504,000 lbs (or 228,610 kg). The total cost of all mitigation activities, which include specific items intended to address the cultural dimension of the loss (e.g., an annual conference of youth and elders to impart the cultural significance of subsistence and promote the retention of local knowledge), was estimated to be $19,454,164 ($2001). This implies a replacement cost of approximately $85/kg; inflated to current dollars using the Consumer Price Index (U.S. Department of Labor 2010), the implied cost is approximately $105/kg.

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[18] The planning areas in which whale harvest losses can be calculated are Cook Inlet, North Aleutian Basin, St. Matthew Hall, Norton Basin, Hope Basin, Chukchi Sea, and Beaufort Sea.

7.4 REFERENCES – SUBSISTENCE

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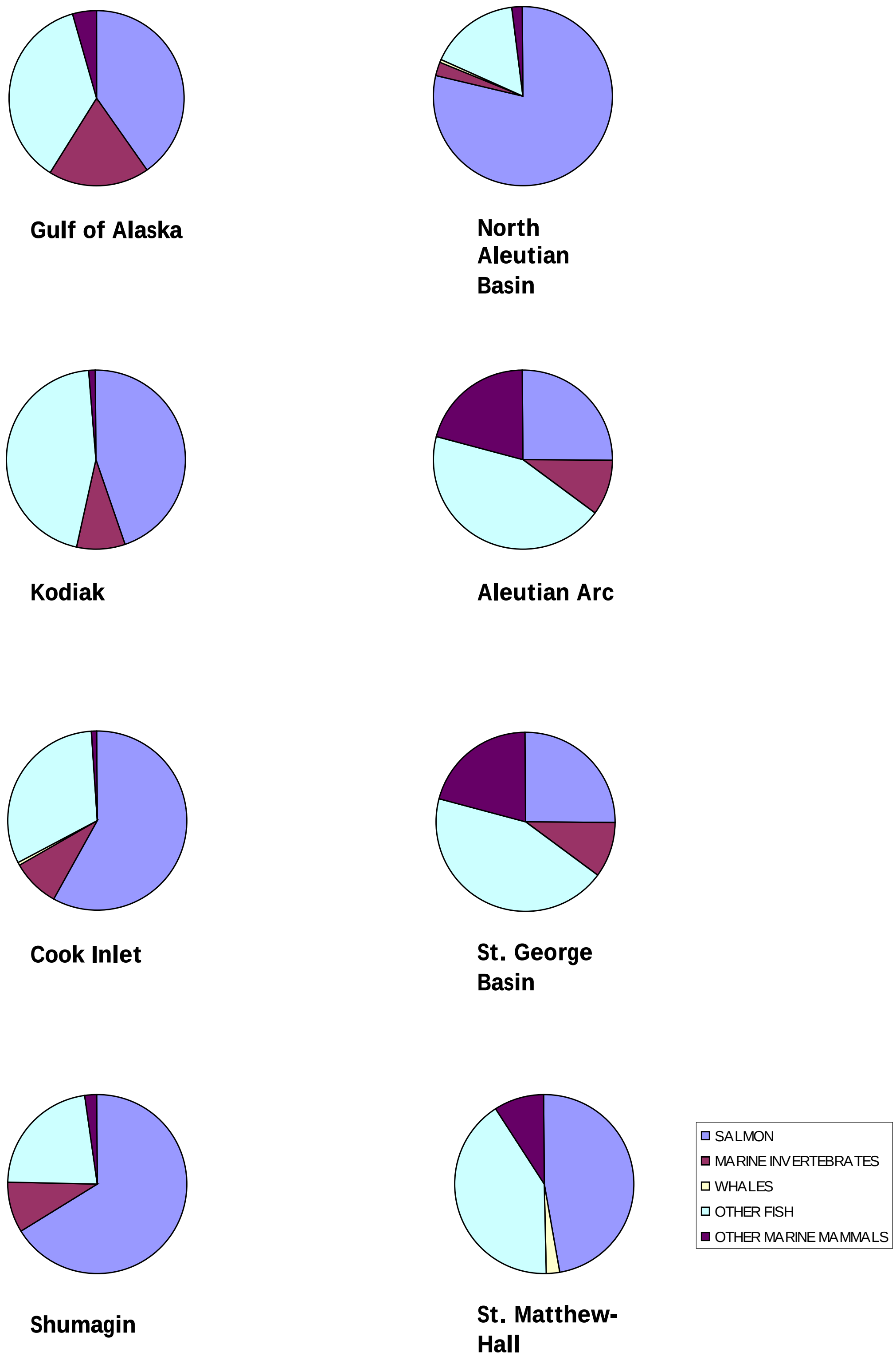
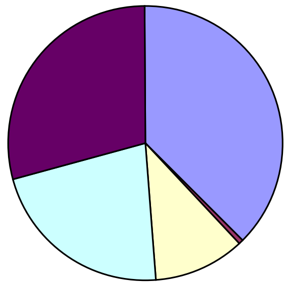
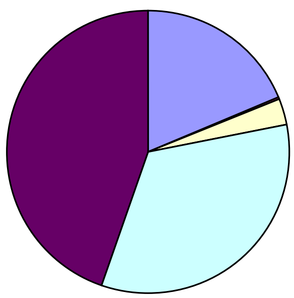
Figure 4 Marine Harvest Profiles for Alaska Planning Areas

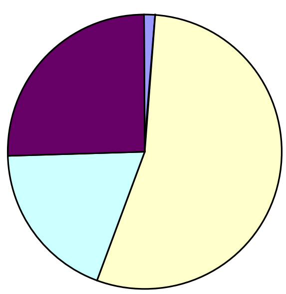




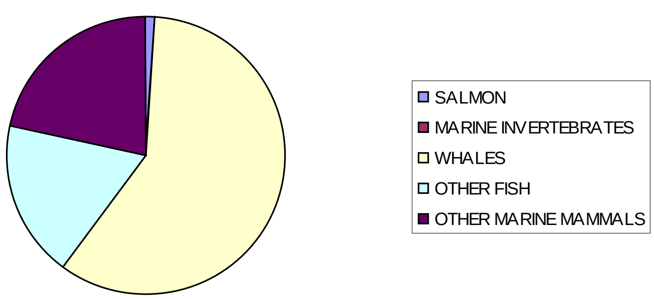
Norton Basin



Hope Basin



Chukchi Sea



Beaufort Sea

8 COMMERCIAL FISHING

8.1 OVERVIEW

The Commercial Fisheries Impact Model measures the costs of fishing area pre-emption caused by the placement of oil and gas infrastructure (platforms and pipelines) in the OCS.[19] The model assumes that there will be buffer zones around platforms—in most cases the buffer zones will be a circle with a radius of 805 meters (0.5 miles). The buffer zones decrease the area of the ocean that is available for fishing. The model assumes that the buffer zones cause a proportional redistribution of fishing effort within each planning area, and that the redistribution of effort can lead to cost increases, particularly when effort is re-distributed from a low-cost area to a high-cost area.

A key element in the model is that the distribution of fishing effort within each planning area is highly variable. Fishery data from the National Marine Fisheries Service (NMFS) confirms that in many planning areas fishing effort is highly concentrated. If the oil and gas infrastructure is placed in an area where little or no fishing takes place, the pre-emption impacts will be zero. If platforms are placed in important fishing areas, impacts will be greater.

The model also assumes that the total amount harvested is unaffected by oil and gas infrastructure. This assumption follows from the fact that nearly all fisheries in federally managed waters are managed with annual catch limits that are set at levels well below the harvestable biomass.[20]

The model also assumes that, in general, seabed pipelines do not affect harvesting. Federal regulations require that all seabed pipes that are in waters less than 200 feet deep must be buried. The model—which uses the metric system for distances, depths and areas—assumes that all pipe in waters 60 meters or less (196.9 feet) are buried. Buried pipeline is assumed not to affect fisheries. Evidence from interviews with harvesters and gear manufacturers around the United States in Norway, and elsewhere around the world indicates that unburied pipe is also unlikely to affect fish harvesting, with the exception of dredges used to harvest scallops and clams.[21] The model for the North Atlantic and Mid-Atlantic includes pre-emption impacts of unburied pipelines on the scallop fisheries and quahog fisheries that occur in waters deeper than 60 meters.

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[19] The Commercial Fisheries Impact Model currently operates external to the OECM and generates coefficients that the OECM uses to estimate total commercial fishery-related costs, as described later in this section.

[20] There do not appear to be significant concerns that oil and gas platform cause negative impacts on the biomass of commercial fish species. In fact there is considerable debate about whether platforms may actually increase fishable biomasses of certain species. In this case, we have chosen to err on the conservative side of the issues and have assumed for purpose of the model that additional platforms will not increase biomass levels of commercial fish species.

[21] In our research for this model, we spoke with a Dr. Gordon Kruse, a recognized crab biologist in Alaska, regarding the question of whether seabed pipeline could impact migrations of crab. Dr. Kruse indicated that it was very possible that unburied pipeline could affect migrations of king and tanner crab in the Bering Sea. Dr. Kruse indicated that to his knowledge there had not been any research directly on the topic, and that it would be difficult to estimate an impact without more research and without specific information regarding the locations of the pipelines. In the absences of specific information regarding potential impacts of pipelines on crab migrations, we have chosen not to speculate, but note that there may be additional impacts beyond those reflected in the model.

This commercial fisheries impact model is significantly different than the commercial fisheries impact model developed in the 2001 version of the OECM. The previous version of the OECM assumed that fish harvests were uniformly distributed throughout a planning area, and that harvests were reduced in proportion to the amount of the planning area pre-empted by oil and gas infrastructure. Thus, if there were 10,000 square miles in a planning area and oil and gas platforms and pipelines pre-empted 100 square miles, then fish harvests were assumed to be reduced by one percent multiplied by a mobility factor specific to various species. For very mobile species the mobility factor was very low or zero, while for less mobile species the factor was set at a higher level.

Note that the OECM does not currently estimate the impact of oil spills on commercial fishing. While there is no question that spills attributable to OCS activity can and do affect this industry, especially when the spill is large enough or of long enough duration to require the closure of a fishery for some period of time, the ability to model the potential costs associated with a specific E&D scenario is constrained by a number of factors. Producing a credible prediction of spill-related costs would require assumptions, for example, about the spill's biological impact, if any, on future stocks; about the relative impact of a spill on different commercial species; about the timing of a spill and whether it would occur during a period when commercial activity is occurring at a particular location; and about a spill's influence on consumer behavior (i.e., whether demand would change due to real or perceived risks). Making these assumptions, and building a sufficiently credible model of spill-related costs, was beyond the scope of our effort to date. We also note that the most significant costs would result from low probability/high consequence events that the model is not intended to address.

8.2 BASIC CALCULATION

This section provides a summary of the methodology used to estimate pre-emption impacts of oil and gas infrastructure on commercial fisheries.

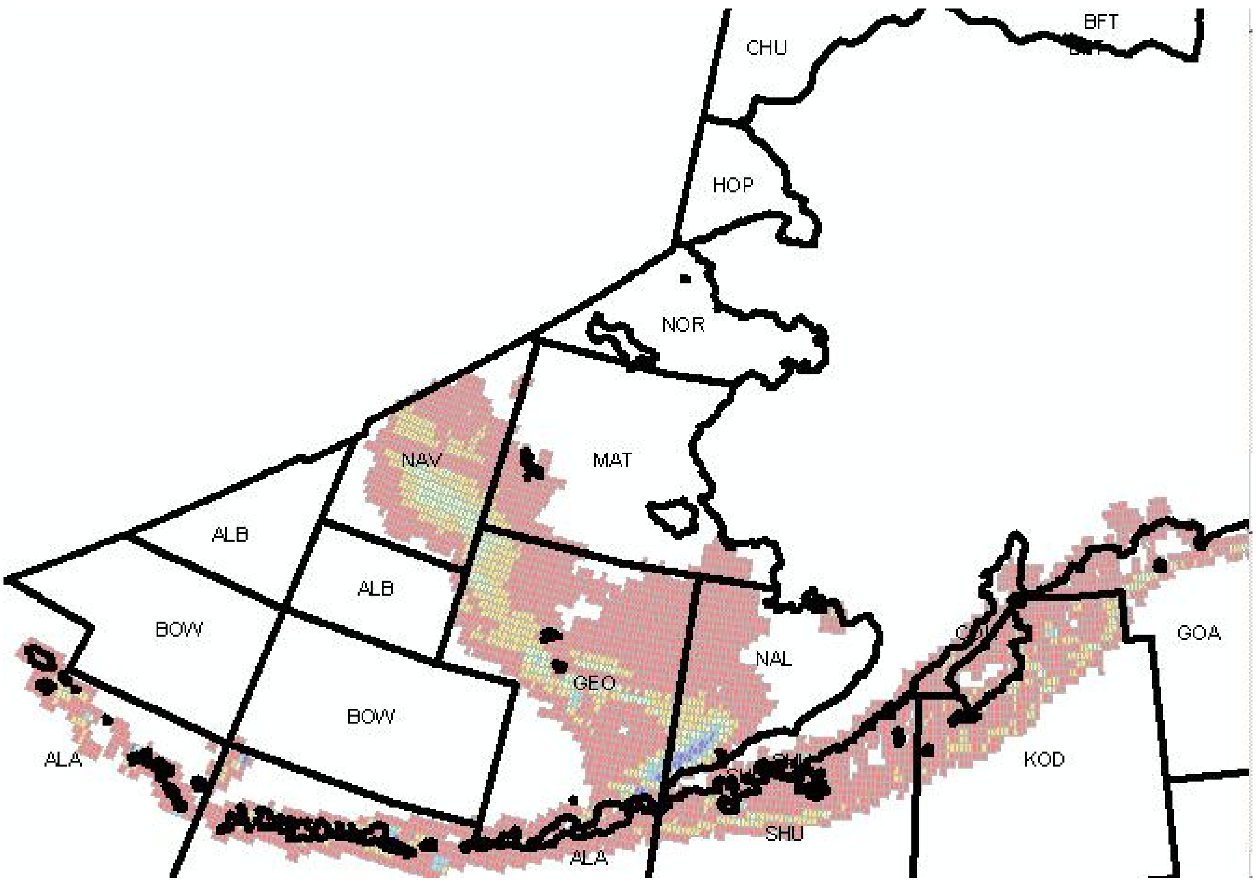
Each planning area has been divided into cells comprising 10 minutes of latitude and 10 minutes of longitude (10×10 cells). The cells within each planning area are classified by the depth of the cell at its centroid using published bathymetric data from NOAA. Five different depth ranges were used, based on platform and pipeline characteristics applicable for infrastructure at those depths. The radius of fishery buffer zones is set at 805 meters for all ranges except for depth range 3, where the buffer zone increases with depth. The depth ranges and platform types associated with each range are listed below:

- Depth Range 1: 0 m – 60 m; Fixed Platforms and Buried Pipelines
- Depth Range 2: 60 m – 150 m; Fixed Platforms
- Depth Range 3: 150 m – 300 m; Floating Anchored Platforms; Radius of buffer zones will be equal to 805 meters + 2 × cell depth at centroid.
- Depth Range 4: 300 m – 1,500 m; Tension Leg Platforms;
- Depth Range 5: 1,500 m +; Dynamically Positioned Floating Platforms

Data estimating the value of commercial fisheries harvested from each 10×10 cell has been generated using available data from NMFS or from other available sources of fishery data. A summary of these data by region are provided in the next section of this overview. The remainder of this section uses examples from Alaska to describe the model and the way it generates estimates of impacts of oil and gas infrastructure on commercial fisheries.

Figure 5 shows groundfish harvests in Alaska planning areas. From Figure 5 it is clear that with the exception of the St. George (GEO) Basin, Navarin Basin (NAV) and the North Aleutian Basin (NAL), a relatively small portion of the Alaska OCS is utilized in the groundfish fisheries. It is expected that the distribution of fishing effort in other planning areas around the United States are similar.

Figure 5 Locations of Alaska Groundfish Harvests by Planning Area (2006 – 2009)



Source: Developed for the OECM by Alaska Map Company based on data supplied by NMFS.

Pre-emption impacts are derived from data in the E&D scenario. The model assumes that, if development is expected to occur in a planning area, the E&D scenario will provide information about one or more groups of platforms. For each group of platforms it is expected that among other information, the following will be provided:

- Number of platforms in the group
- Average depth of platforms in the group

The fisheries model assigns the platforms to one of the five depth ranges described earlier, based on the average of the depths indicated in the E&D scenario for each platform group. The model then randomly assigns platforms to 10×10 cells within the depth range corresponding to the E&D scenario. Assume for example that the E&D scenario indicates the following:

- Group 1: 5 platforms with average depth of 40 meters
- Group 2: 7 platforms with average depth of 55 meters

The model randomly assigns platforms to twelve different 10×10 cells in depth range 1 as both Group 1 and Group 2 fall into that range. The model assumes that no more than one new platform can be located in a single cell. It should be noted that if a legacy platform (pre-2010) already exists in that cell then it is assumed new platforms may be added.

Once the platforms are assigned, the model calculates the size of the buffer zone required for each platform and reduces the fishing area in the cell by an appropriate amount. Fishery values are proportionally redistributed in a two-step process:

1. Reduce the fishery value in each cell with a platform in proportion to the reduction in available fishing area in the cell caused by the introduction of the platform—Preliminary Revenue for the cell (PRc) = Baseline Revenue for the cell (BRc) × (Cell area – buffer zone) ÷ Cell Area.
2. Increase the fishery value in all cells proportionally such that the total fishery value in all cells in the Planning Area is unchanged, and such that percentage of the fishery value in each cell is equal to the percentage of total revenue after the revenue reduction calculated in step 1—Final Revenue (FRc) = PRc × ∑IRc ÷ ∑PRc

Once fishery values are re-distributed across the planning area, the model estimates the differences in fishing costs that result. Reliable fishing cost data are not generally available, so the model uses an assumption that fishing costs are lowest in the cell within the planning area that has the highest revenue. Cost differentials in all other cells are estimated as an increasing percentage of revenue up to a 20 percent differential.[22]

In order to estimate the cost impact of grounds pre-emption, the estimated fishing cost differentials are applied to baseline revenue distribution by fishing area, and then reapplied to the revenue distribution after fishing grounds have been pre-empted due to oil and gas infrastructure. The incremental difference in cost over all areas between the baseline and post-infrastructure case constitutes the estimate of the cost of grounds pre-emption for the fishery.

The estimation of the fishing cost differentials for the set of platforms in the E&D scenario is highly dependent on the location of the platforms within the depth range. If the platforms are

[22] The following formulation will be used to estimate the fishing cost differential across 10×10 cells:

$dCp_c = (1 - Rp_c \div Rp_{Max}) \times dCp_{zero}$; where

- dCp_c = difference in fishing cost percentage in the cell relative to the fishing cost percentage in the cell with the maximum revenue.
- Rp_c = revenue in the cell as a percent of total revenue in the planning area.
- Rp_{Max} = revenue in the cell with the maximum revenue as a percent of total planning area revenue.
- dCp_{zero} = difference in fishing cost percentage as revenue in a cell approaches zero; as noted the model assumes this to be 20 percent.

located in cells where very little fishing takes place, the cost impacts will be negligible. On the other hand, if the platforms are located in cells where a lot of value is generated, the impacts will be greater. In other words, if the model assigns the same number of platforms to a different set of cells the cost estimate will be different. The coefficients incorporated in this version of the OECM result from regressions on thousands of simulation iterations[23] for each planning area. Each simulation represents a random placement of platforms, with the number of new platforms in each depth band ranging from zero up to the number of cells in the band. Within each iteration, platforms are assigned randomly to cells in 250 different location-configurations, and cost impacts are calculated for each location configuration.[24] The "result" for each iteration is the average of the cost differentials calculated over all 250 randomly drawn location- configurations for that particular E&D scenario. The model can also report the cost differentials if platforms are intentionally assigned to the cells that generate the highest amount of revenue and thus are likely to generate a "worst case" scenario in term of impacts.[25]

8.3 REGRESSION COEFFICIENTS

The OECM, as currently configured, will generate estimated impacts on commercial fisheries that result from BOEM supplied E&D scenarios through the use of regression coefficients and equations.. The estimated cost impacts for each simulated scenario were compiled into a regression dataset for each planning area. We estimated regressions coefficients assuming that impacts were of the form $Y = a_i x_i + b_i x_i^2$. The dependent variable (Y) is the estimated cost impact for each scenario and x_i is the number of new platforms in depth range i. We have included regression coefficients for the square of x_i to account for the fact that if the number of new platforms is relatively large, then the incremental impact of additional platforms are likely to be diminishing. In most cases, the regression coefficient for the un-squared term (a) will be positive while the regression coefficient for the squared term (b) will be negative and smaller in absolute magnitude. If this is the case then the squared terms will provide a dampening effect on the un-squared terms. If increasingly greater numbers of cells have platforms, then the redistribution of effort will have an increasingly smaller impact on fishing costs. If large numbers of platforms are placed in depths with relatively low fishing revenues, it is possible that the estimated cost-impacts may turn negative. In these instances the model assigns a zero cost outcome to the E&D scenario.

There are also a limited number of instances in which the coefficients for the un-squared terms are negative. A full listing of the coefficients is provided later in the document. A negative coefficient in the un-squared term implies that while there is fishing activity in the depth range,

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[23] For most planning areas over 20,000 simulation iterations were generated. Exceptions to this were in the North and Mid-Atlantic, for which 10,000 simulations were run.

[24] Because of the large number of 10×10 cells in each planning area, the spreadsheets that are used to calculate results are quite large. For example, the spreadsheet used to interactively calculate the 250 location configuratioins in the St. Matthew Hall Planning Area (with 1,447 cells) is over 23 meagabytes in size. Increasing the number of iterations to 1,000 per iteration would make the estimate of the cost impacts somewhat more robust because it is more likely that the random assignment of platforms will choose a set of platform locations that correspond to important fishing areas. To account for the possibility that the mean may be skewed to a lower estimate, the model also includes an estimate of costs assuming that the platforms are assigned to the highest ranked areas in each depth range.

[25] This last set of regression coefficients has not been included with this version of the OECM, but could potentially be added at a later date.

fishing revenues are low relative to other depth ranges in the planning area. Therefore, shifting effort out of the depth range moves effort to areas where revenues are higher and costs are lower. This could result in an overall reduction in fishing costs for an E&D scenario, particularly if the majority of platforms in the E&D scenario are placed in the ranges with negative coefficients for the un-squared term. Because we really do not believe that displacing fishing effort will result in overall cost reductions, the model returns a zero value for any negative cost results.

In part because of the fact that negative coefficients for the un-squared terms occur, but also because there are likely to fewer interactions between depth ranges when all platforms are located in a single depth range, a second set of regression coefficient has been generated. This second set of coefficients should be used in cases if the E&D scenario places platforms in only one depth range within the planning area. For the most part the issue of negative coefficients for un-squared terms is eliminated with this second set of coefficients. However, there is still one instance of a negative coefficient, that occurs in the Bowers Basin, an Alaska planning area with very limited fishing activity. As indicated above, any model outcomes that result in a negative cost impact should be treated as a zero-cost scenario.

8.4 EXAMPLES OF MODEL USAGE

Tables 9 and 10 show the fishery data inputs and the regression coefficients for the St. George Basin Planning Area in Alaska. These two tables are provided as examples of the data and model result tables for the other planning areas. The St. George Basin Planning Area is home to some of the most prolific fishing grounds in Alaska. Table 8 summarizes the data by depth range used to develop the impact model for the St. George Basin. The table shows:

1) The number of 10 × 10 cell by depth range.
2) The water area in terms of millions of hectares within each depth range.
3) The number of 10 × 10 cells in each depth range that were assigned fishery revenues.
4) The 4-year average of total fishery revenues in millions of 2009 dollars in that depth range.
5) The number of existing oil and gas platform in each depth range
6) The number of cells containing the existing oil and gas platforms.

In the St. George Basin most of the planning area is from 60 to 150 meters in depth, and over two-thirds of the fishery revenue is generated from cells in that depth range.

Table 9 Commercial Fishing Modeling: Data Summary for St. George Basin, Alaska

Variable	0m - 60m	60m - 150m	150m - 300m	300m - 1,500m	1,500m +	Total
Cell by Depth Range	216	774	102	151	304	1,547
Water Area (HA M)	3.7	14.5	2.0	3.0	6.0	29.2
Cells with Revenue	184	743	102	138	88	1,255
Fishery Revenue (Real $ M)	14.5	213.8	44.8	32.1	0.9	306.1
Existing Platforms	0	0	0	0	0	0
Cells With Platforms	0	0	0	0	0	0

Table 9 summarizes the regression coefficient that result from the thousands of simulations run through the St. George Basin Planning Area model. The table contains two independent sets of regressions coefficients. The first set of coefficients assumes that platforms are assigned to multiple depth ranges within a given simulation. The number of platforms in each depth range could range from zero to as high as the number cells that exist in the depth range. We assumed that for most areas it would be more likely that the number of platforms would be relatively small and therefore we over-sampled potential scenarios in the range from 0 to 9 platforms.

The second set of regression coefficients should be used if the E&D scenario calls for platforms within a single depth range. Because the number of interactions between platforms in different depth ranges is eliminated, the number of model simulations for these regressions was significantly reduced. We ran the simulations four times for each number of platforms up to the maximum of 50 platforms in each depth range. Note that each simulation for a given number of platforms generates 250 location-configurations, each with its own cost impact estimate.

The rows in each section of the table show the results for each depth range (D1 – D5). The value of the regression coefficients (a and b) are shown in the first two number columns after the depth range specifications; that is, the regression coefficient for the number of platforms in D1 is -0.6107 and the coefficient for the square of platforms in D1 is -0.0199. The last two columns in the table show the p-values indicating the statistical significance of the coefficient. P-values less than five percent are generally considered significantly different than zero. The fact that both coefficients for platforms in Depth Band 1are negative implies that additional platforms in this depth ranges will dampen the negative impacts of platforms in other depth range (D3 for example).

It also should be noted that the estimated impacts are in terms of annual cost impacts in real dollars. Thus a coefficient of 22.0 in D3 implies that adding an additional platform in depth range 3 in conjunction with platforms in other depth ranges generates a cost impact of $22 per year to fisheries in the St. George Basin. Given that fisheries in St. George Basin are estimated to generate over $300 million per year, it appears that the estimated pre-emption cost impacts of oil and gas platforms in the St. George Basin are quite small.

The fact that the regression coefficients for both the number and the square of the number of platforms are negative underscores the need for the second set of coefficients, that are to be used if platforms are to be placed in only one depth range within the E&D scenario. As seen in the lower section of Table 10, the regression coefficients for the number of platforms in D1 are positive while the coefficients for the square are negative.

Table 10 Commercial Fishing Modeling: Fishery Impact Coefficients for St. George Basin, Alaska

Depth Band	Depth Range	Regression Coefficients a	Regression Coefficients b	P-values (Significant if <5%) a	P-values (Significant if <5%) B
Use these coefficients if platforms will be placed in multiple depth ranges					
D1	0m - 60m	-0.6107	-0.0199	0.00%	0.00%
D2	60m - 150m	6.5774	-0.0083	0.00%	0.00%
D3	150m - 300m	22.0001	-0.2567	0.00%	0.00%
D4	300m - 1,500m	25.7349	-0.1509	0.00%	0.00%
D5	1,500m +	2.3083	-0.0098	0.00%	0.00%
Use these coefficients if platforms will be placed in only one depth range					
D1	0m - 60m	0.0153	-0.0004	0.00%	0.00%
D2	60m - 150m	23.0807	-0.1633	0.00%	0.00%
D3	150m - 300m	39.9362	-0.5776	0.00%	0.00%
D4	300m - 1,500m	36.8306	-0.2414	0.00%	0.00%
D5	1,500m +	0	0		

Note: Regressions coefficients should be used in the regression equation $Y = a_i x_i + b_i x_i^2$, where Y are cost impacts to commercial fisheries and x_i are the number of platforms that will be developed in depth range i. If no p-values are provided and the coefficients are shown as 0 then no impacts are estimated for platforms in the depth range.

The following is a numerical example of the way the model coefficients should be used under two different sets of circumstances.

Example 1: Assume an E&D scenario for the St. George Basin in which two platforms will be placed in depth range 1 and five platforms will be placed in depth range 2—in this case $x_1 = 3$ and $x_2 = 5$. Annual fishery impact $Y = (-0.6107 \times 2) + (-0.0199 \times 2^2) + (6.5774 \times 5) + (-0.0083 \times 5^2) = 31.3785$.

Example 2: Assume an E&D scenario for the St. George Basin in which two platforms will be placed in depth range 2, and no other platforms will be developed. The annual fishery impacts would be estimated as $Y = (23.0807 \times 2) + (-0.1633 \times 2^2) = 45.5082$.

8.5 FISHERY DATA SOURCES AND ALLOCATION METHODS

Fisheries data were divided into four general regions: 1) Alaska, 2) the Pacific Coast, 3) the GOM and South Atlantic, and 4) the Mid- and North Atlantic. The level of detail available for each region varied considerably as did the process of assigning harvests to the 10 × 10 cells. An overview of the data sources and processes is provided below.

8.5.1 Alaska

The Alaska Region of NMFS provided data for groundfish by harvests by gear in 10 × 10 cells for all of Alaska for the years 2006 - 2009 (Lewis, 2010). The Alaska Region has spent a considerable amount of time developing the data that combine reports from logbooks, observers, and their standard catch accounting system to assign harvests algorithmically to very precise geographic locations. These data were provided to Northern Economics by year, fishery, and 10 × 10 cell, as long as more than three vessels contributed harvests to the landings (otherwise the landings were considered confidential). NMFS also provide total harvest summaries by year and fishery in larger management areas. It was assumed that landings in cells with three or fewer harvesters would be small relative to landings in other cells with more harvesters and therefore that these landings could be distributed proportionally to other cells that had landings without materially affecting the model outcomes. If anything this process would lead to higher concentrations of landings in particular cells, which would have the effect of increasing the potential impact of oil and gas platforms.

In additional to groundfish, crab and halibut are also harvested in significant quantities in federal waters in which OCS development could occur. Crab data were provided by the Commercial Fishing Entry Commission (CFEC) through a specific data request (Huntsman, 2010) by fishery year for the years 2006 -2009. In Alaska, crab landings are reported by statistical areas (stat-area) covering one-half of a degree of latitude and one degree of longitude. Given that these stat-areas are already geographically based, it was a straightforward process to subdivide the landings by stat-area into 10 × 10 cells, with each cell receiving a portion of the landings equal to its share of the water in the stat-area. CFEC also reported total landings by fishery and year; from these data we were able to infer the amount of crab landings that were considered confidential. We assigned these “confidential” harvests to stat-areas that were adjacent to the stat-area that had landings on a pro-rata basis, and these further assigned harvests to cells within each stat-area. Because crab data in general were provided at a more aggregated level of geographic detail, it has the effect of smoothing our overall harvests within planning areas.

Data on halibut landings in Alaska were provided in a manner similar to the crab data by the International Pacific Halibut Commission (IPHC) for the years 2006 – 2009 (Kong, 2010). In the Bering Sea, halibut landings are reported using the same geographically-defined stat-areas. In the Gulf of Alaska, stat-areas specifically for halibut are used. In general, we employed essentially the same process to assign harvests to 10 × 10 cells with one important twist. It was assumed that within a stat-area halibut harvested were distributed to 10 × 10 cells in proportion to the amount of water area in each cell. In the case of halibut, however, we also used information from the IPHC that indicated that harvests of halibut are generally limited to water less than 500 fathoms (914 meters) of depth. Thus we did not assign halibut harvest to cells in which the depth of the centroid was greater than 914 meters.

Once all of the harvests by species were assigned to cells, we independently assigned average ex-vessel harvest values by species and year. The ex-vessels values were adjusted to account for inflation to 2009 dollars using the U.S. Bureau of Labor Statistics’ producer price index for unprocessed and packaged fish (http://data.bls.gov:8080/PDQ/outside.jsp?survey=wp). The final harvest value assigned to each cell was the average over four years of the annual adjusted value.

It should be noted in this section that we did not include salmon harvests in the Alaska data. While salmon fisheries are very important in Alaska, accounting for roughly one-third of the ex-vessel value in Alaska (Hiatt, 2010), the vast majority of harvests take place inside state waters and therefore would not be directly affected by the placement of oil and gas platforms in federal waters. Herring fisheries and other shellfish (oysters, geoducks, etc) harvests were excluded for the same reason.

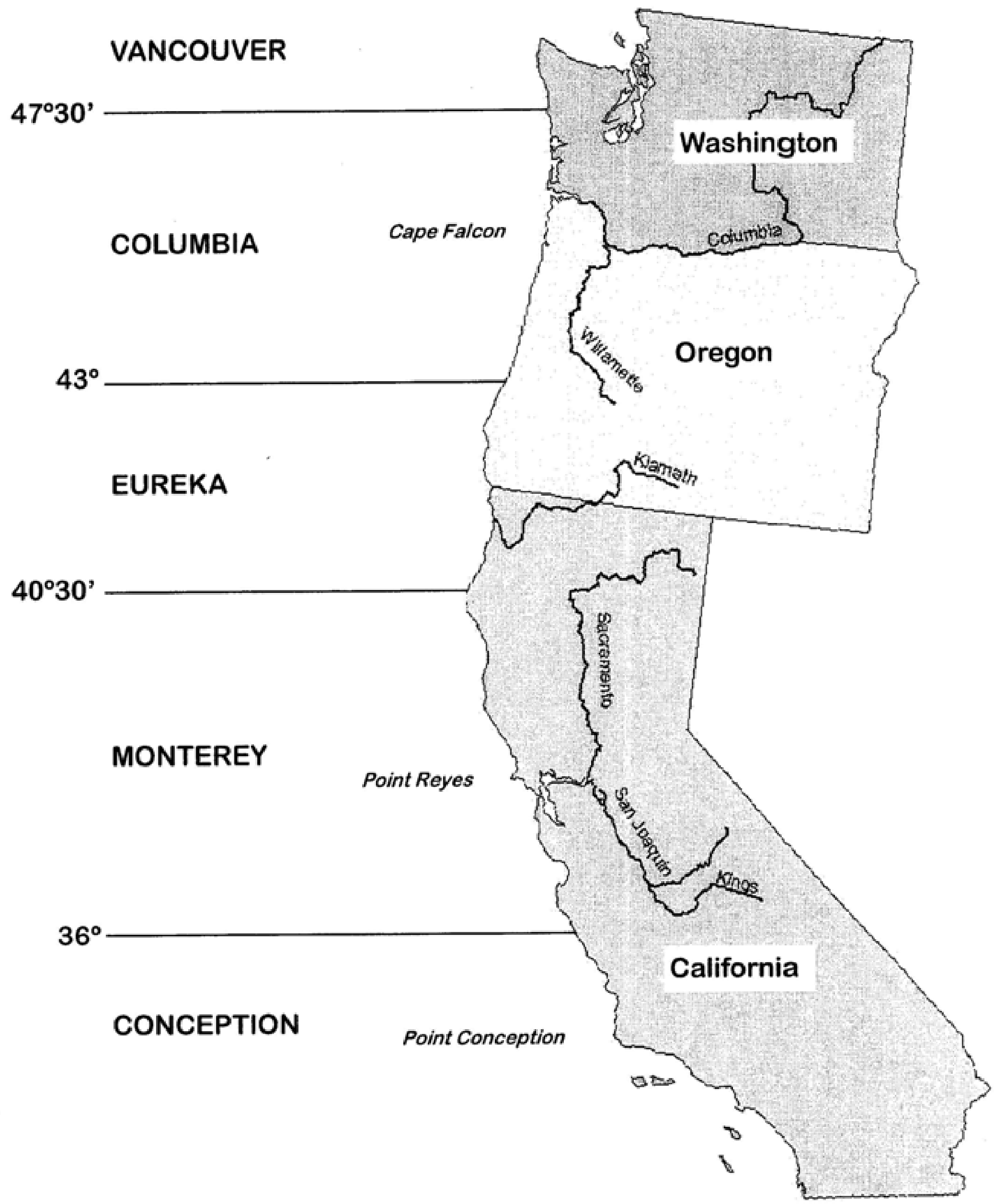
8.5.2 Pacific Coast

Estimates of groundfish trawl harvest for the Pacific Coast were provided in 10 × 10 cells for 2006 – 2009 from two sources. Harvests in the offshore Pacific whiting fishery were provided from observer data by the NMFS Northwest Fishery Science Center through a special request

(Tuttle, 2010). Estimates of harvests of shorebased trawl by 10 × 10 cells were developed using logbook data and were provided by the Pacific Fisheries Information Network (PacFIN) through a special request (Stenberg, 2010). As for Alaska, summary totals over all areas by fisheries were also provided. This allowed us to calculate data that had been withheld for confidentiality. Confidential harvest amounts were then assigned back to the non-confidential cell in proportion to the landings in the non-confidential cells.

Assignment of landings of other West Coast fisheries was more problematic than with non-groundfish landings in Alaska. In general, geographically-specific estimates of non-trawl landings on the Pacific Coast are reported only for relatively large areas known as INPFC Areas. These areas were established by the International North Pacific Fisheries Commission (INPFC) under the International Convention for the High Seas Fisheries of the North Pacific Ocean in 1952. Although the INPFC has been dissolved, the INPFC stat-areas remain in use, and are the most geographically precise reporting areas in general use on the Pacific Coast. As seen in Figure 6, five INPFC Areas comprise the U.S. Exclusive Economic Zone (EEZ) off the Pacific Coast. Harvest data from INPFC areas are reported by PacFIN on an annual basis (PacFin, 2010).

Figure 6 International North Pacific Fishery Commission (INPFC) Statistical Areas.



For non-trawl landings of groundfish (primarily landings of sablefish and rockfish) we combined the landings data by INPFC Areas with fishery specific landings data for 10×10 cell for trawls and assigned non-trawl landings to 10×10 cells in each INPFC Area in proportion to the landings those cells had in trawl fisheries for the same species. For example, non-trawl landings of rockfish in the Monterey INPFC area were assigned to the same 10×10 cells that had rockfish trawl landings. In this case, we assumed that areas of high abundance of particular species would be used by all gears.

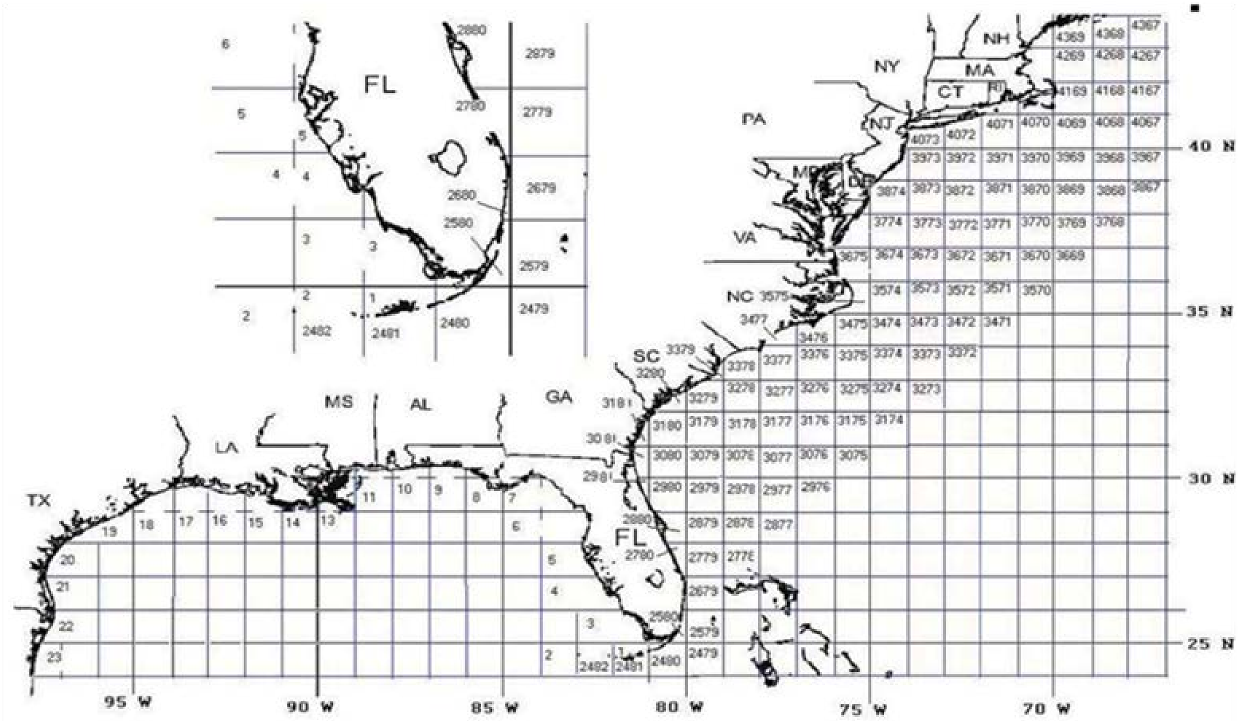
An exception to the general approach for non-trawl groundfish was in the Conception INPFMC area. Trawling for groundfish has not been allowed in the area for several years, and therefore there were no 10×10 data with which to associate non-trawl landings. In this case, we estimated the proportion of landings by depth in areas north of the Conception INPFC areas for those fisheries that occur inside the Conception area. We then assigned harvests to cells inside the Conception area in proportion to the estimated water areas of cells by depth.

There are other important fisheries on the Pacific Coast including the Dungeness crab fishery, the salmon fishery and the shrimp trawl fishery. Both the Dungeness crab and salmon fisheries take place primarily inside state waters, are unlikely to be displaced by oil and gas platforms, and therefore have not been included in the commercial fisheries impact model. The shrimp trawl fishery is more likely to be affected because the majority of shrimp harvests occur in waters from 300 to 650 feet in depth (CDFG 2007), which could range out farther into the EEZ. Based on this information we assigned landings data by INFPC areas from PacFIN, to 10×10 cells in these depth ranges in proportion to water area.

8.5.3 Gulf of Mexico and South Atlantic

Information on commercial fish harvests for the GOM and for the South Atlantic were provided as a result of a formal data request from BOEM to the Science Director of NMFS Southeast Fisheries Science Center (Labelle, 2010). The information was provided in terms of the standard stat-areas in general use throughout the region. The stat-areas over which these data were reported are shown in Figure 7.

Figure 7 Statistical Areas for Gulf of Mexico and South Atlantic Fisheries



Source: Provided by NMFS Southeast Fisheries Science Center as part of the BOEM data request. (Jamir, 2010).

In the GOM there are 23 stat-areas. Areas 19 – 23 and 1 – 7 extend in east-west directions outward from the coastline until they meet the stat-area running from north to south. In particular Area 18 is the eastern boundary of for Areas 19 – 23 and Area 8 is the western boundary of Areas 1- 7. Areas 8 – 18 extend in a north-south direction from the coastline to international waters in the south.

In the South Atlantic, stat-areas are linked to specific geographic coordinates. Each stat-area covers one degree of longitude and one degree of latitude and is designated based on the coordinates of the lower right corner.

NFMS provided harvest data and ex-vessel values from 2006 – 2009 for the fisheries shown in Table 11.

Table 11 Data Provided for Gulf of Mexico and South Atlantic Fisheries

Region	Fishery
Gulf of Mexico	Reeffish
Gulf of Mexico, South Atlantic	Shrimp
Gulf of Mexico, South Atlantic	Coastal Migratory
Gulf of Mexico, South Atlantic	Spiny Lobster
Gulf of Mexico, South Atlantic	Large Pelagics
Gulf of Mexico, South Atlantic	Stone Crab, Red Drum
Gulf of Mexico, South Atlantic	Red Drum
South Atlantic	Snapper/Grouper
South Atlantic	Dolphin/Wahoo

South Atlantic	Golden Crab

We note that the sizes of many of the stat-areas, particularly in the GOM, are quite large. Therefore, we determined that, in order to provide more realistic geographic distributions of harvests, it would be appropriate to augment the landings data with information on the maximum depth at which significant species within each fishery are likely to be found. Depth distributions for significant species were taken from the database maintained by Aquamaps.org. Table 12 shows the maximum cell depth to which landings were allocated for each of the fisheries within stat-areas. For example, if there were 1,000 metric tons (MT) of reeffish landings reported for stat-area GOM 12, then only those cells in the stat-area which had depths of 540 meters or less would be assigned reeffish landings. The cells with depths greater than 540 meter would not be assigned reeffish harvests. In general, we did not constrain fisheries to be harvested in cells with depths greater than some minimum. The exception to this rule was for Golden Crab. In that fishery, cells had to have a minimum depth of 250 meters to receive an allocation.

Table 12 Maximum Cells Depths to which Fisheries Were Assigned Landings by Fishery and Region

Region	Fishery	Maximum Cell Depth (meters)
Gulf of Mexico	Reeffish	540
Gulf of Mexico, South Atlantic	Shrimp, Coastal Migratory, Spiny Lobster	200
Gulf of Mexico, South Atlantic	Large Pelagics	9,850
Gulf of Mexico, South Atlantic	Stone Crab, Red Drum	51
South Atlantic	Snapper Grouper	540
South Atlantic	Dolphin/Wahoo	85
South Atlantic	Golden Crab	1400

As with other regions, there are significant harvests of species in fisheries that are not federally managed. In the GOM, for example, there are very significant harvests of oysters and menhaden. Since these fisheries are not managed by NMFS, it was assumed that their harvest occurs in water three miles or nearer to shore, and therefore that they would not be displaced by new oil and gas platforms on the OCS.

8.5.4 North and Mid-Atlantic

Data for most of the major fisheries in the North and Mid-Atlantic were provided as a result of a data request to NMFS Northeast Fishery Science Center. Dr. Eric Thunberg provided estimates based on logbook data and dealer reports of harvests from 10×10 cells for the years 2006 – 2009 for the fisheries listed in Table 13. Dr. Thunberg also provided summaries of dealer reports that enable the estimation of ex-vessel values within the various fisheries. These were used to assign ex-vessel price to landings and as a means to assign harvests to cells for which fishery-specific data were noted as confidential. While the data provide by Dr. Thunberg are relatively comprehensive in terms of fisheries that take place in federal waters, the data do not include landings or values of highly migratory pelagic species, nor did they include landings or values of lobster. Other fisheries that are primarily harvested inside of three miles were also excluded, blue crab harvests for example.

Table 13 Federal Fisheries for which Data Were Requested and Provided in the North and Mid-Atlantic Regions

North Atlantic		Mid-Atlantic
black sea bass	monkfish gillnet	black sea bass
bluefish	monkfish trawl	Bluefish
butterfish	other	butterfish
dogfish	scallop	dogfish
fluke	scup	Fluke
groundfish gillnet	shrimp	monkfish gillnet
groundfish hook	skates	Other
groundfish trawl	small mesh multispecies	Scallop
herring	squid	Shrimp
mackerel	surf clam	Skates
	tilefish	Squid
		Tilefish

There are in fact significant levels of lobster harvests in federal waters of the North Atlantic, as well as significant harvests of large pelagic species (e.g., bluefin tuna and swordfish) that were not included in the Thunberg data. We believe that these fisheries could be affected by oil and gas platforms in the federal waters and therefore found alternative sources of information. We used estimates of commercial fisheries harvest volumes and values by state compiled by NMFS Office of Science and Technology for the years 2006 – 2009 as source data for lobster and large pelagics in the North and Mid-Atlantic (NMFS, 2010).

Estimated harvests by state were allocated to 10×10 cells by latitude. For example, cells with latitude of 43 degrees and higher were assigned to Maine, while cells from 41.6 degree to 42.9 degrees were assigned to Massachusetts and New Hampshire. Lobster landings reported in the NMFS database for the State of Maine were assigned to the 10×10 cells in Maine in proportion to each cell's water area. It should be noted that we also added a maximum depth limit for lobster harvests. Cells with centroid depths greater than 100 meters did not receive assignments of lobster harvests.

Harvests of large pelagic species in the North and Mid-Atlantic were assigned to cells using a similar state-based allocation using NMFS Commercial Fisheries harvest database (NMFS, 2010). In this case, we did not constrain harvests to specific depths. Harvests were allocated to all cells by state in proportion to the water area of the cell.

8.6 SUMMARY TABLES OF FISHERY DATA AND REGRESSION COEFFICIENTS FOR ALASKA PLANNING AREAS

This section provides fishery data and regression coefficients for the Alaska Planning Areas. Two tables with the same formats as the example for the St. George Basin above are provided for each Planning Area in Alaska. Note that there are no commercial fisheries in federal waters in Hope Basin, the Chukchi Sea, and the Beaufort Sea, so fishery data and impact models for those areas are not provided. Tables are arranged in a north to south and west to east progression.

Table 14 Commercial Fishing Modeling: Data Summary for Norton Basin

Variable	0m - 60m	60m - 150m	150m - 300m	300m - 1,500m	1,500m +	Total
Cell by Depth Range	998	130				1,128
Water Area (HA M)	13.5	2.0				15.5
Cells with Revenue	252	0				252
Fishery Revenue (Real $ M)	1.6	0.0				1.6
Existing Platforms	0	0				0
Cells With Platforms	0	0				0

Table 15 Commercial Fishing Modeling: Fishery Impact Coefficients for Norton Basin

		Regression Coefficients		P-values (Significant if <5%)	
Depth Band	Depth Range	a	b	a	B
Use these coefficients if platforms will be placed in multiple depth ranges					
D1	0m - 60m	0.1850	-0.0001	0.0%	0.0%
D2	60m - 150m	0.2952	-0.0105	0.0%	0.0%
D3	150m - 300m	0.0000	0.0000		
D4	300m - 1,500m	0.0000	0.0000		
D5	1,500m +	0.0000	0.0000		
Use these coefficients if platforms will be placed in only one depth range					
D1	0m - 60m	0.4889	-0.0047	0.0%	0.0%
D2	60m - 150m	0.0000	0.0000		
D3	150m - 300m	0.0000	0.0000		
D4	300m - 1,500m	0.0000	0.0000		
D5	1,500m +	0.0000	0.0000		

Note: Regressions coefficients should be used in the regression equation $Y = a_i x_i + b_i x_i^2$, where Y are cost impacts to commercial fisheries and x_i are the number of platforms that will be developed in depth range i. If no p-values are provided and the coefficients are shown as 0, then no impacts are estimated for platforms in the depth range.

Table 16 Commercial Fishing Modeling: Data Summary for Navarin Basin

Variable	0m - 60m	60m - 150m	150m - 300m	300m - 1,500m	1,500m +	Total
Cell by Depth Range	17	635	167	107	217	1,143
Water Area (HA M)	0.3	10.6	2.9	1.9	3.9	19.4
Cells with Revenue	12	351	109	53	44	569
Fishery Revenue (Real $ M)	3.6	90.4	36.2	5.2	0.8	136.2
Existing Platforms	0	0	0	0	0	0
Cells With Platforms	0	0	0	0	0	0

Table 17 Commercial Fishing Modeling: Fishery Impact Coefficients for Navarin Basin

		Regression Coefficients		P-values (Significant if <5%)	
Depth Band	Depth Range	a	b	a	B
Use these coefficients if platforms will be placed in multiple depth ranges					
D1	0m - 60m	57.1660	-3.4547	0.0%	0.0%
D2	60m - 150m	5.4190	-0.0086	0.0%	0.0%
D3	150m - 300m	42.5967	-0.3323	0.0%	0.0%
D4	300m - 1,500m	-6.3399	-0.1090	0.0%	0.0%
D5	1,500m +	2.0710	-0.0221	0.0%	0.0%
Use these coefficients if platforms will be placed in only one depth range					
D1	0m - 60m	35.0192	-1.9134	0.0%	0.0%
D2	60m - 150m	21.1382	-0.2104	0.0%	0.0%
D3	150m - 300m	66.7881	-0.7613	0.0%	0.0%
D4	300m - 1,500m	0.0011	0.0000	35.4%	37.2%
D5	1,500m +	0.0000	0.0000		

Note: Regressions coefficients should be used in the regression equation $Y = a_i x_i + b_i x_i^2$, where Y are cost impacts to commercial fisheries and x_i are the number of platforms that will be developed in depth range i. If no p-values are provided and the coefficients are shown as 0, then no impacts are estimated for platforms in the depth range.

Table 18 Commercial Fishing Modeling: Data Summary for St Matthew Hall

Variable	0m - 60m	60m - 150m	150m - 300m	300m - 1,500m	1,500m +	Total
Cell by Depth Range	1,145	283	14			1,442
Water Area (HA M)	17.7	4.8	0.2			22.7
Cells with Revenue	282	105	14			401
Fishery Revenue (Real $ M)	5.3	4.7	2.9			12.9
Existing Platforms	0	0	0			0
Cells With Platforms	0	0	0			0

Table 19 Commercial Fishing Modeling: Fishery Impact Coefficients for St. Matthew Hall

		Regression Coefficients		P-values (Significant if <5%)	
Depth Band	Depth Range	a	b	a	B
Use these coefficients if platforms will be placed in multiple depth ranges					
D1	0m - 60m	0.3618	-0.0005	0.0%	0.0%
D2	60m - 150m	-2.1276	0.0003	0.0%	18.9%
D3	150m - 300m	259.0227	-0.8606	0.0%	0.0%
D4	300m - 1,500m	0.0000	0.0000		
D5	1,500m +	0.0000	0.0000		
Use these coefficients if platforms will be placed in only one depth range					
D1	0m - 60m	1.1314	0.0004	0.0%	86.7%
D2	60m - 150m	0.0041	-0.0001	0.0%	0.0%
D3	150m - 300m	264.0219	0.1602	0.0%	57.1%
D4	300m - 1,500m	0.0000	0.0000		
D5	1,500m +	0.0000	0.0000		

Note: Regressions coefficients should be used in the regression equation $Y = a_i x_i + b_i x_i^2$, where Y are cost impacts to commercial fisheries and x_i are the number of platforms that will be developed in depth range i. If no p-values are provided and the coefficients are shown as 0, then no impacts are estimated for platforms in the depth range.

Table 20 Commercial Fishing Modeling: Data Summary for St. George Basin, Alaska

Variable	0m - 60m	60m - 150m	150m - 300m	300m - 1,500m	1,500m +	Total
Cell by Depth Range	216	774	102	151	304	1,547
Water Area (HA M)	3.7	14.5	2.0	3.0	6.0	29.2
Cells with Revenue	184	743	102	138	88	1,255
Fishery Revenue (Real $ M)	14.5	213.8	44.8	32.1	0.9	306.1
Existing Platforms	0	0	0	0	0	0
Cells With Platforms	0	0	0	0	0	0

Table 21 Commercial Fishing Modeling: Fishery Impact Coefficients for St. George Basin, Alaska

		Regression Coefficients		P-values (Significant if <5%)	
Depth Band	Depth Range	a	b	a	B
Use these coefficients if platforms will be placed in multiple depth ranges					
D1	0m - 60m	-0.6107	-0.0199	0.00%	0.00%
D2	60m - 150m	6.5774	-0.0083	0.00%	0.00%
D3	150m - 300m	22.0001	-0.2567	0.00%	0.00%
D4	300m - 1,500m	25.7349	-0.1509	0.00%	0.00%
D5	1,500m +	2.3083	-0.0098	0.00%	0.00%
Use these coefficients if platforms will be placed in only one depth range					
D1	0m - 60m	0.0153	-0.0004	0.00%	0.00%
D2	60m - 150m	23.0807	-0.1633	0.00%	0.00%
D3	150m - 300m	39.9362	-0.5776	0.00%	0.00%
D4	300m - 1,500m	36.8306	-0.2414	0.00%	0.00%
D5	1,500m +	0	0		

Note: Regressions coefficients should be used in the regression equation $Y = a_i x_i + b_i x_i^2$, where Y are cost impacts to commercial fisheries and x_i are the number of platforms that will be developed in depth range i. If no p-values are provided and the coefficients are shown as 0, then no impacts are estimated for platforms in the depth range.

Table 22 Commercial Fishing Modeling: Data Summary for North Aleutian Basin

Variable	0m - 60m	60m - 150m	150m - 300m	300m - 1,500m	1,500m +	Total
Cell by Depth Range	596	262				858
Water Area (HA M)	9.5	5.0				14.5
Cells with Revenue	406	259				665
Fishery Revenue (Real $ M)	29.4	151.3				180.6
Existing Platforms	0	0				0
Cells With Platforms	0	0				0

Table 23 Commercial Fishing Modeling: Fishery Impact Coefficients for North Aleutian Basin

		Regression Coefficients		P-values (Significant if <5%)	
Depth Band	Depth Range	a	b	a	B
Use these coefficients if platforms will be placed in multiple depth ranges					
D1	0m - 60m	-5.6643	0.0006	0.0%	24.5%
D2	60m - 150m	58.1161	-0.0771	0.0%	0.0%
D3	150m - 300m	0.0000	0.0000		
D4	300m - 1,500m	0.0000	0.0000		
D5	1,500m +	0.0000	0.0000		
Use these coefficients if platforms will be placed in only one depth range					
D1	0m - 60m	0.0000	0.0000		
D2	60m - 150m	107.0198	-0.8597	0.0%	0.0%
D3	150m - 300m	0.0000	0.0000		
D4	300m - 1,500m	0.0000	0.0000		
D5	1,500m +	0.0000	0.0000		

Note: Regressions coefficients should be used in the regression equation $Y = a_i x_i + b_i x_i^2$, where Y are cost impacts to commercial fisheries and x_i are the number of platforms that will be developed in depth range i. If no p-values are provided and the coefficients are shown as 0, then no impacts are estimated for platforms in the depth range.

Table 24 Commercial Fishing Modeling: Data Summary for Aleutian Basin

Variable	0m - 60m	60m - 150m	150m - 300m	300m - 1,500m	1,500m +	Total
Cell by Depth Range			1	6	1,305	1,312
Water Area (HA M)			0.0	0.1	24.2	24.3
Cells with Revenue			1	4	5	10
Fishery Revenue (Real $ M)			0.3	0.5	0.0	0.8
Existing Platforms			0	0	0	0
Cells With Platforms			0	0	0	0

Table 25 Commercial Fishing Modeling: Fishery Impact Coefficients for Aleutian Basin

		Regression Coefficients		P-values (Significant if <5%)	
Depth Band	Depth Range	a	b	a	B
Use these coefficients if platforms will be placed in multiple depth ranges					
D1	0m - 60m	0.0000	0.0000		
D2	60m - 150m	0.0000	0.0000		
D3	150m - 300m	0.0000	0.0000		
D4	300m - 1,500m	0.0000	0.0000		
D5	1,500m +	0.0000	0.0000		
Use these coefficients if platforms will be placed in only one depth range					
D1	0m - 60m	0.0000	0.0000		
D2	60m - 150m	0.0000	0.0000		
D3	150m - 300m	158.6262	0.0000	0.0%	
D4	300m - 1,500m	0.0000	0.0000		
D5	1,500m +	0.0000	0.0000		

Note: Regressions coefficients should be used in the regression equation $Y = a_i x_i + b_i x_i^2$, where Y are cost impacts to commercial fisheries and x_i are the number of platforms that will be developed in depth range i. If no p-values are provided and the coefficients are shown as 0, then no impacts are estimated for platforms in the depth range.

Table 26 Commercial Fishing Modeling: Data Summary for Bowers Basin

Variable	0m - 60m	60m - 150m	150m - 300m	300m - 1,500m	1,500m +	Total
Cell by Depth Range	1	1	3	87	1,859	1,951
Water Area (HA M)	0.0	0.0	0.1	1.8	37.1	39.0
Cells with Revenue	0	0	0	5	73	78
Fishery Revenue (Real $ M)	0.0	0.0	0.0	0.0	0.0	0.0
Existing Platforms	0	0	0	0	0	0
Cells With Platforms	0	0	0	0	0	0

Table 27 Commercial Fishing Modeling: Fishery Impact Coefficients for Bowers Basin

		Regression Coefficients		P-values (Significant if <5%)	
Depth Band	Depth Range	a	b	a	B
Use these coefficients if platforms will be placed in multiple depth ranges					
D1	0m - 60m	0.0000	0.0000		
D2	60m - 150m	0.0000	0.0000		
D3	150m - 300m	0.0116	-0.0041	0.0%	0.0%
D4	300m - 1,500m	0.0023	0.0000	0.0%	0.0%
D5	1,500m +	0.0019	0.0000	0.0%	0.0%
Use these coefficients if platforms will be placed in only one depth range					
D1	0m - 60m	0.0000	0.0000		
D2	60m - 150m	0.0000	0.0000		
D3	150m - 300m	0.0000	0.0000		
D4	300m - 1,500m	-0.0007	0.0000	0.0%	0.0%
D5	1,500m +	0.0027	0.0000	0.0%	19.7%

Note: Regressions coefficients should be used in the regression equation $Y = a_i x_i + b_i x_i^2$, where Y are cost impacts to commercial fisheries and x_i are the number of platforms that will be developed in depth range i. If no p-values are provided and the coefficients are shown as 0, then no impacts are estimated for platforms in the depth range.

Table 28 Commercial Fishing Modeling: Data Summary for Aleutian Arc

Variable	0m - 60m	60m - 150m	150m - 300m	300m - 1,500m	1,500m +	Total
Cell by Depth Range	122	119	86	293	5,289	5,909
Water Area (HA M)	1.8	2.5	1.8	6.2	116.5	128.7
Cells with Revenue	122	116	85	270	933	1,526
Fishery Revenue (Real $ M)	8.6	25.7	15.4	31.0	5.3	86.0
Existing Platforms	0	0	0	0	0	0
Cells With Platforms	0	0	0	0	0	0

Table 29 Commercial Fishing Modeling: Fishery Impact Coefficients for Aleutian Arc

		Regression Coefficients		P-values (Significant if <5%)	
Depth Band	Depth Range	a	b	a	B
Use these coefficients if platforms will be placed in multiple depth ranges					
D1	0m - 60m	15.8745	-1.1003	0.0%	0.0%
D2	60m - 150m	36.1643	-0.1989	0.0%	0.0%
D3	150m - 300m	16.0232	-0.2565	0.0%	0.0%
D4	300m - 1,500m	14.1891	-0.0146	0.0%	0.0%
D5	1,500m +	-0.2148	0.0000	0.0%	1.4%
Use these coefficients if platforms will be placed in only one depth range					
D1	0m - 60m	0.0000	0.0000		
D2	60m - 150m	56.9089	-0.5447	0.0%	0.0%
D3	150m - 300m	26.4894	-0.4417	0.0%	0.0%
D4	300m - 1,500m	33.1780	-0.2485	0.0%	0.0%
D5	1,500m +	0.0000	0.0000		

Note: Regressions coefficients should be used in the regression equation $Y = a_i x_i + b_i x_i^2$, where Y are cost impacts to commercial fisheries and x_i are the number of platforms that will be developed in depth range i. If no p-values are provided and the coefficients are shown as 0, then no impacts are estimated for platforms in the depth range.

Table 30 Commercial Fishing Modeling: Data Summary for Shumagin

Variable	0m - 60m	60m - 150m	150m - 300m	300m - 1,500m	1,500m +	Total
Cell by Depth Range	188	192	84	56	1,406	1,926
Water Area (HA M)	2.6	3.8	1.6	1.1	29.8	38.9
Cells with Revenue	188	192	84	54	39	557
Fishery Revenue (Real $ M)	21.2	22.2	9.1	12.3	1.0	65.9
Existing Platforms	0	0	0	0	0	0
Cells With Platforms	0	0	0	0	0	0

Table 31 Commercial Fishing Modeling: Fishery Impact Coefficients for Shumagin

		Regression Coefficients		P-values (Significant if <5%)	
Depth Band	Depth Range	a	b	a	B
Use these coefficients if platforms will be placed in multiple depth ranges					
D1	0m - 60m	5.2925	-0.0303	0.0%	0.0%
D2	60m - 150m	-1.4832	0.0055	0.0%	0.0%
D3	150m - 300m	-6.1889	0.0656	0.0%	0.0%
D4	300m - 1,500m	7.2769	-0.0163	0.0%	0.0%
D5	1,500m +	0.1119	-0.0001	0.0%	0.0%
Use these coefficients if platforms will be placed in only one depth range					
D1	0m - 60m	22.8590	-0.2496	0.0%	0.0%
D2	60m - 150m	8.2160	-0.1190	0.0%	0.0%
D3	150m - 300m	0.0910	-0.0022	1.6%	2.1%
D4	300m - 1,500m	18.2711	-0.0281	0.0%	0.0%
D5	1,500m +	0.0000	0.0000		

Note: Regressions coefficients should be used in the regression equation $Y = a_i x_i + b_i x_i^2$, where Y are cost impacts to commercial fisheries and x_i are the number of platforms that will be developed in depth range i. If no p-values are provided and the coefficients are shown as 0, then no impacts are estimated for platforms in the depth range.

Table 32 Commercial Fishing Modeling: Data Summary for Kodiak

Variable	0m - 60m	60m - 150m	150m - 300m	300m - 1,500m	1,500m +	Total
Cell by Depth Range	115	189	95	93	1,597	2,089
Water Area (HA M)	1.5	3.5	1.7	1.8	32.0	40.5
Cells with Revenue	115	189	95	85	32	516
Fishery Revenue (Real $ M)	15.6	43.7	22.8	23.4	1.3	106.9
Existing Platforms	0	0	0	0	0	0
Cells With Platforms	0	0	0	0	0	0

Table 33 Commercial Fishing Modeling: Fishery Impact Coefficients for Kodiak

		Regression Coefficients		P-values (Significant if <5%)	
Depth Band	Depth Range	a	b	a	B
Use these coefficients if platforms will be placed in multiple depth ranges					
D1	0m - 60m	-3.1155	-0.2197	0.0%	0.0%
D2	60m - 150m	9.9260	-0.0547	0.0%	0.0%
D3	150m - 300m	3.4458	-0.1301	0.0%	0.0%
D4	300m - 1,500m	33.9909	0.0812	0.0%	0.0%
D5	1,500m +	0.2553	-0.0003	0.0%	0.0%
Use these coefficients if platforms will be placed in only one depth range					
D1	0m - 60m	0.0004	0.0000	74.8%	75.7%
D2	60m - 150m	23.4770	-0.2662	0.0%	0.0%
D3	150m - 300m	14.2944	-0.2833	0.0%	0.0%
D4	300m - 1,500m	57.3254	-0.0684	0.0%	0.0%
D5	1,500m +	0.0000	0.0000		

Note: Regressions coefficients should be used in the regression equation $Y = a_i x_i + b_i x_i^2$, where Y are cost impacts to commercial fisheries and x_i are the number of platforms that will be developed in depth range i. If no p-values are provided and the coefficients are shown as 0, then no impacts are estimated for platforms in the depth range.

Table 34 Commercial Fishing Modeling: Data Summary for Cook Inlet

Variable	0m - 60m	60m - 150m	150m - 300m	300m - 1,500m	1,500m +	Total
Cell by Depth Range	231	33	62	1		327
Water Area (HA M)	2.2	0.6	1.1	0.0		3.9
Cells with Revenue	229	33	62	1		325
Fishery Revenue (Real $ M)	7.3	2.6	7.0	0.1		17.0
Existing Platforms	19	0	0	0		19
Cells With Platforms	9	0	0	0		9

Table 35 Commercial Fishing Modeling: Fishery Impact Coefficients for Cook Inlet

		Regression Coefficients		P-values (Significant if <5%)	
Depth Band	Depth Range	a	b	a	B
Use these coefficients if platforms will be placed in multiple depth ranges					
D1	0m - 60m	0.0911	-0.1270	51.2%	0.0%
D2	60m - 150m	4.1009	-0.2174	0.0%	0.0%
D3	150m - 300m	53.6277	-0.1231	0.0%	0.0%
D4	300m - 1,500m	0.0000	0.0000		
D5	1,500m +	0.0000	0.0000		
Use these coefficients if platforms will be placed in only one depth range					
D1	0m - 60m	0.0008	0.0000	68.8%	69.8%
D2	60m - 150m	3.3460	-0.1402	0.0%	0.0%
D3	150m - 300m	112.7147	-0.2888	0.0%	0.0%
D4	300m - 1,500m	0.0000	0.0000		
D5	1,500m +	0.0000	0.0000		

Note: Regressions coefficients should be used in the regression equation $Y = a_i x_i + b_i x_i^2$, where Y are cost impacts to commercial fisheries and x_i are the number of platforms that will be developed in depth range i. If no p-values are provided and the coefficients are shown as 0, then no impacts are estimated for platforms in the depth range.

Table 36 Commercial Fishing Modeling: Data Summary for Gulf of Alaska

Variable	0m - 60m	60m - 150m	150m - 300m	300m - 1,500m	1,500m +	Total
Cell by Depth Range	732	241	277	165	2,072	3,487
Water Area (HA M)	5.0	4.2	4.9	3.1	39.8	57.0
Cells with Revenue	600	229	262	132	59	1,282
Fishery Revenue (Real $ M)	21.8	22.0	35.7	35.7	4.2	119.4
Existing Platforms	0	0	0	0	0	0
Cells With Platforms	0	0	0	0	0	0

Table 37 Commercial Fishing Modeling: Fishery Impact Coefficients for Gulf of Alaska

		Regression Coefficients		P-values (Significant if <5%)	
Depth Band	Depth Range	a	b	a	B
Use these coefficients if platforms will be placed in multiple depth ranges					
D1	0m - 60m	30.1512	-1.3129	0.0%	0.0%
D2	60m - 150m	-3.7119	-0.0151	0.0%	0.0%
D3	150m - 300m	-4.1361	-0.0166	0.0%	0.0%
D4	300m - 1,500m	71.5700	0.1964	0.0%	0.0%
D5	1,500m +	0.4133	-0.0003	0.0%	0.0%
Use these coefficients if platforms will be placed in only one depth range					
D1	0m - 60m	0.0000	0.0000		
D2	60m - 150m	0.3350	-0.0081	0.0%	0.0%
D3	150m - 300m	13.7071	-0.2405	0.0%	0.0%
D4	300m - 1,500m	111.8007	-0.0521	0.0%	3.4%
D5	1,500m +	0.0414	-0.0004	0.0%	0.0%

Note: Regressions coefficients should be used in the regression equation $Y = a_i x_i + b_i x_i^2$, where Y are cost impacts to commercial fisheries and x_i are the number of platforms that will be developed in depth range i. If no p-values are provided and the coefficients are shown as 0, then no impacts are estimated for platforms in the depth range.

8.7 SUMMARY TABLES OF FISHERY DATA AND REGRESSION COEFFICIENTS FOR WEST COAST PLANNING AREAS

This section provides fishery data and regression coefficients for the West Coast planning areas.

Table 38 Commercial Fishing Modeling: Data Summary for Washington/Oregon

Variable	0m - 60m	60m - 150m	150m - 300m	300m - 1,500m	1,500m +	Total
Cell by Depth Range	224	103	52	127	1,233	1,739
Water Area (HA M)	2.7	2.4	1.2	3.0	29.9	39.3
Cells with Revenue	53	88	47	81	3	272
Fishery Revenue (Real $ M)	1.3	24.4	15.7	39.7	0.2	81.3
Existing Platforms	0	0	0	0	0	0
Cells With Platforms	0	0	0	0	0	0

Table 39 Commercial Fishing Modeling: Fishery Impact Coefficients for Washington Oregon

		Regression Coefficients		P-values (Significant if <5%)	
Depth Band	Depth Range	a	b	a	B
Use these coefficients if platforms will be placed in multiple depth ranges					
D1	0m - 60m	49.7169	-6.3516	0.0%	0.0%
D2	60m - 150m	13.3141	-0.3552	0.0%	0.0%
D3	150m - 300m	27.7859	-1.4289	0.0%	0.0%
D4	300m - 1,500m	27.8188	0.0261	0.0%	0.0%
D5	1,500m +	0.2841	-0.0004	0.0%	0.0%
Use these coefficients if platforms will be placed in only one depth range					
D1	0m - 60m	0.0000	0.0000		
D2	60m - 150m	30.2198	-0.6552	0.0%	0.0%
D3	150m - 300m	27.5531	-0.9806	0.0%	0.0%
D4	300m - 1,500m	48.0148	-0.2051	0.0%	0.0%
D5	1,500m +	0.0000	0.0000		

Note: Regressions coefficients should be used in the regression equation $Y = a_i x_i + b_i x_i^2$, where Y are cost impacts to commercial fisheries and x_i are the number of platforms that will be developed in depth range i. If no p-values are provided and the coefficients are shown as 0, then no impacts are estimated for platforms in the depth range.

Table 40 Commercial Fishing Modeling: Data Summary for Northern California

Variable	0m - 60m	60m - 150m	150m - 300m	300m - 1,500m	1,500m +	Total
Cell by Depth Range	26	18	4	48	674	770
Water Area (HA M)	0.2	0.5	0.1	1.3	17.7	19.7
Cells with Revenue	9	16	4	38	0	67
Fishery Revenue (Real $ M)	0.4	2.1	2.1	8.0	0.0	12.5
Existing Platforms	0	0	0	0	0	0
Cells With Platforms	0	0	0	0	0	0

Table 41 Commercial Fishing Modeling: Fishery Impact Coefficients for Northern California

		Regression Coefficients		P-values (Significant if <5%)	
Depth Band	Depth Range	a	b	a	B
Use these coefficients if platforms will be placed in multiple depth ranges					
D1	0m - 60m	0.0000	9.6002		0.0%
D2	60m - 150m	-2.3562	-0.7016	0.0%	0.0%
D3	150m - 300m	480.4073	-15.7714	0.0%	0.0%
D4	300m - 1,500m	15.2975	-0.3703	0.0%	0.0%
D5	1,500m +	0.1348	-0.0002	0.0%	0.0%
Use these coefficients if platforms will be placed in only one depth range					
D1	0m - 60m	0.0000	0.0000		
D2	60m - 150m	0.0000	0.0000		
D3	150m - 300m	512.8884	-12.0618	0.0%	5.9%
D4	300m - 1,500m	22.3296	-0.4914	0.0%	0.0%
D5	1,500m +	0.0000	0.0000		

Note: Regressions coefficients should be used in the regression equation $Y = a_i x_i + b_i x_i^2$, where Y are cost impacts to commercial fisheries and x_i are the number of platforms that will be developed in depth range i. If no p-values are provided and the coefficients are shown as 0, then no impacts are estimated for platforms in the depth range.

Table 42 Commercial Fishing Modeling: Data Summary for Central California

Variable	0m - 60m	60m - 150m	150m - 300m	300m - 1,500m	1,500m +	Total
Cell by Depth Range	28	24	4	27	651	734
Water Area (HA M)	0.4	0.6	0.1	0.7	17.8	19.6
Cells with Revenue	15	16	4	21	0	56
Fishery Revenue (Real $ M)	1.0	0.6	0.5	1.7	0.0	3.8
Existing Platforms	0	0	0	0	0	0
Cells With Platforms	0	0	0	0	0	0

Table 43 Commercial Fishing Modeling: Fishery Impact Coefficients for Central California

		Regression Coefficients		P-values (Significant if <5%)	
Depth Band	Depth Range	a	b	a	B
Use these coefficients if platforms will be placed in multiple depth ranges					
D1	0m - 60m	73.4460	-5.3453	0.0%	0.0%
D2	60m - 150m	-2.0906	-0.1640	0.0%	0.0%
D3	150m - 300m	111.2114	-12.3236	0.0%	0.0%
D4	300m - 1,500m	1.2845	-0.1046	0.0%	0.0%
D5	1,500m +	0.0247	0.0000	0.0%	0.0%
Use these coefficients if platforms will be placed in only one depth range					
D1	0m - 60m	0.0000	0.0000		
D2	60m - 150m	129.8943	-14.5836	0.0%	0.0%
D3	150m - 300m	2.4434	-0.1020	0.0%	0.0%
D4	300m - 1,500m	0.0000	0.0000		
D5	1,500m +	66.0736	-0.8313	0.0%	24.5%

Note: Regressions coefficients should be used in the regression equation $Y = a_i x_i + b_i x_i^2$, where Y are cost impacts to commercial fisheries and x_i are the number of platforms that will be developed in depth range i. If no p-values are provided and the coefficients are shown as 0, then no impacts are estimated for platforms in the depth range.

Table 44 Commercial Fishing Modeling: Data Summary for Southern California

Variable	0m - 60m	60m - 150m	150m - 300m	300m - 1,500m	1,500m +	Total
Cell by Depth Range	42	23	19	209	1,297	1,590
Water Area (HA M)	0.6	0.6	0.5	6.0	37.4	45.0
Cells with Revenue	42	23	19	196	2	282
Fishery Revenue (Real $ M)	1.5	1.0	0.5	2.4	0.0	5.3
Existing Platforms	0	0	0	0	0	0
Cells With Platforms	0	0	0	0	0	0

Table 45 Commercial Fishing Modeling: Fishery Impact Coefficients for Southern California

		Regression Coefficients		P-values (Significant if <5%)	
Depth Band	Depth Range	a	b	a	B
Use these coefficients if platforms will be placed in multiple depth ranges					
D1	0m - 60m	9.8322	1.7319	0.0%	0.0%
D2	60m - 150m	1.1087	-0.0887	0.0%	0.0%
D3	150m - 300m	-1.2919	0.0156	0.0%	0.0%
D4	300m - 1,500m	1.2125	-0.0066	0.0%	0.0%
D5	1,500m +	0.0073	0.0000	0.0%	0.0%
Use these coefficients if platforms will be placed in only one depth range					
D1	0m - 60m	23.0426	0.1588	0.0%	4.0%
D2	60m - 150m	0.2636	-0.0198	0.0%	0.0%
D3	150m - 300m	0.0304	-0.0020	5.4%	6.5%
D4	300m - 1,500m	1.4216	-0.0073	0.0%	0.0%
D5	1,500m +	0.0000	0.0000		

Note: Regressions coefficients should be used in the regression equation $Y = a_i x_i + b_i x_i^2$, where Y are cost impacts to commercial fisheries and x_i are the number of platforms that will be developed in depth range i. If no p-values are provided and the coefficients are shown as 0, then no impacts are estimated for platforms in the depth range.

8.8 SUMMARY TABLES OF FISHERY DATA AND REGRESSION COEFFICIENTS FOR GULF OF MEXICO PLANNING AREAS

This section provides fishery data and regression coefficients for the GOM planning areas.

Table 46 Commercial Fishing Modeling: Data Summary for Western Gulf of Mexico

Variable	0m - 60m	60m - 150m	150m - 300m	300m - 1,500m	1,500m +	Total
Cell by Depth Range	300	65	21	201	235	822
Water Area (HA M)	7.1	2.0	0.6	6.1	7.2	23.1
Cells with Revenue	238	52	19	177	106	592
Fishery Revenue (Real $ M)	103.4	22.6	8.3	74.4	45.5	254.1
Existing Platforms	544	88	7	10	2	651
Cells With Platforms	113	28	4	8	2	155

Table 47 Commercial Fishing Modeling: Fishery Impact Coefficients for Western Gulf of Mexico

		Regression Coefficients		P-values (Significant if <5%)	
Depth Band	Depth Range	a	b	a	B
Use these coefficients if platforms will be placed in multiple depth ranges					
D1	0m - 60m	41.1558	0.0856	0.0%	0.0%
D2	60m - 150m	17.1473	-0.4121	0.0%	0.0%
D3	150m - 300m	96.8024	-3.9112	0.0%	0.0%
D4	300m - 1,500m	-5.9425	-0.0090	0.0%	0.0%
D5	1,500m +	2.1800	-0.0706	0.0%	0.0%
Use these coefficients if platforms will be placed in only one depth range					
D1	0m - 60m	58.8368	-0.0017	0.0%	17.5%
D2	60m - 150m	15.4988	-0.3156	0.0%	0.0%
D3	150m - 300m	99.2532	-3.4300	0.0%	0.0%
D4	300m - 1,500m	1.6356	-0.0111	0.0%	0.0%
D5	1,500m +	5.2442	-0.0513	0.0%	0.0%

Note: Regressions coefficients should be used in the regression equation $Y = a_i x_i + b_i x_i^2$, where Y are cost impacts to commercial fisheries and x_i are the number of platforms that will be developed in depth range i. If no p-values are provided and the coefficients are shown as 0, then no impacts are estimated for platforms in the depth range.

Table 48 Commercial Fishing Modeling: Data Summary for Central Gulf of Mexico

Variable	0m - 60m	60m - 150m	150m - 300m	300m - 1,500m	1,500m +	Total
Cell by Depth Range	352	47	15	109	393	916
Water Area (HA M)	6.5	1.4	0.4	3.3	12.1	23.7
Cells with Revenue	268	47	15	109	293	732
Fishery Revenue (Real $ M)	153.5	40.4	26.1	180.3	402.7	803.1
Existing Platforms	2,185	190	13	30	8	2,426
Cells With Platforms	170	40	8	25	6	249

Table 49 Commercial Fishing Modeling: Fishery Impact Coefficients for Central Gulf of Mexico

		Regression Coefficients		P-values (Significant if <5%)	
Depth Band	Depth Range	a	b	a	B
Use these coefficients if platforms will be placed in multiple depth ranges					
D1	0m - 60m	-166.4307	0.6090	0.0%	0.0%
D2	60m - 150m	23.0788	-2.0727	0.0%	0.0%
D3	150m - 300m	929.2590	-13.1703	0.0%	0.0%
D4	300m - 1,500m	224.2500	-0.0830	0.0%	0.5%
D5	1,500m +	84.9431	-0.0305	0.0%	0.0%
Use these coefficients if platforms will be placed in only one depth range					
D1	0m - 60m	2.5466	-0.0198	0.0%	0.0%
D2	60m - 150m	153.1490	-0.6535	0.0%	0.0%
D3	150m - 300m	1362.5590	-2.9497	0.0%	0.0%
D4	300m - 1,500m	0.0000	0.0000		
D5	1,500m +	0.0000	0.0000		

Note: Regressions coefficients should be used in the regression equation $Y = a_i x_i + b_i x_i^2$, where Y are cost impacts to commercial fisheries and x_i are the number of platforms that will be developed in depth range i. If no p-values are provided and the coefficients are shown as 0, then no impacts are estimated for platforms in the depth range.

Table 50 Commercial Fishing Modeling: Data Summary for Eastern Gulf of Mexico

Variable	0m - 60m	60m - 150m	150m - 300m	300m - 1,500m	1,500m +	Total
Cell by Depth Range	470	130	81	145	474	1,300
Water Area (HA M)	12.3	4.0	2.5	4.4	14.6	37.7
Cells with Revenue	454	130	81	141	332	1138
Fishery Revenue (Real $ M)	64.4	17.7	9.4	22.3	54.4	168.2
Existing Platforms	3	0	0	1	0	4
Cells With Platforms	2	0	0	1	0	3

Table 51 Commercial Fishing Modeling: Fishery Impact Coefficients for Eastern Gulf of Mexico

		Regression Coefficients		P-values (Significant if <5%)	
Depth Band	Depth Range	a	b	a	B
Use these coefficients if platforms will be placed in multiple depth ranges					
D1	0m - 60m	-0.5223	0.0013	0.0%	0.0%
D2	60m - 150m	0.2414	-0.0059	0.0%	0.0%
D3	150m - 300m	-0.9243	0.0027	0.0%	1.8%
D4	300m - 1,500m	2.1622	-0.0080	0.0%	0.0%
D5	1,500m +	0.7573	-0.0020	0.0%	0.0%
Use these coefficients if platforms will be placed in only one depth range					
D1	0m - 60m	0.0147	-0.0001	0.0%	0.0%
D2	60m - 150m	0.1527	-0.0014	0.0%	0.0%
D3	150m - 300m	0.0908	-0.0014	0.1%	0.2%
D4	300m - 1,500m	6.2401	-0.0071	0.0%	0.0%
D5	1,500m +	2.2147	-0.0045	0.0%	0.0%

Note: Regressions coefficients should be used in the regression equation $Y = a_i x_i + b_i x_i^2$, where Y are cost impacts to commercial fisheries and x_i are the number of platforms that will be developed in depth range i. If no p-values are provided and the coefficients are shown as 0, then no impacts are estimated for platforms in the depth range.

8.9 SUMMARY TABLES OF FISHERY DATA AND REGRESSION COEFFICIENTS FOR EAST COAST PLANNING AREAS

This section provides fishery data and regression coefficients for the East Coast planning areas. The models for the Mid-Atlantic and the North Atlantic differ from models for other regions in that they assume that unburied pipelines that can occur in depth ranges 2 and 3 (from 60 m – 300 m) create an additional, one-half mile wide buffer zone that precludes scallop dredges from operating.

Table 52 Commercial Fishing Modeling: Data Summary for Straits of Florida

Variable	0m - 60m	60m - 150m	150m - 300m	300m - 1,500m	1,500m +	Total
Cell by Depth Range	89	16	31	193	14	343
Water Area (HA M)	2.1	0.5	1.0	6.0	0.4	10.0
Cells with Revenue	51	12	27	90	6	186
Fishery Revenue (Real $ M)	20.1	8.7	29.4	67.2	0.6	126.0
Existing Platforms	0	0	0	0	0	0
Cells With Platforms	0	0	0	0	0	0

Table 53 Commercial Fishing Modeling: Fishery Impact Coefficients for Straits of Florida

		Regression Coefficients		P-values (Significant if <5%)	
Depth Band	Depth Range	a	b	a	B
Use these coefficients if platforms will be placed in multiple depth ranges					
D1	0m - 60m	-17.8965	-7.6203	0.0%	0.0%
D2	60m - 150m	39.8724	-17.8959	0.0%	0.0%
D3	150m - 300m	519.6629	-2.6130	0.0%	0.0%
D4	300m - 1,500m	100.4700	-0.1348	0.0%	0.0%
D5	1,500m +	0.0000	0.0000		
Use these coefficients if platforms will be placed in only one depth range					
D1	0m - 60m	0.0000	0.0000		
D2	60m - 150m	0.0000	0.0000		
D3	150m - 300m	591.6000	-3.3874	0.0%	0.0%
D4	300m - 1,500m	136.0181	-0.5571	0.0%	0.0%
D5	1,500m +	0.0000	0.0000		

Note: Regressions coefficients should be used in the regression equation $Y = a_i x_i + b_i x_i^2$, where Y are cost impacts to commercial fisheries and x_i are the number of platforms that will be developed in depth range i. If no p-values are provided and the coefficients are shown as 0, then no impacts are estimated for platforms in the depth range.

Table 54 Commercial Fishing Modeling: Data Summary for the South Atlantic

Variable	0m - 60m	60m - 150m	150m - 300m	300m - 1,500m	1,500m +	Total
Cell by Depth Range	317	18	31	432	124	922
Water Area (HA M)	6.8	0.5	0.9	12.8	3.7	24.8
Cells with Revenue	258	18	29	379	30	714
Fishery Revenue (Real $ M)	44.1	2.5	1.8	33.0	2.7	84.0
Existing Platforms	0	0	0	0	0	0
Cells With Platforms	0	0	0	0	0	0

Table 55 Commercial Fishing Modeling: Fishery Impact Coefficients for the South Atlantic

		Regression Coefficients		P-values (Significant if <5%)	
Depth Band	Depth Range	a	b	a	B
Use these coefficients if platforms will be placed in multiple depth ranges					
D1	0m - 60m	13.0727	0.0160	0.0%	0.0%
D2	60m - 150m	10.6494	-0.4229	0.0%	0.0%
D3	150m - 300m	6.9703	-0.4178	0.0%	0.0%
D4	300m - 1,500m	-3.5769	0.0053	0.0%	0.0%
D5	1,500m +	4.5347	-0.0707	0.0%	0.0%
Use these coefficients if platforms will be placed in only one depth range					
D1	0m - 60m	25.8040	-0.0574	0.0%	0.0%
D2	60m - 150m	0.5119	-0.0333	0.0%	0.0%
D3	150m - 300m	0.0000	0.0000		
D4	300m - 1,500m	0.0000	0.0000		
D5	1,500m +	0.0000	0.0000		

Note: Regressions coefficients should be used in the regression equation $Y = a_i x_i + b_i x_i^2$, where Y are cost impacts to commercial fisheries and x_i are the number of platforms that will be developed in depth range i. If no p-values are provided and the coefficients are shown as 0, then no impacts are estimated for platforms in the depth range.

Table 56 Commercial Fishing Modeling: Data Summary for the Mid-Atlantic

Variable	0m - 60m	60m - 150m	150m - 300m	300m - 1,500m	1,500m +	Total
Cell by Depth Range	427	38	17	99	1,523	2,104
Water Area (HA M)	7.9	1.1	0.5	2.8	43.5	55.7
Cells with Revenue	427	38	17	99	1523	2104
Fishery Revenue (Real $ M)	193.8	63.9	0.1	35.1	54.9	347.9
Existing Platforms	0	0	0	0	0	0
Cells With Platforms	0	0	0	0	0	0

Table 57 Commercial Fishing Modeling: Fishery Impact Coefficients for the Mid-Atlantic

		Regression Coefficients		P-values (Significant if <5%)	
Depth Band	Depth Range	a	b	a	B
Use these coefficients if platforms will be placed in multiple depth ranges					
D1	0m - 60m	338.5462	0.1483	0.0%	0.0%
D2	60m - 150m	969.9951	-23.2053	0.0%	0.0%
D3	150m - 300m	184.4773	-14.5967	0.0%	0.0%
D4	300m - 1,500m	13.8066	-0.4718	0.0%	0.0%
D5	1,500m +	-7.6396	-0.0009	0.0%	0.6%
Use these coefficients if platforms will be placed in only one depth range					
D1	0m - 60m	485.5860	-0.7344	0.0%	0.0%
D2	60m - 150m	872.2275	-17.9010	0.0%	0.0%
D3	150m - 300m	0.0000	0.0000		
D4	300m - 1,500m	0.2734	-0.0068	0.1%	0.1%
D5	1,500m +	0.7569	-0.0171	0.0%	0.0%

Note: Regressions coefficients should be used in the regression equation $Y = a_i x_i + b_i x_i^2$, where Y are cost impacts to commercial fisheries and x_i are the number of platforms that will be developed in depth range i. If no p-values are provided and the coefficients are shown as 0, then no impacts are estimated for platforms in the depth range.

Table 58 Commercial Fishing Modeling: Data Summary for the North Atlantic

Variable	0m - 60m	60m - 150m	150m - 300m	300m - 1,500m	1,500m +	Total
Cell by Depth Range	469	320	246	64	1,022	2,121
Water Area (HA M)	8.6	8.2	6.2	1.7	27.4	52.1
Cells with Revenue	469	320	246	64	1022	2121
Fishery Revenue (Real $ M)	924.7	649.6	119.0	34.7	17.7	1,745.8
Existing Platforms	0	0	0	0	0	0
Cells With Platforms	0	0	0	0	0	0

Table 59 Commercial Fishing Modeling: Fishery Impact Coefficients for the North Atlantic

		Regression Coefficients		P-values (Significant if <5%)	
Depth Band	Depth Range	a	b	a	B
Use these coefficients if platforms will be placed in multiple depth ranges					
D1	0m - 60m	42.8581	-0.1396	0.0%	0.0%
D2	60m - 150m	53.5270	-0.3556	0.0%	0.0%
D3	150m - 300m	27.8205	-0.2662	0.0%	0.0%
D4	300m - 1,500m	363.6121	-8.6874	0.0%	0.0%
D5	1,500m +	11.1531	-0.0176	0.0%	0.0%
Use these coefficients if platforms will be placed in only one depth range					
D1	0m - 60m	125.1157	-0.7609	0.0%	0.0%
D2	60m - 150m	551.4754	-5.8763	0.0%	0.0%
D3	150m - 300m	63.8554	-0.6173	0.0%	0.0%
D4	300m - 1,500m	0.0000	0.0000		
D5	1,500m +	0.0000	0.0000		

Note: Regressions coefficients should be used in the regression equation $Y = a_i x_i + b_i x_i^2$, where Y are cost impacts to commercial fisheries and x_i are the number of platforms that will be developed in depth range i. If no p-values are provided and the coefficients are shown as 0, then no impacts are estimated for platforms in the depth range.

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9 ECOLOGICAL

9.1 OVERVIEW

To assess ecological costs associated with offshore oil and gas development, the 2001 OECM employed a habitat equivalency analysis (HEA)-based, restoration cost approach to determining dollar damages. We use a similar approach in the revised OECM. However, our approach:

- Updates the restoration cost data used in the OECM, and
- Updates the way the restoration cost data are applied and damages calculated.

Consistent with the standard economic view of natural resources as assets that provide flows of services, ecosystems are understood to provide a flow of ecosystem services. These services are valued by society, as demonstrated by our WTP for their protection and/or enhancement. Changes in the quality or quantity of these services (e.g., due to ecosystem injuries caused by oil spills and/or development) have implications in terms of the value of the benefits they provide.

One way to estimate the economic value of services adversely affected by offshore oil and gas development would be to conduct an original economic valuation study or apply dollar values from the existing literature. In the context of natural resource damage assessment (NRDA), the use of economic valuation techniques to scale the monetary compensation required for the interim loss of natural resource services establishes the sum of money that will be available to accomplish additional, "compensatory" restoration of injured natural resources. In other words, economic valuation determines the amount of money available for restoration actions that have not yet been defined.

However, results from economic valuation studies are often viewed as controversial. Furthermore, given the nationwide scope of the OECM and the challenge of conducting a large-scale economic valuation study to ascertain potential geographic variability of values, such an approach would be incredibly complex and financially prohibitive.

In many instances in NRDA, instead of applying economic valuation tools, natural resource trustees will identify and scale appropriate compensatory restoration actions. These actions are scaled to make the public whole for interim losses of natural resource services. Restoration is intended to compensate the public for any and all resource services lost due to injury.[26] Restoration costs can also be viewed as costs that the public has demonstrated a willingness to pay, and therefore are believed to be a lower bound estimate of WTP, or the “value” of lost services, as long as restoration actions are scaled appropriately to match the magnitude of lost resources. In NRDA, when a restoration cost approach is taken, dollar damages are the cost to implement the necessary compensatory restoration projects.

Resource economists commonly use HEA, or a variant of HEA called *resource* equivalency analysis (REA) to scale restoration projects. HEA is an analytical tool specifically designed to

[26] Importantly, this compensation would be in addition to any actions that have been or will be taken to restore the injured habitat to its baseline condition (i.e., remedial actions or so-called “primary” restoration). In some cases (e.g., smaller oil spills in remote locations that may go unnoticed), no primary restoration will take place, leading to longer time periods of injury until resource services are returned to their baseline condition. In the case of the OECM, we assume that oil spills naturally degrade over time or are cleaned up such that adverse impacts resolve within 3-5 years (French McCay, 2009).

balance the magnitude of restoration (or service credit) with the magnitude of resource loss (or service debit). REA, as an extension of HEA, is an analytical tool by which restoration aimed at a specific resource (e.g., fish or birds) may be scaled to appropriately compensate for injury to that specific resource. One of the primary economic notions behind the use of HEA and REA is that natural resources can and should be discounted over time to account for changes in the value the public holds for material goods (or in this case, resource services) over time (i.e., the time-value of money). Compounding natural resource service losses or gains in the past and discounting future resource services, as one would similarly adjust dollar values in any economic analysis, allows for the integration of resource service value over time. In this way service credits and debits can be balanced in present value terms using units that incorporate space and time (e.g., acre-years of habitat, or in the case of a REA, units such as bird-years).

In the context of the OECM, the use of HEA and REA, in combination with restoration costs as a lower bound estimate of the value the public holds for ecological resources provides a robust way to quantify damages stemming from injuries caused by a range of potential ecological impacts of offshore oil and gas development.

9.2 Overview of the 2001 Model

For calculations of damages from adverse ecological impacts of offshore oil and gas development, the 2001 OECM model relies generally on a HEA and REA/restoration cost-based approach. Specifically:

- It focuses exclusively on ecological impacts from modeled oil spills. It. does not quantify any other potential causes of ecological harm associated with offshore oil and gas development, such as noise and vibration, impacts associated with the physical destruction or displacement of resources, etc.
- It uses the NRDAM/CME model (i.e., the NRDA Type A model) to forecast ecological injuries stemming from three "average" modeled oil spill scenarios for each region: small spill, large platform/pipeline spill, and large tanker spill.
- Outputs from the NRDAM/CME model take the form of acre-years of habitat[27] oiled. broken down by: sand beach, wetland, mudflat, rocky coast, and gravel beach and total numbers of wildlife killed which is calculated based on the area of habitat oiled and region-specific wildlife density information, and is broken down by: birds, marine mammals, and reptiles killed. Outputs are by region, and are single point estimates for each of the three "average size" spill scenarios.
- Based upon a single, generic, credit HEA for a hypothetical salt marsh restoration project with a fixed 25-year lifespan, and a 2:1 compensation ratio to account for services provided by the habitat prior to restoration. a fixed benefit of 4.23 acre-years is determined and relied upon in damages calculations nationwide.
- Per-acre low and high restoration costs to restore each of the habitat and wildlife categories noted above are determined from restoration costs spent at similar sites or to

[27] An "acre-year" is a measure of the ecological services provided by one acre of habitat over the course of one year. Actual output from the model is presented in square meter-days, a unit that is readily converted to acre-years through simple area- and time-conversions. What is relevant about this approach is that injury is expressed on a time and area basis.

replace similar wildlife through re-stocking presented in a variety of documents, but relying heavily on the NOAA document entitled "Primary Restoration: Guidance Document for Natural Resource Damage Assessment under the Oil Pollution Act of 1990" (http://www.darrp.noaa.gov/library/1_d.html). The simplifying assumption that the high estimate for restoration costs for salt marsh represents the upper bound cost for all restoration projects is used to justify cost ranges. When high or low cost estimates are unavailable in the literature, the assumption that high range costs are approximately five to seven times greater than low cost estimates (based on salt marsh data) is used to estimate whichever end of the range is missing.

- Per-acre low and high restoration costs (which are assumed to provide 4.23 acre-years of benefits per acre of habitat restored; or expressed simply on a per-bird, per-reptile, or per-marine mammal basis), are converted to damages estimates based on the NRDAM/CME-output estimates of habitat or wildlife injured per billion barrels of oil spilled on a regional basis. Damages are expressed as either low or high by applying the low or high restoration costs, respectively, and are expressed on a per-billion barrels of oil produced basis when used in OECM calculations.
- Resultant damages are increased by nine percent to account for NRDA administrative costs; a percentage calculated based on cost components from six NRDAs.[28]

9.3 MODIFICATIONS TO THE 2001 MODEL

In general, a HEA and REA/restoration cost-based approach for assessing ecological damages from offshore oil and gas development continues to be appropriate. However, several important updates are incorporated into the revised model.

- Instead of the NRDAM/CME model, Applied Science Associate's more recent SIMAP model is used to forecast the likely scale of ecological injury stemming from oil spills. Further, SIMAP has been run iteratively to produce functional relationship equations for predicting the scale of injury as a function of volume of oil spilled and season for use in the OECM. Specifically, injury is determined by estimating:
    - the aerial extent of surficial oiling of intertidal habitat, and
    - on a wildlife-class-by-wildlife-class basis, the biomass of wildlife killed as a result of oiling.
- Restoration cost estimates have been updated by:
    - Utilizing restoration cost data beyond those used in the 2001 model,
    - Applying actual restoration costs as opposed to NRDA settlement amounts, and
    - Incorporating geographic differences in restoration costs.
- Rather than using a single compensation ratio, the model applies information about the relative productivity of habitats and more realistic estimates of restoration project lifetimes and expected service benefits (see below).
- Cost estimates exclude administrative cost components.

[28] Note that this calculation is made *ex post facto*, on a regional basis, outside of the actual OECM model.

As in the 2001 model, the revised OECM addresses only on those adverse ecological impacts caused by oil spills. Although other adverse ecological effects likely occur as a result of offshore oil and gas development (for example, adverse effects from noise and vibration and wildlife kills related to collisions with off-shore structures have been evaluated in the context of programmatic environmental impact statements), reliable methods to quantify such impacts on a planning area basis are currently unavailable. An assumption is also made that adverse ecological effects related to onshore construction and development-related projects are addressed through permitting-related mitigation efforts and thus do not merit assessment as externalities. Finally, estimation of costs in an international context (i.e., costs that might be realized in non-U.S. jurisdictions due to an increase or decrease in U.S. oil or gas imports) is beyond the current scope of this effort.

9.4 ECOLOGICAL DAMAGES CALCULATIONS

The calculation of ecological damages in the OECM is performed in five steps.

1) The extent of oiling is estimated using regression equations generated through the process of running SIMAP iteratively. These regressions are used to forecast the extent of oiling based on a variety of factors, but predominantly oil production.
2) Habitat impacts (extent of intertidal zone oiling) are calculated.
3) Wildlife impacts are calculated.
    a. Numbers of individual wildlife organisms killed are calculated from wildlife abundance in sea and shoreline areas oiled above mortality thresholds.
    b. The biomass of biota killed is calculated based on the number of individual organisms killed and the average mass of the given organism.
    c. Information about the average regional primary productivity of salt marsh habitat and the trophic transfer of biomass up the food chain is used to calculate the salt marsh habitat acre-equivalent of biomass loss.
4) Using HEA, the number of acres of salt marsh restoration required to replace injured habitat from Step 2 above and to replace the acre-equivalent of habitat from Step 3 above is calculated. (See discussion of model drivers below for more details).
5) Impacts are monetized by determining the cost of restoring the required area of salt marsh determined in the HEA in Step 4.

9.4.1 Basic Calculation

The model develops an estimate of ecological damages based on the two equations detailed below, which are specific to a given planning area.

First, habitat damages are calculated using the equation:

$$O \times R_{HEA} \times C$$

where:

O = Area of intertidal habitat over which spill impact occurs (m^2 of oiled surface area)

R_{HEA} = Habitat restoration factor (m^2 of marsh habitat required to be restored per m^2 of oiled surface area)

C = Per-m^2 restoration cost (dollars per m^2 to restore marsh habitat)

Second, wildlife damages are calculated using the equation:

$$\sum (O_i \times M_i \times R_{REAi} \times C)$$

where:

O_i = Area or volume of spill impact (m^2 of oiled surface area for wildlife species or m^3 of water for fish and macroinvertebrates above a mortality threshold for species *i*)

M = Mortality factor for the mass of species killed per unit area or volume of spill impact (kg lost per m^2 or m^3 of spill impact for species *i*)

R_{REAi} = Habitat restoration factor (m^2 of marsh habitat required to be restored per kg lost of species *i*)

C = Per-m^2 restoration cost (dollars per m^2 to restore marsh habitat)

9.4.2 Calculation Drivers

<u>Area or volume of water in which spill impact occurs</u>
The SIMAP model quantifies areas swept by floating oil of varying thicknesses and the fates and concentrations of subsurface oil components (dissolved and particulate). Regressions on the results of multiple SIMAP iterations in representative regions, simulating a range of oil types, volumes, spill distance from shore, and environmental conditions, produce equations that generally relate spill volume to water area or water column volume exposed to oil above a specified impact threshold.

<u>Mortality factors</u>
SIMAP calculates the oil/hydrocarbon exposure, dose, and resulting percent mortality for organisms in the contaminated exposure areas (wildlife) and water volumes (fish, invertebrates). SIMAP applies these results to region-specific biological databases, which describe population densities for each of several organism types, to arrive at mortality factors per unit water area or water volume. For the ecological component of the OECM, species-level data are aggregated into the following biological groups:

- *Birds*: waterfowl, seabirds, wading birds, shorebirds, and raptors and kingfishers;
- *Whales:* baleen and piscivorous;
- *Other marine mammals:* pinnipeds and sea otters;
- *Marine invertebrates:* crustaceans and mollusks;

- *Fish:* small pelagic fish, large pelagic fish, demersal fish; and
- *Polar Bears* (in Alaska planning areas only).

Habitat Equivalency Analysis (HEA) Restoration Factor

A modified HEA is used to estimate the quantity of restored habitat required to compensate for habitat areas injured by oiling. Rather than focusing on intertidal habitat area alone (e.g., acres), area is adjusted based on invertebrate production. The approach, equations, and assumptions are described in greater detail in NOAA (1997, 1999), LA DEQ et al. (2003), and French-McCay and Rowe (2003).

In the case of the OECM, habitat impacts (the debit, or loss side of the analysis) are quantified when saltmarsh, mangrove, rocky shore, gravel and sand beach, and mudflat habitats are oiled with sufficient oil to adversely affect invertebrates associated with the intertidal habitat (greater than 0.1millimeters (mm) thickness results in invertebrate injuries). Benthic invertebrate production rates for each habitat type are taken into account when determining injury. Time for recovery for intertidal invertebrates (based on a natural recovery curve) is estimated as 3-5 years (French McCay, 2009). The total loss of intertidal invertebrates from shoreline oiling greater than 0.1 mm thick is calculated as a factor of daily production rate, taking into consideration the number years to recovery and applying an annual discount rate of three percent.

The area (m^2) of salt marsh requiring restoration per m^2 of habitat oiled is calculated by scaling benthic invertebrate production gains afforded by such restoration to losses. Gains in invertebrate production provided by an area of restored salt marsh (the credit, or gain side of the analysis) are calculated by multiplying the kilograms of benthic invertebrate production by the area (m^2) of marsh restored.

This HEA calculation was performed for habitat types in which a benthic invertebrate injury would occur (i.e., rocky shore, sand beach, gravel beach, macroalgal bed, fringing mudflat, and fringing wetland). In order to get one estimate for intertidal injury per OECM geographic region, a weighted average of the area of saltmarsh restored per m^2 oiled for these individual habitats was calculated based on the percent of that habitat type present in the entire habitat grid for the particular OECM region.

Resource Equivalency Analysis (REA) Restoration Factor

In addition to general habitat impacts, we calculate and employ REA restoration factors, which are derived using a combined REA-trophic web model, to calculate the required area of restored habitat to produce biomass lost due to an oil spill. As noted above, the basis for using this model is that restoration should provide equivalent quality fish, wildlife, and invertebrate biomass to compensate for lost fish, wildlife, and invertebrate production. Equivalent quality implies the same or similar species with an equivalent ecological role. Equivalent production or replacement that occurs in the future is discounted to account for the interim loss between the time of the injury and the time when restoration provides equivalent ecological services.

Scaling methods used here were initially developed for use in the *North Cape* oil spill damage assessment, as described in French et al. (2001), French McCay and Rowe (2003) and French

McCay et al. (2003a). These methods have also been used in several other cases, as well as in successful claims for 23 cases submitted by the Florida Department of Environmental Protection to the U.S. Coast Guard, National Pollution Fund Center (French McCay et al., 2003b).

The concept is that the restored habitat leads to a net gain in wildlife, fish, and invertebrate production over and above that produced by the location before the restoration. In a manner similar to the HEA described above, the size of the habitat (on an area basis) is scaled to compensate for the injury (interim loss) and we use primary production to measure the benefits of the restoration. However, in this case, the transfer of production up the food web is taken into consideration. Specifically, the total injuries in kilograms are translated into equivalent plant (angiosperm) production as follows.

1. Plant biomass passes primarily through the detrital food web via detritivores consuming the plant material and attached microbial communities. When macrophytes are consumed by detritivores, the ecological efficiency is low because of the high percentage of structural material produced by the plant, which must be broken down by microorganisms before it can be used by the detritivore.
2. Each species group is assigned a trophic level relative to that of the detritivores. If the species group is at the same trophic level as detritivores, it is assumed 100 percent equivalent, as the resource injured would presumably have the same ecological value in the food web as the detritivores. If the injured resource preys on detritivores or that trophic level occupied by the detritivores, the ecological efficiency is that for trophic transfer from the prey to the predator. Values for production of predator per unit production of prey (i.e., ecological efficiency) are taken from the ecological literature, as reviewed by French McCay and Rowe (2003).
3. The equivalent compensatory amount of angiosperm (plant) biomass of the restored resource is calculated as kg of injury divided by ecological efficiency. The ecological efficiency is the product of the efficiency of transfer from angiosperm to invertebrate detritivore and efficiency from detritivore to the injured resource, accounting for each step up the food chain from detritivore to the trophic level of concern. The productivity gained by the created habitat is corrected for less than full functionality during recovery using a sigmoid recovery curve.
4. Discounting at three percent per year is included for delays in production because of development of the habitat, and delays between the time of the injury and when the production is realized in the restored habitat. The equations and assumptions may be found in French McCay and Rowe (2003).

Additional data needs for the scaling calculations are as follows.

Number of years for development of full function in a restored habitat;

- Annual primary production rate per unit area (P) of restored habitat at full function (which may be less than that of natural habitats);
- Delay before restoration project begins; and
- Project lifetime (years the restored habitat will provide services).

In this case, we assume that marsh creation or restoration is performed, that the marsh requires 15 years to reach full function (based on LA DEQ et al., 2003), ultimately reaches 80 percent of natural habitat productivity and that the project lifetime is 20 years. The restoration creation project is assumed to begin three years after the date of injury. Primary production estimates, which are regionally-specific are detailed below.

- North/Mid-Atlantic: Above-ground primary production rates for a New England salt marsh were used from Nixon and Oviatt (1973) as 500 g dry weight m^{-2} yr^{-1}. In addition, benthic microalgal production provides another 105 g dry weight m^{-2} (Van Raalte, et al., 1976). Thus, estimated total primary production rate in saltmarshes in this region is 605 g dry weight m^{-2} yr^{-1}.
- GOM and South Atlantic: Above-ground primary production rates of saltmarsh cord grasses in Georgia were used as estimated by Nixon and Oviatt (1973), based on Teal (1962), as 1,290 g dry weight m^{-2} yr^{-1}. In addition, benthic microalgal production provides another 105 g dry weight m^{-2} (Van Raalte, et al., 1976). Thus, estimated total primary production rate in saltmarshes in this region is 1,395 g dry weight m^{-2} yr^{-1}.
- Northern, Central, and Southern California: Above-ground primary production rates of saltmarshes in the Central California coast were used as estimated by Continental Shelf Associates (CSA) (1991) as 3,666 g dry weight m^{-2} yr^{-1}. In addition, benthic microalgal production provides another 312 g dry weight m^{-2} (CSA, 1991). Thus, estimated total primary production rate in saltmarshes in this region is 3,978 g dry weight m^{-2} yr^{-1}.
- Washington and Oregon: Above-ground primary production rates of saltmarshes in the Oregon coast were used as estimated by CSA (1991) as 2,636 g dry weight m^{-2} yr^{-1}. In addition, benthic microalgal production provides another 375 g dry weight m^{-2} (CSA, 1991). Thus, estimated total primary production rate in saltmarshes in this region is 3,011 g dry weight m^{-2} yr^{-1}.
- Gulf of Alaska: Above-ground primary production rates of saltmarshes in the Lower Cook Inlet were used as estimated by CSA (1991). The daily rates were applied to a 6-month growing season, with the annual total being 681 g dry weight m^{-2} yr^{-1}. In addition, benthic microalgal production over a 6-month growing season provides another 1,488 g dry weight m^{-2} (CSA, 1991). Thus, estimated total primary production rate in saltmarshes in this region is 2,170 g dry weight m^{-2} yr^{-1}.
- Northern Alaska: Above-ground primary production rates of saltmarshes in the Lower Cook Inlet were used as estimated by CSA (1991). The daily rates were applied to a 3-month growing season, with the annual total being 341 g dry weight m^{-2} yr^{-1}. In addition, benthic microalgal production over a 6-month growing season provides another 744 g dry weight m^{-2} (CSA, 1991). Thus, estimated total primary production rate in saltmarshes in this region is 1,085 g dry weight m^{-2} yr^{-1}.

For the injured resources, all weights are as wet weight and dry weight is assumed 22 percent of wet weight (Nixon and Oviatt, 1973). The ratio of carbon to dry weight is assumed to be 0.45 (French et al., 1996). For the wildlife, body mass per animal (from French et al. (1996) or from Sibley (2003)) is used to estimate injury in kilograms (multiplying by number killed and summing each species category).

Restoration Cost Factor

Planning area-specific per-acre coastal marsh restoration costs are applied in the OECM. These costs are derived through the estimation of salt marsh restoration project costs in the Northeast (the region for which the most data are available for coastal marsh restoration costs), and the extrapolation of these costs to other geographical regions based on a recent survey of nationwide wetland restoration costs. Specifically, we combine data from a meta-analysis of wetland restoration costs by Louis Berger & Associates (1997) with data on seven marsh creation projects provided by Carl Alderson (2010) of the NOAA Restoration Center. Costs are extrapolated geographically based on data presented in a report by the Environmental Law Institute (ELI) (2007). We bring all costs up to 2009 dollars.

The Louis Berger study presents cost data for two sets of projects. The first set includes 65 restoration and creation projects in the states of New York, Rhode Island, Maine, Massachusetts, Connecticut and New Hampshire, for several wetland types. We apply data from the subset of 11 estuarine wetland restoration and two creation projects.[29] Presented costs included three components: planning, construction, and monitoring. We apply all three cost components and calculate and apply per-acre costs for purposes of this analysis. The second set of data presented in the Louis Berger study is for projects conducted in the State of Connecticut by the Connecticut Department of Environmental Protection. These are primarily inexpensive restoration projects, with lower planning costs. Of 33 Connecticut projects presented in the report, we apply costs from a subset of 15 that involve estuarine wetland restoration, include complete construction costs, and comprise substantial restoration. Because data provided for the Connecticut projects do not include monitoring costs, we calculate and apply a ratio of monitoring to planning and construction costs based on data from Louis Berger (1997) to estimate monitoring costs for these projects.

We combine these selected cost data from Louis Berger with data on seven coastal marsh creation projects provided by Carl Alderson to populate a restoration costs database of 26 restoration projects and nine creation projects. Based on these data, we calculate average per-acre restoration and average per-acre creation costs for coastal marsh habitat in the Northeast.[30] We then apply the midpoint of the restoration cost and creation cost averages as our per-acre cost estimate for the Northeast.

In order to account for the variability of restoration costs in different regions of the United States, we use data from the ELI on wetland compensatory restoration costs for 38 cities and regions in the United States. Although restoration cost data presented in this document do not apply directly to coastal marsh restoration (as they include costs for freshwater wetland restoration), they provide a basis for quantifying differences in regional expenditures on habitat restoration.

To apply these data in the scaling of coastal restoration costs, we create planning area-specific ratios of restoration costs based on the ELI (2007) data. Specifically, we calculate ratios of

[29] Costs from one coastal wetland restoration project (Logan Airport) were determined to be excessive, and were not used in calculations. In addition we exclude data from two combination restoration and creation projects.

[30] Although one heavily-cited article in the peer-reviewed literature suggests that wetland restoration and creation costs do not differ significantly in magnitude (King and Boehlen 1994), our data clearly suggest that wetland creation costs greatly exceed wetland restoration costs.

restoration costs for each planning area, relative to restoration costs in the North Atlantic Planning Area.[31] To establish planning area-specific costs estimates for use in calculating ratios, we average data presented for coastal cities in a given planning area. In instances where data are not available from cities in a particular planning area, we apply the average of neighboring planning areas.

The final step in the cost estimation process is to extrapolate the average per-acre marsh restoration cost based on the Louis Berger (1997) and Alderson (2010) data using the ratios calculated using the ELI (2007) data. In this way we determine planning area-specific per-acre coastal marsh restoration costs for application in the OECM.[32]

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[31] Per-acre restoration costs from New England and New York are averaged to determine a baseline restoration cost for the North Atlantic Planning Area.
[32] Note that per-acre restoration costs are converted to units of dollars per-m^2.

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APPENDIX A: OIL SPILL MODELING FOR THE OFFSHORE ENVIRONMENTAL COST MODEL (OECM)

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1. Introduction

As part of the update to the Offshore Environmental Cost Model (OECM), Applied Science Associates, Inc. (ASA) undertook a separate modeling effort to better understand the potential environmental, social, and economic consequences of oil spills. Such spills could occur in the context of outer continental shelf (OCS) oil and gas exploration and development, or in the context of imports that might serve as alternatives to OCS production. As described below, the projected consequences are entered into the OECM as oil spill model-derived algorithms that relate quantity and location of spilled oil (forecast separately) to bio-physical consequence metrics. The OECM will be applied by the Bureau of Ocean Energy Management (BOEM) to understand the potential impact of offshore oil and gas development in all 26 OCS planning areas, covering the offshore areas on all marine coastlines of the lower 48 states plus Alaska. Thus, the modeling study used to develop the OECM equations addressed spills of varying oil types and sizes in all of these areas under a wide range of conditions.

Given the infeasibility of modeling every possible situation that could occur in each of the 26 planning areas, our technical approach was designed to address the major variables to which oil spill consequences are sensitive. In addition, the OECM cannot include highly complex oil spill modeling within its coding. Thus, our general approach was to:

- Use an existing, well-vetted and validated oil spill impact model system, SIMAP (described in French-McCay, 2004, 2009), to project consequences associated with a matrix of potential conditions;
- Summarize the model output data that quantify areas, shore lengths, and volumes where impacts would occur with regression equations that can be applied within the OECM;
- Within the OECM, multiply the areas, shore lengths and volumes affected by receptor densities and/or costs in the locations of concern; and
- Allow the OECM to be updated with new receptor information, as needed and available, to which the regression results can be applied.

We approached the assessment of oil spill risk by applying the standard technical definition of risk that includes both the likelihood (i.e., probability) of spill incidents of various types occurring and the impacts or consequences of those incidents. In other words,

Spill risk = probability of spill x impacts of spill

The probability of a spill is a combination of the likelihood a spill will occur and the likely sizes of spills once they occur. Data to estimate both of these are discussed in this report.

Impacts of a spill depend on the spill size, oil type, environmental conditions, resources present and exposed, toxicity and other impact mechanisms, and population/ecosystem recovery following direct exposure. This report describes the approach, model, data inputs, and results of the modeling. Inputs include habitat and depth mapping, winds, currents, other environmental conditions, chemical composition and properties of the oils most likely to be spilled, specifications of the release (amount, location, etc.), toxicity parameters, and biological abundance. The input data for modeling impacts are available from government-run websites (e.g., winds, temperatures), government reports, published literature, and data libraries that ASA has compiled over many years of performing similar modeling. Where feasible, ASA also used current data from BOEM-sponsored hydrodynamic modeling studies, which are used by BOEM in its oil spill risk assessment modeling analyses.

In summary, the SIMAP model was used to develop data (i.e., areas, shore lengths and water volumes affected as a function of oil type, spill volume, and environmental conditions) that were then described using regression analysis. The resulting functions are the basis for estimating oil spill-related costs within the OECM. The oil impact model was developed for a matrix of potential environmental conditions representative of those in all 26 of the planning areas. The results for a given set of environmental conditions are applicable to all planning areas where those conditions occur at some time of the year. The OECM model will apply the appropriate regressions for conditions occurring in the planning area being modeled, along with the resource density data for that planning area. In this way, estimates of potential consequences can be made for all 26 planning areas.

Section 2 describes the modeling approach used for this analysis, including model input data and impact measures. Sections 3 and 4 discuss the approach for the Habitat Equivalency Analysis (HEA) and spill rate/volume estimation, respectively. Results of the model are described in Section 5. Discussion and conclusions are in Section 6. Section 7 contains the references cited. Appendices provide the details of the input data and model results, in tables, maps, and other figures.

2. SIMAP Modeling Approach

The modeling approach involved estimating the areas of water surface, lengths of shoreline and volumes of water exposed above consequence thresholds (oil thickness or concentrations) for a series of oil spill volumes and a matrix of potential conditions that might occur in any of the 26 planning areas. For any given oil volume spilled in open water under a set of environmental conditions (e.g., winds, temperature), the spreading and transport of oil is such that the areas and volumes affected are similar regardless of where the spill occurs. Thus, we ran oil spill model simulations for a matrix of oil types, environmental conditions, and series of spill volumes, and developed regression models fit to the data. This allows prediction of the area of water surface, shore length, and volume of water that would be affected for any spill volume, regardless of the location of the spill. The resulting regression models will then be included in the OECM and used to estimate impacts of spills as a function of the planning area, distance from shore, the oil type, and the spill volume.

The oil spill modeling for the OECM was performed using SIMAP (French McCay, 2003, 2004), which uses wind data, current data, and transport and weathering algorithms to calculate the mass of oil components in various environmental compartments (water surface, shoreline, water column, atmosphere, sediments, etc.), oil pathway over time (trajectory), surface oil distribution, and concentrations of the oil components in water and sediments. SIMAP was derived from the physical fates and biological effects submodels in the Natural Resource Damage Assessment

Models for Coastal and Marine and Great Lakes Environments (NRDAM/CME and NRDAM/GLE), which were developed for the U.S. Department of the Interior (DOI) as the basis of Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) Natural Resource Damage Assessment (NRDA) regulations for Type A assessments (French et al., 1996; Reed et al., 1996).

SIMAP contains physical fate and biological effects models, which estimate exposure and impact on each habitat and species (or species group) in the area of the spill. Environmental, geographical, physical-chemical, and biological databases supply required information to the model for computation of fates and effects. The technical documentation for the model can be found in French McCay (2003, 2004, 2009).

Modeling was conducted using SIMAP's stochastic model to determine the range of distances and directions oil spills are likely to travel from a particular set of spill sites, given historical wind and current speed and direction data for the area. For each model run used to develop the statistics, the spill date is randomized, which provides a probability distribution of wind and current conditions during the spill. The stochastic model performs a large number of simulations for a given set of spill sites, varying the spill time and thus the wind and current conditions, for each run. The stochastic modeling outputs provide a distribution of spill results, which can be summarized by statistics such as mean and standard deviation.

Using these statistics from the SIMAP model, the worst case exposure was calculated as the 99^{th} percentile value for each impact category, location, and oil type. These 99^{th} percentile values were then plotted as regressions of exposure area/volume versus spill volume and applied within the OECM to predict the areas, shore lengths, and water volumes affected for spills in any location (planning area).

2.1 Scenarios Modeled

A matrix of 230 scenarios was run in SIMAP to determine mean, standard deviation, and range of exposures (areas, shore lengths, and volumes) to floating oil, shoreline stranded oil, and water contamination for a range of five spill volumes (see Tables 1 and 2 below). We then used the 99^{th} percentile results from each scenario to develop regressions of exposures versus volume of oil spilled for each of the locations modeled (Table 3). The resulting sets of regressions were mapped to each of the 26 planning areas as described in Table 3.

Table 1. Spill volumes and durations for crude oils.

Spill Volume (gallons)	Duration of release (hours)
1,000,000	24
500,000	16
100,000	10
10,000	4
1,000	1

Table 2. Spill volumes and durations for heavy fuel oil and diesel.

Spill Volume (gallons)	Duration of release (hours)
100,000	10
50,000	5
10,000	2
1,000	1
100	0

Table 3. SIMAP model scenarios from which the OECM model equations were developed.

Region	# of Spill Locations	Ice in Winter	# of Scenarios	Spill Sites	Oil types	Planning areas Represented
Atlantic	2	No	30	Virginia lease area; near Delaware (nearshore and offshore)	Light crude, heavy crude, heavy fuel oil	North Atlantic, Mid-Atlantic, South Atlantic
Straits of Florida	1	No	10	Along straits	Light crude, heavy fuel oil	Straits of Florida
Gulf of Mexico	2	No	30	Central Gulf of Mexico planning area (nearshore and offshore)	Light crude, heavy fuel oil, diesel	Eastern Gulf, Central Gulf, Western Gulf
California	2	No	30	Offshore southern California (Santa Maria Basin); Santa Barbara Channel (Santa Barbara-Ventura Basin)	Light (Arab) crude, heavy crude, heavy fuel oil	Southern California, Central California
Washington/ Oregon	1	No	30	Mid-Washington (nearshore and offshore)	Medium crude, heavy fuel oil, diesel	Northern California, Washington/ Oregon
Gulf of Alaska	2	No	20	Gulf of Alaska near Yakutat (nearshore and offshore)	Medium crude, heavy fuel oil	Gulf of Alaska, Kodiak, Shumagin, Aleutian Arc
Cook Inlet & Shelikof Strait	1	No	15	Cook Inlet planning area	Medium crude, heavy fuel oil, diesel	Cook Inlet
Bering Sea	1	No	15	North Aleutian Basin program area	Medium crude, heavy fuel oil, diesel	North Aleutian Basin, St. George Basin, St. Matthew Hall, Bowers Basin, Aleutian Basin, Navarin Basin, Norton Basin
Chukchi Sea	2	Yes	30	Chukchi sea planning area (nearshore and offshore)	Light crude, heavy crude, heavy fuel oil	Hope Basin, Chukchi Sea
Beaufort Sea	2	Yes	20	Beaufort sea planning area (nearshore and offshore)	Medium crude, heavy fuel oil	Beaufort Sea
Total	**17**		**230**			

2.2 Model Input Data

Detailed descriptions of input data for each location modeled are provided in Subappendix A to this document. A general overview of model input data is provided in the sections below.

2.2.1 Geographical and Model Grid

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

The intertidal habitats are assigned based on the shore types in digital Environmental Sensitivity Index (ESI) maps distributed by National Oceanic and Atmospheric Administration (NOAA) HAZMAT (CD-ROM). These data were gridded using the ESRI Arc/Info compatible Spatial Analyst program. Open water areas were defaulted to sand bottom, as open water bottom type has no influence on the model results.

2.2.2 Environmental Data

The model uses hourly wind speed and direction for the time of the spill and simulation. A long term wind record is sampled at random to develop a probability distribution of environmental conditions that might occur at the time of a spill. The model can use multiple wind files, spatially interpolating between them to determine local wind speed and direction.

Surface water temperature in the model varies by month, based on data from French et al. (1996). The air immediately above the water is assumed to have the same temperature as the water surface, this being the best estimate of air temperature in contact with floating oil. Salinity is assumed to be the mean value for the location of the spill site, based on data compiled in French et al. (1996). The salinity value assumed in the model runs has little influence on the fate of the oil, as salinity is used to calculate water density (along with temperature), which is used to calculate buoyancy, and none of the oils evaluated have densities near that of the water.

Suspended sediment is assumed to be 10 mg/L, a typical value for coastal waters (Kullenberg, 1982). The sedimentation rate is set at 1 m/day. These default values have no significant effect on the model trajectory. Sedimentation of oil and polyaromatic hydrocarbons (PAHs) becomes significant at about 100 mg/L suspended sediment concentration.

The horizontal diffusion (randomized mixing) coefficient is assumed as 10 m^2/sec for floating oil and 1 m^2/sec for surface and deep waters. The vertical diffusion (randomized mixing) coefficient is assumed as 0.0001 m^2/sec. These are reasonable values for coastal waters based on empirical data (Okubo and Ozmidov, 1970; Okubo, 1971) and modeling experience.

2.2.3 Currents

Currents have significant influence on the trajectory and oil fate, and are critical data inputs. Dependent upon geographic location, wind-driven, tidal and background currents are included in the modeling analysis. The tidal currents and background (other than tidal) currents are input to model from a current file that is prepared for this purpose. See Subappendix A for a detailed description of currents for each location.

2.2.4 Oil Properties and Toxicity

The spilled oil used in the OECM modeling consisted of a variety of types, including various crude oils, heavy fuel oil, and diesel. Physical and chemical data on these oils are summarized in Subappendix B.

The oil's content of volatile and semi-volatile aliphatics and aromatics (which are also soluble and cause toxicity in the water column) is defined and input to the model. The volatile aliphatics rapidly volatilize from surface water, and their mass is accounted for in the overall mass balance. However, as they do not dissolve in significant amounts, they have limited influence on the biological effects on water column and benthic organisms.

For crude oil, diesel, and heavy fuel oil spills at/near the water surface, monoaromatic hydrocarbons (MAHs) do not have a significant impact on aquatic organisms for the following reasons. MAH concentrations are less than 3 percent in fresh fuel oils. MAHs are soluble, and so some become bioavailable (dissolved). MAH compounds are also very volatile and will volatilize from the water surface and water column very quickly after a spill. The threshold for toxic effects for these compounds is about 500 parts per billion (ppb) for sensitive species (French McCay, 2002). MAHs evaporate faster than they dissolve, such that toxic concentrations are not reached. The small concentrations of MAHs in the water will quickly be diluted to levels well below toxic thresholds immediately after a spill.

2.2.5 Shoreline Oil Retention

Retention of oil on a shoreline depends on the shoreline type, width and angle of the shoreline, viscosity of the oil, the tidal amplitude, and the wave energy. In the NRDAM/CME (French et al., 1996), shore holding capacity was based on observations from the *Amoco Cadiz* spill in France and the *Exxon Valdez* spill in Alaska (based on Gundlach, 1987) and later work summarized in French et al. (1996). This approach and data were used in the present study.

2.3 Impact Measures

To develop regressions for incorporation into the OECM, a number of impact measures were evaluated, as described in Table 4 and the following sections. All regressions used the 99th percentile value for each oil type, spill volume, and impact measure.

Table 4. Impact measures used to estimate consequences.

Consequence	Impact Measure	Impact Threshold
Impact to wildlife: seabirds, waterfowl, marine mammals, and sea turtles	Water surface area exposed to floating oil	10 g/m^2 (French et al., 1996; French McCay, 2009)
Impact to wildlife: shorebirds and waders	Shore area exposed	100 g/m^2 (French et al., 1996; French McCay, 2009)
Impact to water column organisms	Aromatic dosage (volume exposed to dissolved aromatic concentrations)	Acute: ppb-hrs as a function of temperature (French McCay, 2002)
Impact to benthic organisms	Sediment area exposed to dissolved aromatic concentrations (assume 10 cm deep biological zone)	Chronic and tainting: 1 ppb Acute: 45 ppb (French McCay, 2002)
Shoreline recreation and tourism	Shore length exposed	Sheen (1 g/m^2)
Shoreline cleanup	Shore area exposed	Sheen (1 g/m^2)
Boating/shipping	Water surface area exposed to floating oil	Sheen (1 g/m^2)
Water surface cleanup	Water surface area exposed to floating oil	Sheen (1 g/m^2)

2.3.1 Biological Impacts

As described in the sections below, birds and other wildlife are affected in proportion to the water and shoreline surface area oiled above a threshold thickness for effects. Impacts to fish and invertebrates in the water and on the sediments are related to water column and sediment pore water concentrations of dissolved aromatics.

Biological impacts are calculated in the OECM as the area or volume affected times the density of animals in the location of interest. Densities of biological resources in each planning region are available in the Type A model that ASA developed for the DOI in support of the CERCLA NRDA regulations (French et al., 1996); these data sets are included in the OECM and provided in Subappendix E. Because of this direct multiplication performed within the OECM itself, other and updated biological densities may be inserted in the OECM at any time (by BOEM or others). Also note that the numbers of animals oiled is directly proportional to animal density. Thus, if the density increases by a factor of two, so do the impact results calculated by the model. This allows complete flexibility in adding or updating the densities of receptors.

Impacts to Wildlife: Marine Mammals, Sea Turtles, Seabirds and Waterfowl

Impacts to marine mammals, sea turtles, seabirds, and waterfowl were evaluated as the water surface area exposed to floating oil with a thickness of 10 g/m^2 or higher. Regressions were developed of area exposed versus spill volume for each oil type. To determine biological density information for each species, we multiplied the annual average number per km^2 (from the Type A model) by the probability of oiling for that species' behavior group (Table 5) to estimate the number killed per km^2. Estimates for the probabilities shown in Table 5 are derived from information on behavior and field observations of mortality after spills (reviewed in French et al., 1996 and French McCay, 2009). We also multiplied the number killed per km^2 by the mean weight per individual of each species to calculate the kilograms killed per km^2. This information is summarized for each location in the enclosed digital appendix (Subappendix E).

Table 5. Combined probability of encounter with the slick and mortality once oiled, if present in the area swept by a slick exceeding the thickness threshold.

Wildlife Behavior Group	Probability
Dabbling and surface-feeding waterfowl*	99%
Nearshore aerial divers	35%
Surface seabirds	99%
Aerial seabirds	5%
Wetland wildlife (waders and shorebirds)	35%
Cetaceans	0.1%
Furbearing marine mammals	75%
Pinnipeds, manatee, sea turtles	1%

*Dabblers, geese, and swans were not included in the modeling because they are not found in significant numbers in areas affected by offshore spills.

Impacts to Wildlife: Shorebirds and Waders

Impacts to shorebirds and waders were evaluated as the shore area exposed to oil with a thickness of 100 g/m^2 or higher. Shore area exposed was calculated by summing the impacts for rock, gravel, sand, mudflat, and wetland shore types. We excluded impacts to artificial shore types from this total because artificial shorelines are typically not suitable shorebird/wader habitat. Regressions were developed of area exposed versus spill volume for each oil type. To determine biological density information for each species, we multiplied the annual average number per km^2 (from the Type A model) by the probability of oiling for that species' behavior group (Table 5, French et al., 1996 and French McCay, 2009) to estimate the number killed per km^2. We also multiplied the number killed per km^2 by the mean weight per individual of each species to calculate the kilograms killed per km^2. This information is summarized for each location in the enclosed digital appendix (Subappendix E).

It should be noted that, because of the resolution of the modeling, shorebird/wader impacts are likely to be underestimated. In the model, the shore area exposed to oil is averaged based on the length of the shore cell in the habitat grid for each location. Because of the geographic extent of potential oiling in the OECM locations for the spills examined, our habitat grids were large, resulting in large individual shore cell lengths (shore cell size information for each location can be found in Subappendix A). These large shore cells tend to dilute the effect of shore oiling, and thereby underestimate shorebird/wader impacts.

Impacts to Water Column Organisms

Contamination in the water column changes rapidly in space and time, such that a dosage measure as the product of concentration and time is a more appropriate index of impacts than simply peak concentration. Toxicity to aquatic organisms increases with time of exposure, such that organisms may be unaffected by brief exposures to the same concentration that is lethal at long times of exposure. Toxicity data indicate that the 96-hour LC50 (which may serve as an acute lethal threshold) for dissolved aromatics (primarily PAHs) averages about 50 µg/l (ppb, French McCay, 2002).

Impacts to water column organisms (fish and invertebrates) were evaluated as the volume of water exposed to aromatic concentrations above a lethal dose threshold (in ppb-hrs). The lethal dose threshold was based on LC50 = 50 ppb at infinite time of exposure (the time to approach equilibrium of tissue concentration with ambient concentration) and is a function of temperature (Table 6 below, French McCay, 2002). For temperatures not listed in the table, the lethal dose was interpolated.

Table 6. Lethal dose of aromatics as a function of temperature.

Temperature (°C)	Lethal Dose (ppb-hrs)
25	5000
20	9000
15	14000
10	24000
2	58000

To calculate water column organisms impacts, we used two different model outputs, (1) the volume of water that had dissolved aromatic concentrations exceeding 1 ppb and (2) the average dose of dissolved aromatics, as ppb-hrs in that volume. Using the annual average surface water temperature for each location (from French et al., 1996), if the average dose exceeded the lethal threshold, then the entire volume of water exceeding 1 ppb is assumed to be exposed to a lethal dose (i.e., the kill volume). If the average dose did not exceed the lethal threshold, the kill volume is calculated as:

Volume Killed = (Average Dose)/(Lethal Threshold) * (Volume exceeding 1 ppb)

Regressions were then developed for the water volume killed as a function of the spill volume. In the OECM, these regressions are multiplied by the total fish and invertebrate injury per unit volume killed. Total fish and invertebrate injury per unit volume killed was determined by running SIMAP's biological model for the 99th percentile run of the scenario with the largest spill volume of crude oil. This model outputs the total injury in kilograms for each species, which we then divided by the volume killed for that run to determine the injury in kilograms per unit volume. This information is summarized for each location in the enclosed digital appendix (Subappendix E).

It should be noted that these fish and invertebrate impacts were calculated assuming all the species were of average sensitivity to dissolved aromatics. Some species will be much more sensitive, and impacts to those species would be higher. There would also likely be species less sensitive than average. As there are insufficient toxicity data available to quantify the degree of sensitivity to aromatics for all species in every planning area, there is considerable uncertainty around the results based on average sensitivity. Experience with past modeling efforts indicate the uncertainty in the impact estimate related to species sensitivity is on the order of a factor ten higher or lower (95% confidence range). As there is a mix of species sensitivity present, the uncertainty in the total fish and invertebrate impact would be less than a factor ten.

Impacts to Benthic Organisms

Impacts to benthic organisms were planned to be evaluated using the sediment area exposed to dissolved aromatic concentrations above an acute threshold. However, after initial model testing, it was discovered that the dissolved sediment pore water concentration would not be acutely lethal for the spills evaluated. Only sublethal effects of those dissolved aromatic concentrations would likely be significant, and SIMAP is only able to evaluate acute lethal effects. While literature studies suggest that sublethal effects of the soluble aromatics and other hydrocarbons can occur, it was beyond the scope of our current work to perform a model evaluation of these potential impacts; thus, we excluded this impact category from further analysis.

2.3.2 Shoreline Recreation and Tourism Impacts

Impacts to shoreline recreation and tourism were evaluated as the shore length (by shore type) exposed to an oil thickness greater than 1 g/m^2. Regressions were developed of shore length exposed versus spill volume for each oil type for the following shore type categories:

- Rock + Gravel;
- Sand;
- Mudflat + Wetland; and
- Artificial.

2.3.3 Shoreline Cleanup Impacts

Shoreline cleanup impacts were evaluated as the shore area (by shore type) exposed to an oil thickness greater than 1 g/m^2. Regressions were developed of shore area exposed versus spill volume for each oil type for the following shore type categories:

- Rock + Gravel;
- Sand;
- Mudflat + Wetland; and
- Artificial.

2.3.4 Boating/Shipping and Water Surface Cleanup Impacts

Boating/shipping and water surface cleanup impacts were combined into the same category because they were evaluated using the same impact measure, that is, the water surface area exposed to floating oil with a thickness greater than that of sheen, 1 g/m^2. Regressions were developed of water surface area exposed versus spill volume for each oil type.

3. Habitat Equivalency Analysis (HEA)

In NRDAs in the United States, damages (costs) for biological impacts are commonly based on restoration costs to replace the ecological and related services. Habitat Equivalency Analysis (HEA) has been used by state and federal trustees to estimate the restored habitat required to compensate for habitat and biological resources injured, taking into account the time before the project is begun (lag time after the spill and injuries occur), the time for development of the restored habitat, the ultimate productivity of services in the new habitat as compared to that injured, the duration of the restoration project life, and discounting of future habitat services at 3 percent per year. The approach, equations, and assumptions are described in NOAA (1997, 1999), LA DEQ et al. (2003), and French-McCay and Rowe (2003).

A detailed description of the HEA analysis used for the OECM is provided as Subappendix C to this document.

4. Spill Rate and Volume Analysis

As part of the OECM analysis, Environmental Research Consulting used in-house databases, including data provided by BOEMRE, to summarize the spill risk from offshore exploration and production activities (i.e., from platforms, drilling rigs, drill ships, Floating Production, Storage and Offloading units, pipelines, and offshore service vessels) and from transport of oil by tankers. As part of this analysis, the probability of spillage (i.e., how likely is a spill to occur from any particular offshore facility or tanker) was calculated, as well as the probability distribution function of the spill volumes of different oil types should a spill occur from one of these sources.

This analysis incorporated two sets of spill volume probability distribution functions for spills, developed based on past U.S. spill histories (as in Etkin, 2009). The first set was for spills associated with the OCS program (i.e., from offshore platforms/wells and pipelines, as well as from vessels servicing the platforms). The second set of probability distribution functions was for the volumes of spills associated with the alternative to OCS oil production (i.e., importing crude and products by tanker). For each of these spill and oil types, spill volumes were divided into the following size classes: very small, small, medium, large, very large, and for tanker spills only, extra-large volumes. The results of this analysis are summarized in Subappendix D to this document.

These data could be adjusted to reflect future changes (such as changes in tanker traffic, volumes of oil cargo being carried, etc.) or to include more (or less) of particular types of incidents as required for future analyses.

5. Model Results

Regression results and biological database tables are provided in the enclosed digital appendix (Subappendix E). Each set of regressions applies to a particular location, distance from shore, and biological database, as summarized in Table 7.

Table 7. Summary of OECM regressions and biological databases.

Planning Area	Distance from Shore (nautical miles)	Regression Set to Use	Biological Database to Use
Mid-Atlantic	0 - 50 50+	ATL-ON ATL-OFF	Delmarva Shelf Offshore Mid-Atlantic
Straits of Florida	All	SFL	Straits of Florida
Central Gulf of Mexico	0 - 65 65+	CGM-ON CGM-OFF	LA-No. Texas Shelf Offshore Gulf of Mexico
Southern California*	Santa Barbara Channel Other	SCA-SBVB SCA-SMB	Santa Barbara Channel Central Calif. Offshore
Washington/Oregon	0 -25 25+	WAS-ON WAS-OFF	Washington Outer Coast Oregon-Wash. Offshore
Gulf of Alaska (North Pacific)	0 -75 75+	GOA-ON GOA-OFF	Yakutat Gulf of Alaska
Cook Inlet/Shelikof Strait	All	CIS	Shelikof Strait
Bering Sea	All	BER	So. Bering Sea Shelf
Chukchi Sea	0 - 40 40+	CHU-ON CHU-OFF	Chukchi Sea Chukchi Sea
Beaufort Sea	0 - 40 40+	BEA-ON BEA-OFF	Beaufort Sea Beaufort Sea

*Rather than offshore and nearshore scenarios, for Southern California we modeled two locations, (1) the Santa Barbara-Ventura Basin, representing spills within the Santa Barbara Channel, and (2) the Santa Maria Basin, representing all other Southern California spills.

6. Conclusions

The modeling performed herein addresses oil spills associated with OCS development and oil imports that effectively occur at or near the water surface. In the SIMAP modeling, we assumed the release was at the water surface. For subsurface releases, oil behavior and fate would be considerably different than that modeled herein. Because the oil would not be immediately in contact with the atmosphere, the soluble and semi-soluble aromatics, the most toxic fractions of the oil, would dissolve rather than evaporating (to varying degrees, depending on the compound). This would result in considerably more impact to water column biota. The impacts to water column biota may be increased by application of dispersants either on the water surface or at the source of the release. Sea-bed blowouts are certainly a much more detrimental situation for water column biota, and application of dispersants to the release at the source amplifies the impact considerably. Thus, the environmental impacts estimated by the OECM, as configured herein, are not applicable to subsurface (e.g., seabed) releases, and particularly not to crude oil blowouts.

In addition, the spill volumes used to develop the regressions covering water-surface spills span the range from small spills to 1 million gallons of crude oil. The largest tanker spill in U.S. history, the Exxon Valdez oil spill (EVOS), was 11 million gallons. The EVOS was not a catastrophic loss of the entire cargo. The largest "super" tankers used today (Ultra-Large Cargo Carriers) transport up to 3.52 million barrels (148 million gallons). While extrapolation of the regressions to 11 million gallons might be justifiable as reliable, the model results cannot be reliably extrapolated to spills of a size on the order of 148 million gallons.

Note that for surface spills in the range of volumes studied, the calculated physical spreading and transport of oil, exposure doses, and percentages of biota affected would not require updating if there are changes in receptors that BOEM would wish to evaluate or if biological densities or distributions change. Physical processes are a function of environmental conditions, and the model design allows for selection of appropriate environmental conditions in each planning area, which in turn will indicate the appropriate regression equations quantifying exposure to employ for the planning area of interest. Thus, the SIMAP-modeled exposure data provided in the OECM will not need to be updated.

Furthermore, we do not anticipate a need to update the regression models of exposure area/volume versus oil type, spill size, and environmental conditions, unless in the future BOEM sees the need to develop a more detailed and site-specific model than is described herein. The modeling used to develop the regressions incorporated into the OECM was generalized to allow extrapolation to all potential (surface) spills in all potential locations of 26 planning areas; thus, these results will not be accurate for specific spill cases. For such incidents, the environmental and biological specifics for the scenario should be used to estimate environmental impacts when case-specific spill assessments are performed.

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Oil Spill Modeling for the Offshore Environmental Cost Model (OECM)

SUBAPPENDIX A

Detailed Model Input Information for Each Location

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Mid-Atlantic

Habitat Grid

The digital shoreline, shore type, and habitat mapping for the Mid-Atlantic region were obtained from the Environmental Sensitivity Index (ESI) Atlas databases compiled for the Eastern U.S. States of New Jersey to North Carolina by Research Planning, Inc. (RPI). These data are distributed by NOAA HAZMAT (Seattle, WA).

Depth data were based on soundings available from the NOAA National Ocean Service Hydrographic Survey Data (NOAA, 2009). Grid cells with missing data were then filled with ETOP01 modeled data (Amante et al., 2009). ETOP01 is a one arc-minute global relief model of the Earth's surface that integrates land topography and ocean bathymetry.

The gridded habitat and depth data are shown in Figures A-1 and A-2.

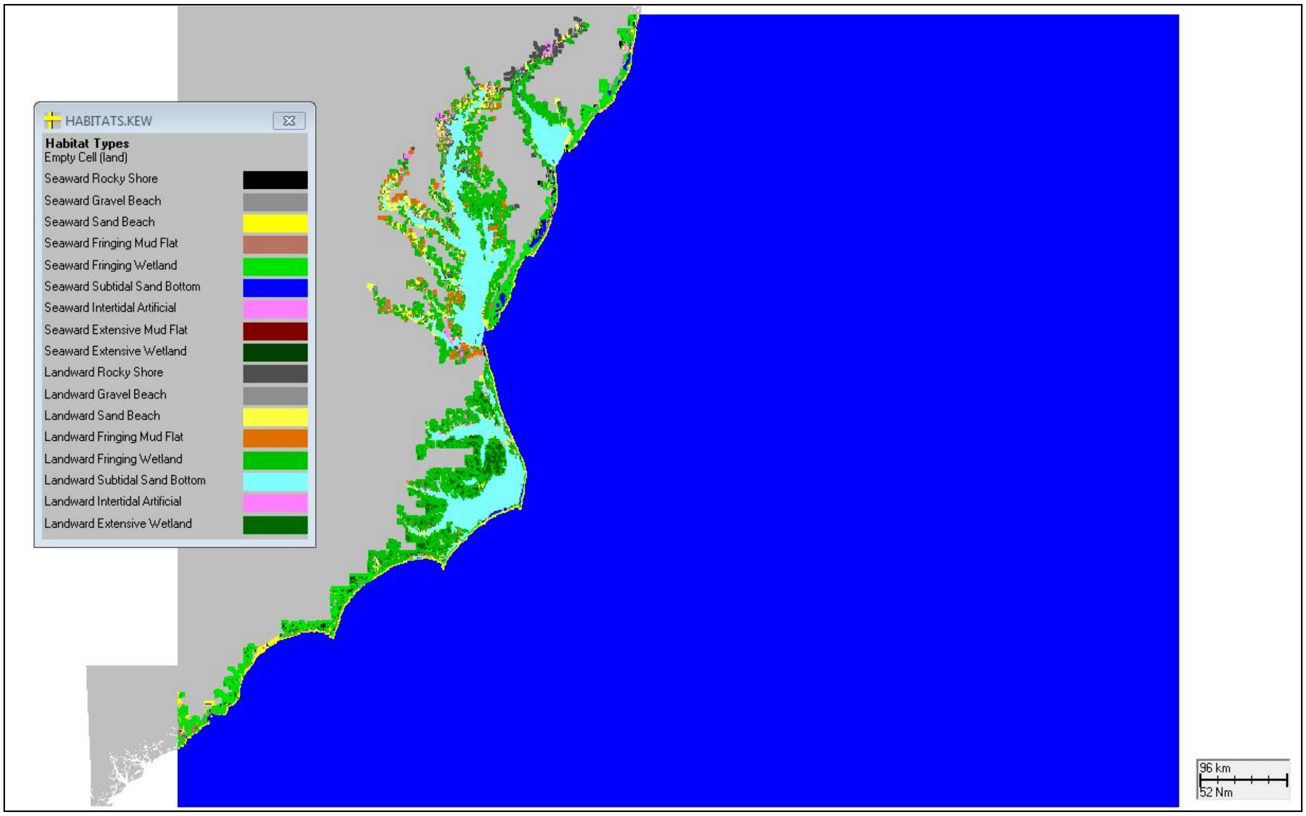

Figure A-1. Habitat grid developed for the Mid-Atlantic region.

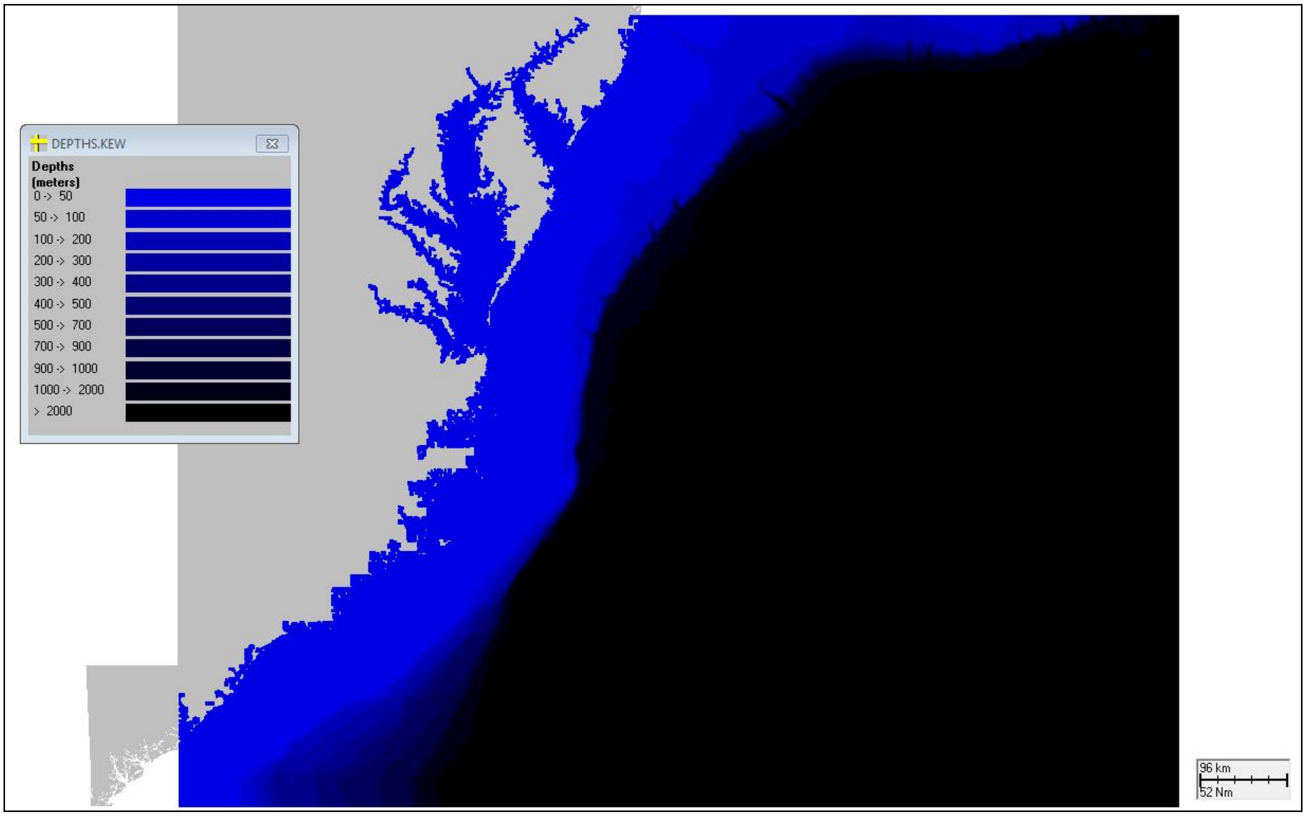

Figure A-2. Depth grid developed for the Mid-Atlantic region.

Table A-1. Dimensions of the habitat grid cells used to compile statistics for Mid-Atlantic model runs.

Habitat grid	OECM-ATLANTIC.HAB
Grid W edge	79° 58.856'W
Grid S edge	31° 59.649' N
Cell size (° longitude)	0.013° W
Cell size (° latitude)	0.013° N
Cell size (m) west-east	1,233.23
Cell size (m) south-north	1,454.10
# cells west-east	991
# cells south-north	632
Water cell area (m^2)	1,793,233.00
Shore cell length (m)	1,339.12
Shore cell width – Rocky shore (m)	2.0
Shore cell width – Artificial shore (m)	0.1
Shore cell width – Gravel beach (m)	3.0
Shore cell width – Sand beach (m)	10.0
Shore cell width – Mud flat (m)	140.0
Shore cell width – Wetlands (fringing, m)	140.0

Currents

Currents were based on the study "Mid-Atlantic Ocean Model Calculations" performed for BOEM by Oey and Xu (2010, Princeton University). The hydrodynamic model is the Princeton Ocean Model (POM; http://www.aos.princeton.edu/WWWPUBLIC/htdocs.pom/), which includes wind, waves, rivers, tides, slope and shelf-break currents, the Gulf Stream, rings and eddies, as well as the large-scale Atlantic Ocean influences. The model operates a nesting scheme with ECCO (Estimating the Circulation and Climate of the Ocean; an MIT8 JPL-SIO consortium model based on the MIT GCM with data assimilation). The hindcast simulation (year 1993-2008) was forced by winds from the blended NCEP/QSCAT product and a regional high-resolution atmospheric model, surface heat and salt fluxes, weekly discharges from major rivers along the east coast, ECCO temperature and salinity fields as initial conditions, ECCO density and transport at the eastern PROFS (Princeton Regional Ocean Forecast System) open boundary in the Atlantic Ocean and tides. BOEM provided the hindcast data set, and ASA subsequently subset surface velocities to the appropriate SIMAP domain for the period 1993 to June 2000.

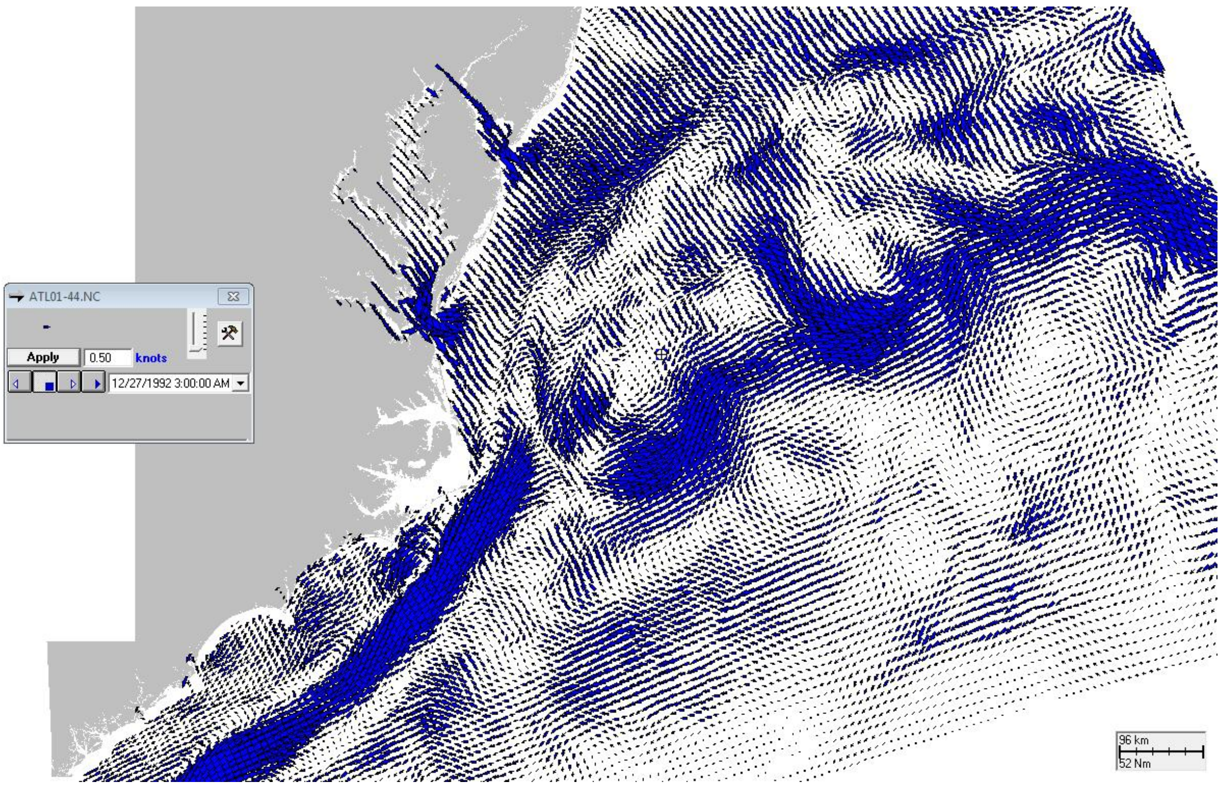

Figure A-3. Example of current component data used in modeling for the Mid-Atlantic region. Vector length indicates speed in the indicated direction.

Winds

Standard meteorological data were acquired from the National Data Buoy Center (NDBC) Internet site for the nearest NDBC buoy, number 44009, “Delaware Bay,” at 38.464°N, 74.702°W. Hourly mean wind speed and direction for the time period 12/27/1992 to 2/19/2000 were compiled in the SIMAP model input file format.

<u>Spill Sites</u>

Spill sites for the Mid-Atlantic region were placed within the Proposed Final Program Area (2007-2012), including buffer areas and the non-obstruction zone (Figure A-4). Twenty spill sites were placed within the nearshore spill area, and twenty spill sites were placed within the offshore spill area. The coordinates of these points are provided in Tables A-2 and A-3.

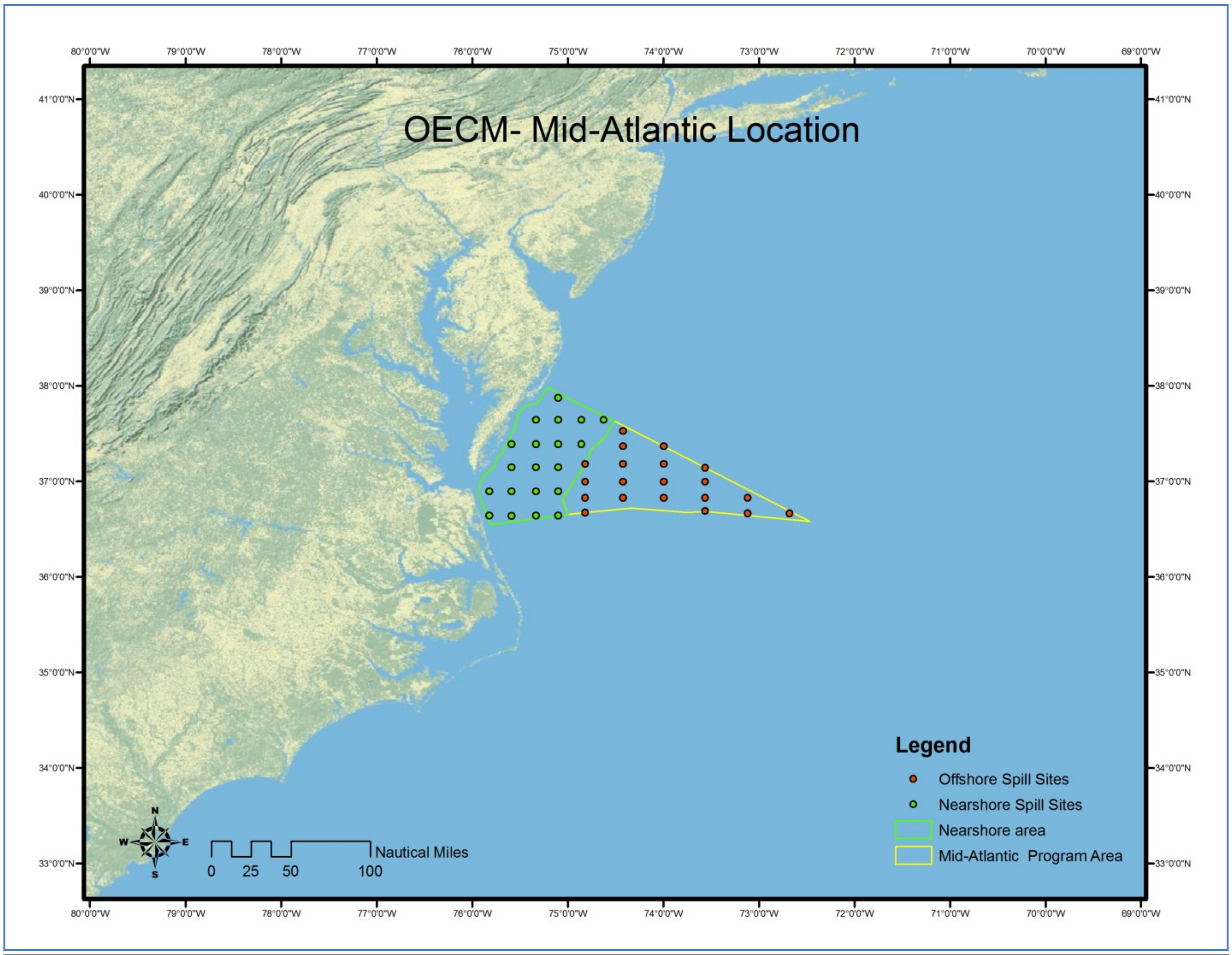

Figure A-4. Spill sites developed for the Mid-Atlantic region.

Table A-2. Mid-Atlantic nearshore spill sites.

Spill Site #	Latitude	Longitude
1	36.64093	-75.81953
2	36.89273	-75.81953
3	36.64093	-75.58961
4	36.89273	-75.58961
5	37.14602	-75.58961

Spill Site #	Latitude	Longitude
6	37.39152	-75.58961
7	36.64093	-75.33350
8	36.89273	-75.33350
9	37.14602	-75.33350
10	37.39152	-75.33350
11	37.64084	-75.33350
12	36.64093	-75.10066
13	36.89273	-75.10066
14	37.14602	-75.10066
15	37.39152	-75.10066
16	37.64084	-75.10066
17	37.87324	-75.10066
18	37.39152	-74.85619
19	37.64084	-74.85619
20	37.64084	-74.62335

Table A-3. Mid-Atlantic offshore spill sites.

Spill Site #	Latitude	Longitude
1	36.67137	-74.81720
2	36.82661	-74.81720
3	36.99366	-74.81720
4	37.18119	-74.81720
5	36.82661	-74.42013
6	36.99366	-74.42013
7	37.18119	-74.42013
8	37.36466	-74.42013
9	37.52585	-74.42013
10	36.82661	-73.99588
11	36.99366	-73.99588
12	37.18119	-73.99588
13	37.36466	-73.99588
14	36.68968	-73.55950
15	36.82661	-73.55950
16	36.99366	-73.55950
17	37.14251	-73.55950
18	36.66295	-73.11707
19	36.82661	-73.11707
20	36.66295	-72.67766

Straits of Florida

<u>Habitat Grid</u>

The digital shoreline, shore type, and habitat mapping for the Straits of Florida were obtained from the Florida ESI Atlas database compiled for the state of Florida by the Florida and Wildlife Institute.

Bathymetry data were available from bathymetric contours contained within the GEBCO Digital Atlas (GEBCO, 2003).

The gridded habitat and depth data are shown in Figures A-5 and A-6.

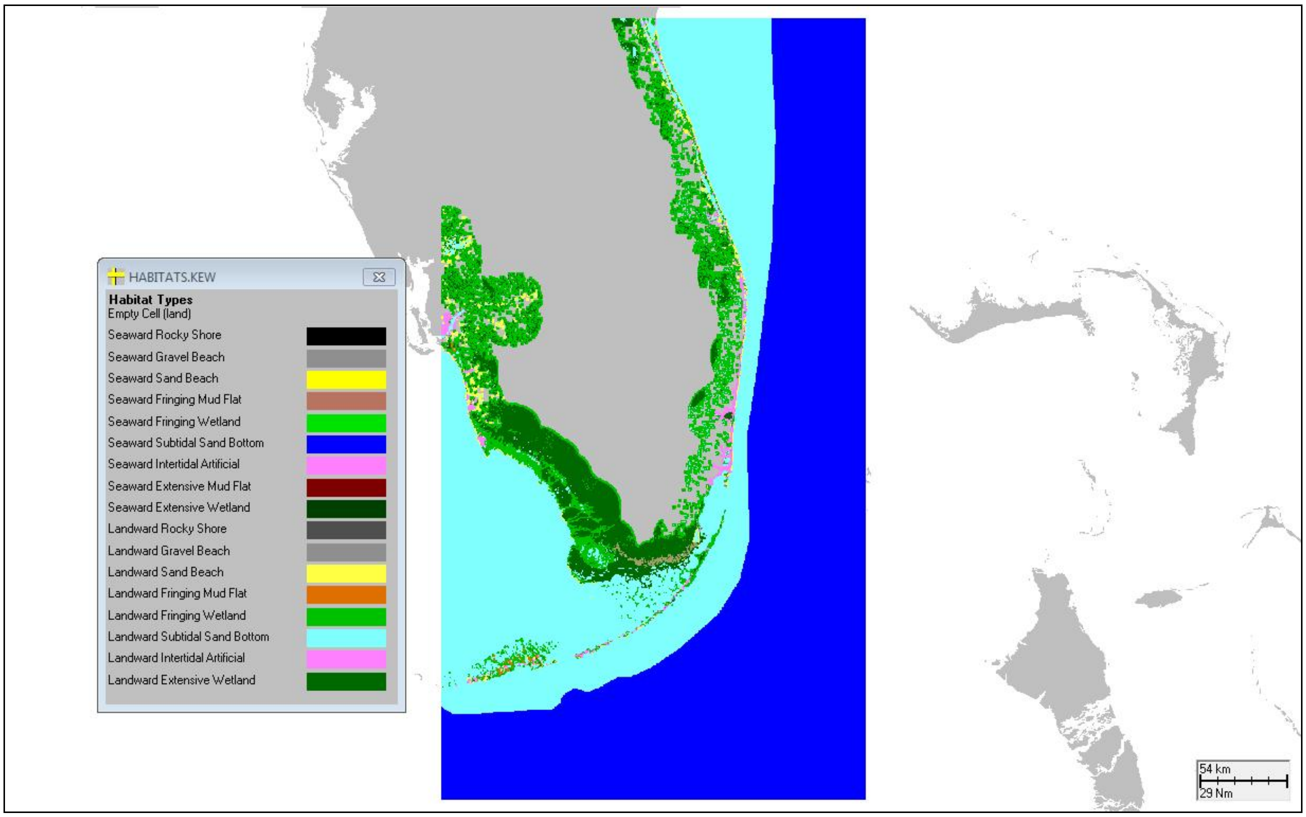

Figure A-5. Habitat grid developed for the Straits of Florida region.

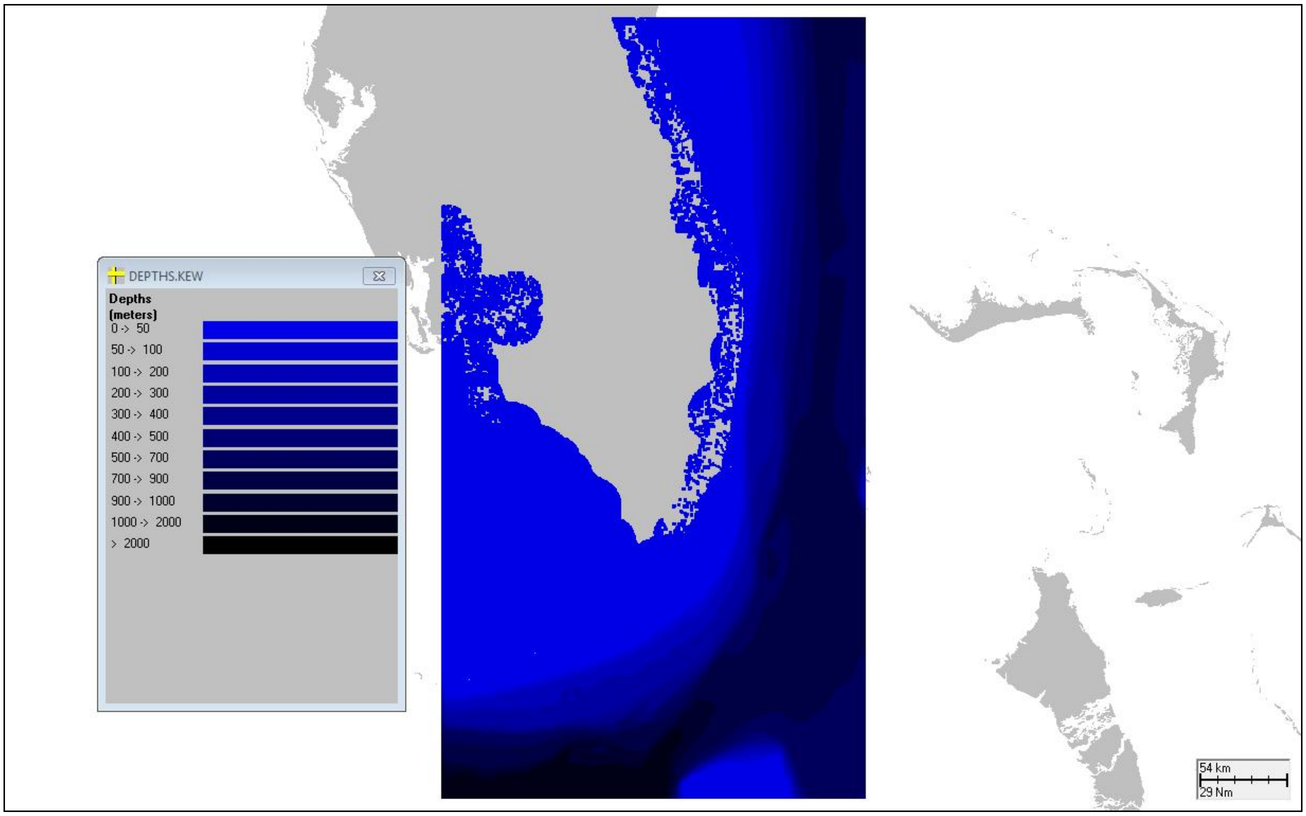

Figure A-6. Depth grid developed for the Straits of Florida region.

Table A-4. Dimensions of the habitat grid cells used to compile statistics for Straits of Florida model runs.

Habitat grid	OECM-FLSTRAITS.HAB
Grid W edge	81° 58.520'W
Grid S edge	23° 52.095' N
Cell size (° longitude)	0.0045 W
Cell size (° latitude)	0.0045° N
Cell size (m) west-east	455.97
Cell size (m) south-north	498.61
# cells west-east	600
# cells south-north	993
Water cell area (m^2)	227,352.05
Shore cell length (m)	476.81
Shore cell width – Rocky shore (m)	2.0
Shore cell width – Artificial shore (m)	0.1
Shore cell width – Gravel beach (m)	3.0
Shore cell width – Sand beach (m)	10.0
Shore cell width – Mud flat (m)	140.0
Shore cell width – Wetlands (fringing, m)	140.0

Currents

Currents for the Straits of Florida were mainly assembled from CUPOM (Colorado University Princeton Ocean Model; see Gulf of Mexico currents description for more detail). As the CUPOM model domain ends at 80.85°W (approximately the narrowest section between Cuba and Florida), the eastern portion was augmented using currents from POP (Parallel Ocean Program). CUPOM currents are available daily from year 1993 to 1999. Hence, the western portion of currents vary in time. However, currents in the eastern portion were filled with time-average of POP currents, thus constant in time. POP is the global ocean circulation model forced by observed temperature, salinity, and wind stress (Maltrud et al., 1998). The original simulation period extended from 1/1/1985 to 12/31/1995, and produced daily outputs with an average horizontal resolution of 1/6 degree.

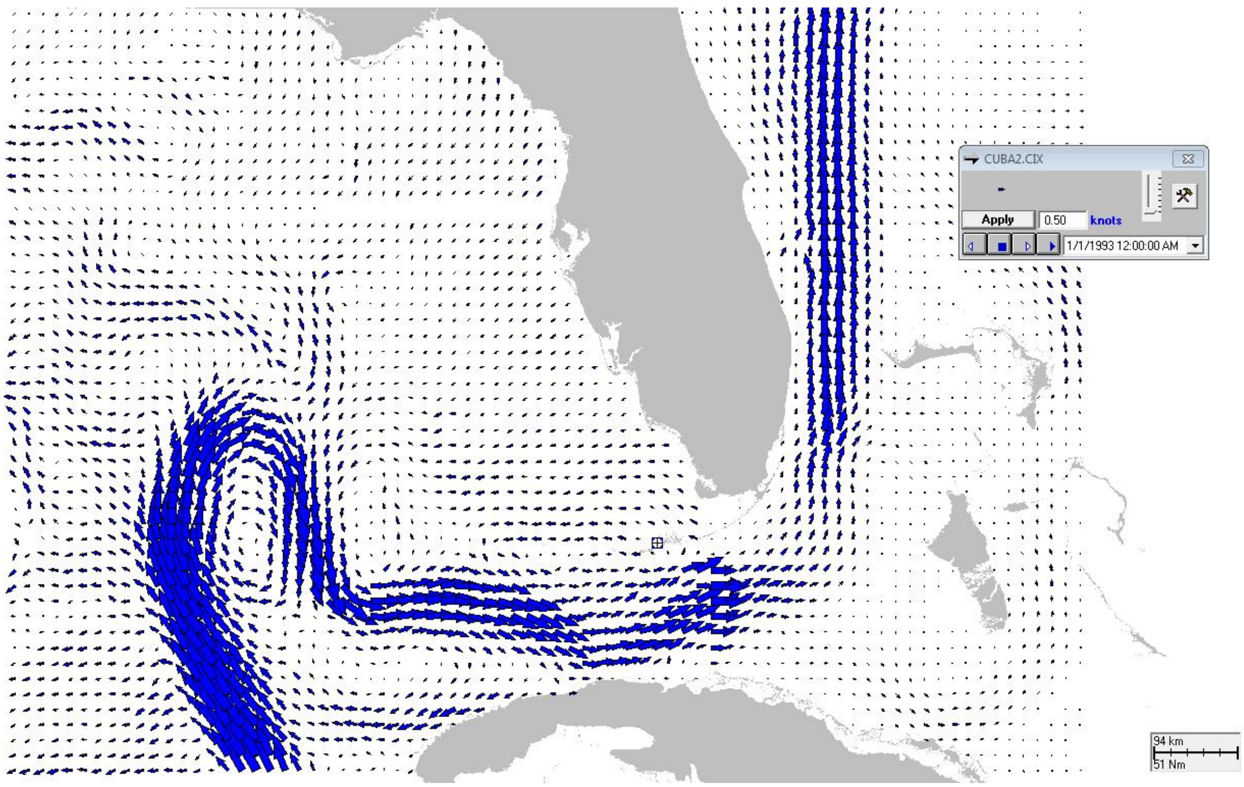

Figure A-7. Example of current component data used in modeling for the Straits of Florida region. Vector length indicates speed in the indicated direction.

<u>Winds</u>

Standard meteorological data were acquired from the NDBC Internet site for the nearest NDBC buoys with sufficient records, number FWYF1, “Fowey Rocks,” at 25.590°N, 80.097°W, and number SMKF1, “Sombrero Key,” at 24.627°N, 81.110°W. Hourly mean wind speed and direction for the time period 12/31/1995 to 12/28/2008 (FWYF1) and 1/1/1993 to 11/30/1999 (SMKF1) were compiled in the SIMAP model input file format.

<u>Spill Sites</u>

Spill sites for the Straits of Florida region were randomly distributed within a small portion of the Straits of Florida Planning Area (Figure A-8) to provide a representative set of model results for potential release locations the indicated distances from shore. The locations were placed on the upstream side of the model grid, so the transport would remain within the grid. A total of twenty spill sites were placed within the spill area. The coordinates of these points are provided in Table A-5.

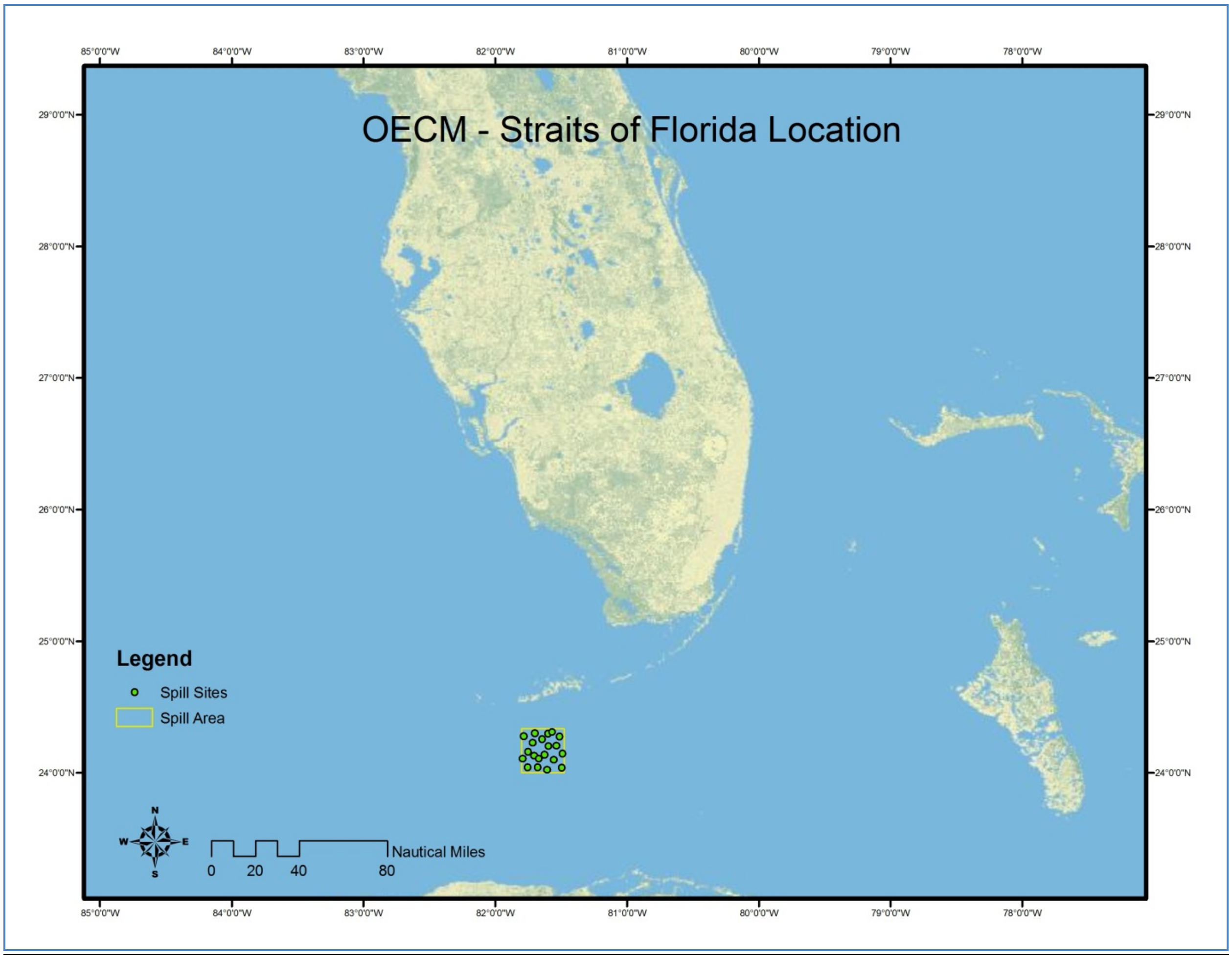

Figure A-8. Spill sites developed for the Straits of Florida region.

Table A-5. Straits of Florida spill sites.

Spill Site #	Latitude	Longitude
1	24.04264	-81.67753
2	24.30002	-81.59861
3	24.16146	-81.74880
4	24.13037	-81.70384
5	24.02205	-81.60536
6	24.20515	-81.53698
7	24.14667	-81.48918

Spill Site #	Latitude	Longitude
8	24.10032	-81.55524
9	24.13743	-81.62534
10	24.28058	-81.78421
11	24.10804	-81.79195
12	24.25780	-81.64454
13	24.30164	-81.69879
14	24.27776	-81.51076
15	24.20202	-81.59468
16	24.22763	-81.71558
17	24.04198	-81.75251
18	24.10701	-81.66911
19	24.31069	-81.56680
20	24.03964	-81.49442

Gulf of Mexico

<u>Habitat Grid</u>

The digital shoreline used to create the habitat grid was the "Land and Water Interface of the Louisiana Coastal Region" from LOSCO, published in 2000. Although, there is a more recent shoreline from LOSA published in the year 2002, the 2000 shoreline was a better fit to the other habitat GIS data that were used to create the grid. Shore type and habitat mapping were obtained from the G-WIS Environmental Sensitivity Index dataset published by the U.S. Minerals Management Service and the U.S. Geological Survey Land Cover Institute.

Bathymetry data were available from bathymetric contours contained within the GEBCO Digital Atlas (GEBCO, 2003).

The gridded habitat and depth data are shown in Figures A-9 and A-10.

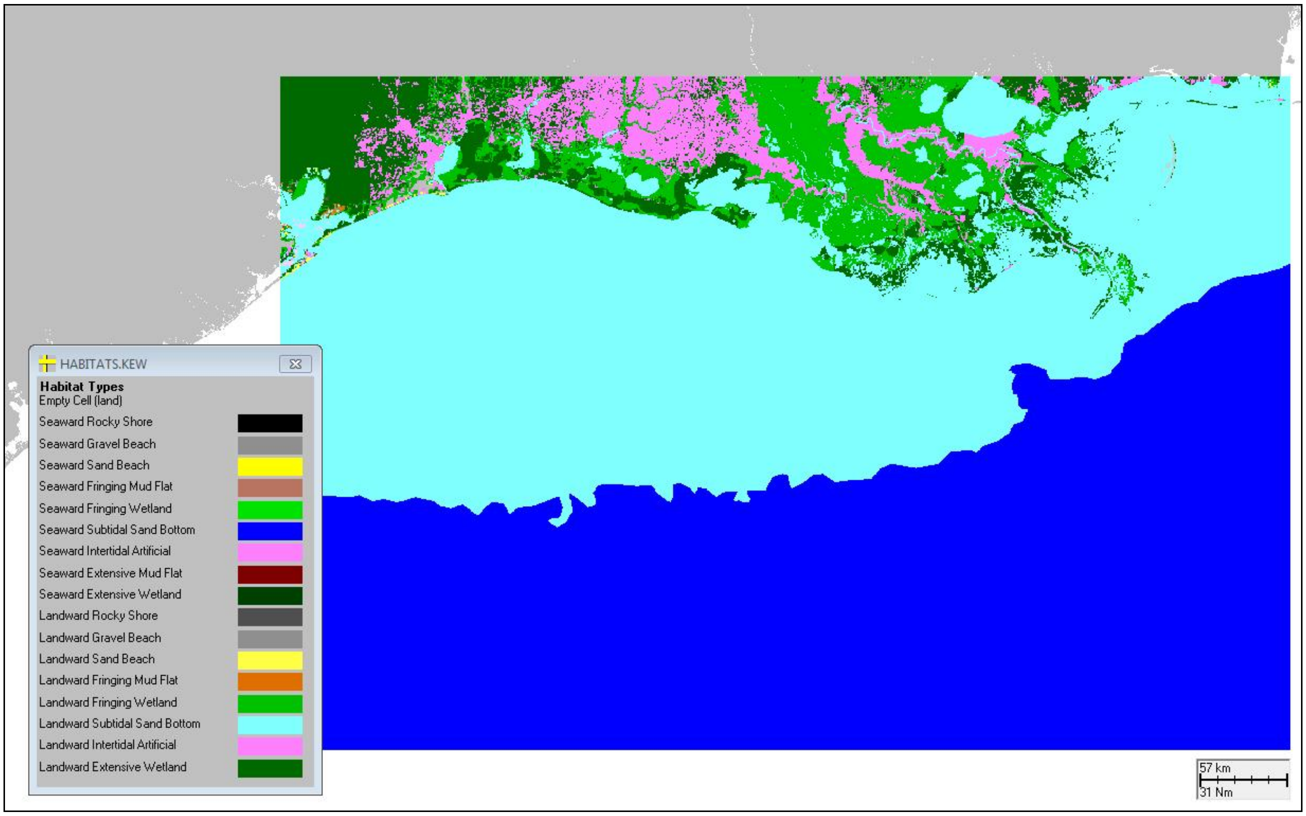

Figure A-9. Habitat grid developed for the Gulf of Mexico region.

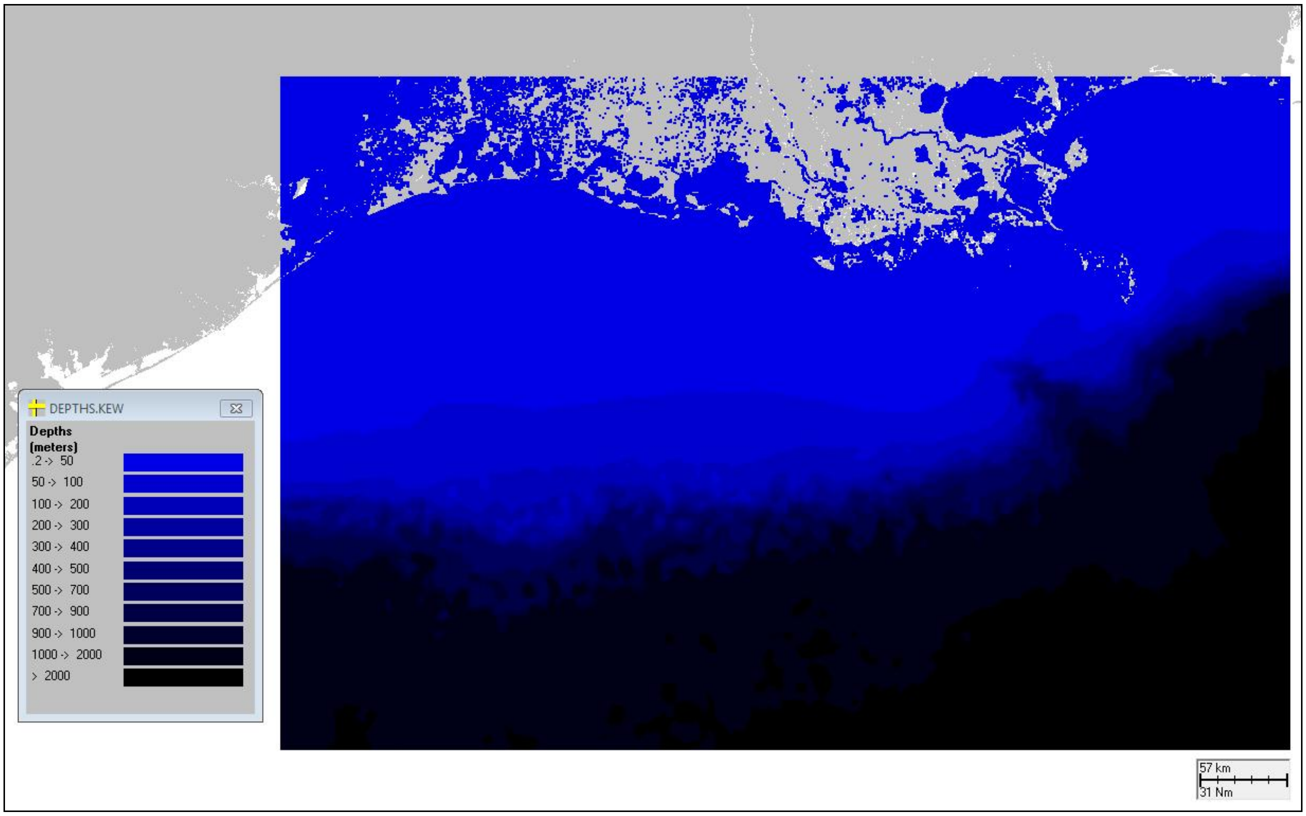

Figure A-10. Depth grid developed for the Gulf of Mexico region.

Table A-6. Dimensions of the habitat grid cells used to compile statistics for Gulf of Mexico model runs.

Habitat grid	OECM-CENTRALGOM.HAB
Grid W edge	94° 59.638'W
Grid S edge	26° 18.173' N
Cell size (° longitude)	0.0077° W
Cell size (° latitude)	0.0068° N
Cell size (m) west-east	768.73
Cell size (m) south-north	753.92
# cells west-east	900
# cells south-north	600
Water cell area (m^2)	579,564.12
Shore cell length (m)	761.29
Shore cell width – Rocky shore (m)	1.0
Shore cell width – Artificial shore (m)	0.1
Shore cell width – Gravel beach (m)	2.0
Shore cell width – Sand beach (m)	10.0
Shore cell width – Mud flat (m)	20.0
Shore cell width – Wetlands (fringing, m)	50.0

Currents

Currents for the Gulf of Mexico were based on a study by Kantha et al. (1999) that produced current hindcasts of the Gulf of Mexico using the CUPOM model. The model was developed by Dr. Lakshmi Kantha and colleagues at the University of Colorado (CU) with partial support from an industry-sponsored study on Climatology and Simulation of Eddies. It is the CU version of the Princeton Ocean Model adapted for the Gulf of Mexico, referred to by the acronym CUPOM. The horizontal resolution is 1/12 degree and the vertical resolution is 24 sigma levels. The model run was for the years 1993 through 1999. The model assimilates altimeter data for the region in water depths of 1000 meters or more. It also assimilates satellite sea surface temperature data, but uses climatological sea surface salinity. The 6-hourly, 1.125° resolution ECMWF wind stresses are used for the wind forcing. The inflow boundary is at 21.333°N in the Yucatan Channel, with a geophysically balanced inflow prescribed using typical monthly temperature and salinity profiles. The outflow boundary is at the Florida Straits; the boundary condition is set to be balanced and in phase with the inflow boundary. The data assimilation module is the same as in Horton et al. (1997) and Clifford et al. (1997). Details of the specifics with respect to the Gulf of Mexico can be found in Kantha et al. (1999).

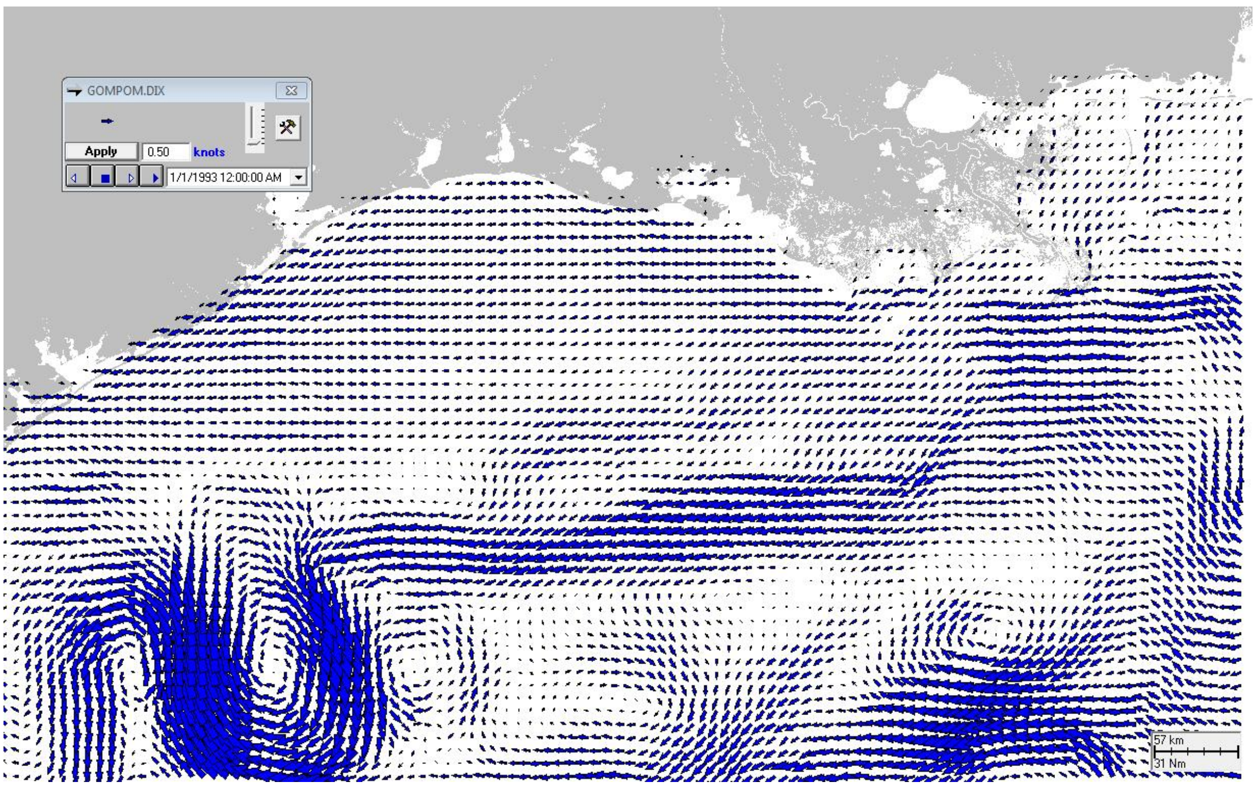

Figure A-11. Example current component data used in modeling for the Gulf of Mexico region. Vector length indicates speed in the indicated direction.

<u>Winds</u>

Standard meteorological data were acquired from the NDBC Internet site for the nearest NDBC buoys with sufficient records, number 42001, “Mid-Gulf,” at 25.900°N, 89.667°W, and number 42019, “Freeport,” at 27.913°N, 95.353°W. Hourly mean wind speed and direction for the time period 1/1/1993 to 11/30/1999 (42001) and 1/1/1993 to 12/14/1999 (42019) were compiled in the SIMAP model input file format.

Spill Sites

Spill sites for the Gulf of Mexico region were randomly distributed within a portion of the Central Gulf of Mexico Planning Area (Figure A-12) to provide representative results for the entire planning area (and other Gulf of Mexico planning areas). The delineation between the nearshore and offshore spill areas was based on the 200 meter depth contour. Twenty-five spill sites were placed within the nearshore spill area, and twenty-five spill sites were placed within the offshore spill area. The coordinates of these points are provided in Tables A-7 and A-8.

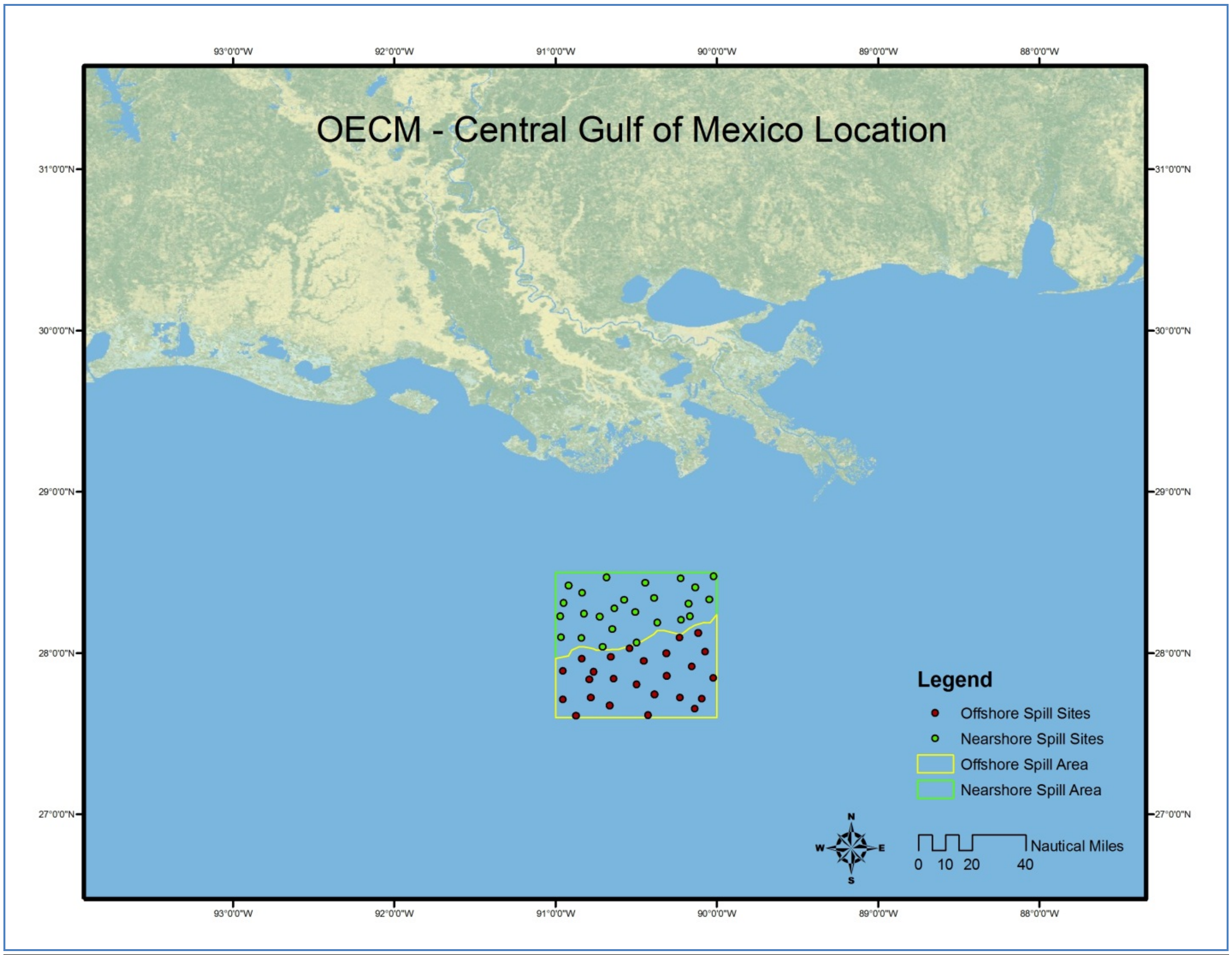

Figure A-12. Spill sites developed for the Gulf of Mexico region.

Table A-7. Gulf of Mexico nearshore spill sites.

Spill Site #	Latitude	Longitude
1	28.27809	-90.63407
2	28.32999	-90.57522
3	28.18947	-90.36839
4	28.09871	-90.96342
5	28.34223	-90.38914
6	28.40739	-90.13332
7	28.33234	-90.04664
8	28.09267	-90.83830
9	28.43589	-90.44322
10	28.46975	-90.68286
11	28.41958	-90.91776
12	28.46293	-90.22270
13	28.25360	-90.50444
14	28.22976	-90.96986
15	28.20711	-90.21975
16	28.30773	-90.17396
17	28.22805	-90.16437
18	28.06677	-90.49718
19	28.03898	-90.70642
20	28.22692	-90.72602
21	28.24542	-90.82115
22	28.37421	-90.83320
23	28.47609	-90.01843
24	28.14758	-90.64695
25	28.31080	-90.94804

Table A-8. Gulf of Mexico offshore spill sites.

Spill Site #	Latitude	Longitude
1	28.02883	-90.54000
2	27.97720	-90.65663
3	27.95121	-90.45292
4	28.12660	-90.11544
5	27.84080	-90.63855
6	28.00041	-90.31300
7	27.83616	-90.78981
8	27.72352	-90.22744
9	27.72410	-90.77993
10	27.71269	-90.95298
11	27.65610	-90.13622
12	27.96562	-90.83508
13	28.09683	-90.23034
14	27.88465	-90.76178
15	27.61588	-90.42420
16	27.67656	-90.66392
17	27.71794	-90.09253
18	27.91786	-90.15377
19	27.85827	-90.31076

Spill Site #	Latitude	Longitude
20	27.61158	-90.87315
21	27.80592	-90.49699
22	27.84537	-90.02027
23	27.89021	-90.95233
24	28.00849	-90.07113
25	27.74505	-90.38673

Southern California

Habitat Grid

The digital shoreline, shore type, and habitat mapping for Central and Southern California were obtained from ESI Atlas database compiled for the area by Research Planning, Inc. (RPI). These data are distributed by NOAA Hazmat (Seattle, WA).

Bathymetry data were available from bathymetric contours contained within the GEBCO Digital Atlas (GEBCO, 2003).

The gridded habitat and depth data are shown in Figures A-13 and A-14.

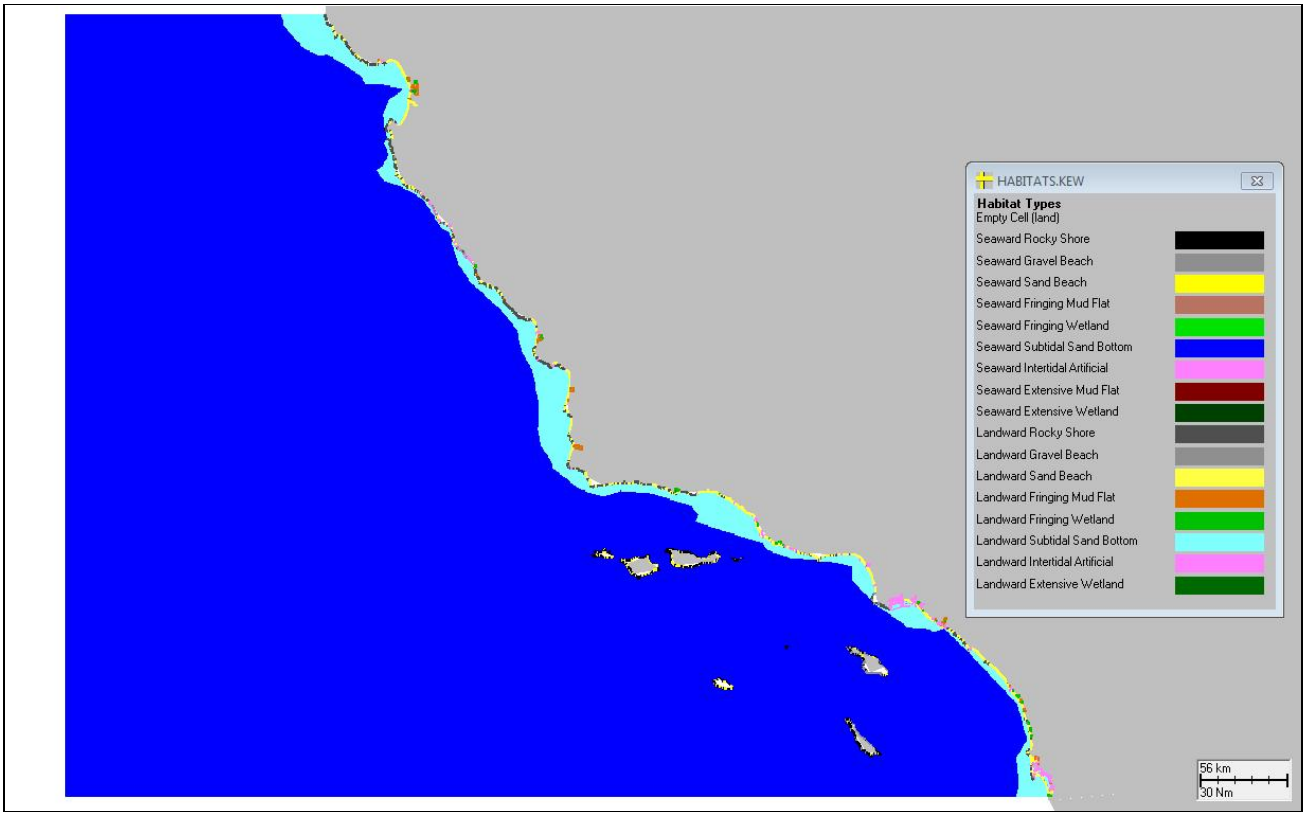

Figure A-13. Habitat grid developed for the Southern California region.

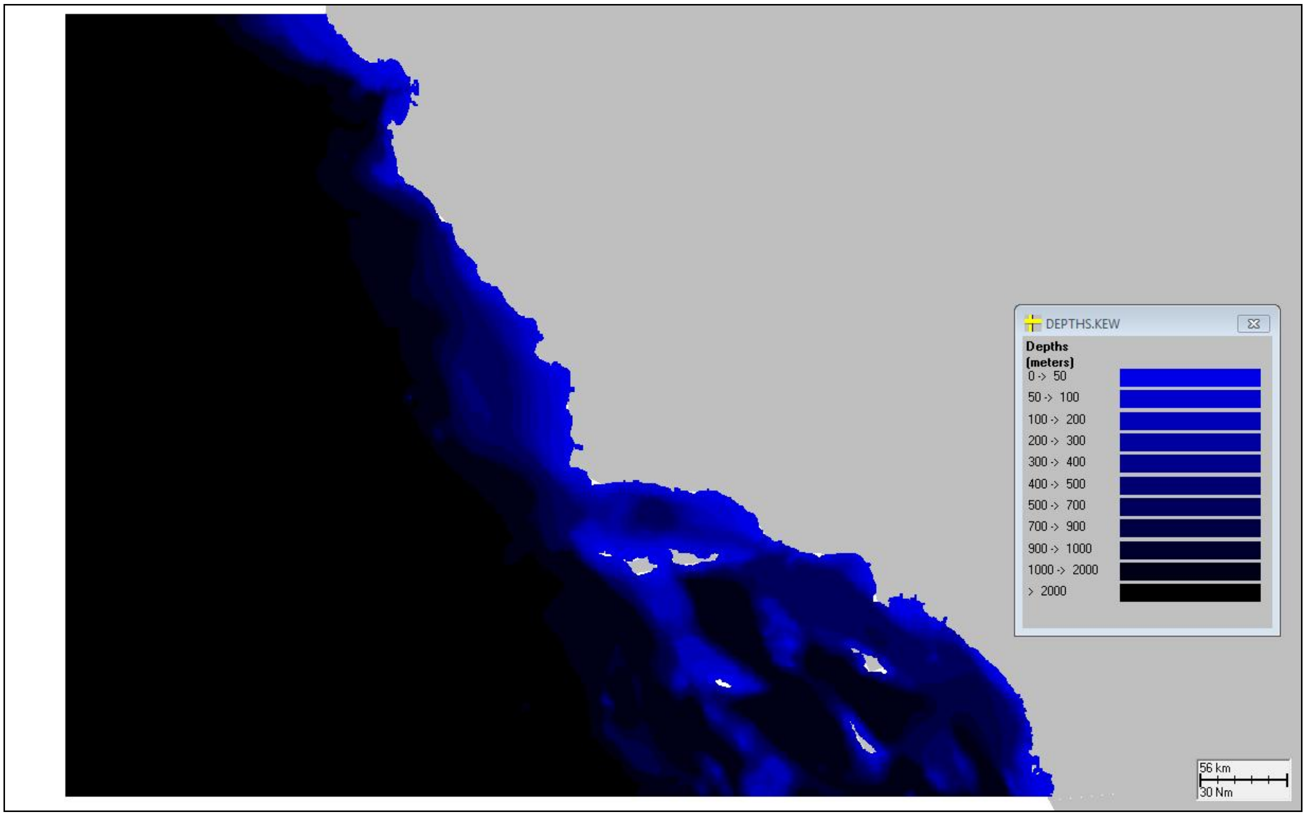

Figure A-14. Depth grid developed for the Southern California region.

Table A-9. Dimensions of the habitat grid cells used to compile statistics for Southern California model runs.

Habitat grid	OECM-SOUTHERNCA.HAB
Grid W edge	124^o 18.873'W
Grid S edge	32^o 33.413' N
Cell size (^{o} longitude)	0.0073^o W
Cell size (^{o} latitude)	0.0073^o N
Cell size (m) west-east	681.28
Cell size (m) south-north	808.30
# cells west-east	997
# cells south-north	643
Water cell area (m^2)	550,682.75
Shore cell length (m)	742.08
Shore cell width – Rocky shore (m)	2.0
Shore cell width – Artificial shore (m)	0.1
Shore cell width – Gravel beach (m)	2.0
Shore cell width – Sand beach (m)	10.0
Shore cell width – Mud flat (m)	120.0
Shore cell width – Wetlands (fringing, m)	120.0

<u>Currents</u>

Mean offshore currents for January, March, May, July, September, and November were compiled using data from the California Cooperative Oceanic Fisheries Investigations Atlas No. 4 (State of California Marine Research Committee, 1966). Data were taken from maps showing mean monthly geostrophic flow off the coast of California for the years 1950-1965. These maps contain contour lines showing ocean surface topography. The current files were created by marking points along each of the contour lines and placing corresponding current vectors at those points. The magnitude of the current vectors was determined by measuring the distance between adjacent contour lines and estimating the current velocity using a conversion chart provided in the atlas. Once these vectors were entered into a grid, a vector spreading algorithm filled in the vectors for the remainder of the gridded area. The current velocities are estimates and have an error margin of roughly ± 5 cm/s.

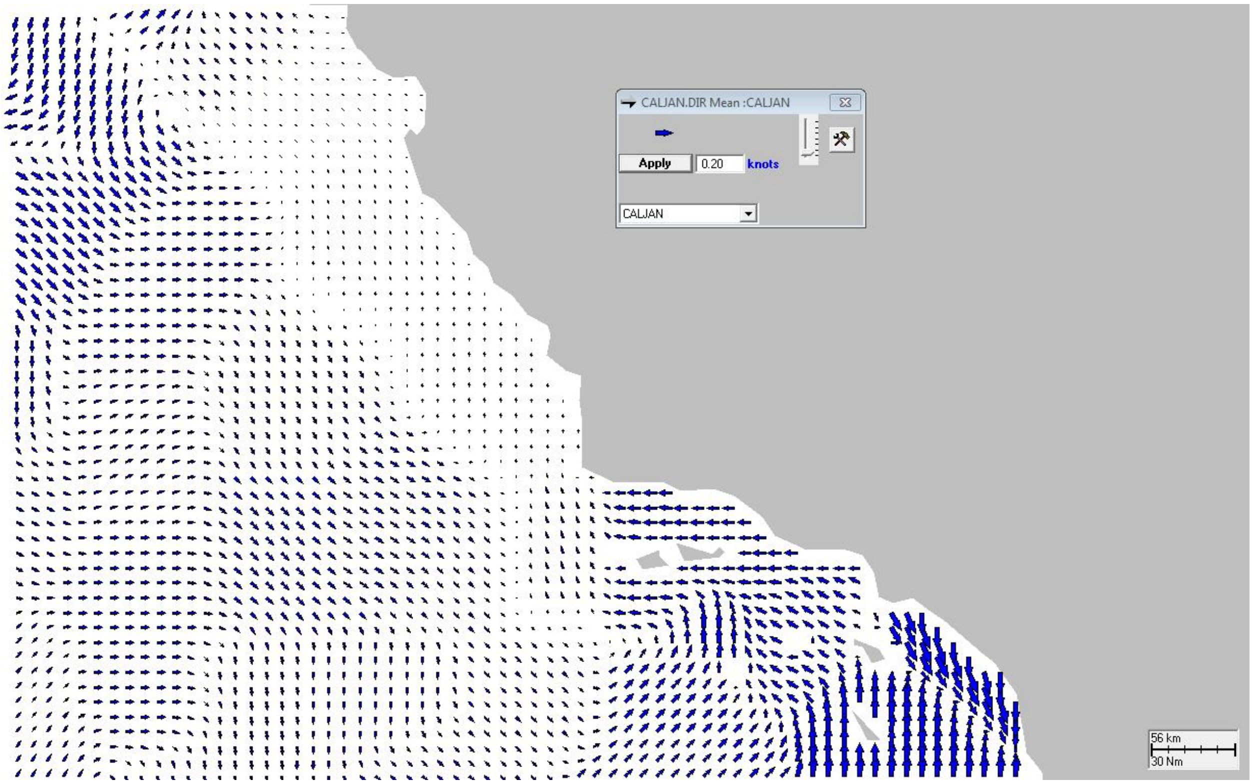

Figure A-15. Example current component data used in modeling for the Southern California region. Vector length indicates speed in the indicated direction.

Winds

Standard meteorological data were acquired from the NDBC Internet site for the nearest NDBC buoys with sufficient records, number 46011, “Santa Maria,” at 34.868°N, 120.857°W, and number 46053, “E. Santa Barbara,” at 34.248°N, 119.841°W. Hourly mean wind speed and direction for the time period 1/1/1998 to 11/23/2009 (46011) and 4/28/1998 to 12/31/2009 (46053) were compiled in the SIMAP model input file format.

Spill Sites

Spill sites for the Southern California region were randomly distributed within two areas, the Santa Maria Basin Draft Proposed Program Area (2010-2015; January 2009), and a representative portion of the Santa Barbara-Ventura Basin Draft Proposed Program Area (2010-2015; January 2009) (Figure A-16). Ten spill sites were placed within the Santa Barbara-Ventura Basin spill area, and twenty spill sites were placed within the Santa Maria Basin spill area. The coordinates of these points are provided in Tables A-10 and A-11.

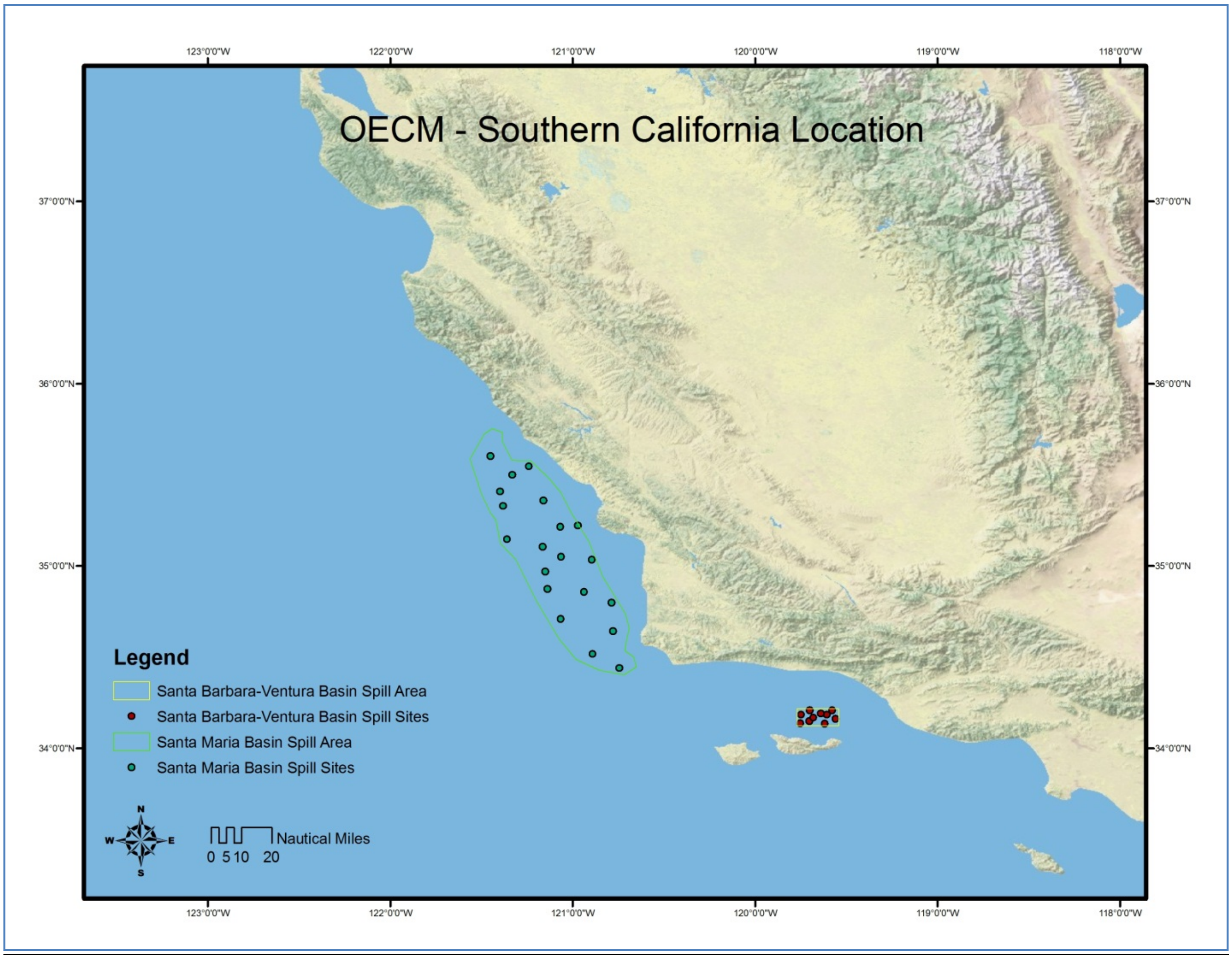

Figure A-16. Spill sites developed for the Southern California region.

Table A-10. Southern California Santa Barbara-Ventura Basin spill sites.

Spill Site #	Latitude	Longitude
1	34.14906	-119.70352
2	34.18444	-119.60804
3	34.20766	-119.70123
4	34.20849	-119.57720
5	34.13387	-119.61862
6	34.13745	-119.75179
7	34.16097	-119.55994

Spill Site #	Latitude	Longitude
8	34.18316	-119.74798
9	34.18931	-119.64070
10	34.16694	-119.68029

Table A-11. Southern California Santa Maria Basin spill sites.

Spill Site #	Latitude	Longitude
1	35.21500	-121.06691
2	34.96865	-121.15132
3	34.85808	-120.93869
4	34.51589	-120.89091
5	34.87350	-121.13914
6	35.03428	-120.89563
7	35.60317	-121.45206
8	34.64221	-120.77935
9	35.10547	-121.16538
10	34.70945	-121.06548
11	35.14592	-121.36015
12	34.79824	-120.78795
13	35.54632	-121.24035
14	35.32874	-121.38281
15	35.04960	-121.06353
16	34.43887	-120.74410
17	35.49837	-121.33215
18	35.40780	-121.39807
19	35.35871	-121.16099
20	35.22194	-120.97173

Washington/Oregon

Habitat Grid

The digital shoreline, shore type, and habitat mapping for the outer coast of Washington and the Columbia River were obtained from ESI Atlas database compiled for the area by Research Planning, Inc. (RPI). These data are distributed by NOAA Hazmat (Seattle, WA).

Depth data for the offshore and coastal waters were obtained from Hydrographic Survey Data supplied on CD-ROM by the NOAA National Geophysical Data Center. Hydrographic survey data consist of large numbers of individual depth soundings. The depth soundings were interpolated into the model grid for each area by averaging all soundings falling within a cell.

The gridded habitat and depth data are shown in Figures A-17 and A-18.

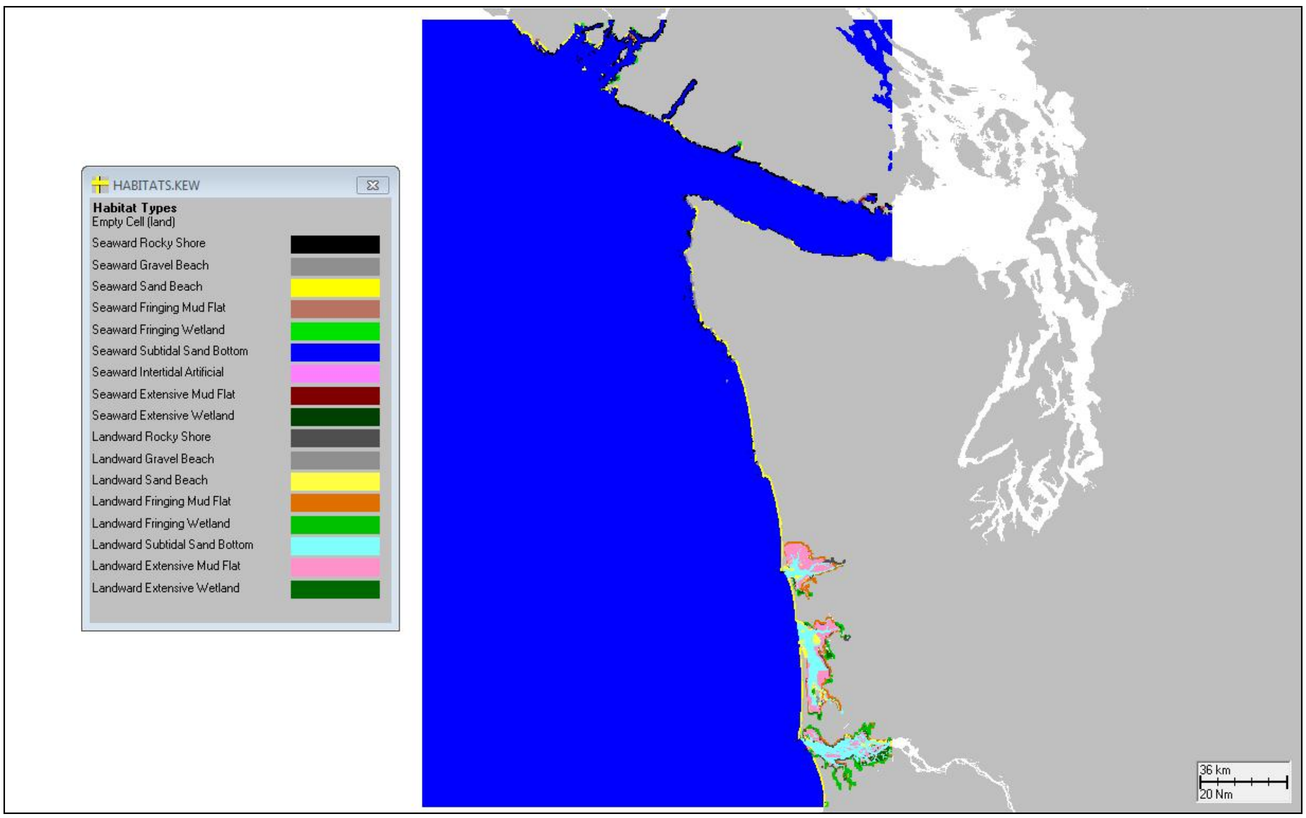

Figure A-17. Habitat grid developed for the Washington/Oregon region.

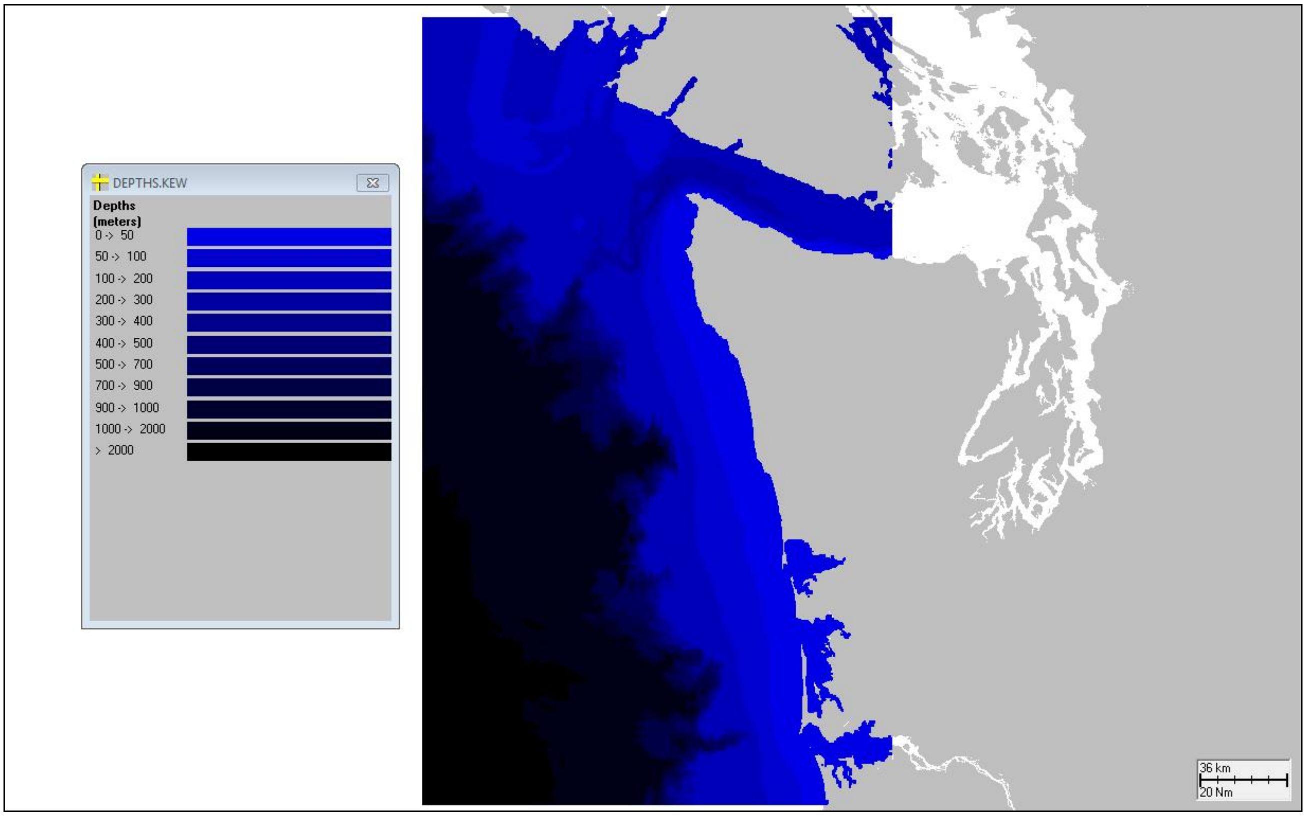

Figure A-18. Depth grid developed for the Washington/Oregon region.

Table A-12. Dimensions of the habitat grid cells used to compile statistics for Washington/Oregon model runs.

Habitat grid	OC_SL_HAB-DEPTH.HAB
Grid W edge	126^{o} 13.958'W
Grid S edge	46^{o} 0.085' N
Cell size (^{o} longitude)	0.0031^{o} W
Cell size (^{o} latitude)	0.0031^{o} N
Cell size (m) west-east	236.87
Cell size (m) south-north	340.99
# cells west-east	875
# cells south-north	993
Water cell area (m^2)	80,769.68
Shore cell length (m)	284.20
Shore cell width – Rocky shore (m)	3.0
Shore cell width – Artificial shore (m)	0.1
Shore cell width – Gravel beach (m)	4.0
Shore cell width – Sand beach (m)	15.0
Shore cell width – Mud flat (m)	210.0
Shore cell width – Wetlands (fringing, m)	210.0

<u>Currents</u>

A barotropic hydrodynamic model, HYDROMAP (Isaji et al., 2002) was used to obtain the depth-averaged tidal currents for this region. HYDROMAP is a globally re-locatable hydrodynamic model, capable of simulating complex circulation patterns due to tidal forcing and wind stress. HYDROMAP operates over a spatially-nested, rectangular grid that may have up to six step-wise changes in resolution in the horizontal plane. The spatial nesting capability allows the model resolution to step up as land or complex bathymetry is approached. The spatial nesting of the grid provided the hydrodynamic model with a good resolution on the offshore and a fine resolution near the coast, especially in Grays Harbor, Grays Bay, and Willapa Bay. The grid used in this study consisted of 22,200 active water cells, with cell size varying from 5 km x 5 km in the offshore to about 625 m x 625 m near the coast. The tidal forcing for the 5 major harmonic constituents (M2, S2, N2, K1, and O1), derived from the Global Ocean Tidal Model (TPOX5.1) developed at the Oregon State University (Egbert et al., 1994) was applied along the offshore open boundaries.

Seasonal components (climatic winter and summer) of the offshore currents for the present study were assembled from results of the three-dimensional hydrodynamic simulations from a high-resolution global ocean circulation model, Parallel Ocean Program (POP). The time-averaged daily outputs of the results from POP, for the global ocean at a horizontal resolution of 1/6 degree, forced by observed temperature and wind stress during 1985-1995 (Maltrud et al., 1998) was used to obtain the seasonally averaged currents used in the present study. The seasonal currents thus assembled from POP compared well with a schematic of the large-scale boundary currents off the U.S. West Coast given in Hickey (1998).

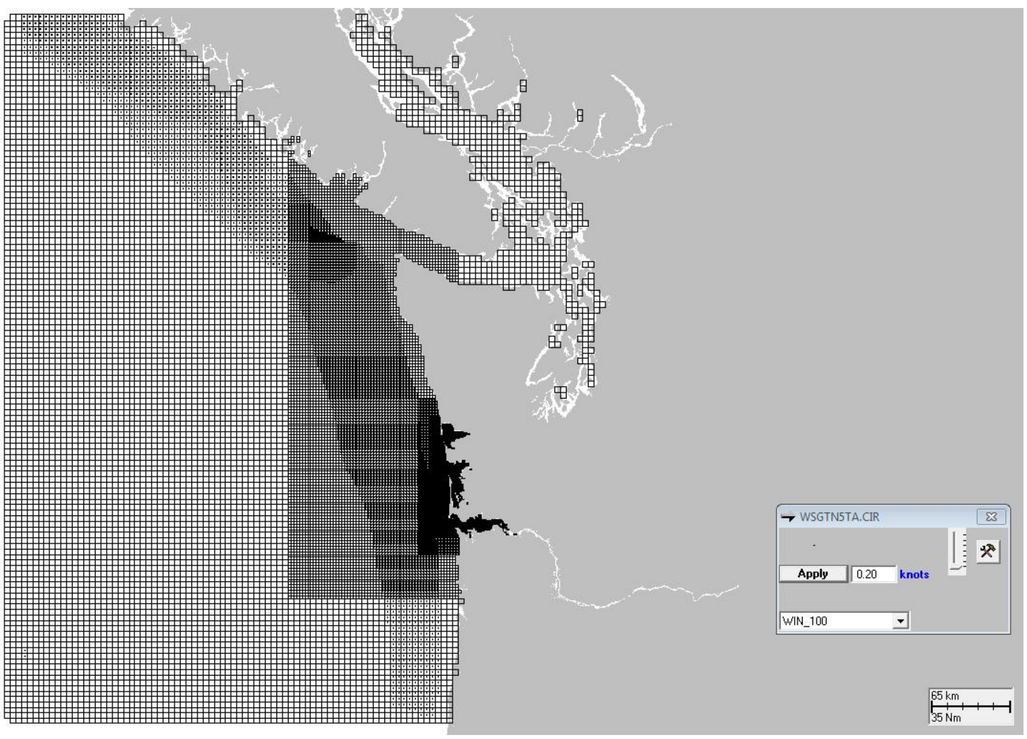

Figure A-19. Extent of current data used in modeling for the Washington/Oregon region.

<u>Winds</u>

Standard meteorological data were acquired from the NDBC Internet site for the nearest NDBC buoy with sufficient records, number 46041, "Cape Elizabeth," at 47.353°N, 124.731°W. Hourly mean wind speed and direction for the time period 6/9/1987 to 12/31/2004 were compiled in the SIMAP model input file format.

<u>Spill Sites</u>

Spill sites for the Washington/Oregon region were randomly distributed within a portion of the Washington/Oregon Planning Area (Figure A-20). The delineation between the nearshore and offshore spill areas was based on the 200 meter depth contour. One hundred spill sites were placed within the nearshore area, and one hundred spill sites were placed within the offshore area. The coordinates of these points are provided in Tables A-13 and A-14.

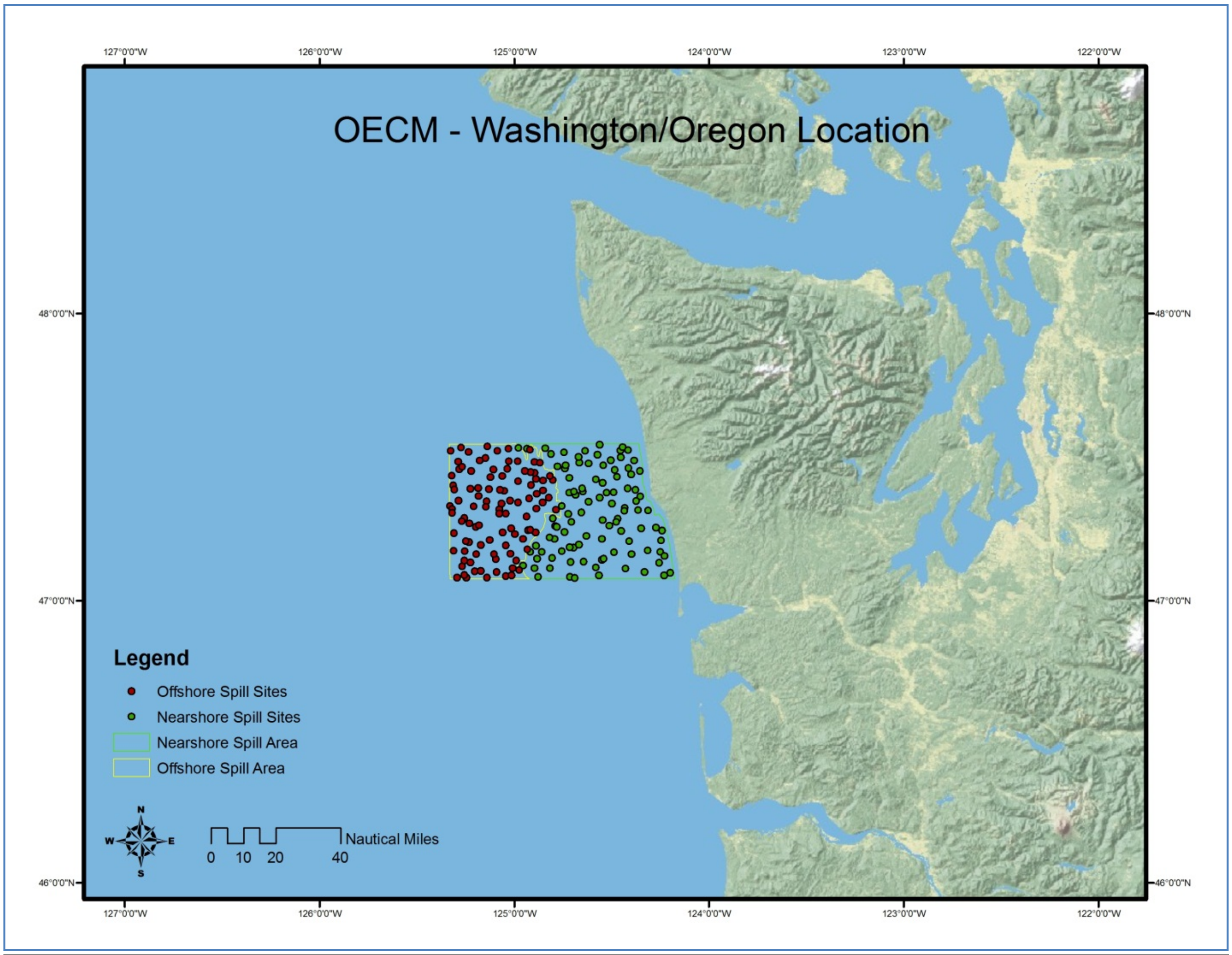

Figure A-20. Spill sites developed for the Washington/Oregon region.

Table A-13. Washington/Oregon nearshore spill sites.

Spill Site #	Latitude	Longitude

Spill Site #	Latitude	Longitude
1	47.51954	-124.74392
2	47.14469	-124.55124
3	47.46402	-124.74055
4	47.11469	-124.81603
5	47.25659	-124.27336
6	47.21658	-124.79418
7	47.43057	-124.71784
8	47.53395	-124.97780
9	47.17453	-124.75512
10	47.13653	-124.71076
11	47.52575	-124.45525
12	47.42527	-124.58143
13	47.09871	-124.19774
14	47.10118	-124.33207
15	47.30507	-124.72367
16	47.26208	-124.78960
17	47.18656	-124.69440
18	47.51110	-124.57377
19	47.31630	-124.31316
20	47.53642	-124.44312
21	47.34097	-124.49943
22	47.24598	-124.24019
23	47.17088	-124.85868
24	47.53256	-124.84121
25	47.37855	-124.71731
26	47.16981	-124.48679
27	47.37001	-124.68517
28	47.34961	-124.37346
29	47.47395	-124.54357
30	47.37838	-124.52586
31	47.28832	-124.46899
32	47.48241	-124.66634
33	47.38187	-124.69296
34	47.28275	-124.54693
35	47.24095	-124.74290
36	47.32572	-124.43238
37	47.08979	-124.56549
38	47.30931	-124.65400
39	47.21679	-124.55065
40	47.50408	-124.67038
41	47.26376	-124.51271
42	47.51419	-124.81133
43	47.46457	-124.41277
44	47.22730	-124.62976
45	47.34764	-124.61915
46	47.44336	-124.40071
47	47.17141	-124.91648

Spill Site #	Latitude	Longitude
48	47.49186	-124.50514
49	47.37913	-124.49046
50	47.08402	-124.71409
51	47.46960	-124.77871
52	47.27661	-124.47534
53	47.17651	-124.31404
54	47.08410	-124.87745
55	47.31544	-124.43371
56	47.50229	-124.45415
57	47.38204	-124.64668
58	47.11327	-124.42872
59	47.08097	-124.68835
60	47.36195	-124.56128
61	47.27598	-124.70540
62	47.12388	-124.95523
63	47.38922	-124.37773
64	47.17085	-124.25009
65	47.14845	-124.54034
66	47.49019	-124.38492
67	47.16394	-124.39779
68	47.11732	-124.58139
69	47.45876	-124.48375
70	47.33145	-124.75647
71	47.19720	-124.66769
72	47.25480	-124.34857
73	47.52473	-124.63568
74	47.43333	-124.47281
75	47.52730	-124.41498
76	47.26007	-124.78190
77	47.14743	-124.88243
78	47.39370	-124.65059
79	47.18840	-124.71570
80	47.47344	-124.73762
81	47.53234	-124.93523
82	47.28916	-124.80094
83	47.13418	-124.25604
84	47.15643	-124.22940
85	47.24532	-124.45071
86	47.54648	-124.56244
87	47.45479	-124.35502
88	47.48023	-124.61887
89	47.13718	-124.64353
90	47.22228	-124.81857
91	47.41307	-124.54564
92	47.39449	-124.41689
93	47.36500	-124.35267
94	47.11463	-124.89561

Spill Site #	Latitude	Longitude
95	47.20847	-124.40985
96	47.19336	-124.88976
97	47.08966	-124.23142
98	47.31746	-124.36319
99	47.15100	-124.80461
100	47.21148	-124.24550

Table A-14. Washington/Oregon offshore spill sites.

Spill Site #	Latitude	Longitude
1	47.33123	-125.32982
2	47.10728	-124.97417
3	47.28993	-125.25624
4	47.45446	-125.22185
5	47.46040	-125.28207
6	47.44767	-124.89719
7	47.27879	-125.26936
8	47.20694	-125.23301
9	47.31911	-124.78539
10	47.46825	-125.26655
11	47.10385	-125.20255
12	47.25398	-125.01548
13	47.21701	-124.95518
14	47.18103	-124.93181
15	47.38567	-124.85259
16	47.40459	-125.31313
17	47.34821	-125.14237
18	47.52441	-125.32582
19	47.30554	-125.04369
20	47.20840	-125.24732
21	47.14190	-124.98866
22	47.32051	-125.07793
23	47.40507	-124.91441
24	47.12075	-125.26664
25	47.29508	-124.93681
26	47.08208	-125.13957
27	47.48809	-125.02683
28	47.11455	-125.00904
29	47.32316	-124.88726
30	47.45105	-124.91517
31	47.43287	-125.12307
32	47.38469	-125.05274
33	47.24016	-124.89041
34	47.42193	-124.80174
35	47.43725	-125.32122
36	47.39183	-125.13110
37	47.38879	-125.07291
38	47.10170	-125.08943

Spill Site #	Latitude	Longitude
39	47.32986	-125.14581
40	47.24814	-124.92950
41	47.24030	-125.05951
42	47.27156	-125.23168
43	47.25922	-125.19778
44	47.43632	-124.81578
45	47.08127	-125.24699
46	47.23331	-124.99669
47	47.48611	-124.89601
48	47.53634	-125.27324
49	47.48257	-124.86831
50	47.52805	-124.91932
51	47.36678	-125.18274
52	47.43669	-125.06113
53	47.42066	-124.85287
54	47.53127	-125.02871
55	47.16405	-125.19430
56	47.39476	-125.18604
57	47.48679	-125.28779
58	47.08680	-125.04200
59	47.34051	-125.06537
60	47.14713	-125.09410
61	47.19553	-125.17268
62	47.53995	-125.13768
63	47.39196	-125.22588
64	47.41776	-124.97983
65	47.17424	-125.25464
66	47.08206	-125.29426
67	47.19512	-125.04331
68	47.52045	-125.23509
69	47.45400	-124.94670
70	47.09146	-125.25534
71	47.50001	-125.14747
72	47.35104	-125.02156
73	47.49080	-125.17734
74	47.34455	-124.85385
75	47.42650	-124.88815
76	47.52405	-125.08651
77	47.36182	-124.82298
78	47.24873	-124.91653
79	47.16307	-125.10354
80	47.34474	-124.98050
81	47.33097	-125.20805
82	47.38952	-125.30719
83	47.32093	-125.31789
84	47.37445	-124.88461
85	47.45945	-125.10720

Spill Site #	Latitude	Longitude
86	47.30859	-125.31901
87	47.10459	-125.17208
88	47.35076	-125.28658
89	47.16434	-125.01922
90	47.21292	-125.12637
91	47.46187	-125.03605
92	47.30620	-125.07710
93	47.48807	-124.98131
94	47.35945	-124.92376
95	47.13437	-125.22563
96	47.14106	-125.25651
97	47.09007	-125.01457
98	47.23720	-125.30891
99	47.26415	-125.18111
100	47.17534	-125.31137

Gulf of Alaska

<u>Habitat Grid</u>

The digital shoreline, shore type, and habitat mapping for the Gulf of Alaska region were obtained from the ESI Atlas databases for Prince William Sound, Cook Inlet, and Southeast Alaska compiled for the state of Alaska by Research Planning, Inc. (RPI). These data are distributed by NOAA Hazmat (Seattle, WA).

Bathymetry data were available from bathymetric contours contained within the GEBCO Digital Atlas (GEBCO, 2003).

The gridded habitat and depth data are shown in Figures A-21 and A-22.

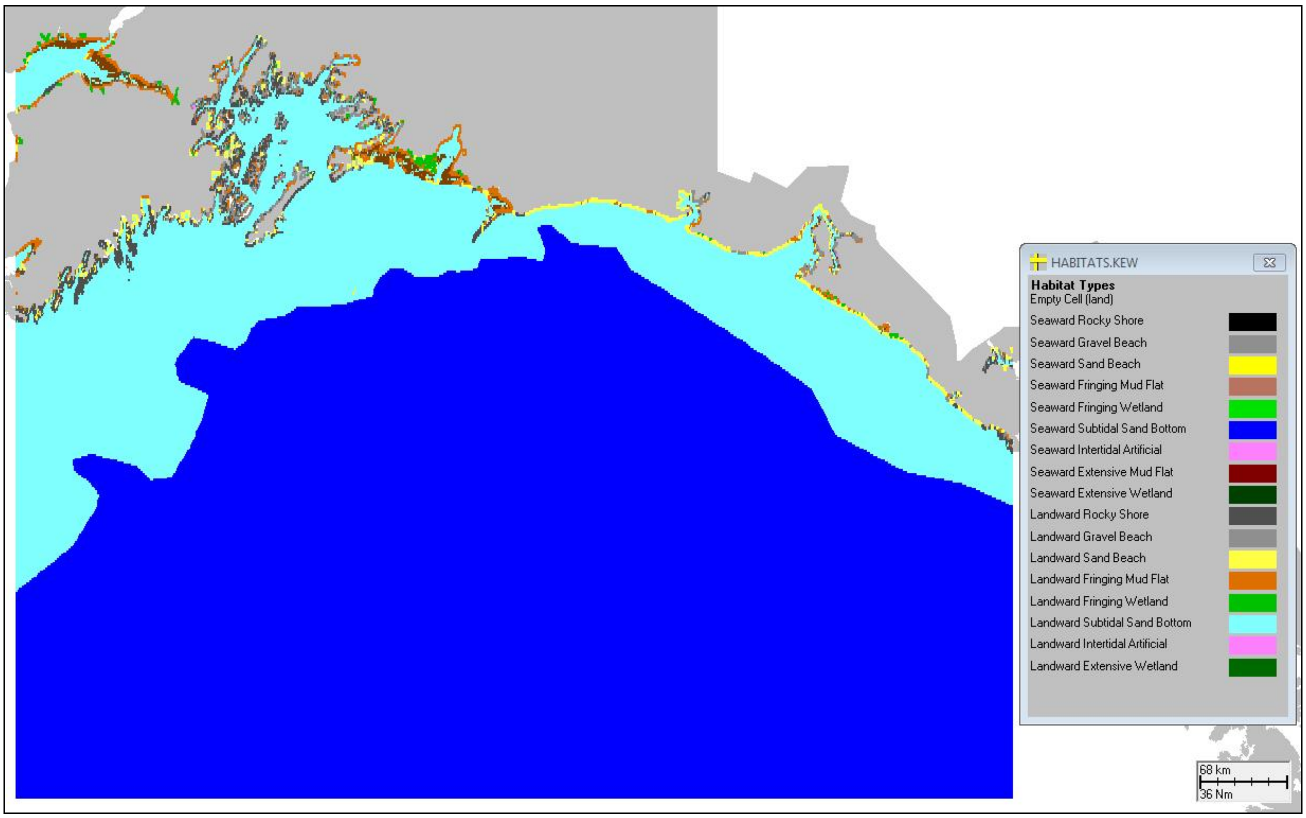

Figure A-21. Habitat grid developed for the Gulf of Alaska region.

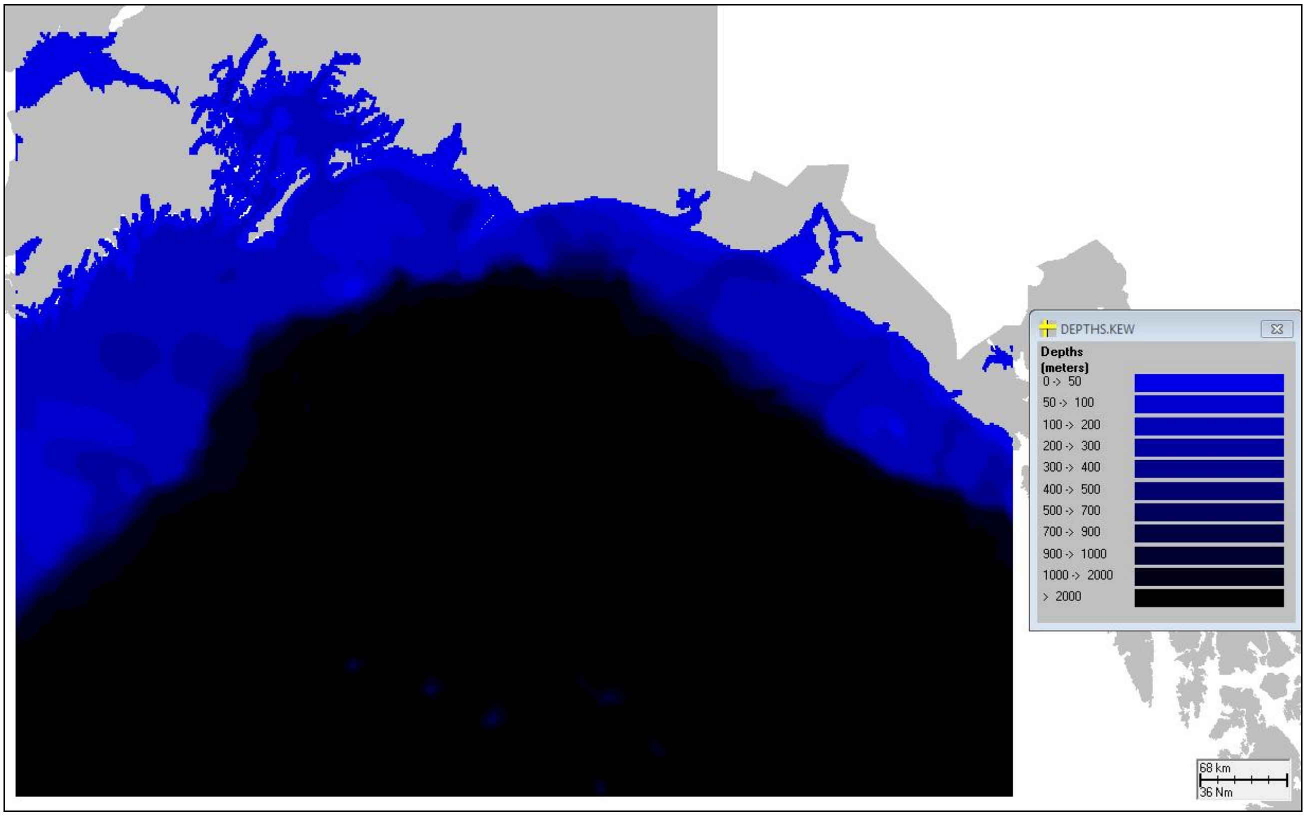

Figure A-22. Depth grid developed for the Gulf of Alaska region.

Table A-15. Dimensions of the habitat grid cells used to compile statistics for Gulf of Alaska model runs.

Habitat grid	OECM-GULFOFAK.HAB
Grid W edge	151° 17.549'W
Grid S edge	55° 26.991' N
Cell size (° longitude)	0.0147° W
Cell size (° latitude)	0.0147° N
Cell size (m) west-east	926.39
Cell size (m) south-north	1,633.48
# cells west-east	992
# cells south-north	397
Water cell area (m^2)	1,513,233.25
Shore cell length (m)	1,230.14
Shore cell width – Rocky shore (m)	3.0
Shore cell width – Artificial shore (m)	0.1
Shore cell width – Gravel beach (m)	6.0
Shore cell width – Sand beach (m)	20.0
Shore cell width – Mud flat (m)	300.0
Shore cell width – Wetlands (fringing, m)	300.0

Currents

Currents were based on outputs from the NEP ROMS oceanographic model jointly developed by the National Marine Fisheries Service (NMFS), Pacific Marine Environmental Laboratory (PMEL) and the University Washington (http://www.pmel.noaa.gov/people/dobbins/nep3/index.html#details). NEP ROMS is a 3-dimensional (3D) oceanographic model based on the Regional Oceanographic Modeling System (Haidvogel et al., 2000) and covers the northeast Pacific with a terrain-following finite difference grid of 42 vertical levels and horizontal grid spacing of approximately 10 km. The program host provided ASA surface (layer 1) velocities subset for the period January 1997 to June 2003.

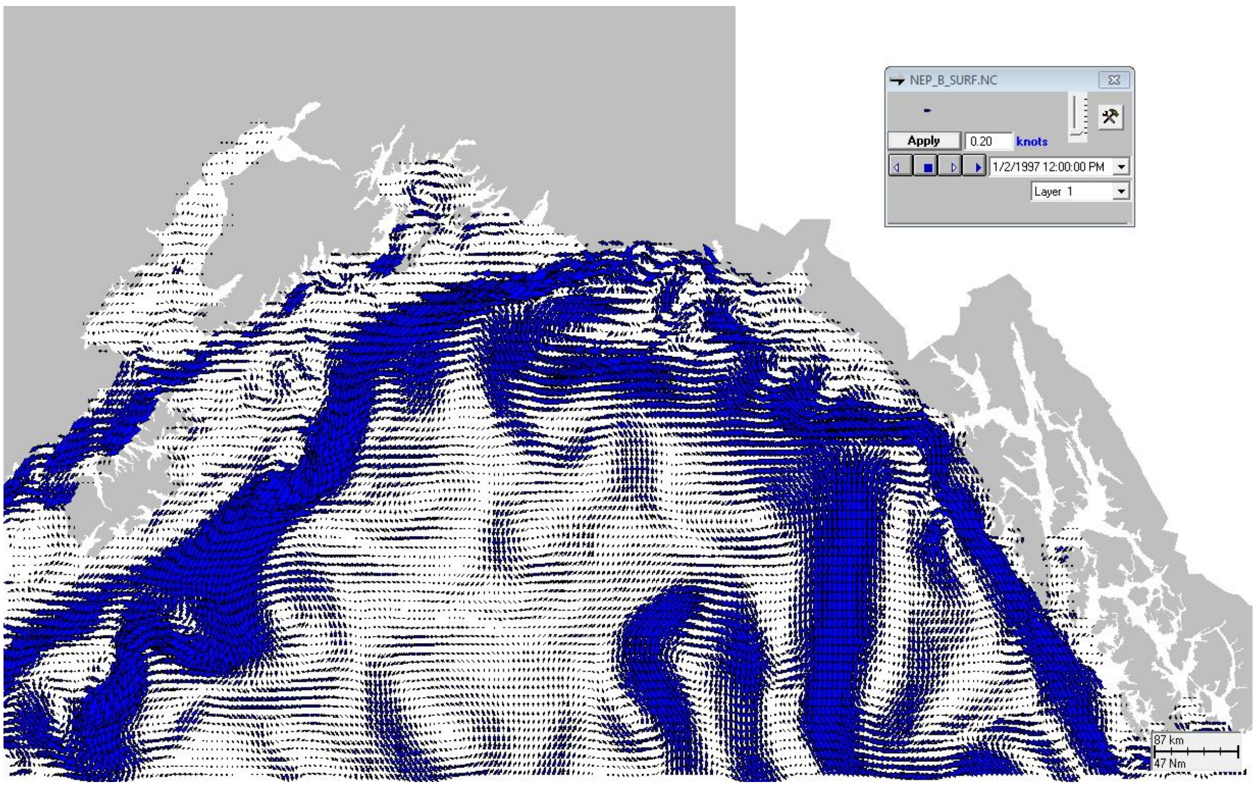

Figure A-23. Example current component data used in modeling for the Gulf of Alaska region. Vector length indicates speed in the indicated direction.

Winds

Standard meteorological data were acquired from the NDBC Internet site for the nearest NDBC buoys with sufficient records:

- 46001, "Gulf of Alaska," at 56.300°N, 148.021°W;
- 46080, "Northwest Gulf," at 58.035°N, 149.994°W;
- 46082, "Cape Suckling," at 59.688°N, 143.399°W; and
- 46083, "Fairweather Grounds," at 58.243°N, 137.993°W.

For station 46001, hourly mean wind speed and direction for the time period 6/1/1997 to 5/31/2003 were compiled in the SIMAP model input file format. The other three stations used for this location had sufficient wind records, but did not have data for all the years encompassed by the time-stamped currents file. To extend the wind records to match the currents, we used data from later years as a proxy for the missing earlier years, as described below.

For station 46080, the original wind record was late 2002-2009, so data for years 2004-2009 were relabeled as 1997-2002 (original data were used for year 2003). That is, data for years 2004, 2005, 2006, 2007, 2008, and 2009 were relabeled as years 1997, 1998, 1999, 2000, 2001, and 2002, respectively. Hourly mean wind speed and direction for the time period 7/9/1997 to 6/1/2003 were then compiled in the SIMAP model input file format.

For stations 46082 and 46083, data from years 2004-2009 were relabeled as 1997-2002 (original data was used for year 2003). Hourly mean wind speed and direction for the time period 6/1/1997 to 6/1/2003 were then compiled in the SIMAP model input file format.

Spill Sites

Spill sites for the Gulf of Alaska region were randomly distributed within a representative portion of the Gulf of Alaska Planning Area (Figure A-24). The delineation between the nearshore and offshore spill areas was based on the 200 meter depth contour. Twenty-five spill sites were placed within the nearshore area, and twenty-five spill sites were placed within the offshore area. The coordinates of these points are provided in Tables A-16 and A-17.

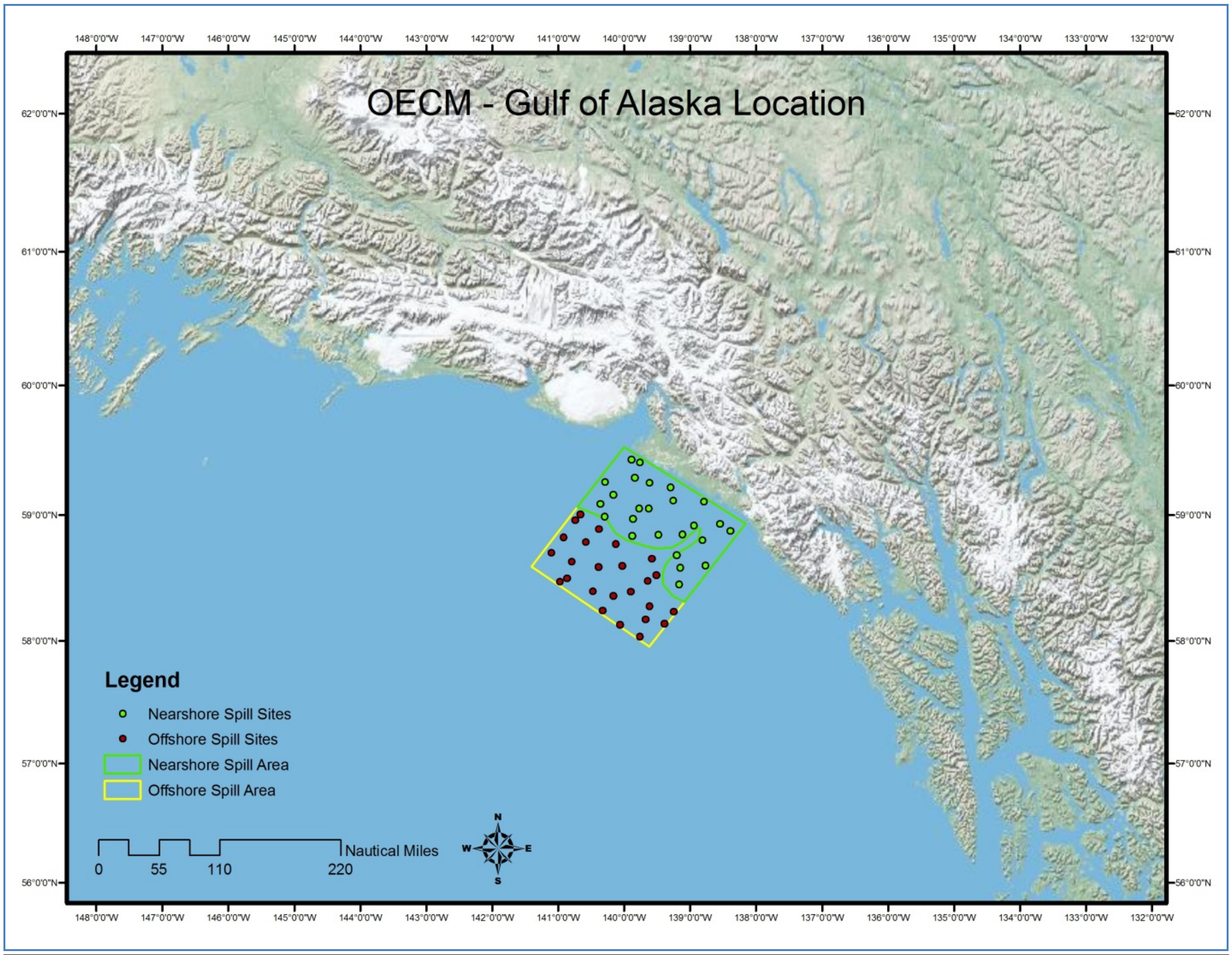

Figure A-24. Spill sites developed for the Gulf of Alaska region.

Table A-16. Gulf of Alaska nearshore spill sites.

Spill Site #	Latitude	Longitude
1	59.25638	-140.28613
2	59.05296	-139.62432
3	58.84889	-139.11253
4	58.60369	-138.76499
5	58.58578	-139.14629
6	59.05238	-139.76825
7	59.40949	-139.75890
8	58.84560	-139.48058
9	59.43231	-139.88639
10	59.10423	-138.78885
11	58.80299	-138.81081
12	58.68438	-139.20439
13	59.21802	-139.29475
14	59.15781	-140.16484
15	58.92961	-138.54802
16	58.83876	-139.87945
17	58.91929	-138.93752

Spill Site #	Latitude	Longitude
18	59.25115	-139.61176
19	58.87416	-138.38803
20	59.08766	-140.35988
21	58.45319	-139.16451
22	59.29274	-139.83694
23	59.11175	-139.25354
24	58.97117	-139.86721
25	58.98738	-140.29472

Table A-17. Gulf of Alaska offshore spill sites.

Spill Site #	Latitude	Longitude
1	58.13984	-139.38958
2	58.77348	-140.12530
3	58.23517	-139.24711
4	58.27960	-139.61293
5	58.47333	-140.97327
6	58.24460	-140.32702
7	58.95843	-140.74139
8	58.39584	-139.89962
9	58.52728	-139.51145
10	58.17358	-139.67521
11	58.59186	-140.38587
12	58.13068	-140.06509
13	58.65782	-139.57738
14	59.00662	-140.66443
15	58.36217	-140.16284
16	58.39703	-140.47164
17	58.70253	-141.10434
18	58.78795	-140.58091
19	58.03546	-139.76069
20	58.48011	-139.64262
21	58.63312	-140.79054
22	58.88851	-140.38132
23	58.50026	-140.86414
24	58.59998	-140.02921
25	58.82478	-140.91625

Cook Inlet/Shelikof Strait

<u>Habitat Grid</u>

The digital shoreline, shore type, and habitat mapping for the Cook Inlet/Shelikof Strait region were obtained from the ESI Atlas databases for Aleutians, Bristol Bay, Cook Inlet, Kodiak, Prince William Sound and Western Alaska compiled for the state of Alaska by Research Planning, Inc. (RPI). These data are distributed by NOAA Hazmat (Seattle, WA).

Bathymetry data were available from bathymetric contours contained within the GEBCO Digital Atlas (GEBCO, 2003).

The gridded habitat and depth data are shown in Figures A-25 and A-26.

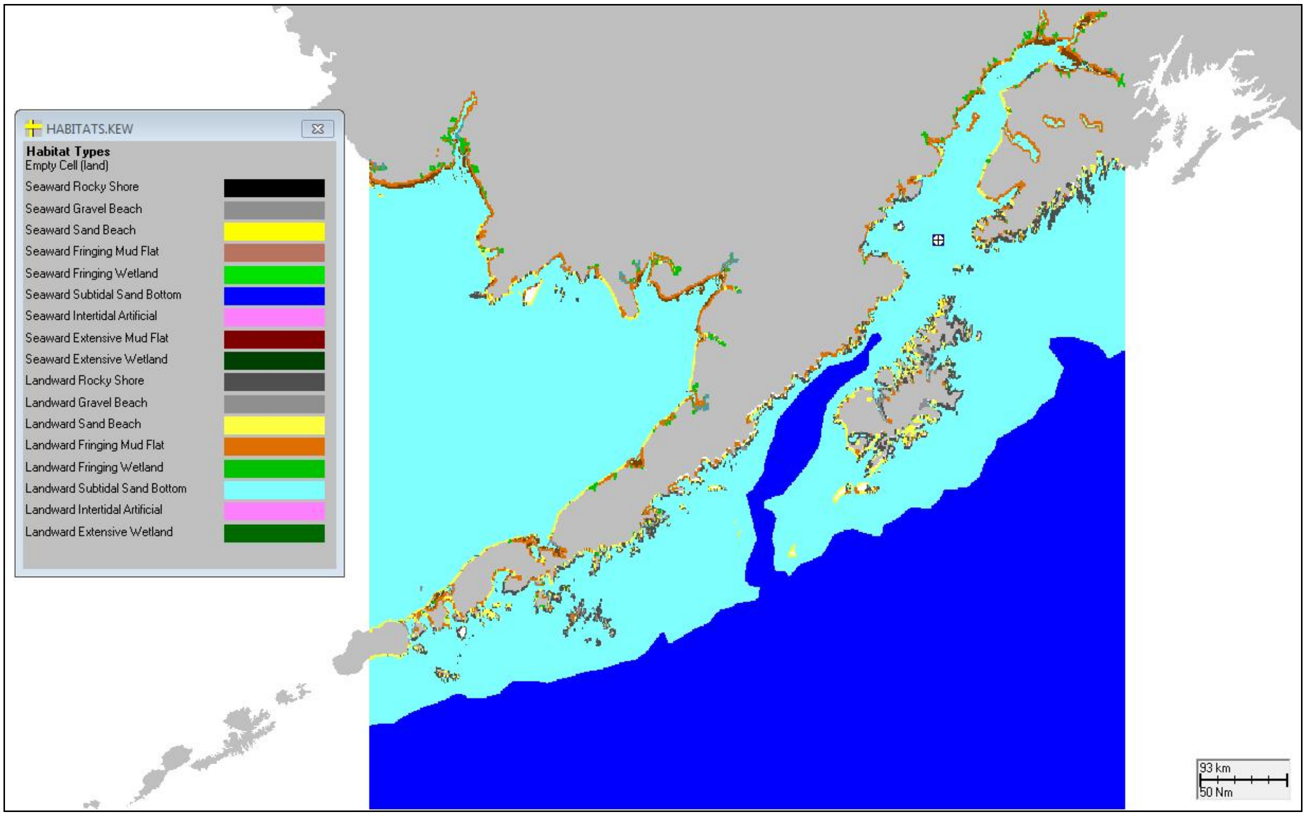

Figure A-25. Habitat grid developed for the Cook Inlet/Shelikof Strait region.

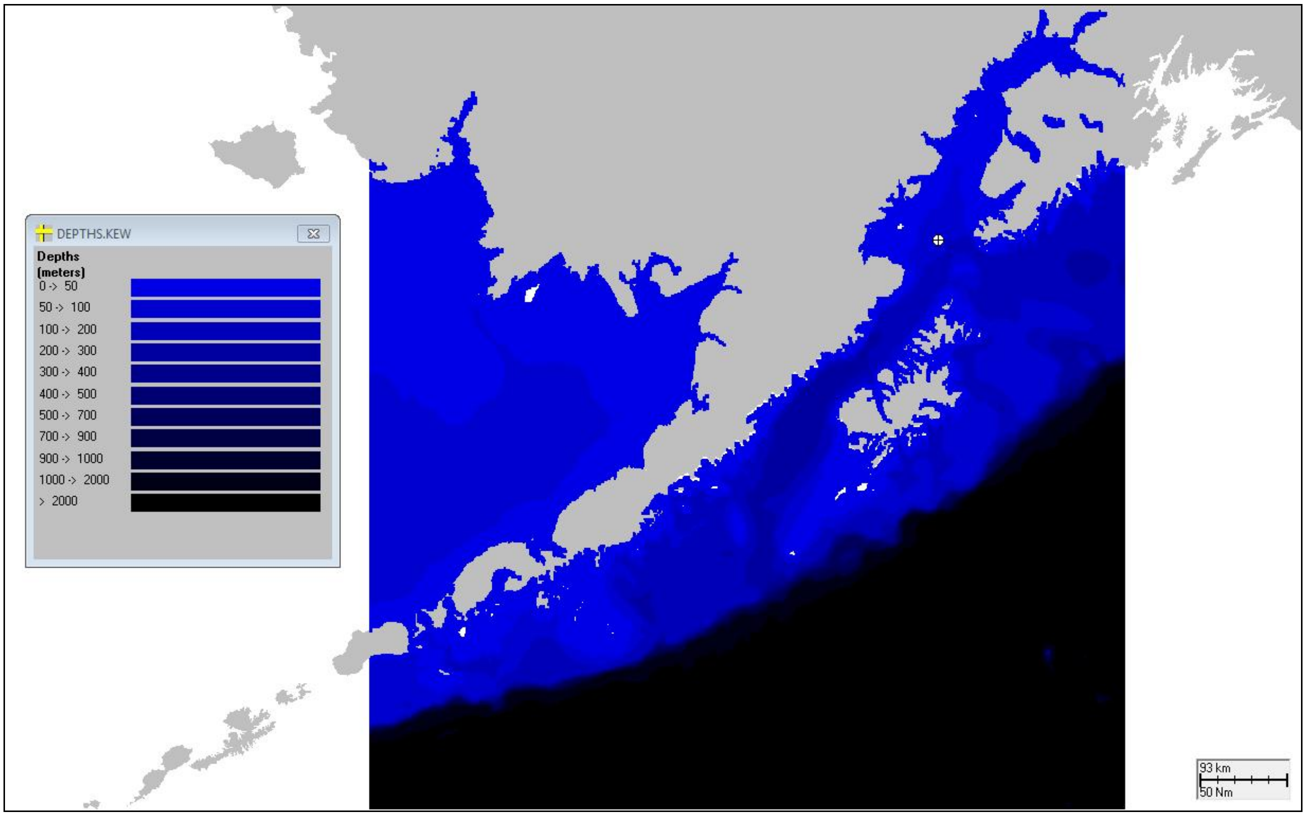

Figure A-26. Depth grid developed for the Cook Inlet/Shelikof Strait region.

Table A-18. Dimensions of the habitat grid cells used to compile statistics for Cook Inlet/Shelikof Strait model runs.

Habitat grid	OECM-COOKINLET.HAB
Grid W edge	164^{o} 11.938’W
Grid S edge	52^{o} 47.926’ N
Cell size (^{o} longitude)	0.0154^{o} W
Cell size (^{o} latitude)	0.0154^{o} N
Cell size (m) west-east	1,034.47
Cell size (m) south-north	1,710.95
# cells west-east	993
# cells south-north	566
Water cell area (m^2)	1,769,930.75
Shore cell length (m)	1,330.39
Shore cell width – Rocky shore (m)	3.0
Shore cell width – Artificial shore (m)	0.1
Shore cell width – Gravel beach (m)	6.0
Shore cell width – Sand beach (m)	20.0
Shore cell width – Mud flat (m)	300.0
Shore cell width – Wetlands (fringing, m)	300.0

<u>Currents</u>

Currents were based on outputs from the NEP ROMS oceanographic model jointly developed by NMFS, PMEL and the University Washington (http://www.pmel.noaa.gov/people/dobbins/nep3/index.html#details). NEP ROMS is a 3-dimensional (3D) oceanographic model based on the Regional Oceanographic Modeling System (Haidvogel et al., 2000) and covers the northeast Pacific with a terrain-following finite difference grid of 42 vertical levels and horizontal grid spacing of ~10 km. The program host provided ASA surface (layer 1) velocities subset for the period January 1997 to June 2003.

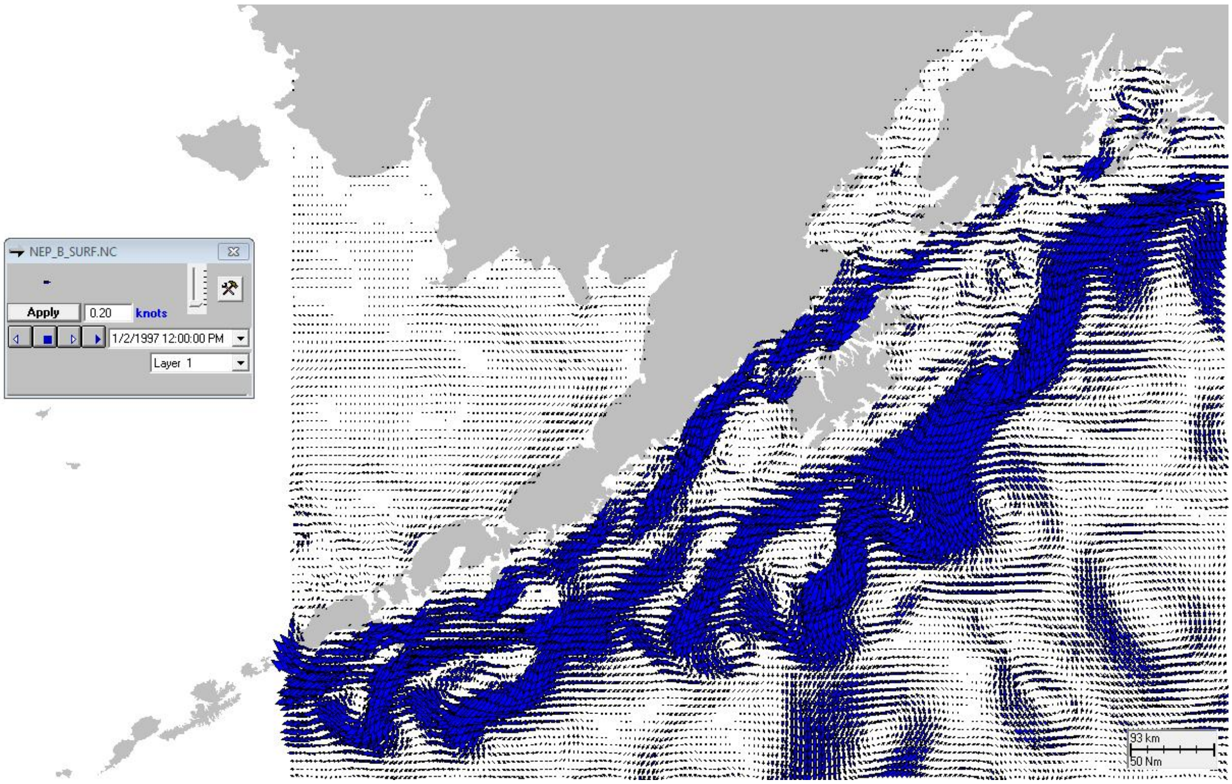

Figure A-27. Example current component data used in modeling for the Cook Inlet/Shelikof Strait region. Vector length indicates speed in the indicated direction.

<u>Winds</u>

Standard meteorological data were acquired from the NDBC Internet site for the nearest NDBC buoys/meteorological stations with sufficient records:

- 46080, "Northwest Gulf," at 58.035°N, 149.994°W;
- AUGA2, "Augustine Island," at 59.378°N, 153.348°W; and
- DRFA2, "Drift River Terminal," at 60.533°N, 152.137°W.

These three stations used for this location had sufficient wind records, but did not have data for all the years encompassed by the time-stamped currents file. To extend the wind records to match the currents, we used data from later years as a proxy for the missing earlier years, as described below.

For station 46080, the original wind record was late 2002-2009, so data for years 2004-2009 were relabeled as 1997-2002 (original data were used for year 2003). That is, data for years 2004, 2005, 2006, 2007, 2008, and 2009 were relabeled as years 1997, 1998, 1999, 2000, 2001, and 2002, respectively. Hourly mean wind speed and direction for the time period 7/9/1997 to 6/1/2003 were then compiled in the SIMAP model input file format.

For stations AUGA2 and DRFA2, data for years 2004-2006 were relabeled as years 1997-1999 (original data were used for years 2000-2003). Hourly mean wind speed and direction for the time period 6/1/1997 to 6/1/2003 were then compiled in the SIMAP model input file format.

Spill Sites

Spill sites for the Cook Inlet/Shelikof Strait region were randomly distributed within the entirety of the Cook Inlet Planning Area/Proposed Final Program Area (2007-2012) (Figure A-28). Twenty-five spill sites were placed within the spill area; the coordinates of these points are provided in Table A-19.

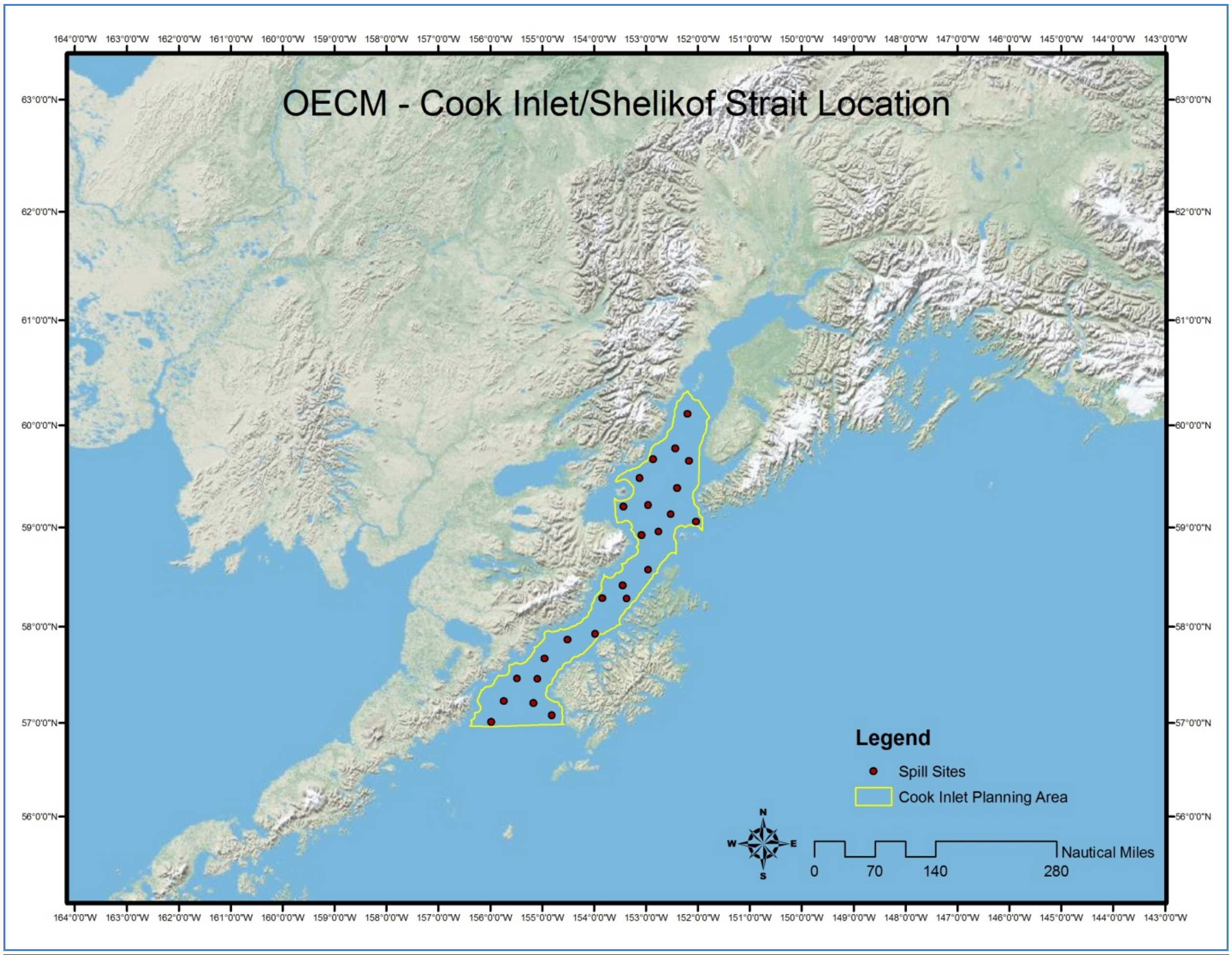

Figure A-28. Spill sites developed for the Cook Inlet/Shelikof Strait region.

Table A-19. Cook Inlet/Shelikof Strait spill sites.

Spill Site #	Latitude	Longitude
1	57.20782	-155.16895
2	59.67250	-152.86635
3	59.22465	-152.95397
4	59.39124	-152.39976
5	59.65776	-152.17027
6	59.20755	-153.43753
7	57.66893	-154.95491
8	57.08036	-154.81524
9	58.57756	-152.95397
10	57.01014	-155.98131
11	59.05936	-152.03583
12	57.22846	-155.73861
13	59.78027	-152.43599
14	58.95866	-152.75387
15	58.42016	-153.44840
16	58.92738	-153.08662
17	58.28740	-153.84528
18	57.92627	-153.98005
19	57.46068	-155.09342
20	57.86392	-154.51652
21	60.11031	-152.20362
22	58.28420	-153.37415
23	59.48858	-153.12071
24	57.46238	-155.48558
25	59.13050	-152.52043

Bering Sea

Habitat Grid

The digital shoreline, shore type, and habitat mapping for the Bering Sea region were obtained from the ESI Atlas databases for Aleutians, Bristol Bay and Western Alaska compiled for the state of Alaska by Research Planning, Inc. (RPI). These data are distributed by NOAA Hazmat (Seattle, WA).

Bathymetry data were available from bathymetric contours contained within the GEBCO Digital Atlas (GEBCO, 2003).

The gridded habitat and depth data are shown in Figures A-29 and A-30.

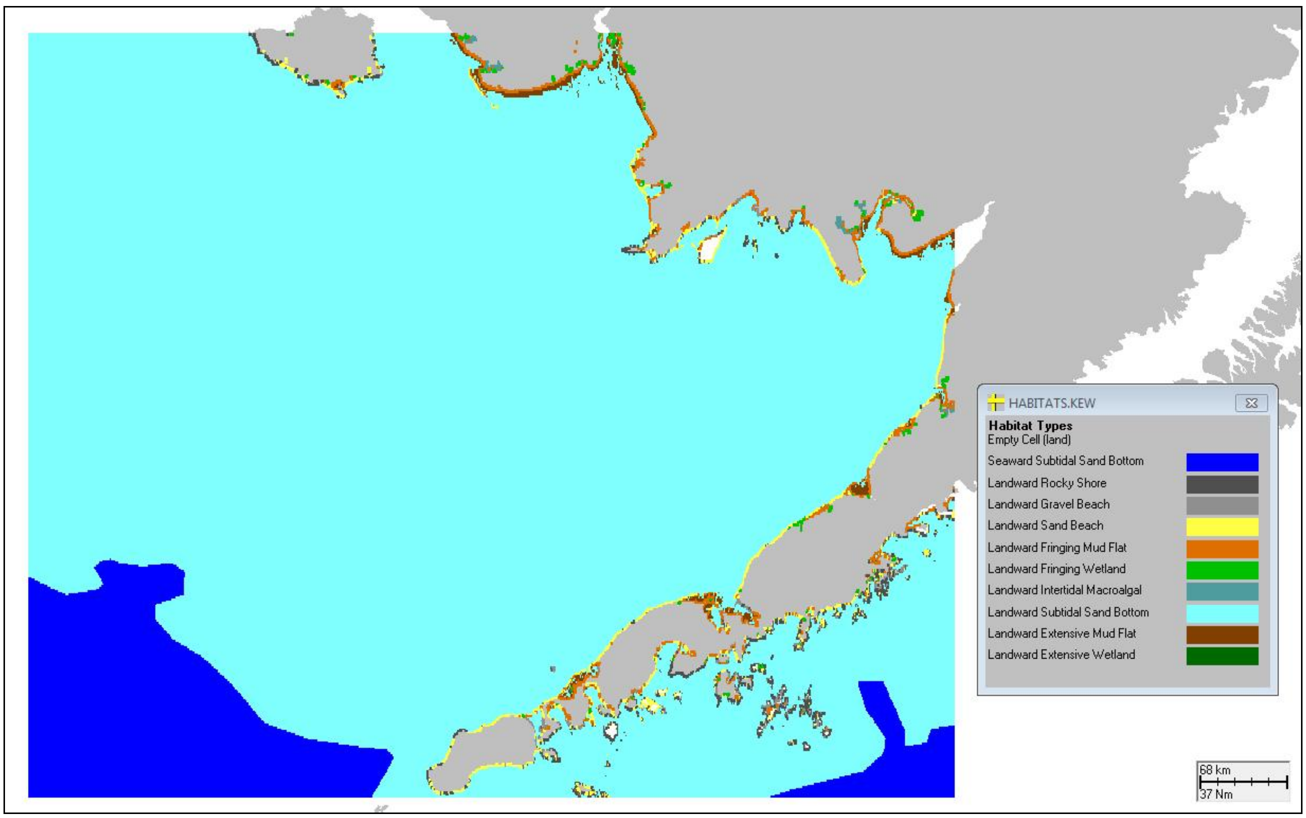

Figure A-29. Habitat grid developed for the Bering Sea region.

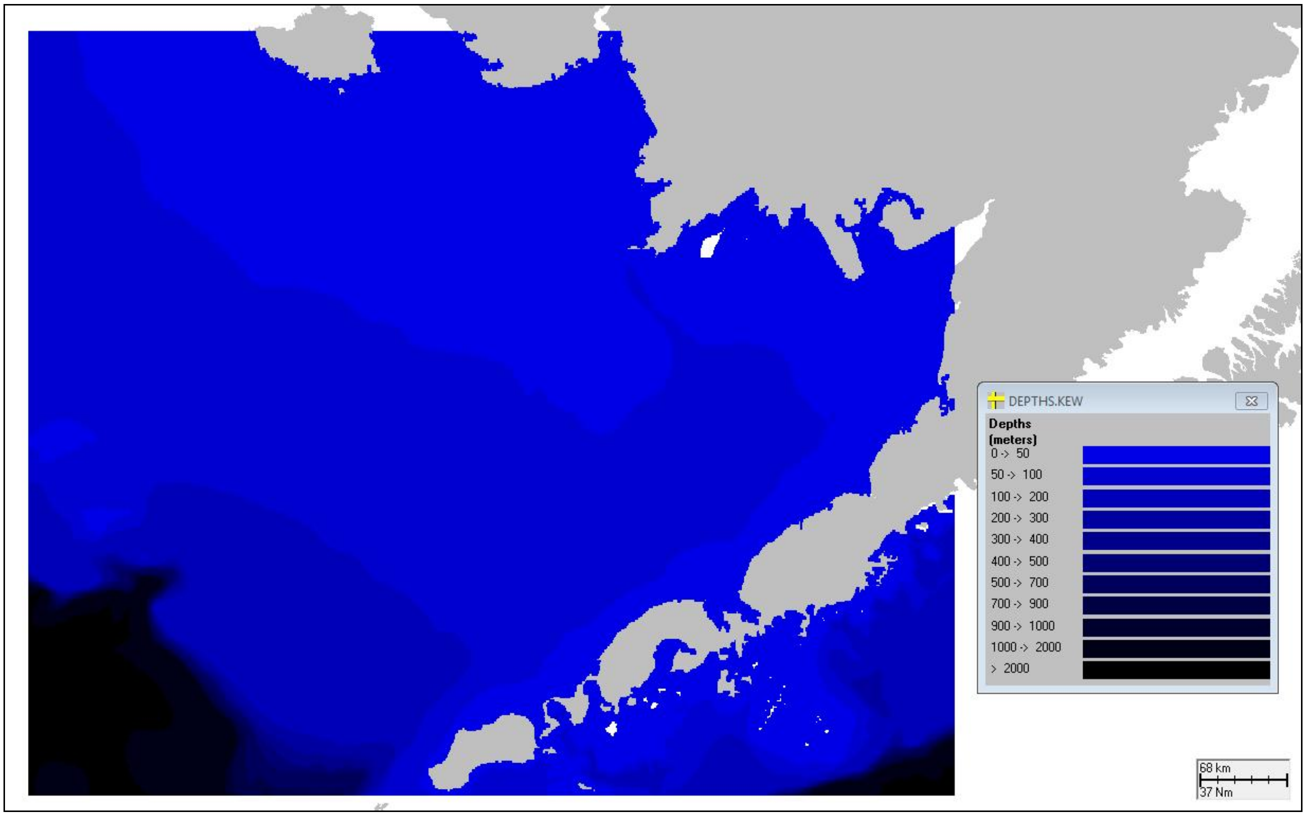

Figure A-30. Depth grid developed for the Bering Sea region.

Table A-20. Dimensions of the habitat grid cells used to compile statistics for Bering Sea model runs.

Habitat grid	OECM-BERING.HAB
Grid W edge	170^{o} 35.380’W
Grid S edge	54^{o} 22.155’ N
Cell size (^{o} longitude)	0.0132^{o} W
Cell size (^{o} latitude)	0.0132^{o} N
Cell size (m) west-east	853.89
Cell size (m) south-north	1,465.76
# cells west-east	994
# cells south-north	442
Water cell area (m^2)	1,251,591.62
Shore cell length (m)	1,118.75
Shore cell width – Rocky shore (m)	3.0
Shore cell width – Artificial shore (m)	0.1
Shore cell width – Gravel beach (m)	6.0
Shore cell width – Sand beach (m)	20.0
Shore cell width – Mud flat (m)	300.0
Shore cell width – Wetlands (fringing, m)	300.0

<u>Currents</u>

Currents were based on outputs from the NEP ROMS oceanographic model jointly developed by NMFS, PMEL and the University Washington (http://www.pmel.noaa.gov/people/dobbins/nep3/index.html#details). NEP ROMS is a 3-dimensional (3D) oceanographic model based on the Regional Oceanographic Modeling System (Haidvogel et al., 2000) and covers the northeast Pacific with a terrain-following finite difference grid of 42 vertical levels and horizontal grid spacing of ~10 km. The program host provided ASA surface (layer 1) velocities subset for the period January 1997 to June 2003.

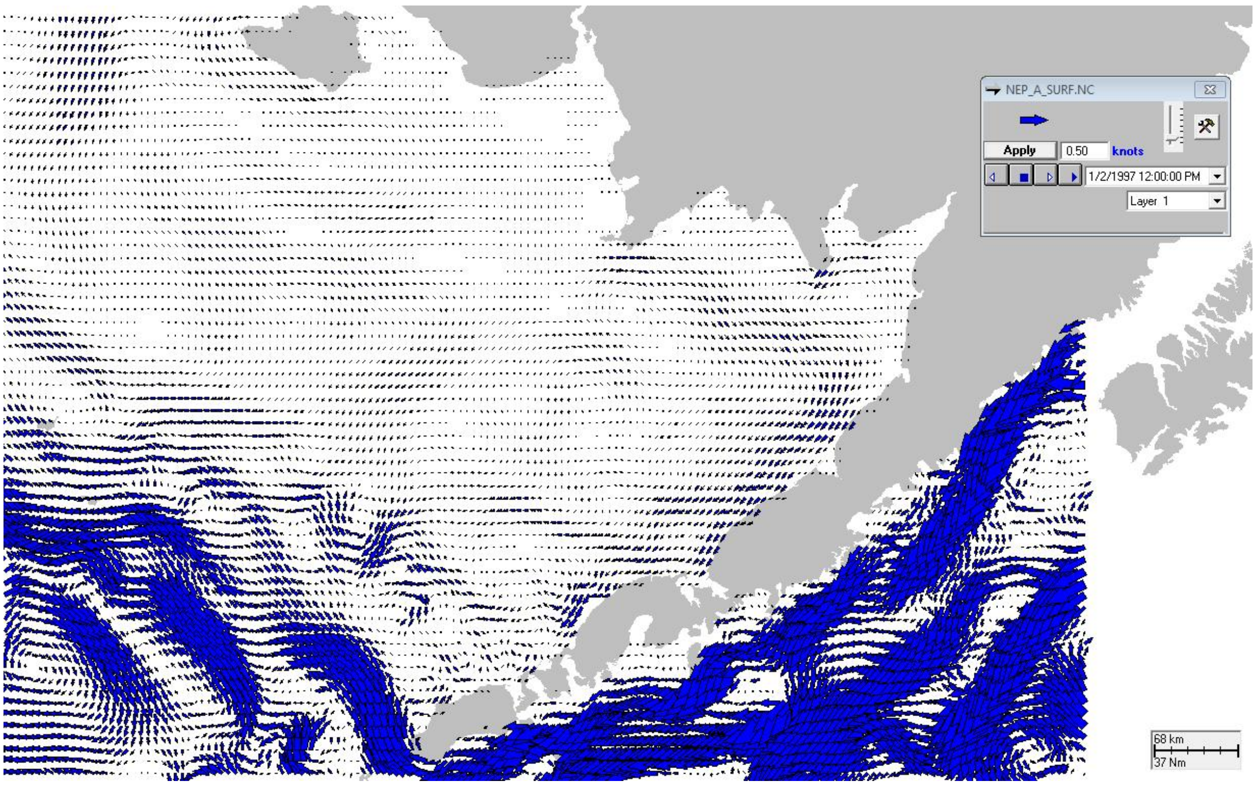

Figure A-31. Example current component data used in modeling for the Bering Sea region. Vector length indicates speed in the indicated direction.

Winds

Sufficient historical buoy records were not available for this region, so standard meteorological data were acquired from the National Climatic Data Center Internet site for the nearest weather observation stations, Cold Bay Airport at 55.2166°N, 162.7333°W, and St. Paul Island Airport at 57.1666°N, 170.2166°W. Hourly mean wind speed and direction for the time period 6/1/1997 to 6/1/2003 were compiled in the SIMAP model input file format.

Spill Sites

Spill sites for the Bering Sea region were randomly distributed within the entirety of the North Aleutian Basin Proposed Final Program Area (2007-2012) (Figure A-32). Twenty spill sites were placed within the spill area; the coordinates of these points are provided in Table A-21.

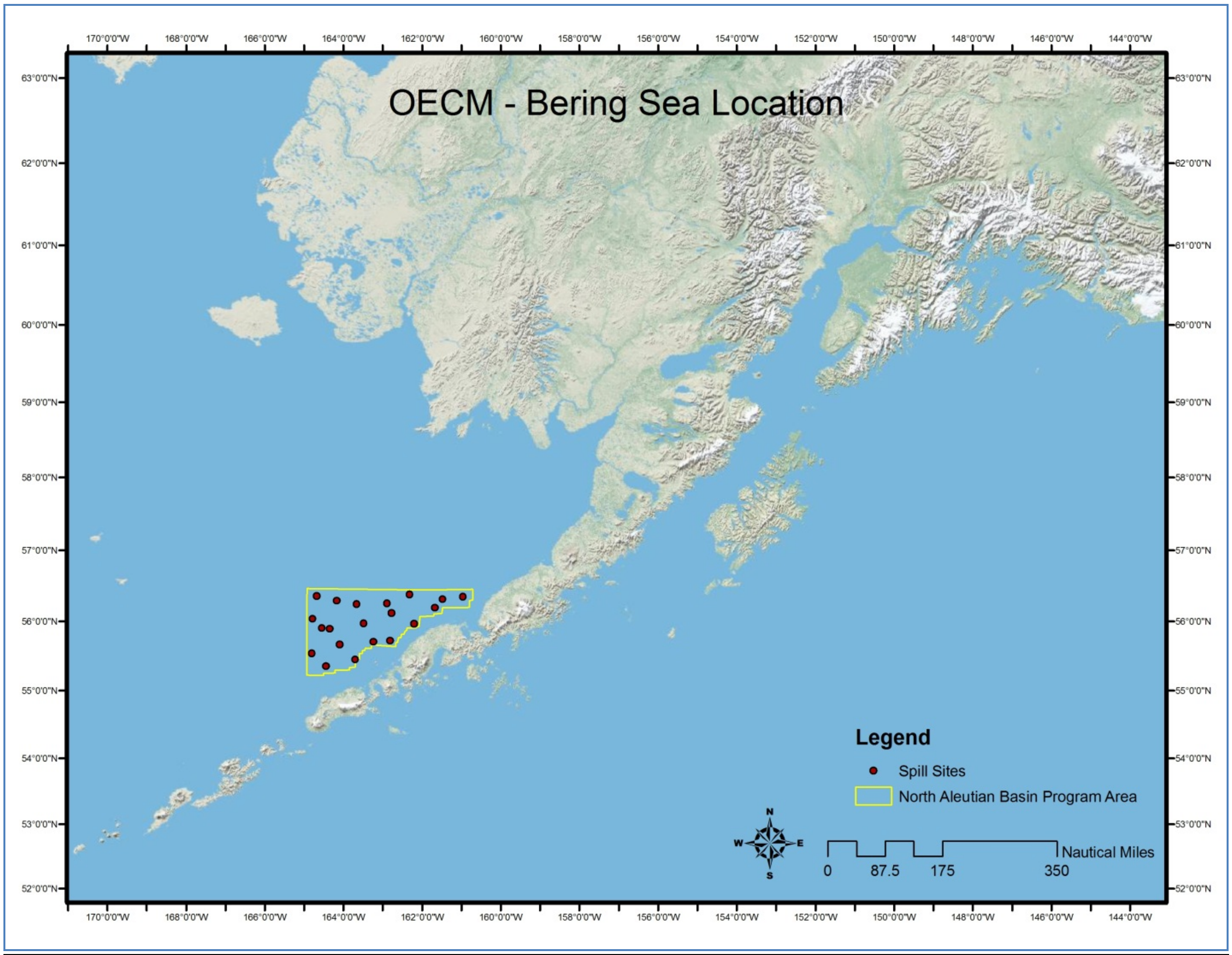

Figure A-32. Spill sites developed for the Bering Sea region.

Table A-21. Bering Sea spill sites.

Spill Site #	Latitude	Longitude
1	55.89743	-164.35828
2	55.71157	-163.23842
3	56.25903	-162.89722
4	56.31636	-161.47658
5	56.19551	-161.68012
6	56.03558	-164.78367
7	55.90328	-164.55477
8	55.35427	-164.44818
9	56.38417	-162.31786
10	56.11979	-162.78089
11	55.54512	-164.80593

Spill Site #	Latitude	Longitude
12	56.36158	-164.67885
13	56.24949	-163.66265
14	55.45074	-163.70036
15	56.35405	-160.96096
16	55.66995	-164.09538
17	56.29373	-164.17680
18	55.96789	-162.20930
19	55.72360	-162.81991
20	55.97550	-163.48478

Chukchi Sea

<u>Habitat Grid</u>

The digital shoreline, shore type, and habitat mapping for the Chukchi Sea region were obtained from the Northwest Arctic and North Slope ESI Atlas databases compiled for the state of Alaska by Research Planning, Inc. (RPI). These data are distributed by NOAA Hazmat (Seattle, WA).

Depth data were based on soundings available from the NOAA NOS Hydrographic Survey Data (NOAA, 2009). Soundings were interpolated on to the model grid for areas where the depth data were missing.

The gridded habitat and depth data are shown in Figures A-33 and A-34.

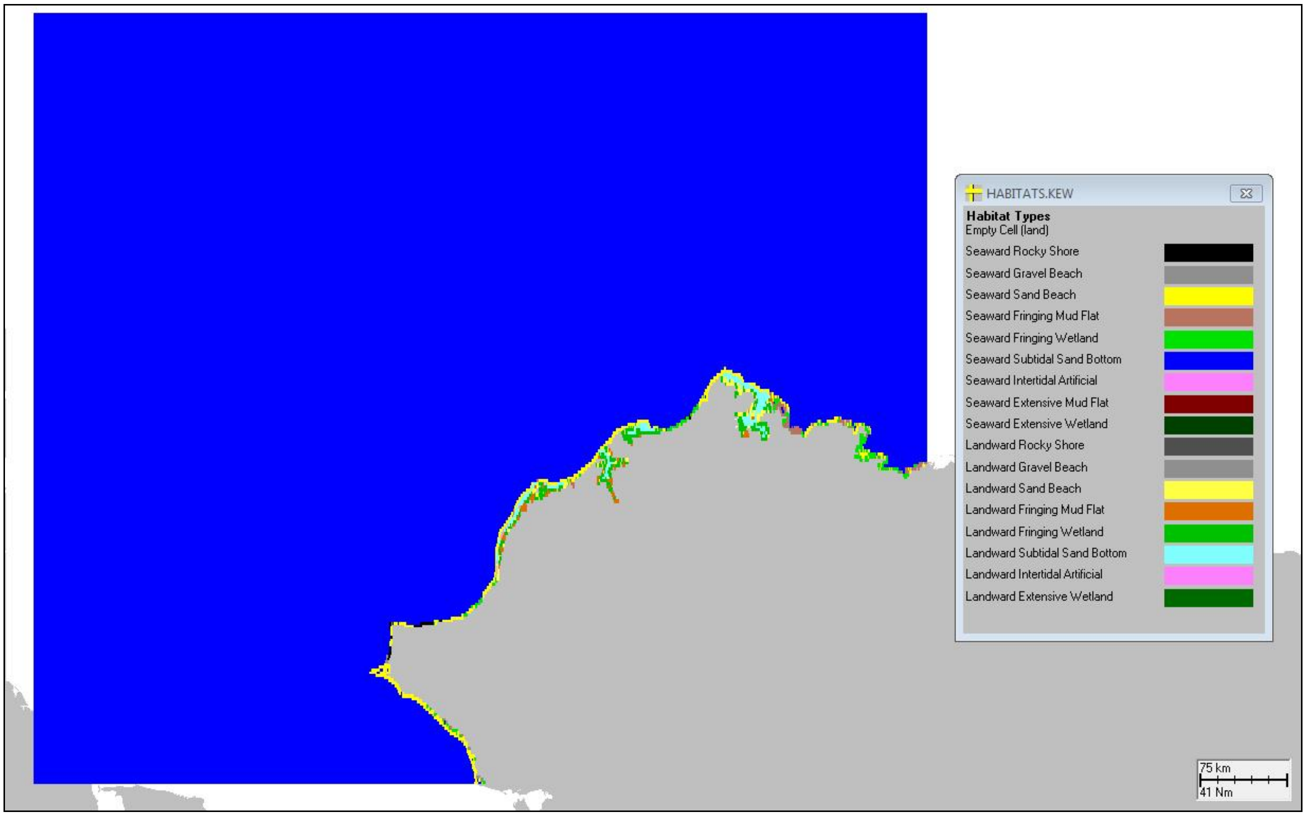

Figure A-33. Habitat grid developed for the Chukchi Sea region.

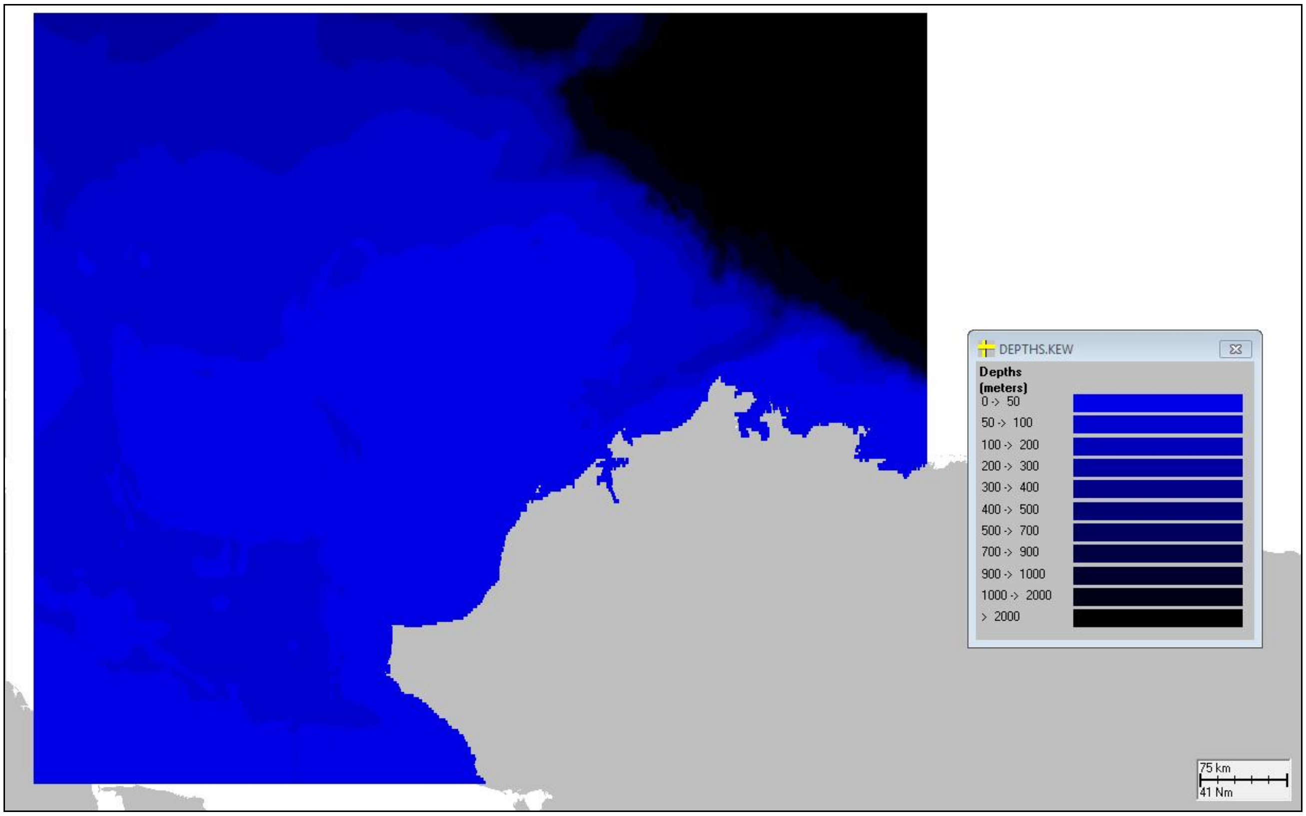

Figure A-34. Depth grid developed for the Chukchi Sea region.

Table A-22. Dimensions of the habitat grid cells used to compile statistics for Chukchi Sea model runs.

Habitat grid	CHUKCHI-OECM_HABS.HAB
Grid W edge	176° 36.041’W
Grid S edge	67° 7.309’ N
Cell size (° longitude)	0.029° W
Cell size (° latitude)	0.029° N
Cell size (m) west-east	1,249.73
Cell size (m) south-north	3,214.56
# cells west-east	898
# cells south-north	252
Water cell area (m^2)	4,017,342.25
Shore cell length (m)	2,004.33
Shore cell width – Rocky shore (m)	3.0
Shore cell width – Artificial shore (m)	0.1
Shore cell width – Gravel beach (m)	6.0
Shore cell width – Sand beach (m)	20.0
Shore cell width – Mud flat (m)	300.0
Shore cell width – Wetlands (fringing, m)	300.0

<u>Currents</u>

Currents were based on data from BOEM's annual means analysis of the Haidvogel, Hedstrom and Francis (2001) coupled ice-ocean model. Offshore of the 10- to 20-meter bathymetry contour, the wind-driven and density-induced ocean-flow fields and the ice-motion fields are simulated using a three-dimensional coupled ice-ocean hydrodynamic model (Haidvogel, Hedstrom, and Francis, 2001). The model is based on the ocean model of Haidvogel, Wilkin, and Young (1991) and the ice models of Hibler (1979) and Mellor and Kantha (1989). This model simulates flow properties and sea ice evolution in the western Arctic during the years 1982-1996. The coupled system uses the S-Coordinate Rutgers University Model (SCRUM) and Hibler viscous-plastic dynamics and the Mellor and Kantha thermodynamics. It is forced by daily surface geostrophic winds and monthly thermodynamic forces. The model is forced by thermal fields for the years 1982-1996. The thermal fields are interpolated in time from monthly fields. The location of each trajectory at each time interval is used to select the appropriate ice concentration. The pack ice is simulated as it grows and melts. The edge of the pack ice is represented on the model grid. Depending on the ice concentration, either the ice or water velocity with wind drift from the stored results of the Haidvogel, Hedstrom and Francis (2001) coupled ice-ocean model is used. A major assumption used in this analysis is that the ice-motion velocities and the ocean daily flows calculated by the coupled ice ocean model adequately represent the flow components. Comparisons with data illustrate that the model captures the first-order transport and the dominant flow (Haidvogel, Hedstrom, and Francis, 2001).

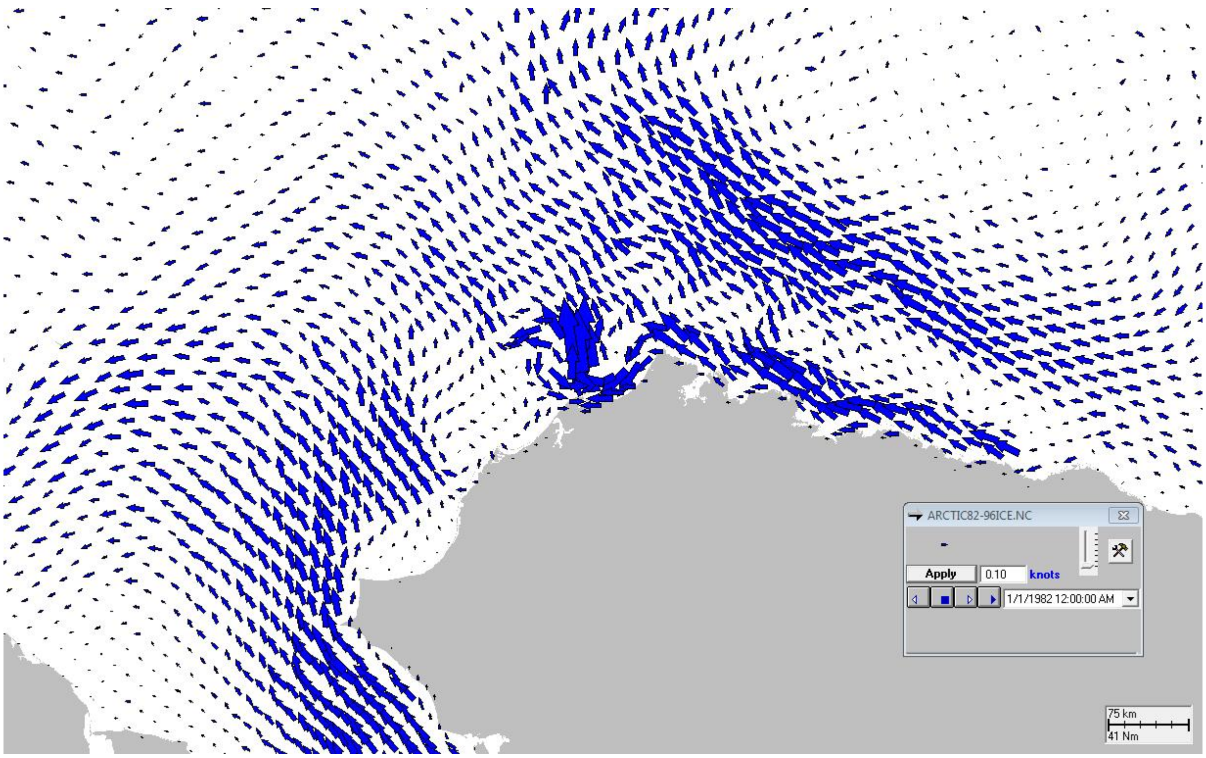

Figure A-35. Example current component data used in modeling for the Chukchi Sea region. Vector length indicates speed in the indicated direction.

<u>Ice</u>

As mentioned above, ice distribution was included in the model analysis and was treated in the same manner as current velocities. The program host provided the model outputs in original binary format. ASA subsequently converted them in to NetCDF format for SIMAP model usage.

Winds

ASA received wind data files that were used to force the coupled ice-ocean model. The period of the wind data extended daily from 1/1/1982 to 12/31/1996. ASA subsequently converted them into the SIMAP model input file format.

Spill Sites

Spill sites for the Chukchi Sea region were randomly distributed within the Sale 193 Lease Sale Area, as well as a nearshore spill area between the lease area and shore (Figure A-36). Fifty spill sites were placed within the nearshore spill area, and one hundred spill sites were placed within the offshore spill area. The coordinates of these points are provided in Tables A-23 and A-24.

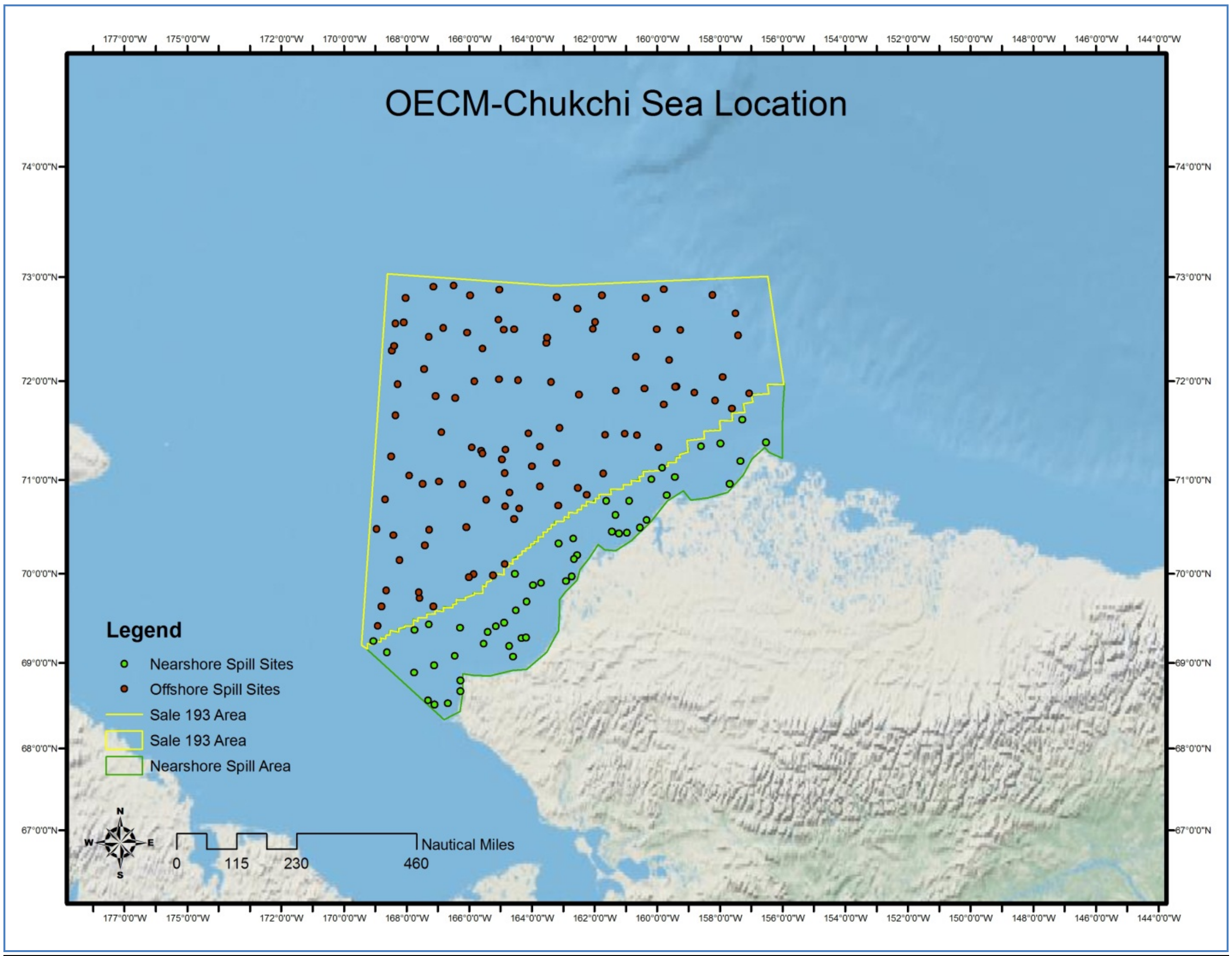

Figure A-36. Spill sites developed for the Chukchi Sea region.

Table A-23. Chukchi Sea nearshore spill sites.

Spill Site #	Latitude	Longitude

Spill Site #	Latitude	Longitude
1	68.80251	-166.28573
2	71.02819	-159.43650
3	71.34568	-158.60270
4	69.87216	-163.96762
5	70.57997	-160.33417
6	68.52057	-167.11132
7	69.45986	-164.88673
8	71.12524	-159.83501
9	69.43817	-167.28959
10	71.19232	-157.34682
11	68.53220	-166.68482
12	70.78150	-160.89181
13	69.21929	-165.53565
14	70.45479	-161.45151
15	70.44305	-160.96306
16	69.28126	-164.32847
17	69.69478	-164.17194
18	70.78138	-161.61954
19	69.08198	-166.46510
20	69.37443	-167.74802
21	70.63369	-161.33107
22	69.12355	-168.62024
23	70.50124	-160.55358
24	69.35443	-165.40538
25	70.83822	-159.69201
26	71.61517	-157.29102
27	68.97434	-167.11750
28	70.96058	-157.69149
29	68.88972	-167.76460
30	70.32692	-163.15407
31	69.91732	-162.91041
32	71.00610	-160.18830
33	71.37710	-157.98790
34	68.67538	-166.28326
35	69.41614	-165.15221
36	69.39960	-166.29136
37	69.89731	-163.71011
38	69.97028	-162.73033
39	70.37986	-162.67941
40	69.29252	-164.19189
41	69.59682	-164.50646
42	70.19909	-162.56209
43	71.38619	-156.52521
44	70.43495	-161.22769
45	70.15946	-162.65819
46	68.57023	-167.31760
47	69.99947	-164.54262

Spill Site #	Latitude	Longitude
48	69.19607	-164.71789
49	69.07496	-164.60936
50	69.24981	-169.06530

Table A-24. Chukchi Sea offshore spill sites.

Spill Site #	Latitude	Longitude
1	71.92936	-160.41165
2	72.43589	-167.28961
3	72.88615	-159.79134
4	71.83674	-166.45084
5	72.82983	-161.76844
6	71.94995	-159.38638
7	72.20713	-159.61815
8	71.45993	-160.64299
9	71.86930	-162.49988
10	70.95694	-166.21624
11	71.90616	-161.31514
12	70.91950	-162.53362
13	72.57356	-168.09370
14	71.07125	-164.86758
15	71.24247	-168.49455
16	71.33546	-165.91325
17	71.46233	-161.66241
18	71.21312	-164.95780
19	72.37240	-163.54577
20	70.14865	-168.22286
21	70.48523	-168.95809
22	72.49724	-159.25866
23	72.01791	-165.05015
24	72.65726	-157.49342
25	70.30754	-167.41901
26	71.99233	-163.38693
27	70.93487	-163.73603
28	70.98280	-166.96406
29	71.30183	-165.62369
30	72.90926	-167.14628
31	72.57767	-161.98319
32	69.81513	-168.64268
33	72.50634	-160.01427
34	71.34174	-163.73638
35	71.27379	-165.57891
36	72.70301	-162.54825
37	72.47364	-166.07357
38	70.72216	-164.85489
39	69.72906	-167.58467
40	70.41722	-168.42607
41	71.88031	-157.05767

Spill Site #	Latitude	Longitude
42	71.97243	-168.27634
43	72.50604	-164.57449
44	70.10337	-164.85982
45	71.85271	-167.07432
46	71.66131	-168.35190
47	71.33480	-159.96276
48	72.01163	-164.44316
49	72.12142	-167.44217
50	70.96090	-167.48849
51	69.63964	-168.80214
52	69.63937	-167.14220
53	72.42569	-163.51771
54	72.92037	-166.49295
55	70.58959	-164.56552
56	71.72754	-157.61223
57	72.24041	-160.68334
58	71.88655	-158.81334
59	72.03956	-157.91582
60	72.50384	-164.90532
61	71.06678	-161.71957
62	70.50225	-166.09321
63	69.99500	-165.85293
64	72.88198	-165.03866
65	72.80670	-168.03689
66	72.50975	-162.04557
67	72.32033	-165.56966
68	70.84432	-162.25083
69	71.53586	-163.11424
70	72.52016	-166.82811
71	71.80884	-158.14457
72	70.86805	-164.71200
73	72.80629	-160.37520
74	72.00042	-165.83125
75	72.45025	-157.41283
76	69.79513	-167.61006
77	69.96372	-166.01639
78	71.77068	-159.78731
79	70.79339	-165.45720
80	71.47257	-161.02885
81	72.59875	-165.06284
82	69.41989	-168.92478
83	72.81331	-163.20682
84	71.47801	-164.11186
85	71.48900	-166.88244
86	71.04396	-167.91722
87	70.70016	-164.39985
88	69.98332	-165.24292

Spill Site #	Latitude	Longitude
89	72.83466	-158.23320
90	70.47644	-167.27234
91	70.79677	-168.68739
92	72.82949	-165.98163
93	71.94684	-159.42457
94	71.13974	-164.00366
95	70.73232	-163.15751
96	71.17573	-163.22685
97	71.31242	-164.83903
98	72.30332	-168.46872
99	72.56200	-168.34908
100	72.34657	-168.40539

Beaufort Sea

<u>Habitat Grid</u>

The digital shoreline, shore type, and habitat mapping for the Beaufort Sea region were obtained from the North Slope ESI Atlas database compiled for the state of Alaska by Research Planning, Inc. (RPI). These data are distributed by NOAA Hazmat (Seattle, WA).

Bathymetry data were available from bathymetric contours contained within the GEBCO Digital Atlas (GEBCO, 2003).

The gridded habitat and depth data are shown in Figures A-37 and A-38.

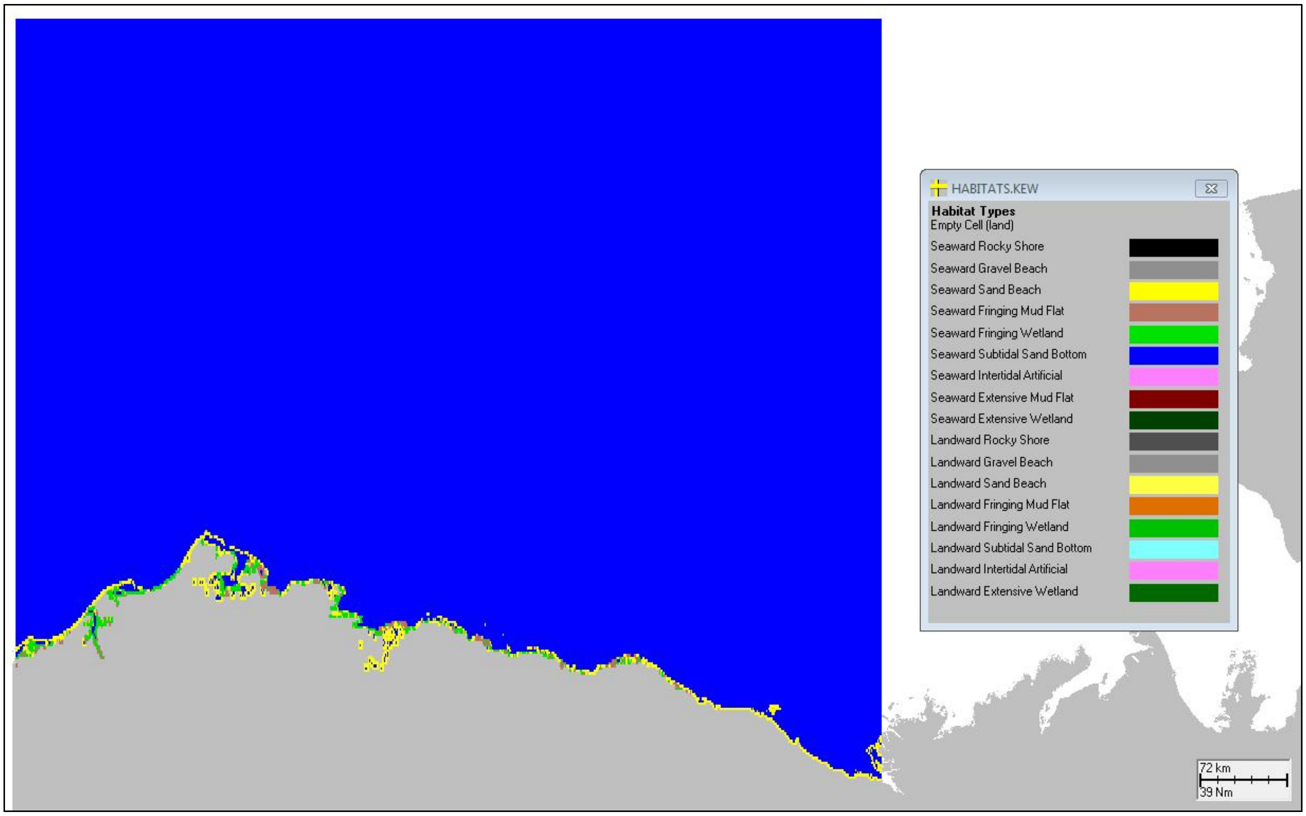

Figure A-37. Habitat grid developed for the Beaufort Sea region.

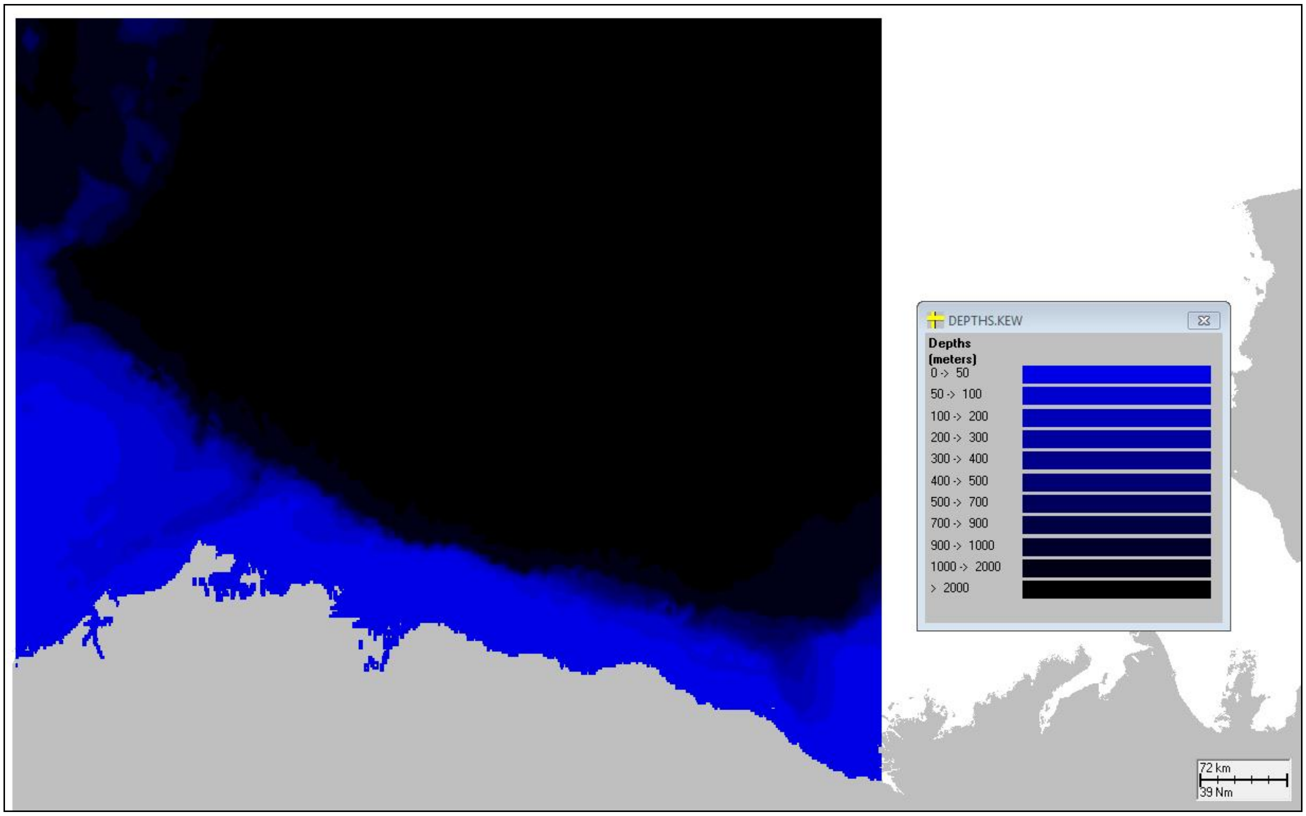

Figure A-38. Depth grid developed for the Beaufort Sea region.

Table A-25. Dimensions of the habitat grid cells used to compile statistics for Beaufort Sea model runs.

Habitat grid	OECM-BEAUFORT.HAB
Grid W edge	162° 17.630'W
Grid S edge	68° 27.172' N
Cell size (° longitude)	0.0267° W
Cell size (° latitude)	0.0267° N
Cell size (m) west-east	1,087.45
Cell size (m) south-north	2,960.93
# cells west-east	992
# cells south-north	275
Water cell area (m^2)	3,219,849.75
Shore cell length (m)	1,794.39
Shore cell width – Rocky shore (m)	3.0
Shore cell width – Artificial shore (m)	0.1
Shore cell width – Gravel beach (m)	6.0
Shore cell width – Sand beach (m)	20.0
Shore cell width – Mud flat (m)	300.0
Shore cell width – Wetlands (fringing, m)	300.0

Currents

Currents were based on data from BOEMRE's annual means analysis of the Haidvogel, Hedstrom and Francis (2001) coupled ice-ocean model. Offshore of the 10- to 20-meter bathymetry contour, the wind-driven and density-induced ocean-flow fields and the ice-motion fields are simulated using a three-dimensional coupled ice-ocean hydrodynamic model (Haidvogel, Hedstrom, and Francis, 2001). The model is based on the ocean model of Haidvogel, Wilkin, and Young (1991) and the ice models of Hibler (1979) and Mellor and Kantha (1989). This model simulates flow properties and sea ice evolution in the western Arctic during the years 1982-1996. The coupled system uses the SCRUM and Hibler viscous-plastic dynamics and the Mellor and Kantha thermodynamics. It is forced by daily surface geostrophic winds and monthly thermodynamic forces. The model is forced by thermal fields for the years 1982-1996. The thermal fields are interpolated in time from monthly fields. The location of each trajectory at each time interval is used to select the appropriate ice concentration. The pack ice is simulated as it grows and melts. The edge of the pack ice is represented on the model grid. Depending on the ice concentration, either the ice or water velocity with wind drift from the stored results of the Haidvogel, Hedstrom and Francis (2001) coupled ice-ocean model is used. A major assumption used in this analysis is that the ice-motion velocities and the ocean daily flows calculated by the coupled ice ocean model adequately represent the flow components. Comparisons with data illustrate that the model captures the first-order transport and the dominant flow (Haidvogel, Hedstrom, and Francis, 2001).

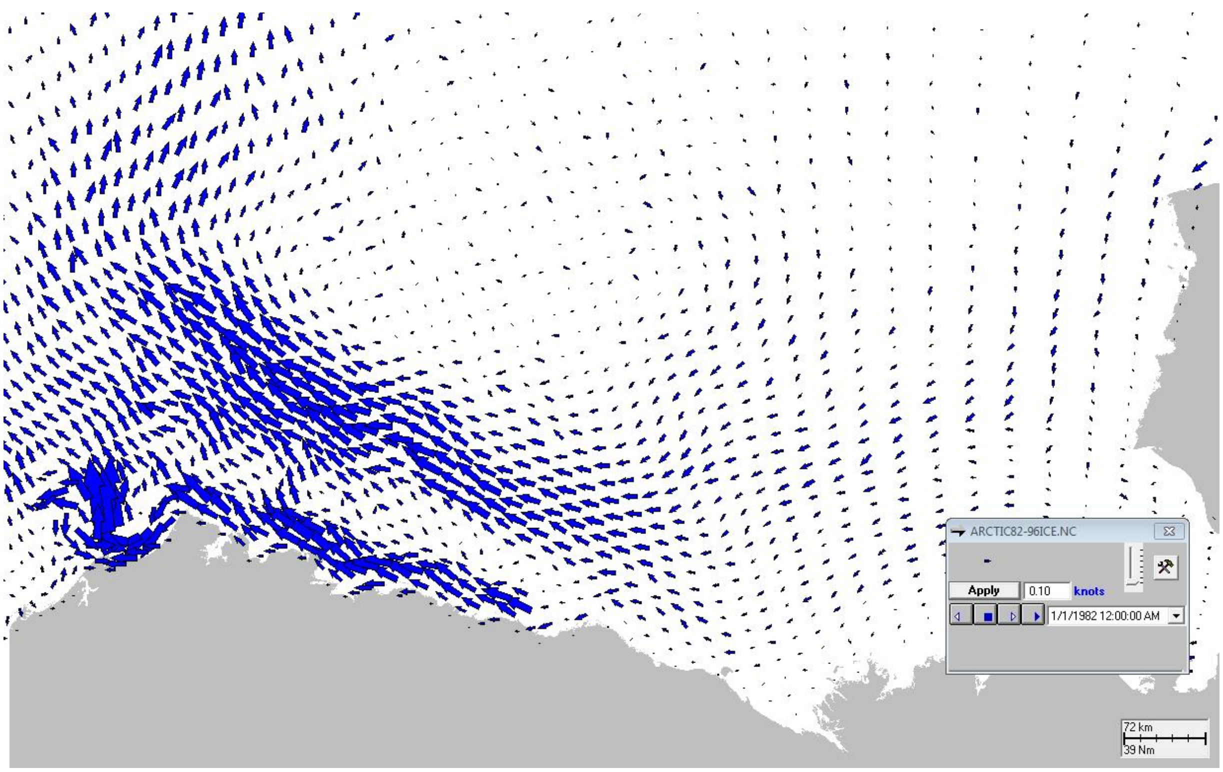

Figure A-39. Example current component data used in modeling for the Beaufort Sea region. Vector length indicates speed in the indicated direction.

Ice

As mentioned above, ice distribution was included in the model analysis and was treated in the same manner as current velocities. The program host provided the model outputs in original binary format. ASA subsequently converted them in to NetCDF format for SIMAP model usage.

<u>Winds</u>

ASA received wind data files that were used to force the coupled ice-ocean model. The period of the wind data extended daily from 1/1/1982 to 12/31/1996. ASA subsequently converted them into the SIMAP model input file format.

<u>Spill Sites</u>

Spill sites for the Beaufort Sea region were randomly distributed within the Beaufort Sea Proposed Final Program Area (2007-2012) (Figure A-40). The delineation between the nearshore and offshore spill areas was based on the 200 meter depth contour. Fifty spill sites were placed within the nearshore spill area, and one hundred spill sites were placed within the offshore spill area. The coordinates of these points are provided in Tables A-26 and A-27.

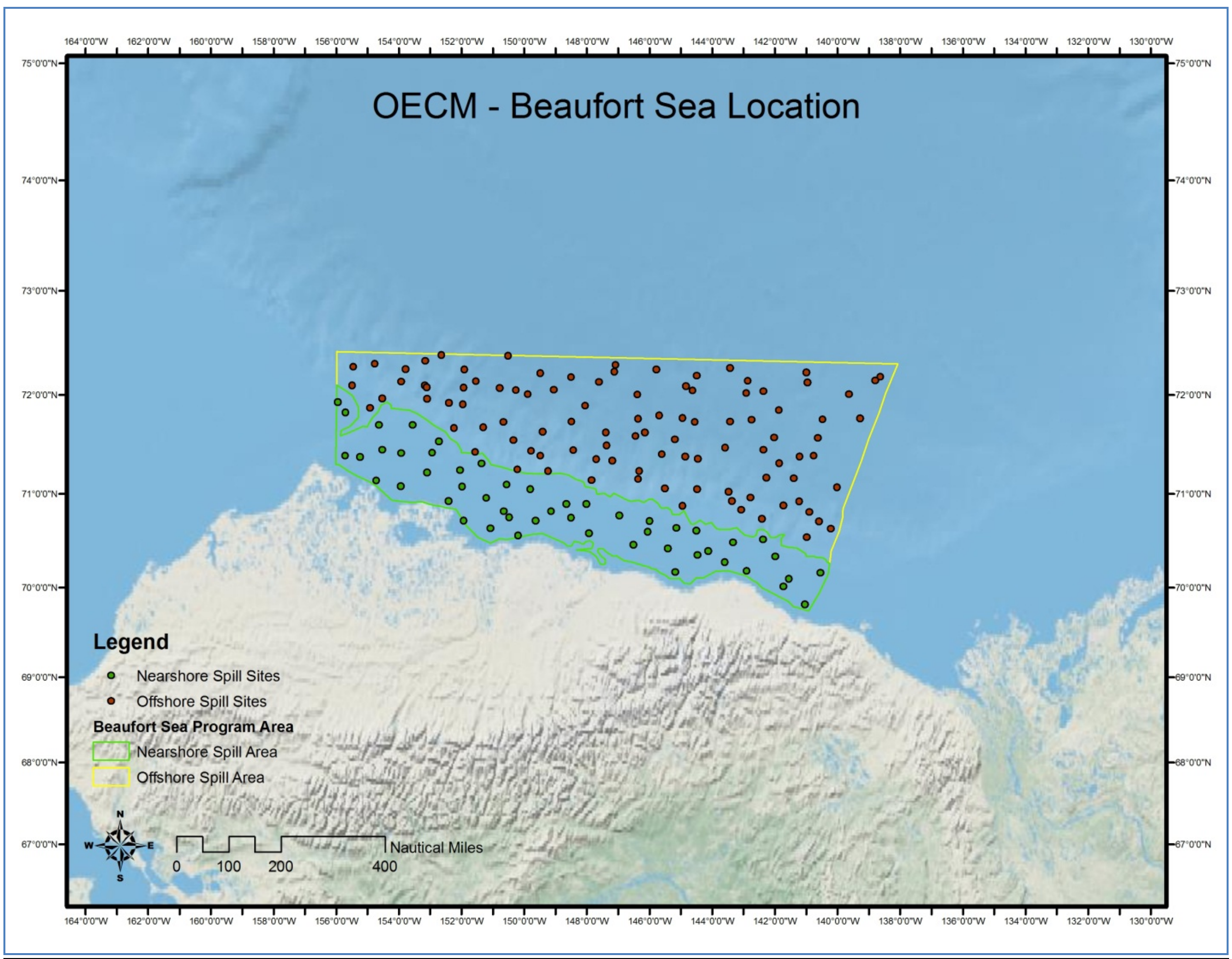

Figure A-40. Spill sites developed for the Beaufort Sea region.

Table A-26. Beaufort Sea nearshore spill sites.

Spill Site #	Latitude	Longitude
1	71.09416	-150.55489
2	71.04977	-149.80843
3	70.16038	-140.54562
4	70.72247	-151.93163
5	71.65489	-155.88458
6	70.63948	-151.08009
7	69.81953	-141.04329
8	70.18409	-142.89296
9	70.81622	-150.64923
10	70.46382	-146.51869
11	70.42556	-145.41750
12	70.89464	-148.01302
13	71.24509	-152.04843
14	71.37994	-155.24213
15	70.89631	-148.65458
16	70.58543	-147.94038
17	70.48751	-143.33026
18	71.41831	-153.93019
19	70.72197	-149.63456
20	70.61578	-144.50381
21	70.60121	-146.05678
22	70.77382	-146.96288
23	71.93125	-155.95195
24	70.95568	-151.21086
25	70.81727	-149.14234
26	71.70420	-154.64078
27	71.13697	-154.71567
28	71.07996	-153.94169
29	71.22144	-153.10001
30	71.82637	-155.25314
31	70.64101	-145.14466
32	71.42288	-152.93646
33	70.92724	-152.42098
34	70.75093	-148.50526
35	71.39407	-155.71131
36	70.09659	-141.54452
37	70.56424	-150.19496
38	70.39671	-144.13115
39	70.33755	-141.98623
40	70.56559	-142.69344
41	70.35553	-144.46766
42	71.71538	-155.87289
43	70.27678	-143.59203
44	70.71670	-145.99497
45	70.01231	-141.73111

Spill Site #	Latitude	Longitude
46	70.69599	-143.26969
47	70.75724	-150.47266
48	71.45252	-154.53263
49	71.07716	-151.98361
50	70.16182	-145.52020

Table A-27. Beaufort Sea offshore spill sites.

Spill Site #	Latitude	Longitude
1	72.29496	-147.08120
2	71.73417	-150.66227
3	72.13888	-142.85791
4	70.88100	-141.72560
5	72.22916	-147.11949
6	71.75584	-142.73912
7	72.00947	-149.88702
8	71.92671	-152.40884
9	71.49766	-147.36808
10	72.04667	-144.62675
11	72.18190	-138.63222
12	71.35929	-147.70307
13	70.92243	-141.21316
14	72.07513	-151.92909
15	72.25540	-153.79302
16	72.05159	-149.05832
17	71.23738	-146.32349
18	72.26839	-143.42684
19	71.39175	-149.48182
20	71.40896	-145.60822
21	71.45490	-145.03830
22	70.43023	-141.14996
23	70.96278	-142.78107
24	72.21686	-149.48586
25	71.45134	-142.37002
26	71.67549	-152.23698
27	71.73836	-143.42921
28	72.25394	-151.90851
29	72.39339	-152.63689
30	71.34515	-147.19502
31	71.38384	-141.20408
32	71.73262	-144.55076
33	71.02140	-143.47386
34	70.71095	-140.58864
35	72.22207	-140.99789
36	71.39158	-140.75832
37	72.01116	-139.62887
38	71.73580	-148.48504
39	71.36116	-144.46177

Spill Site #	Latitude	Longitude
40	71.31775	-141.85878
41	71.76833	-146.36440
42	70.74077	-142.41038
43	71.85086	-141.86780
44	72.01963	-142.91378
45	71.96678	-153.09642
46	72.19083	-144.49330
47	70.63471	-140.21745
48	70.83295	-143.07608
49	71.44030	-149.78383
50	71.91070	-151.95198
51	72.27827	-155.45421
52	71.23903	-149.23539
53	72.14577	-138.79756
54	71.58540	-147.05258
55	71.14155	-147.85344
56	71.72331	-153.82559
57	71.43232	-151.56977
58	71.25138	-150.21080
59	71.97065	-154.53263
60	71.38478	-144.85615
61	71.54977	-150.34206
62	70.76519	-144.91984
63	71.89757	-148.05638
64	72.17640	-148.50076
65	72.09564	-153.17291
66	72.33436	-153.16122
67	70.92831	-143.37199
68	72.07259	-150.78764
69	72.25242	-145.78420
70	71.77156	-139.28180
71	71.05838	-145.50633
72	72.00101	-155.51508
73	71.16242	-141.39111
74	71.47752	-143.58400
75	71.62782	-146.14896
76	71.05028	-144.48335
77	71.62961	-147.39388
78	71.15341	-146.36557
79	72.00669	-146.38091
80	71.57202	-140.62417
81	72.07764	-153.11093
82	71.16951	-142.27154
83	71.77527	-144.94114
84	72.03951	-142.36495
85	72.04944	-150.25811
86	70.80993	-140.89805

Spill Site #	Latitude	Longitude
87	72.12715	-140.95769
88	72.13630	-151.54441
89	71.06806	-140.01054
90	71.63668	-149.41625
91	72.12962	-147.61933
92	71.79935	-145.69031
93	71.34955	-151.59206
94	71.57533	-142.01904
95	72.08866	-144.83869
96	72.38530	-150.51524
97	72.13353	-153.92568
98	71.76075	-140.47483
99	71.55824	-145.19205
100	71.59166	-146.45027

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Oil Spill Modeling for the Offshore Environmental Cost Model (OECM)

SUBAPPENDIX B

Properties of Oils used in SIMAP Modeling

Table B-1. Oil properties for Light Crude used in the SIMAP simulations.

Property	**Value**	**Reference**
Density @ 25 deg. C (g/cm^3)	0.8518	Jokuty et al. (1999)*
Viscosity @ 25 deg. C (cp)	8.0	Jokuty et al. (1999)*
Surface Tension (dyne/cm)	25.9	Jokuty et al. (1999)*
Pour Point (deg. C)	-28.0	Jokuty et al. (1999)*
Adsorption Rate to Suspended Sediment	0.01008	Kolpack et al. (1977)
Adsorption Salinity Coef.(/ppt)	0.023	Kolpack et al. (1977)
Fraction monoaromatic hydrocarbons (MAHs)	0.01478	Jokuty et al. (1999)*
Fraction 2-ring aromatics	0.003161	Henry (1997)
Fraction 3-ring aromatics	0.005055	Henry (1997)
Fraction Non-Aromatics: boiling point < 180^{o}C	0.16522	Jokuty et al. (1999)*
Fraction Non-Aromatics: boiling point 180-264^{o}C	0.185839	Henry (1997)
Fraction Non-Aromatics: boiling point 264-380^{o}C	0.275945	Henry (1997)
Minimum Oil Thickness (mm)	0.00001	McAuliffe (1987)
Maximum Mousse Water Content (%)	75.0	-
Mousse Water Content as Spilled (%)	0.0	-
Water content of oil (not in mousse, %)	0	-
Degradation Rate (/day), Surface & Shore	0.01	French et al. (1996)
Degradation Rate (/day), Hydrocarbons in Water	0.01	French et al. (1996)
Degradation Rate (/day), Oil in Sediment	0.001	French et al. (1996)
Degradation Rate (/day), Aromatics in Water	0.01	Mackay et al. (1992)
Degradation Rate (/day), Aromatics in Sediment	0.001	Mackay et al. (1992)

* – Environment Canada's Oil Property Catalogue (Jokuty et al., 1999) provided total hydrocarbon data for volatile fractions of unweathered oil. The aromatic hydrocarbon fraction was subtracted from the total hydrocarbon fraction to obtain the aliphatic fraction of unweathered oil.

Table B-2. Oil properties for Light Arab Crude used in the SIMAP simulations.

Property	Value	Reference
Density @ 25 deg. C (g/cm^3)	0.8641	Environment Canada (2004)
Viscosity @ 25 deg. C (cp)	32.6	Environment Canada (2004)
Surface Tension (dyne/cm)	21.6	Environment Canada (2004)
Pour Point (deg. C)	-21.0	Environment Canada (2004)
Adsorption Rate to Suspended Sediment	0.01008	Kolpack et al. (1977)
Adsorption Salinity Coef.(/ppt)	0.023	Kolpack et al. (1977)
Fraction monoaromatic hydrocarbons (MAHs)	0.019571	Environment Canada (2004)
Fraction 2-ring aromatics	0.001572	Environment Canada (2004)
Fraction 3-ring aromatics	0.00623	Environment Canada (2004)
Fraction Non-Aromatics: boiling point < 180^{o}C	0.139429	Environment Canada (2004)
Fraction Non-Aromatics: boiling point 180-264^{o}C	0.167188	Environment Canada (2004)
Fraction Non-Aromatics: boiling point 264-380^{o}C	0.13381	Environment Canada (2004)
Minimum Oil Thickness (mm)	0.00005	McAuliffe (1987)
Maximum Mousse Water Content (%)	91.1	Environment Canada (2004)
Mousse Water Content as Spilled (%)	0.0	-
Water content of oil (not in mousse, %)	0.0	-
Degradation Rate (/day), Surface & Shore	0.01	French et al. (1996)
Degradation Rate (/day), Hydrocarbons in Water	0.01	French et al. (1996)
Degradation Rate (/day), Oil in Sediment	0.001	French et al. (1996)
Degradation Rate (/day), Aromatics in Water	0.01	Mackay et al. (1992)
Degradation Rate (/day), Aromatics in Sediment	0.001	Mackay et al. (1992)

Table B-3. Oil properties for Medium Crude used in the SIMAP simulations.

Property	Value	Reference
Density @ 25 deg. C (g/cm^3)	0.8714	-
Viscosity @ 25 deg. C (cp)	23.2	Environment Canada (2004)
Surface Tension (dyne/cm)	27.3	Environment Canada (2004)
Pour Point (deg. C)	-32.0	Environment Canada (2004)
Adsorption Rate to Suspended Sediment	0.01008	Kolpack et al. (1977)
Adsorption Salinity Coef.(/ppt)	0.023	Kolpack et al. (1977)
Fraction monoaromatic hydrocarbons (MAHs)	0.02192	Environment Canada (2004)
Fraction 2-ring aromatics	0.003076	Environment Canada (2004)
Fraction 3-ring aromatics	0.007284	Environment Canada (2004)
Fraction Non-Aromatics: boiling point < 180^oC	0.20408	Environment Canada (2004)
Fraction Non-Aromatics: boiling point $180\text{-}264^oC$	0.121224	Environment Canada (2004)
Fraction Non-Aromatics: boiling point $264\text{-}380^oC$	0.186616	Environment Canada (2004)
Minimum Oil Thickness (mm)	0.00005	McAuliffe (1987)
Maximum Mousse Water Content (%)	72.9	Environment Canada (2004)
Mousse Water Content as Spilled (%)	0.0	-
Water content of oil (not in mousse, %)	0.0	-
Degradation Rate (/day), Surface & Shore	0.01	French et al. (1996)
Degradation Rate (/day), Hydrocarbons in Water	0.01	French et al. (1996)
Degradation Rate (/day), Oil in Sediment	0.001	French et al. (1996)
Degradation Rate (/day), Aromatics in Water	0.01	Mackay et al. (1992)
Degradation Rate (/day), Aromatics in Sediment	0.001	Mackay et al. (1992)

Table B-4. Oil properties for Heavy Crude used in the SIMAP simulations.

Property	Value	Reference
Density @ 0 deg. C (g/cm^3)	0.9465	Environment Canada (2009)
Viscosity @ 0 deg. C (cp)	3220.0	Environment Canada (2009)
Surface Tension (dyne/cm)	30.1	Environment Canada (2009)
Pour Point (deg. C)	-25.0	Environment Canada (2009)
Adsorption Rate to Suspended Sediment	0.01008	Kolpack et al. (1977)
Adsorption Salinity Coef.(/ppt)	0.023	Kolpack et al. (1977)
Fraction monoaromatic hydrocarbons (MAHs)	0.008228	Environment Canada (2009)
Fraction 2-ring aromatics	0.001613	Environment Canada (2009)
Fraction 3-ring aromatics	0.003434	Environment Canada (2009)
Fraction Non-Aromatics: boiling point < 180^{o}C	0.104772	Environment Canada (2009)
Fraction Non-Aromatics: boiling point 180-264^{o}C	0.091787	Environment Canada (2009)
Fraction Non-Aromatics: boiling point 264-380^{o}C	0.129966	Environment Canada (2009)
Minimum Oil Thickness (mm)	0.001	McAuliffe (1987)
Maximum Mousse Water Content (%)	75.6	Environment Canada (2009)
Mousse Water Content as Spilled (%)	0.0	-
Water content of oil (not in mousse, %)	0.0	-
Degradation Rate (/day), Surface & Shore	0.01	French et al. (1996)
Degradation Rate (/day), Hydrocarbons in Water	0.01	French et al. (1996)
Degradation Rate (/day), Oil in Sediment	0.001	French et al. (1996)
Degradation Rate (/day), Aromatics in Water	0.01	Mackay et al. (1992)
Degradation Rate (/day), Aromatics in Sediment	0.001	Mackay et al. (1992)

Table B-5. Oil properties for Heavy Fuel Oil used in the SIMAP simulations.

Property	Value	Reference
Density @ 25 deg. C (g/cm^3)	0.9749	Jokuty et al. (1999)*
Viscosity @ 25 deg. C (cp)	3180.0	Jokuty et al. (1999)*
Surface Tension (dyne/cm)	27.0	Jokuty et al. (1999)*
Pour Point (deg. C)	7.0	Whiticar et al (1994)
Adsorption Rate to Suspended Sediment	0.01008	Kolpack et al. (1977)
Adsorption Salinity Coef.(/ppt)	0.023	Kolpack et al. (1977)
Fraction monoaromatic hydrocarbons (MAHs)	0.001819	Jokuty et al. (1999)*
Fraction 2-ring aromatics	0.003794	Jokuty et al. (1999)*
Fraction 3-ring aromatics	0.015941	Jokuty et al. (1999)*
Fraction Non-Aromatics: boiling point < 180^{o}C	0.008181	Jokuty et al. (1999)*
Fraction Non-Aromatics: boiling point 180-264^{o}C	0.045206	Jokuty et al. (1999)*
Fraction Non-Aromatics: boiling point 264-380^{o}C	0.097059	Jokuty et al. (1999)*
Minimum Oil Thickness (mm)	0.001	McAuliffe (1987)
Maximum Mousse Water Content (%)	30.0	NOAA (2000)
Mousse Water Content as Spilled (%)	0.0	-
Water content of oil (not in mousse, %)	0.0	-
Degradation Rate (/day), Surface & Shore	0.01	French et al. (1996)
Degradation Rate (/day), Hydrocarbons in Water	0.01	French et al. (1996)
Degradation Rate (/day), Oil in Sediment	0.001	French et al. (1996)
Degradation Rate (/day), Aromatics in Water	0.01	Mackay et al. (1992)
Degradation Rate (/day), Aromatics in Sediment	0.001	Mackay et al. (1992)

* – Environment Canada's Oil Property Catalogue (Jokuty et al., 1999) provided total hydrocarbon data for volatile fractions of unweathered oil. The aromatic hydrocarbon fraction was subtracted from the total hydrocarbon fraction to obtain the aliphatic fraction of unweathered oil.

Table B-6. Oil properties for Diesel Fuel Oil used in the SIMAP simulations.

Property	**Value**	**Reference**
Density @ 25 deg. C (g/cm^3)	0.8291	Jokuty et al. (1999)*
Viscosity @ 25 deg. C (cp)	4.0	Jokuty et al. (1999)*
Surface Tension (dyne/cm)	26.9	Jokuty et al. (1999)*
Pour Point (deg. C)	-14.0	Jokuty et al. (1999)*
Adsorption Rate to Suspended Sediment	0.01008	Kolpack et al. (1977)
Adsorption Salinity Coef.(/ppt)	0.023	Kolpack et al. (1977)
Fraction monoaromatic hydrocarbons (MAHs)	0.017793	Jokuty et al. (1999)*
Fraction 2-ring aromatics	0.010175	Lee et al. (1992)
Fraction 3-ring aromatics	0.001976	Lee et al. (1992)
Fraction Non-Aromatics: boiling point < 180^{o}C	0.042207	Jokuty et al. (1999)*
Fraction Non-Aromatics: boiling point 180-264^{o}C	0.335825	Jokuty et al. (1999)*
Fraction Non-Aromatics: boiling point 264-380^{o}C	0.542024	Jokuty et al. (1999)*
Minimum Oil Thickness (mm)	0.00001	McAuliffe (1987)
Maximum Mousse Water Content (%)	0.0	Whiticar et al. (1994)
Mousse Water Content as Spilled (%)	0.0	-
Water content of oil (not in mousse, %)	0.0	-
Degradation Rate (/day), Surface & Shore	0.01	French et al. (1996)
Degradation Rate (/day), Hydrocarbons in Water	0.01	French et al. (1996)
Degradation Rate (/day), Oil in Sediment	0.001	French et al. (1996)
Degradation Rate (/day), Aromatics in Water	0.01	Mackay et al. (1992)
Degradation Rate (/day), Aromatics in Sediment	0.001	Mackay et al. (1992)

* – Environment Canada's Oil Property Catalogue (Jokuty et al., 1999) provided total hydrocarbon data for volatile fractions of unweathered oil. The aromatic hydrocarbon fraction was subtracted from the total hydrocarbon fraction to obtain the aliphatic fraction of unweathered oil.

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SUBAPPENDIX C

Habitat Equivalency Analysis for Habitat Injuries

Habitat Equivalency Analysis (HEA) has been used by state and federal trustees to estimate the restored habitat required to compensate for habitat and biological resources injured, taking into account the time before the project is begun (lag time after the spill and injuries occur), the time for development of the restored habitat, the ultimate productivity of services in the new habitat as compared to that injured, the duration of the restoration project life, and discounting of future habitat services at 3% per year. The approach, equations, and assumptions are described in NOAA (1997, 1999), LA DEQ et al. (2003), and French-McCay and Rowe (2003).

HEA with Trophic Web Model

This model for scaling required compensatory restoration uses HEA with a trophic web model to calculate the required area of restored habitat to produce the same biomass as lost due to a spill. Scaling methods used here were initially developed for use in the *North Cape* case, as described in French et al. (2001), French McCay and Rowe (2003) and French McCay et al. (2003a). These methods have also been used in several other cases, as well as in successful claims for 23 cases submitted by the Florida Department of Environmental Protection to the U.S. Coast Guard, National Pollution Fund Center (French McCay et al., 2003b).

The habitat restoration model is based on food chain transfers, such that equivalent production at the same trophic level as the losses is produced by the restoration project. The approach uses energetic efficiencies to scale across trophic levels. Benefits of habitat to each trophic level are estimated by assuming that the production of consumers is proportional to prey production gained by the restoration of habitat. The habitat restoration model balances the production foregone losses with trophically equivalent production, discounting future gains in compensatory production relative to present losses such that interest is paid, analogous to economic discounting (French and Rowe, 2003).

The basis for using this model is that restoration should provide equivalent quality fish and invertebrate biomass to compensate for the lost fish and invertebrate production. Likewise for wildlife, restoration should also replace the wildlife biomass that was lost. Equivalent quality implies same or similar species with equivalent ecological role and value for human uses. The equivalent production or replacement should be discounted to present-day values to account for the interim loss between the time of the injury and the time when restoration provides equivalent ecological and human services.

Habitat creation or preservation projects have been used to compensate for injuries of wildlife, fish and invertebrates. The concept is that the restored habitat leads to a net gain in wildlife, fish and invertebrate production over and above that produced by the location before the restoration. The size of the habitat (acreage) is scaled to just compensate for the injury (interim loss).

In the model developed by French-McCay and Rowe (2003), the habitat may be seagrass bed, saltmarsh, oyster reef, freshwater or brackish wetland, or other structural habitats that provide such ecological services as food, shelter, and nursery habitat and are more productive than open bottom habitats. The injuries are scaled to the new primary (plant) or secondary (e.g., benthic) production produced by the created habitat, as the entire food web benefits from this production. A preservation project that would avoid the loss of habitat could also be scaled to the production preserved. The latter method would only be of net gain if the habitat is otherwise destined to be destroyed. In this analysis, we assume only habitat creation projects would be undertaken.

The approach used here for scaling the size of the needed project is to use primary production to measure the benefits of the restoration. The total injuries in kg are translated into equivalent plant (angiosperm) production as follows. Plant biomass passes primarily through the detrital food web via detritivores consuming the plant material and attached microbial communities. When macrophytes are consumed by detritivores, the ecological efficiency is low because of the high percentage of structural material produced by the plant, which must be broken down by microorganisms before it can be used by the detritivore. Each species group is assigned a trophic level relative to that of the detritivores. If the species group is at the same trophic level as detritivores, it is assumed 100% equivalent, as the resource injured would presumably have the same ecological value in the food web as the detritivores. If the injured resource preys on detritivores or that trophic level occupied by the detritivores, the ecological efficiency is that for trophic transfer from the prey to the predator. Values for production of predator per unit production of prey (i.e., ecological efficiency) are taken from the ecological literature, as reviewed by French McCay and Rowe (2003). The ecological efficiencies assumed are in Table C-1.

Table C-1. Assumed ecological efficiencies for one trophic step (French McCay and Rowe, 2003).

Consumer	**Prey/food**	**% Efficiency**
Invertebrate or finfish	Macrophyte	0.034
Invertebrate or finfish	Microalgae	10
Invertebrate	Microorganisms	20
Invertebrate or finfish	Detritivores	10
Invertebrate or fish	Invertebrate	20
Invertebrate or fish filter feeder	Plankton	20
Medium (200-1000g) fish piscivore	Finfish	10
Large (>1kg) fish piscivore	Finfish	4
Sea turtles	Invertebrates	2
Birds, mammals, sea turtles (herbivores)	Macrophyte	0.03
Birds, mammals	Invertebrate	2
Birds, mammals (piscivores)	Finfish	2

The equivalent compensatory amount of angiosperm (plant) biomass of the restored resource is calculated as kg of injury divided by ecological efficiency. The ecological efficiency is the product of the efficiency of transfer from angiosperm to invertebrate detritivore and efficiency from detritivore to the injured resource, accounting for each step up the food chain from detritivore to the trophic level of concern. Table C-2 lists the composite ecological efficiency relative to benthic invertebrate production for each trophic group evaluated in the modeling.

The productivity gained by the created habitat is corrected for less than full functionality during recovery using a sigmoid recovery curve. Discounting at 3% per year is included for delays in production because of development of the habitat, and delays between the time of the injury and when the production is realized in the restored habitat. The equations and assumptions may be found in French McCay and Rowe (2003).

Table C-2. Composite ecological efficiency relative to benthic invertebrate production by trophic group.

Species Category	Trophic Level	Ecological Efficiency Relative to Benthic Detritivores (%)
Fish and Invertebrates:		
Small pelagic fish	planktivorous	20
Large pelagic fish	piscivores/predators	0.8
Demersal fish	bottom feeders	10
Crustaceans	bottom feeders	20
Mollusks (large benthic invertebrates)	filter/bottom feeder	100
Intertidal benthic invertebrates	filter/bottom feeder	100
Birds:		
Waterfowl	bottom feeders	2
Seabirds	piscivores	0.4
Waders	piscivores	0.4
Shorebirds	bottom feeders	2
Raptors	piscivores	0.4
Kingfishers	piscivores	0.4
Other wildlife:		
Herbivorous mammals	herbivores	0.03
Sea turtles	invertebrate feeders	2
Sea otters	plankton/benthos	2
Pinnipeds	piscivores	0.04
Cetaceans (baleen)	plankton/benthos	0.4
Cetaceans (piscivores)	piscivores	0.04
Polar bear	Consume piscivores	0.0008

The needed data for the scaling calculations are:

- number of years for development of full function in a restored habitat;
- annual primary production rate per unit area (P) of restored habitat at full function (which may be less than that of natural habitats);
- delay before restoration project begins; and
- project lifetime (years the restored habitat will provide services).

In the regions analyzed for the OECM project, saltmarsh restoration could be undertaken as restoration for wildlife, fish and invertebrate injuries. Other wetlands, such as brackish marshes, intermediate marshes or freshwater wetlands, could also be restored. Seagrass bed restoration is another option. However, this requires good water quality and appropriate environmental conditions to be successful. The calculations below are based on (saltmarsh) wetland restoration, as this habitat is most frequently used for compensation; thus, it is used for estimating the potential restoration needs and Natural Resource Damage Assessment (NRDA) costs.

Saltmarsh Restoration

Restoration scaling calculations for saltmarsh were performed following the methods in French McCay and Rowe (2003). It is assumed that the saltmarsh requires 15 years to reach full function (based on Louisiana Department of Environmental Quality (LA DEQ) et al., 2003), ultimately reaching 80% of natural habitat productivity, the restoration begins in 2013, and the project lifetime is 20 years (LA DEQ et al., 2003).

For the Mid-Atlantic OECM location, above-ground primary production rates for a New England salt marsh were used from Nixon and Oviatt (1973) as 500 g dry weight m^{-2} yr^{-1}. In addition, benthic microalgal production provides another 105 g dry weight m^{-2} (Van Raalte, et al., 1976). Thus, estimated total primary production rate in saltmarshes in this region is 605 g dry weight m^{-2} yr^{-1}.

For the Gulf of Mexico and Straits of Florida OECM locations, above-ground primary production rates of saltmarsh cord grasses in Georgia were used as estimated by Nixon and Oviatt (1973), based on Teal (1962), as 1,290 g dry weight m^{-2} yr^{-1}. In addition, benthic microalgal production provides another 105 g dry weight m^{-2} (Van Raalte, et al., 1976). Thus, estimated total primary production rate in saltmarshes in this region is 1,395 g dry weight m^{-2} yr^{-1}.

For the Southern California OECM location, above-ground primary production rates of saltmarshes in the Central California coast were used as estimated by Continental Shelf Associates (CSA) (1991) as 3,666 g dry weight m^{-2} yr^{-1}. In addition, benthic microalgal production provides another 312 g dry weight m^{-2} (CSA, 1991). Thus, estimated total primary production rate in saltmarshes in this region is 3,978 g dry weight m^{-2} yr^{-1}.

For the Washington/Oregon OECM location, above-ground primary production rates of saltmarshes in the Oregon coast were used as estimated by CSA (1991) as 2,636 g dry weight m^{-2} yr^{-1}. In addition, benthic microalgal production provides another 375 g dry weight m^{-2} (CSA, 1991). Thus, estimated total primary production rate in saltmarshes in this region is 3,011 g dry weight m^{-2} yr^{-1}.

For the Gulf of Alaska, Cook Inlet/Shelikof Strait, and Bering Sea OECM locations, above-ground primary production rates of saltmarshes in the Lower Cook Inlet were used as estimated by CSA (1991). The daily rates were applied to a 6-month growing season, with the annual total being 681 g dry weight m^{-2} yr^{-1}. In addition, benthic microalgal production over a 6-month growing season provides another 1,488 g dry weight m^{-2} (CSA, 1991). Thus, estimated total primary production rate in saltmarshes in this region is 2,170 g dry weight m^{-2} yr^{-1}.

For the Chukchi Sea and Beaufort Sea OECM locations, above-ground primary production rates of saltmarshes in the Lower Cook Inlet were used as estimated by CSA (1991). The daily rates were applied to a 3-month growing season, with the annual total being 341 g dry weight m^{-2} yr^{-1}. In addition, benthic microalgal production over a 6-month growing season provides another 744 g dry weight m^{-2} (CSA, 1991). Thus, estimated total primary production rate in saltmarshes in this region is 1,085g dry weight m^{-2} yr^{-1}.

For the injured resources, all weights are as wet weight and dry weight is assumed 22% of wet weight (Nixon and Oviatt, 1973). The ratio of carbon to dry weight is assumed 0.45 (French et al., 1996). For the wildlife, the body mass per animal (from French et al. (1996) or from Sibley (2003)) is used to estimate injury in kg (multiplying by number killed and summing each species category).

Restoration for Intertidal Injury

In addition to the quantifiable injuries in water habitats, there is also be impact to intertidal invertebrates if saltmarsh, mangrove, rocky shore, gravel and sand beach, and mudflat habitats are oiled with enough oil to impact invertebrates associated with the intertidal habitat (greater than 0.1mm thickness results in invertebrate injuries). Benthic invertebrate production rates for each habitat type are taken into account when determining injury (Tables C-3 to C-9). Time for recovery for intertidal invertebrates (based on a natural recovery curve) is estimated as 3-5 years (French McCay, 2009). The total loss of intertidal invertebrates from shoreline oiling greater than 0.1 mm thick is calculated as a factor of daily production rate, as a function of number of years to 99% recovery and annual discount rate (3%).

For the HEA calculations, the area (m^2) of saltmarsh restored per m^2 oiled was calculated by scaling benthic invertebrates production lost to that gained, by multiplying the kilograms of benthic invertebrate injury per m^2 oiled by the area (m^2) restored per kilogram benthic invert injured. This was done for all habitats in which a benthic invertebrate injury would occur (i.e., rocky shore, sand beach, gravel beach, macroalgal [seagrass or landweed], fringing mudflat and fringing wetland). In order to get one estimate for intertidal injury per OECM geographic location, a weighted average of the area of saltmarsh restored per m^2 oiled for these individual habitats was calculated based on the percent of that habitat type present in the entire habitat grid for the particular OECM location.

Table C-3. Benthic invertebrate production rates by habitat type for Mid-Atlantic location.

Habitat Injured	Production Rate of Habitat (pre-spill) g C/m^2/day	Production Rate of Habitat (pre-spill) g dry wt/m^2/day
Saltmarsh	0.747[1]	2.053
Rocky shore	0.1[2]	0.275
Macroalgal bed	0.1[2]	0.275
Artificial/man made	0.1	0.275
Gravel beach	0.1	0.275
Sand beach	0.002[2]	0.006

Mudflat	0.1[2]	0.275

[1] Nixon and Oviatt, 1973; VanRaale et al., 1976
[2] Raymont, 1980
[12.5 g wet weight/g C, Odum, 1971; dry weight is 22% of wet weight, Nixon and Oviatt, 1973]

Table C-4. Benthic invertebrate production rates by habitat type for Straits of Florida location.

Habitat Injured	Production Rate of Habitat (pre-spill) g C/m²/day	Production Rate of Habitat (pre-spill) g dry wt/m²/day
Saltmarsh	1.7205[1]	4.731
Rocky shore	0.1[2]	0.275
Artificial/man made	0.1[2]	0.275
Gravel beach	0.1[2]	0.275
Sand beach	0.002[2]	0.006
Mudflat	0.1[2]	0.275

[1] Teal, 1962; Van Raalte et al., 1976
[2] Raymont, 1980
[12.5 g wet weight/g C, Odum, 1971; dry weight is 22% of wet weight, Nixon and Oviatt, 1973]

Table C-5. Benthic invertebrate production rates by habitat type for Gulf of Mexico location.

Habitat Injured	Production Rate of Habitat (pre-spill) g C/m²/day	Production Rate of Habitat (pre-spill) g dry wt/m²/day
Mangrove	1.7205[1]	4.731
Saltmarsh	0.072[2]	0.198
Rocky shore	0.1[3]	0.275
Artificial/man made	0.1	0.275
Gravel beach	0.1	0.275
Sand beach	0.002[3]	0.006
Mudflat	0.008[2]	0.022
Coral	2.8[4]	7.700

[1] Teal, 1962; Van Raalte et al., 1976
[2] Flint, 1985
[3] Raymont, 1980
[4] Muscatine, 1980
[12.5 g wet weight/g C, Odum, 1971; dry weight is 22% of wet weight, Nixon and Oviatt, 1973]

Table C-6. Benthic invertebrate production rates by habitat type for Southern California location.

Habitat Injured	Production Rate of Habitat (pre-spill) g C/m²/day	Production Rate of Habitat (pre-spill) g dry wt/m²/day
Saltmarsh	4.905[1]	13.489
Rocky shore	0.1[2]	0.275
Macroalgal bed	0.1[2]	0.275
Artificial/man made	0.1	0.275
Gravel beach	0.1	0.275
Sand beach	0.002[2]	0.006
Mudflat	0.1[2]	0.275

[1] Continental Shelf Associates, Inc., 1991

[2] Raymont, 1990

Table C-7. Benthic invertebrate production rates by habitat type for Washington/Oregon location.

Habitat Injured	Production Rate of Habitat (pre-spill) g C/m^2/day	Production Rate of Habitat (pre-spill) g dry wt/m^2/day
Saltmarsh	3.7125[1]	10.209
Rocky shore	0.1[2]	0.275
Macroalgal bed	0.1[2]	0.275
Artificial/man made	0.1	0.275
Gravel beach	0.1	0.275
Sand beach	0.002[2]	0.006
Mudflat	0.1[2]	0.275

[1] Greeson et al., 1979
[2] Raymont, 1990

Table C-8. Benthic invertebrate production rates by habitat type for Gulf of Alaska, Cook Inlet/Shelikof Strait, and Bering Sea locations.

Habitat Injured	Production Rate of Habitat (pre-spill) g C/m^2/day	Production Rate of Habitat (pre-spill) g dry wt/m^2/day
Saltmarsh	2.675[1]	7.356
Rocky shore	0.1[2]	0.275
Macroalgal bed	0.1[2]	0.275
Artificial/man made	0.1	0.275
Gravel beach	0.1	0.275
Sand beach	0.002[2]	0.006
Mudflat	0.1[2]	0.275

[1] Greeson et al., 1979
[2] Raymont, 1990

Table C-9. Benthic invertebrate production rates by habitat type for Chukchi Sea and Beaufort Sea locations.

Habitat Injured	Production Rate of Habitat (pre-spill) g C/m^2/day	Production Rate of Habitat (pre-spill) g dry wt/m^2/day
Saltmarsh	1.3375[1]	3.678
Rocky shore	0.1[2]	0.275
Macroalgal bed	0.1[2]	0.275
Artificial/man made	0.1	0.275
Gravel beach	0.1	0.275
Sand beach	0.002[2]	0.006
Mudflat	0.1[2]	0.275

[1] Continental Shelf Associates, Inc., 1991
[2] Raymont, 1990

Table C-10. Natural recovery time (in year) by habitat type based on French McCay (2009).

Habitat Injured	Natural Recovery Time (years)
Saltmarsh	5
Mangrove	5
Rocky shore	3
Macroalgal bed	3
Artificial/man made	3
Gravel beach	3
Sand beach	3
Mudflat	3
Coral	3

Table C-11 provides a summary for HEA information for all OECM locations.

Table C-11. Summary of HEA Information used in the OECM.

	Area (m^2) of Saltmarsh Restored per kg of Injury, by OECM Location									
OECM Location Code	**ATL**	**SFL**	**CGM**	**SCA**	**WAS**	**GOA**	**CIS**	**BER**	**CHU**	**BEA**
Birds:										
Waterfowl	82.56	46.37	46.37	16.13	18.75	18.75	18.75	18.75	18.75	18.75
Seabirds	412.82	231.87	231.87	80.63	93.75	93.75	93.75	93.75	93.75	93.75
Wading Birds	412.82	231.87	231.87	80.63	93.75	93.75	93.75	93.75	93.75	93.75
Shorebirds	82.56	46.37	46.37	16.13	18.75	18.75	18.75	18.75	18.75	18.75
Raptors	412.82	231.87	231.87	80.63	93.75	93.75	93.75	93.75	93.75	93.75
Other Wildlife:										
Sea Turtles	82.56	46.37	46.37	82.56	82.56	-	-	-	-	-
Sea Otters	-	-	-	80.63	93.75	52.84	52.84	52.84	52.84	52.84
Pinnipeds	4,128.16	-	-	806.35	937.46	528.37	528.37	1,056.75	1,056.75	1,056.75
Cetaceans (Baleen)	412.82	231.87	231.87	80.63	93.75	52.84	52.84	105.67	105.67	105.67
Cetaceans (Piscivores)	4,128.16	2,318.70	2,318.70	806.35	937.46	528.37	528.37	1,056.75	1,056.75	1,056.75
Polar Bears	-	-	-	-	-	-	-	52,837.31	52,837.31	52,837.31
Herbivorous Mammals	3,091.60	3,091.60	3,091.60	-	-	-	-	-	-	-
Fish and Invertebrates:										
Small Pelagic Fish	8.26	4.64	4.64	1.61	1.87	1.87	1.87	1.87	1.87	1.87
Large Pelagic Fish	206.41	115.94	115.94	40.32	46.87	46.87	46.87	46.87	46.87	46.87
Demersal Fish	16.51	9.27	9.27	3.23	3.75	3.75	3.75	3.75	3.75	3.75
Crustaceans	8.26	4.64	4.64	1.61	1.87	1.87	1.87	1.87	1.87	1.87
Molluscs (Large Benthic Invertebrates)	8.26	4.64	4.64	0.32	1.87	1.87	1.87	1.87	1.87	1.87
	Area (m^2) of Saltmarsh Restored per Area (m^2) Oiled, by OECM Location									
Intertidal Injury	9.375	15.514	0.725	0.757	2.616	0.378	0.480	0.597	2.243	1.765

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Oil Spill Modeling for the Offshore Environmental Cost Model (OECM)

SUBAPPENDIX D

Spill Rate and Volume Data for OECM Modeling

This appendix summarizes the analysis performed by Environmental Research Consulting (ERC) of (1) the probability of oil spillage (i.e., the likelihood that a spill will occur from any particular offshore facility or tanker) and (2) the probability distribution function of the spill volumes of different oil types (crude, bunker fuel, diesel) should a spill occur from one of these sources. In particular, the analysis requires two sets of spillage rates and spill volume probability distribution functions (PDFs) for spills. The first set is for spills associated with the OCS program (i.e., from offshore platforms/wells [Table D-1], pipelines [Table D-2], and from vessels servicing the platforms [Table D-3]). The PDFs include:

- Crude oil spills from OCS platforms/wells (Table D-1);
- Operational diesel spills from OCS platforms/wells (Table D-1);
- Crude oil spills from offshore pipelines (Table D-2);
- Diesel spills from offshore pipelines (Table D-2); and
- Diesel spills[33] from offshore supply or service vessels (Table D-3).

For each of these spill types, a very small spill volume (with negligible consequences), a small volume, a medium volume, a large volume, and a very large (but not worst-case-discharge) were determined.

The second set of PDFs (Table D-4) is for the spillage rates and volumes for spills associated with the alternative to OCS oil production (i.e., importing crude and products by tanker):

- Cargo spills for tankers transporting crude oil;
- Cargo spills for tankers transporting petroleum products;[34]
- Bunker fuel spills[35] for tankers transporting crude oil and petroleum products; and
- Diesel fuel spills[36] for tankers transporting crude oil and petroleum products.

For each of these spill types, a very small spill (with negligible consequences), a small volume, a medium volume, a large volume, a very large volume, and an extra-large volume were determined.

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[33] The smaller vessels that service the offshore platforms are fueled by diesel rather than heavy fuel oil.

[34] Petroleum products will be represented by diesel fuel in the modeling scenarios.

[35] Heavy fuel oil

[36] Tankers in the future will most likely be fueled with diesel rather than heavy fuel oil to meet air pollution standards.

Table D-1. Spill rates and spill size distributions for spills associated with OCS platforms and wells (without Deepwater Horizon incident).

Oil Source	Oil Type[37]	Spill Rate (bbl spilled per bbl produced)	Size Class	Spill Size Range (bbl)	Mean bbl[38]	Median bbl	% of Spills
OCS Platforms/Wells *(w/o Deepwater Horizon incident)*	Light crude	0.0000038	Very Small	1 – 10	4	3.5	75.56%
			Small	11 – 100	29	21	15.85%
			Medium	101 – 1,000	334	262	5.89%
			Large	1,001 – 10,000	3,312	3,500	2.18%
			Very Large	10,001 – 100,000	47,937	20,000	0.51%
	Heavy crude	0.0000038	Very Small	1 – 10	4	3.5	75.56%
			Small	11 – 100	29	21	15.85%
			Medium	101 – 1,000	334	262	5.89%
			Large	1,001 – 10,000	3,312	3,500	2.18%
			Very Large	10,001 – 100,000	47,937	20,000	0.51%
	Medium crude	0.0000038	Very Small	1 – 10	4	3.5	75.56%
			Small	11 – 100	29	21	15.85%
			Medium	101 – 1,000	334	262	5.89%
			Large	1,001 – 10,000	3,312	3,500	2.18%
			Very Large	10,001 – 100,000	47,937	20,000	0.51%
	Diesel	0.00000009	Very Small	1	1	1	7.64%
			Small	2 – 10	4	4	62.53%
			Medium	11 - 100	31	24	23.39%
			Large	101 – 1,000	312	239	5.25%
			Very Large	1,001 – 3,600	1,941	1,500	1.19%

[37] No heavy fuel oil spills would be expected from platforms.

[38] Mean spill volume within the spill range.

Table D-2. Spill rates and spill size distributions for spills associated with OCS pipelines.

Oil Source	Oil Type[39]	Spill Rate (bbl spilled per bbl produced)	Size Class	Spill Size Range (bbl)	Mean bbl[40]	Median bbl	% of Spills
OCS Pipelines	Light crude	0.00000162	Very Small	1 – 10	4	3	67.9%
			Small	11 – 100	28	18	17.6%
			Medium	101 – 1,000	404	323	9.0%
			Large	1,001 – 10,000	3,734	3,700	4.7%
			Very Large	10,001 – 100,000	16,351	15,574	0.8%
	Heavy crude	0.00000162	Very Small	1 – 10	4	3	67.9%
			Small	11 – 100	28	18	17.6%
			Medium	101 – 1,000	404	323	9.0%
			Large	1,001 – 10,000	3,734	3,700	4.7%
			Very Large	10,001 – 100,000	16,351	15,574	0.8%
	Medium crude	0.00000162	Very Small	1 – 10	4	3	67.9%
			Small	11 – 100	28	18	17.6%
			Medium	101 – 1,000	404	323	9.0%
			Large	1,001 – 10,000	3,734	3,700	4.7%
			Very Large	10,001 – 100,000	16,351	15,574	0.8%
	Diesel	0.00000003	Very Small	1	1	1	11.8%
			Small	2 – 10	4.6	5.5	29.4%
			Medium	11 - 100	70	97	17.6%
			Large	101 – 1,000	371	300	29.4%
			Very Large	1,001 – 3,600	2,547	2,547	11.8%

[39] No heavy fuel oil spills would be expected from pipelines.

[40] Mean spill volume within the spill range.

Table D-3. Spill rates and spill size distributions for spills associated with OCS service vessels.

Oil Source	Oil Type[41]	Spill Rate (bbl spilled per bbl produced)	Size Class	Spill Size Range (bbl)	Mean bbl[42]	Median bbl	% of Spills
OCS Vessels	Light crude	0	Very Small	1 – 10	-	-	-
			Small	11 – 100	-	-	-
			Medium	101 – 1,000	-	-	-
			Large	1,001 – 10,000	-	-	-
			Very Large	10,001 – 100,000	-	-	-
	Heavy crude	0	Very Small	1 – 10	-	-	-
			Small	11 – 100	-	-	-
			Medium	101 – 1,000	-	-	-
			Large	1,001 – 10,000	-	-	-
			Very Large	10,001 – 100,000	-	-	-
	Medium crude	0	Very Small	1 – 10	-	-	-
			Small	11 – 100	-	-	-
			Medium	101 – 1,000	-	-	-
			Large	1,001 – 10,000	-	-	-
			Very Large	10,001 – 100,000	-	-	-
	Diesel	0.00000136	Very Small	1	1	1	9.3%
			Small	2 – 10	4.6	4	61.2%
			Medium	11 - 100	30	18	24.0%
			Large	101 – 1,000	230	166	5.5%
			Very Large	1,001 – 3,600	-[43]	-	-

[41] No crude or heavy fuel oil spills would be expected from offshore supply vessels. Minor spills of other oils (lubricating oil) might occur.
[42] Mean spill volume within the spill range.
[43] Theoretical worst-case discharge 3,570 bbl.

Table D-4. Spill rates and spill size distributions for spills associated with tankers importing oil.

Oil Source	Oil Type	Spill Rate (bbl spilled per bbl transport)	Size Class	Spill Size Range (bbl)	Mean bbl	Median bbl	% of Spills
Imported Tankers (this will also be used as proxy for domestic tankers)	Light crude	0.00000287	Very Small	0.1 – 10	4.5	0.24	89.10%
			Small	10.1 - 100	35	40	7.92%
			Medium	101 – 1,000	293	200	1.90%
			Large	1,001 – 10,000	4,220	3,000	0.64%
			Very Large	10,001 – 100,000	29,858	20,000	0.41%
			Extra Large	Over 100,000	250,000	250,000	0.03%
	Heavy crude	0.00000287	Very Small	0.1 – 10	4.5	0.24	89.10%
			Small	10.1 - 100	35	40	7.92%
			Medium	101 – 1,000	293	200	1.90%
			Large	1,001 – 10,000	4,220	3,000	0.64%
			Very Large	10,001 – 100,000	29,858	20,000	0.41%
			Extra Large	Over 100,000	250,000	250,000	0.03%
	Heavy Fuel Oil	0.00000067	Very Small	0.1 – 10	1.1	0.24	91.67%
			Small	10.1 - 100	33	24	6.27%
			Medium	101 – 1,000	393	225	1.28%
			Large	1,001 – 10,000	3,186	2,381	0.57%
			Very Large	10,001 – 100,000	16,905	15,952	0.14%
			Extra Large	Over 100,000	160,714	160,714	0.07%
	Medium crude	0.00000287	Very Small	0.1 – 10	4.5	0.24	89.10%
			Small	10.1 - 100	35	40	7.92%
			Medium	101 – 1,000	293	200	1.90%
			Large	1,001 – 10,000	4,220	3,000	0.64%
			Very Large	10,001 – 100,000	29,858	20,000	0.41%
			Extra Large	Over 100,000	250,000	250,000	0.03%
	Diesel	0.00000117	Very Small	0.1 – 10	0.94	0.19	92.10%
			Small	10.1 - 100	33	24	5.74%
			Medium	101 – 1,000	266	167	1.56%
			Large	1,001 – 10,000	3,790	2,200	0.52%
			Very Large	10,001 – 100,000	24,881	14,881	0.07%
			Extra Large	Over 100,000	-	-	-

Oil Spill Modeling for the Offshore Environmental Cost Model (OECM)

SUBAPPENDIX E

Guide to the Digital Regression Files and Biological Databases

A large number of regression files were created as part of this effort, and are available in this Appendix as digital files (*.xlsx).

Contained in this Appendix are:

- Regression summaries for each region (coded summary table of coefficients from all individual regressions for the region);
- Supporting graphs for each individual regression, organized by region; and
- Biological data files corresponding to each region (may be one or multiple files per region).

The digital files/regressions are identified by codes for region, oil type, and offshore/nearshore location. Codes are defined in the tables below.

Table E-1. Region Codes

Code	**Region**
ATL	Mid-Atlantic
BEA	Beaufort Sea
BER	Bering Sea
CGM	Central Gulf of Mexico
CHU	Chukchi Sea
CIS	Cook Inlet/Shelikof Strait
GOA	Gulf of Alaska (North Pacific)
SCA	Southern California
SFL	Straits of Florida
WAS	Washington/Oregon

Table E-2. Offshore/Nearshore Location Codes

Code	**Region**
OFF	Offshore
ON	Onshore (nearshore)
SBVB*	Santa Barbara-Ventura Basin
SMB*	Santa Maria Basin

*****Applies to Southern California region only

Table E-3. Oil Type Codes

Code	**Region**
ALC	Arab Light Crude
DFO	Diesel Fuel Oil
HC	Heavy Crude
HFO	Heavy Fuel Oil
LC	Light Crude
MC	Medium Crude

APPENDIX B: DERIVATION OF EMISSION FACTORS FOR ONSHORE OIL AND GAS PRODUCTION

To provide additional documentation of the data and methods incorporated into the Offshore Environmental Cost Model (OECM), this appendix provides a detailed description of the data and methods employed to derive emission factors for onshore oil and gas production. These emission factors serve as inputs into the No Action Alternative (NAA) in the OECM and help assess the environmental impacts of energy production displaced by production on the outer continental shelf.

Before describing our approach in detail, we note that there are two main challenges to estimating emissions associated with onshore oil and gas production. The first is the need to distinguish between onshore and offshore oil and gas production, both in quantifying the amount of fuel produced and in identifying emissions sources. The second is the need to allocate total emissions from oil and gas production to either oil production or gas production. Some emissions-producing activities, such as drilling wells, are integral to the production of both crude oil and natural gas, so allocating emissions to each fuel type is not a straightforward process.

As will be discussed below, limitations in the availability of emissions data associated with onshore oil and gas production made it necessary for us to focus only on a subset of ten states: Arizona, Colorado, Montana, North Dakota, New Mexico, Nevada, Oregon, South Dakota, Utah, and Wyoming. Using emissions and fuel production data from these ten states, we develop an estimate of the rate of emissions associated with each unit of onshore crude oil and natural gas produced nationwide. That is, each emission factor was estimated as the ratio of oil (or gas)-related emissions to oil (or gas) production in the states analyzed.

The remainder of this appendix proceeds as follows.

1. We first describe the data sources used to obtain estimates of crude oil and natural gas production and associated emissions from both point and nonpoint sources.

2. We then discuss the methods we followed first to identify emissions associated with production of oil and gas and second to apportion these emissions between oil production and gas production.

3. Finally, we present our estimates of NO_x, SO_2, VOC, CO, $PM_{2.5}$, and PM_{10} emissions for area and point sources associated with production of crude oil and natural gas. Using these values, we then calculate emissions per unit of crude oil or natural gas produced onshore.

Data Sources

In order to develop a per-unit estimate of the emissions caused by onshore production of oil and natural gas, we needed to obtain data on both the quantity of each fuel produced and the emissions from point and area sources associated with production of each fuel.

Onshore oil and gas production

We obtained data on onshore oil and gas production from databases of domestic energy production maintained by the DOE's Energy Information Administration (EIA). EIA's databases include production data from 1967 through 2009 and distinguish between onshore production and offshore production. From these databases, we obtained annual onshore crude oil production data by state and annual onshore marketed natural gas production by state.[44] These totals are presented in Figure 1.

[44] Crude oil production data were obtained at http://tonto.eia.doe.gov/dnav/pet/pet_crd_crpdn_adc_mbbl_a.htm and natural gas production data were obtained at http://tonto.eia.doe.gov/dnav/ng/ng_prod_whv_a_EPG0_VGM_mmcf_a.htm.

Figure 1 Onshore Crude Oil and Marketed Natural Gas Production in 2002

STATE	2002 ONSHORE PRODUCTION OF CRUDE OIL (THOUSAND BARRELS)	2002 MARKETED NATURAL GAS PRODUCTION (MILLION CUBIC FEET)
Alabama	8,631	162,613
Alaska[1]	359,335	358,936
Arizona[1]	63	301
Arkansas	7,344	161,871
California[1]	258,010	309,399
Colorado[1]	17,734	937,245
Florida	3,656	3,353
Illinois	12,051	180
Indiana	1,962	1,309
Kansas	32,721	454,901
Kentucky	2,679	88,259
Louisiana	93,477	1,226,613
Maryland	0	22
Michigan	7,219	274,476
Mississippi	18,015	112,980
Missouri	95	0
Montana[1]	16,855	86,075
Nebraska	2,779	1,188
Nevada[1]	553	6
New Mexico[1]	67,041	1,632,080
New York	165	36,816
North Dakota[1]	30,993	57,048
Ohio	6,004	103,158
Oklahoma	66,642	1,581,606
Oregon[1]	0	837
Pennsylvania	2,233	157,800
South Dakota[1]	1,214	1,025
Tennessee	275	2,050
Texas	411,985	5,084,012
Utah[1]	13,676	274,739
Virginia	22	76,915
West Virginia	1,382	190,249
Wyoming[1]	54,717	1,453,957
Total Onshore Production	1,499,528	14,832,018
WRAP States (minus California and Alaska)	202,846	4,443,313

Source: Department of Energy's Energy Information Administration databases. Crude oil production values were taken from http://tonto.eia.doe.gov/dnav/pet/pet_crd_crpdn_adc_mbbl_a.htm and marketed natural gas production values were taken from http://tonto.eia.doe.gov/dnav/ng/ng_prod_whv_a_EPG0_VGM_mmcf_a.htm.

1. Member of the Western Regional Air Partnership (WRAP)

Emissions

As mentioned above, obtaining data on emissions associated with onshore oil and natural gas production presented a significant challenge. EPA's National Emissions Inventory (NEI) is the most comprehensive database of nationwide emissions information, but it does not fully capture emissions from area sources related to oil and gas production. Emissions from smaller field equipment involved in oil and gas production usually fall below EPA's permitting thresholds and are therefore underrepresented in the NEI. Consequently, we sought emissions information from sources that improved on the NEI by adding information about area sources related to production of oil and natural gas.

As part of their efforts to comply with the Clean Air Act's Regional Haze Rule, states in the Western Regional Air Partnership (WRAP) formed the Oil and Gas Emissions Workgroup tasked with developing a more complete inventory of emissions from oil and gas production.[45] To develop this inventory, WRAP solicited review of the 2002 NEI from individual states, corrected errors, and added an oil and gas field operations area source inventory. For this analysis, we used the final version of the 2002 emissions inventory developed by the WRAP Stationary Sources Joint Forum, which includes point source and area source emissions data for NO_x, SO_2, VOC, CO, PM_{10}, and $PM_{2.5}$[46] Because we rely on the WRAP emissions inventory, the scope of our analysis is limited to the 12 states that belong to the WRAP: Alaska, Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming. Idaho and Washington did not produce crude oil or natural gas in 2002, so we did not consider them in this analysis. In addition, we further excluded Alaska and California from consideration, because both states engaged in onshore as well as offshore production of oil and gas, and we were unable to identify which emissions from oil and gas production were associated only with onshore production. As shown in Figure 1, the remaining ten WRAP states produced over 200 million barrels of crude oil and more than 4.4 trillion cubic feet of natural gas in 2002. These totals represent about 14 percent of total onshore crude oil production in 2002 and about 30 percent of total onshore natural gas production.

Of the states not included in WRAP, Texas, Oklahoma, and Louisiana are the most significant, together accounting for 38 percent of onshore crude oil production and 53 percent of onshore natural gas production. These three states are members of the Central Regional Air Partnership (CENRAP), which is also in the process of developing an improved emissions inventory as part of compliance with the Regional Haze Rule. However, the CENRAP emissions inventory is still in the process of being developed at this time.

Methodology for emissions estimates

We obtained emissions estimates for both point sources and area sources from the WRAP emissions inventory discussed above. For each source category, we first identified emissions associated with oil and gas production and then divided those emissions between oil production and natural gas production.

Emissions data for area sources

The area source emissions database that we obtained from WRAP presents emissions at the state level, organized by Standard Classification Code (SCC). To identify emissions associated with oil and gas production, we simply selected all emissions from the SCCs for "Industrial Processes_Oil and Gas

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[45] "Oil & Gas Emissions Workgroup: About. " Accessed at http://www.wrapair.org/forums/ogwg/index.html.
[46] Both area source and point source emissions were obtained at http://www.wrapair.org/forums/ssjf/pivot.html.

Production." The full list of SCCs we used to identify area source emissions from oil and gas production can be found in Figure 2.

We also used SCC descriptions to determine which emissions were attributable to oil production and which were attributable to natural gas production. As Figure 2 shows, most SCC descriptions indicate whether the emissions source is associated with either crude petroleum or natural gas. Using this process, we allocated about 85 percent of total NO_x emissions, 99 percent of VOC emissions, and 92 percent of CO emissions, but less than one percent of SO_2 emissions from area sources. The primary emissions source that could not be attributed to either natural gas or crude oil production based on the SCC description was the operation of drill rigs (SCC: 2310000220). Because drill rigs are associated with production of both natural gas and crude oil, we did not feel justified in fully allocating emissions from drill rigs to either category. Instead, we divided these emissions between oil and natural gas production according to the division of emissions from all other SCCs. In the case of SO_2 emissions, some states did not have emissions from any sources other than drill rigs. In those states, we divided SO_2 emissions from drill rigs in proportion to the division of NO_x emissions from other sources.

Figure 2 Area Source SCCs

SCC CODE	SCC DESCRIPTION	OIL OR GAS
2310000220	Industrial Processes_Oil and Gas Production_All Processes_Drill rigs	Unable to be determined
2310000330	Industrial Processes_Oil and Gas Production_All Processes_Artificial lift	Unable to be determined
2310000440	Industrial Processes_Oil and Gas Production_All Processes_Saltwater disposal engines	Unable to be determined
2310010000	Industrial Processes_Oil and Gas Production: SIC 13_Crude Petroleum_Total: All Processes	Oil
2310010100	Industrial Processes_Oil and Gas Production_Crude Petroleum_Heaters	Oil
2310010200	Industrial Processes_Oil and Gas Production_Crude Petroleum_Tanks - Flashing & Standing/Working/Breathing	Oil
2310010300	Industrial Processes_Oil and Gas Production_Crude Petroleum_Pneumatic Devices	Oil
2310010700	Industrial Processes_Oil and Gas Production_Crude Petroleum_Well Fugitives	Oil
2310010800	Industrial Processes_Oil and Gas Production_Crude Petroleum_Well Truck Loading	Oil
2310020000	Industrial Processes_Oil and Gas Production: SIC 13_Natural Gas_Total: All Processes	Gas
2310020600	Industrial Processes_Oil and Gas Production_Natural Gas_Compressor Engines	Gas
2310020700	Industrial Processes_Oil and Gas Production_Natural Gas_Gas Well Fugitives	Gas
2310020800	Industrial Processes_Oil and Gas Production_Natural Gas_Gas Well Truck Loading	Gas
2310021100	Industrial Processes_Oil and Gas Production_Natural Gas_Heaters	Gas
2310021300	Industrial Processes_Oil and Gas Production_Natural Gas_Pneumatic Devices	Gas
2310021400	Industrial Processes_Oil and Gas Production_Natural Gas_Dehydrators	Gas
2310021500	Industrial Processes_Oil and Gas Production_Natural Gas_Completion - Flaring and venting	Gas
2310021600	Industrial Processes_Oil and Gas Production_Natural Gas_Gas Well Venting	Gas
2310023000	Industrial Processes_Oil and Gas Production_Natural Gas_CBM - Dewatering pump engines	Gas
31000299	Industrial Processes_Oil and Gas Production_Natural Gas Production_Other Not Classified	Gas
2310030000	Industrial Processes_Oil and Gas Production: SIC 13_Natural Gas Liquids_Total: All Processes	Gas
2310030210	Industrial Processes_Oil and Gas Production_Natural Gas Liquids_Tanks - Flashing & Standing/Working/Breathing, Uncontrolled	Gas
2310030220	Industrial Processes_Oil and Gas Production_Natural Gas Liquids_Tanks - Flashing & Standing/Working/Breathing, Controlled	Gas

Emissions data for point sources

As with emissions from area sources, we first selected all emissions from SCCs for "SCCs for Industrial Processes_Oil and Gas Production." Based on communications with the WRAP Air Quality Project Manager, however, we determined that sources with those SCCs did not account for all emissions from activities associated with oil and natural gas production.[47] As one example, emissions from well compression, pump engines, and electric generators are coded with SCCs for "Internal Combustions_Industrial." Accordingly, the WRAP emissions inventory includes emissions from diesel and natural gas-fueled industrial internal combustion engines. However, the SCCs for industrial internal combustion engines also include sources not associated with oil and natural gas production, such as internal combustion engines used as generators in other industrial processes. The same problem also arises with other SCCs.

To address this limitation of the WRAP point source inventory, we used information from the 2002 NEI to determine what portion of emissions in the WRAP database, by SCC, can reliably be attributed to oil and natural gas production. Each individual emissions source included in the 2002 NEI is classified by SCC and by North American Industry Classification System (NAICS) code. Whereas SCCs specify the kind of equipment or facility that is the source of emissions, NAICS codes provide more information on the industry associated with that source. Using the industry codes in the 2002 NEI, we developed scaling factors—by state, pollutant, and SCC—that allowed us to estimate the emissions in the WRAP database attributable to oil and gas production. We estimated these scaling factors using the following three steps.

1. We identified four NAICS codes assumed to be associated with oil and natural gas production, which we present in Figure 3.
2. We then matched facilities in the WRAP database to facilities in the NEI database in order to assign NAICS codes to each source. Of the 53,062 individual sources in the WRAP point source emissions database, we identified matching facilities with NAICS codes for 39,620, or about 75 percent.
3. For this sample of point sources from the WRAP database, we then determined, by state, SCC, and pollutant, the percent of total emissions that come from facilities with oil and gas production NAICS codes (listed in Figure 3). As an example, for the facilities from the WRAP database with matches in the NEI database, we estimated that 71.1 percent of NO_x emissions from natural gas-fired industrial internal combustion engines in Colorado were associated with oil and natural gas production.

[47] Personal communication with Lee Gribovicz, WRAP Air Quality Project Manager, February 24, 2010.

Figure 3 NAICS Codes Associated with Crude Oil and Natural Gas Production

NAICS CODE	NAICS DESCRIPTION
211111	The U.S. national industry classification for crude petroleum and natural gas extraction
211112	The U.S. national industry classification for natural gas liquid extraction
213111	The U.S. national industry classification for drilling oil and gas wells
213112	The U.S. national industry classification for support activities for oil and gas operations

We used the state-, SCC-, and pollutant-specific scaling factors to estimate emissions associated with oil and gas production. The full list of SCCs for which we estimated point source emissions related to onshore oil and gas production is presented in Figure 4.

Figure 4 Point Source SCCs

SCC CODE	SCC DESCRIPTION	OIL OR GAS
102006	External Combustion Boilers_Industrial_Natural Gas	Unable to be determined
102007	External Combustion Boilers_Industrial_Process Gas	Unable to be determined
201001	Internal Combustion Engines_Electric Generation_Distillate Oil (Diesel)	Unable to be determined
201002	Internal Combustion Engines_Electric Generation_Natural Gas	Unable to be determined
202001	Internal Combustion Engines_Industrial_Distillate Oil (Diesel)	Unable to be determined
202002	Internal Combustion Engines_Industrial_Natural Gas	Gas
202004	Internal Combustion Engines_Industrial_Large Bore Engine	Unable to be determined
203002	Internal Combustion Engines_Commercial/Institutional_Natural Gas	Unable to be determined
280002	Internal Combustion Engines_Diesel Marine Vessels_Commercial	Unable to be determined

SCC CODE	SCC DESCRIPTION	OIL OR GAS
288888	Internal Combustion Engines_Fugitive Emissions_Other Not Classified	Unable to be determined
301032	Industrial Processes_Chemical Manufacturing_Elemental Sulfur Production	Unable to be determined
306001	Industrial Processes_Petroleum Industry_Process Heaters	Oil
306008	Industrial Processes_Petroleum Industry_Fugitive Emissions	Oil
306009	Industrial Processes_Petroleum Industry_Flares	Oil
306099	Industrial Processes_Petroleum Industry_Incinerators	Oil
306888	Industrial Processes_Petroleum Industry_Fugitive Emissions	Oil
310001	Industrial Processes_Oil and Gas Production_Crude Oil Production	Oil
310002	Industrial Processes_Oil and Gas Production_Natural Gas Production	Gas
310003	Industrial Processes_Oil and Gas Production_Natural Gas Processing Facilities	Gas
310004	Industrial Processes_Oil and Gas Production_Process Heaters	Unable to be determined
310005	Industrial Processes_Oil and Gas Production_Liquid Waste Treatment	Unable to be determined
310888	Industrial Processes_Oil and Gas Production_Fugitive Emissions	Unable to be determined
399900	Industrial Processes_Miscellaneous Manufacturing Industries_Miscellaneous Manufacturing Industries	Unable to be determined
399999	Industrial Processes_Miscellaneous Manufacturing Industries_Miscellaneous Industrial Processes	Unable to be determined
402009	Petroleum and Solvent Evaporation_Surface Coating Operations_Thinning Solvents - General	Unable to be determined
403010	Petroleum and Solvent Evaporation_Petroleum Product Storage at Refineries_Fixed Roof Tanks (Varying Sizes)	Oil
403011	Petroleum and Solvent Evaporation_Petroleum Product Storage at Refineries_Floating Roof Tanks (Varying Sizes)	Oil
404001	Petroleum and Solvent Evaporation_Petroleum Liquids Storage (non-Refinery)_Bulk Terminals	Unable to be determined
404002	Petroleum and Solvent Evaporation_Petroleum Liquids Storage (non-Refinery)_Bulk Plants	Unable to be determined
404003	Petroleum and Solvent Evaporation_Petroleum Liquids Storage (non-Refinery)_Oil and Gas Field Storage and Working Tanks	Unable to be determined

In order to apportion point source emissions between crude oil and natural gas production, we initially followed the same approach as described above for area sources. However, a large portion of emissions – particularly VOC emissions – remained uncategorized. For these remaining emissions, we assumed that all emissions from facilities in the 211112 NAICS – the classification for natural gas liquid extraction – were from processes related to natural gas production. This assumption allowed us to assign all but 3.5 percent of VOC emissions to either natural gas production or crude oil production. Finally, we divided all remaining uncategorized emissions between oil and gas production according to the division of emissions from all other SCCs, as we did with area source emissions

Results

In this section, we present our estimates of state-level NO_x, SO_2, VOC, CO, PM_{10}, and $PM_{2.5}$ emissions from point and nonpoint sources associated with onshore oil and natural gas production in 2002. Figures 5 and 6 present emissions from area sources associated with oil and natural gas production, respectively, while Figures 7 and 8 present emissions from point sources. Total emissions from both point and area sources are presented in Figures 9 and 10. Finally, Figures 11 and 12 present total production of crude oil and marketed natural gas, respectively, for the ten states for which we estimated emissions, together with emissions rates for each of the seven pollutants. The totals in Figures 13 and 14 represent our estimates of the nationwide emissions rates associated with oil and gas production.

Figure 5 2002 Area Source Emissions from Onshore Oil Production

STATE NAME	EMISSIONS (TONS)					
	NO_X	SO_2	VOC	CO	PM_{10}	$PM_{2.5}$
Arizona	<1	0	15	<1	0	0
Colorado	10	<1	927	2	0	0
Montana	49	1	4,079	8	0	0
North Dakota	112	9	6,901	15	0	0
New Mexico	369	7	12,890	78	0	0
Nevada	2	<1	128	<1	0	0
Oregon	0	0	0	0	0	0
South Dakota	3	<1	258	<1	0	0
Utah	35	<1	2,930	7	0	0
Wyoming	169	2	10,788	57	0	0
Total	750	19	38,916	168	0	0

Source: WRAP 2002 stationary source inventory for area sources.
Note: Totals may not sum due to rounding

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Figure 6 2002 Area Source Emissions from Onshore Natural Gas Production

STATE NAME	EMISSIONS (TONS)					
	NO_X	SO_2	VOC	CO	PM_{10}	$PM_{2.5}$
Arizona	17	0	31	2	0	0
Colorado	23,508	118	26,332	6,845	0	0
Montana	7,508	224	1,365	1,010	0	0
North Dakota	4,519	350	838	21	0	0
New Mexico	55,872	243	211,381	31,551	0	0
Nevada	60	<1	1	<1	0	0
Oregon	85	0	34	2	0	0
South Dakota	358	6	29	10	0	0
Utah	3,300	16	33,031	552	0	0
Wyoming	14,557	149	108,659	3,490	0	0
Total	109,783	1,106	381,703	43,485	0	0

Source: WRAP 2002 stationary source inventory for area sources.
Note: Totals may not sum due to rounding.

Figure 7 2002 Point Source Emissions from Onshore Oil Production

STATE NAME	EMISSIONS (TONS)					
	NO_X	SO_2	VOC	CO	PM_{10}	$PM_{2.5}$
Arizona	0	0	0	0	0	0
Colorado	21	2	1,399	45	<1	0
Montana	0	0	0	0	0	0
North Dakota	0	0	0	0	0	0
New Mexico	5	463	1,028	4	<1	<1
Nevada	0	0	0	0	0	0
Oregon	0	0	0	0	0	0
South Dakota	0	0	0	0	0	0
Utah	221	2,423	525	561	0	0
Wyoming	10	140	639	129	0	0
Total	256	3,028	3,591	739	<1	<1

Source: WRAP 2002 stationary source inventory for point sources.
Note: Totals may not sum due to rounding.

Figure 8 2002 Point Source Emissions from Onshore Natural Gas Production

STATE NAME	EMISSIONS (TONS)					
	NO_X	SO_2	VOC	CO	PM_{10}	$PM_{2.5}$
Arizona	0	0	0	0	0	0
Colorado	18,683	81	62,062	12,692	257	0
Montana	220	2	63	195	0	0
North Dakota	3,679	2,574	78	1,117	0	0
New Mexico	24,586	13,461	5,483	10,306	197	1,345
Nevada	0	0	0	0	0	0
Oregon	0	0	0	0	0	0
South Dakota	0	0	0	0	0	0
Utah	2,110	<1	814	1,755	116	21
Wyoming	14,765	15,092	5,548	14,118	12	0
Total	64,043	31,209	74,048	40,183	583	1,367

Source: WRAP 2002 stationary source inventory for point sources.
Note: Totals may not sum due to rounding.

Figure 9 Total 2002 Emissions from Onshore Oil Production

STATE NAME	EMISSIONS (TONS)					
	NO_X	SO_2	VOC	CO	PM_{10}	$PM_{2.5}$
Arizona	<1	0	15	<1	0	0
Colorado	31	2	2,326	47	<1	0
Montana	49	1	4,079	8	0	0
North Dakota	112	9	6,901	15	0	0
New Mexico	374	470	13,918	82	<1	<1
Nevada	2	<1	128	<1	0	0
Oregon	0	0	0	0	0	0
South Dakota	3	<1	258	<1	0	0
Utah	255	2,423	3,454	568	0	0
Wyoming	179	141	11,427	186	0	0
Total	1,006	3,047	42,507	907	<1	<1

Source: WRAP 2002 stationary source inventory for area and point sources.
Note: Totals may not sum due to rounding.

Figure 10 Total 2002 Emissions from Onshore Natural Gas Production

STATE NAME	EMISSIONS (TONS)					
	NO_X	SO_2	VOC	CO	PM_{10}	$PM_{2.5}$
Arizona	17	0	31	2	0	0
Colorado	42,191	199	88,394	19,537	257	0
Montana	7,728	226	1,428	1,205	0	0
North Dakota	8,198	2,923	916	1,138	0	0
New Mexico	80,458	13,704	216,864	41,857	197	1,345
Nevada	60	1	1	1	0	0
Oregon	85	0	34	2	0	0
South Dakota	358	6	29	10	0	0
Utah	5,410	16	33,845	2,308	116	21
Wyoming	29,321	15,241	114,207	17,607	12	0
Total	173,826	32,315	455,750	83,668	583	1,367

Source: WRAP 2002 stationary source inventory for area and point sources.
Note: Totals may not sum due to rounding

Figure 11 Tons of Emissions Per Thousand Barrels of Onshore Oil Production

STATE NAME	PRODUCTION (THOUSAND BARRELS)	EMISSIONS PER UNIT (TONS PER THOUSAND BARRELS)					
		NO_X	SO_2	VOC	CO	PM_{10}	$PM_{2.5}$
Arizona	63	0.00236	0.0000	0.240	0.00047	0	0
Colorado	17,734	0.00173	0.0001	0.131	0.00268	2.57E-05	0
Montana	16,855	0.00292	0.0001	0.242	0.00050	0	0
North Dakota	30,993	0.00362	0.0003	0.223	0.00048	0	0
New Mexico	67,041	0.00557	0.0070	0.208	0.00122	2.94E-06	2.67E-06
Nevada	553	0.00411	0.0001	0.232	0.00050	0	0
Oregon	0	0.00000	0.0000	0.000	0.00000	0	0
South Dakota	1,214	0.00252	0.0000	0.213	0.00052	0	0
Utah	13,676	0.01868	0.1772	0.253	0.04155	0	0
Wyoming	54,717	0.00327	0.0026	0.209	0.00339	0	0
Total	202,846	0.00496	0.0150	0.210	0.00447	3.22E-06	8.81E-07

Figure 12 Tons of Emissions Per Million Cubic Feet of Onshore Natural Gas Production

STATE NAME	PRODUCTION (MILLION CUBIC FEET)	EMISSIONS PER UNIT (TONS PER MILLION CUBIC FEET)					
		NO_X	SO_2	VOC	CO	PM_{10}	$PM_{2.5}$
Arizona	301	0.0571	0.00000	0.104	0.0061	0	0
Colorado	937,245	0.0450	0.00021	0.094	0.0208	2.74E-04	0
Montana	86,075	0.0898	0.00262	0.017	0.0140	0	0
North Dakota	57,048	0.1437	0.05124	0.016	0.0199	0	0
New Mexico	1,632,080	0.0493	0.00840	0.133	0.0256	1.21E-04	8.24E-04
Nevada	6	9.3617	0.12438	0.162	0.1144	0	0
Oregon	837	0.1016	0.00000	0.041	0.0029	0	0
South Dakota	1,025	0.3487	0.00549	0.029	0.0102	0	0
Utah	274,739	0.0197	0.00006	0.123	0.0084	4.24E-04	7.71E-05
Wyoming	1,453,957	0.0202	0.01048	0.079	0.0121	8.54E-06	0
Total	4,443,313	0.0391	0.00727	0.103	0.0188	1.31E-04	3.08E-04

APPENDIX C: MODELING THE IMPACTS OF OFFSHORE EMISSIONS ON ONSHORE AIR QUALITY

Introduction and Overview

This appendix documents the methods employed to estimate the impact of offshore criteria pollutant emissions on air quality in the contiguous United States. As described in the main body of this document, we used the Air Pollution Emission Experiments and Policy analysis model (APEEP) (Muller, Mendelsohn, 2007; 2009; Muller, Mendelsohn, Nordhaus, 2010) to assess the onshore air quality effects of emissions from nearly 1,500 offshore source locations in the Atlantic and Pacific Oceans and the Gulf of Mexico (GOM). These particular source locations reflect possible locations of offshore oil and gas exploration and extraction cites. In past applications, APEEP's domain included both sources and receptors in the contiguous United States. In the current application the source domain is extended to include offshore emission sites. This is accomplished using regression analysis.

The transfer coefficients in APEEP, which characterize the impact on air pollution levels in receptor location (j) due to an emission of pollutant species (s) from source location (i), T_{ijs}, are derived from the Gaussian Plume Model (Turner, 1994). Two critical determinants of T_{ijs} are the distance between source and receptor and the compass bearing (direction) between source and receptor. Hence, the T_{ijs} are regressed on distance and bearing to characterize this relationship. Using the fitted regression model, the distance and bearing between each offshore source location and each onshore county in the United States are inserted into the regression model to estimate T_{ijs}.

The results of this exercise indicate that the impact of a source's emissions on air pollution levels at a receptor is inversely related to distance. That is, the further a receptor is from a source, the smaller the impact on air quality. Second, the impact of compass direction on the link between emissions and pollution levels is non-linear. The nature of this non-linearity suggests that sources located nearly due west of a receptor have the greatest impact on its pollution levels, while sources located due east of a receptor have the smallest impact. This is intuitive in the sense that prevailing winds tend to be from the west, on average directing emitted pollutants from west to east.

Methods

An integrated assessment model, APEEP, is used to connect offshore emissions to their onshore consequences in terms of air pollution levels. APEEP has been used in prior analyses to connect emissions from onshore sources to onshore consequences (Muller, Mendelsohn, 2007; 2009; Muller, Mendelsohn, Nordhaus, 2010). Hence, APEEP is currently equipped to this modeling task with one exception, connecting emissions generated offshore to air pollution levels in each county in the coterminous United States. Since running an air quality model nearly 1,500 times to quantify the source-receptor relationships between each offshore source and all onshore counties would be prohibitively expensive and time-consuming, a reduced-form approach is employed.

The air quality model in APEEP is derived from the Gaussian Plume model (Turner, 1994). As such, APEEP contains a series of source-receptor matrices that are comprised of transfer coefficients which depict the relationship between emissions in source location (i) and receptor location (j), denoted T_{ijs}. Note that (s) corresponds to pollution species. Hence, APEEP contains distinct source-receptor matrices for each emitted pollutant. The (i,j) entry in matrix (s) characterizes the impact of one ton of emissions from source (i) on annual average concentrations in receptor location (j). The T_{ijs} are used as the basis for characterizing the impact of offshore emissions on county receptors.

The extension to modeling the impact of offshore emissions on onshore counties relies on developing a regression model that describes the Gaussian transfer coefficients T_{ijs} in APEEP as a function of the distance and compass direction between source and receptor locations. As such, the distance between each modeled offshore source and each onshore county is determined using the formulas in (1) and (2).

The distance (in miles) between offshore source (i) and receptor county (j) is computed using (1).

(1) $D_{ij} = (((Lat_i – Lat_j)^2 \text{ x } 69) + ((Lon_i – Lon_j)^2 \text{ x } 53))^{0.5} \text{ x } (\cos(Lat_j/57.3))$

where: Lat_i = latitude in source grid cell (i)
Lon_i = longitude in source grid cell (i)

Since prevailing wind direction also impacts the emission-concentration relationship, compass bearing is determined. The bearing expressed in radians is determined using the formula in (2).

(2) $\theta_{ij} = (\text{atan2}(\sin(Lon_j - Lon_i)*\cos(Lat_j),$
$\cos(Lat_i)*\sin(Lat_j)-\sin(Lat_i)*\cos(Lat_j)*\cos(Lon_j – Lon_i))).$

This formula is derived from (Williams, 2009). In order to convert the resultant θ_{ij} to degrees, the θ_{ij} is multiplied by 180/Π, or (57.3). Finally, since (2) produces values on the interval -180°, 180°, we add 360° to θ_{ij} and apply the modulus function. This is shown in (3).

(3) $B_{ij} = \text{mod}(360^\circ + \theta_{ij}).$

The next step toward modeling the impact of criteria-pollutant emissions from grid cell-to-county involves the estimation of transfer coefficients that describe the impact on ambient concentrations of pollutant species (s) in county location (j) due to emissions in source (i), denoted T_{ijs} in (4). Note that T_{ijs} is constructed as a function of distance and bearing between (i) and (j).

(4) $T_{ijs} = \beta_{0s} + \beta_{1s}D_{ij} + \beta_{2s}B_{ij} + \beta_{3s}D_{ij}B_{ij} + \varepsilon_{ijs}$

Empirically, this procedure employs the transfer coefficients in the source-receptor matrices in the APEEP, as the T_{jis} in (4). The transfer coefficients are specific to each pollutant species (s) and for particular emission heights. This analysis employs the T_{ijs} corresponding to ground-level emissions since it is unlikely that offshore emissions would be produced by a facility with a tall smokestack similar to what is observed in large industrial facilities or power plants.

The model in (4) forms the basis of a fitted regression model in which the transfer coefficients are regressed on distance and compass bearing for all of the ground-level county-to-county transfer coefficients in APEEP. This estimation procedure results in a set of parameter estimates (β_{ks}) for each pollutant species (s), which describe the T_{ijs} as a function of distance and bearing; the estimated parameters from (4) reflect the impact of distance and bearing on the emission-to-concentration relationships among counties in the coterminous United States.

In order to generate transfer coefficients that capture the impact of emissions from offshore sources on counties in the United States, the coordinates (latitude, longitude) for each offshore source and each county are used to calculate both distance and bearing for each source-county pair denoted (D_{ij}, B_{ij}). The distance and bearing values are inserted into the fitted model for pollutant species (s). The resulting, predicted T_{ijs} reflect the impact of an emission of pollution species (s) from offshore source (i) on ambient county (j).

There is one additional step in the air quality modeling phase of APEEP before concentrations are linked to exposure and damages. The ambient $PM_{2.5}$ level predicted in each county is calculated in a manner that reflects the interactions among ambient NO_x, SO_2, and NH_4 (ammonium). Specifically, a reduced form representation of the processes that link ambient levels of these pollutants to particulate sulfate and particulate nitrate (important constituents of ambient $PM_{2.5}$) is embedded in APEEP and calculated in each onshore receptor location. Hence, when modeling an emission of SO_2 for example from an offshore source, the estimated (T_{ijs}) predict the resulting incremental increase in ambient SO_2 in each receptor county (j). This level of SO_2 is then fed into the existing ammonium sub-module to determine resulting concentrations of particulate sulfate and total $PM_{2.5}$.

In order to compute ambient O_3 levels, offshore emissions of NO_x and VOC are linked to ambient concentrations of NO_x and VOC through the (T_{ijs}) fitted using the approach described above. Then, the resulting NO_x and VOC levels onshore are processed in the O_3 sub-module in APEEP (Muller and Mendelsohn, 2007). Specifically, a reduced form model translates ambient levels of NO_x and VOC into O_3 levels in each receptor county. Note that the model also incorporates the effects of a multitude of other factors on ambient O_3. Connecting the (T_{ijs}) to the O_3 sub-module links offshore emissions of O_3 precursors to onshore ambient levels of O_3.

Results

Tables 1 and 2 display the results from the estimation procedure for model (4), by pollutant species (s). Although there is not a necessarily preferred functional form for (4), we employ a third-order approximating polynomial for the explanatory variables and the natural log form of the dependent variables (T_{ijs}). Table 1 focuses on the impact of emissions of NO_x, SO_2, $PM_{2.5}$, and VOC on ambient concentrations of $PM_{2.5}$. The results shown are ordinary-least-squares estimates. First, the large number of observations (greater than 8 million) results in hypothesis tests with high statistical power; note that most of the ordinary-least-squares coefficients are significant at $\alpha = 0.01$.

For each emitted pollutant, the impact of distance on T_{ijs} is quite similar; both the linear and the cubic forms have a negative impact on T_{ijs} while the quadratic term figures a positive impact. The resulting functional form is shown in Figure 1. The magnitude of T_{ijs} is a first steeply declining as distance between source and receptor increases. At approximately 750 miles, the effect of distance mitigates. The T_{ijs} is no longer declining dramatically as distance increases up to 3,500 miles.

The fitted coefficients for compass direction (bearing) are less uniform across pollutants. For both NO_x, $PM_{2.5}$, and VOC the linear terms are positive, while the quadratic terms are negative. For NO_x, the cubic term is also positive. In contrast, for $PM_{2.5}$ and VOC, the cubic term is negative. Bearing appears to have a somewhat different impact on the T_{ijs} corresponding to SO_2. Specifically, the linear and cubic terms are negative while the quadratic term is positive. The nature of the functional forms for relationship between bearing and the T_{ijs} for $PM_{2.5}$, NO_x, VOC, and SO_2 is shown in Figure 2. This figure indicates that for NO_x, VOC, and $PM_{2.5}$, the T_{ijs} maximize at between approximately 45^o and 90^o. That is, if the receptor is located from the northeast to due east of the source, the T_{ijs} are at the largest magnitude (holding the effect of distance constant). The intuition is that, in North America, prevailing winds tend to be oriented west-to-east. For SO_2, there is not a clear maximum before 90^o. Rather, the T_{ijs} gradually decline from 0^o to 90^o.

Conversely, Figure 2 indicates that for each pollutant, the T_{ijs} minimize between approximately 250^o and 270^o. That is, if the receptor is located approximately due west of the source, the T_{ijs} are at the smallest magnitude (again, holding the effect of distance constant). The intuition for this result is the same; for an emission to travel east to west, it would be moving counter to prevailing winds.

Figure 3 maps the (T_{ijs}) for emissions of primary $PM_{2.5}$ corresponding to four different offshore source locations. The top left panel maps the consequences of emissions from a source just offshore of southern California. Intuitively, the largest impact of emissions is concentrated in southern California. This figure clearly displays the impact of wind direction on emissions; the plume spreads from the source in a generally northeasterly direction. Recall that effect is what Figure 2 implies since the transfer coefficients for primary $PM_{2.5}$ emissions are greatest between 45° and 90° (northeast and due east).

The top right panel of Figure 3 shows the (T_{ijs}) for a source located off of the southeastern United States in the Atlantic Ocean. Again, the importance of bearing is clear in this example. Because the nearest land is located upwind from this source, the impact of emissions extends over a much smaller land area than the source off the coast of California. That is, the greatest impact of the emission in the Atlantic Ocean is likely to be over the ocean since prevailing winds send the emission to the northeast.

The bottom left panel of Figure 3 displays the effect of emissions from a source in the western GOM. This emission has the greatest effect on air quality in Texas and Louisiana. The figure shows that the plume is distorted towards the northeast (again, the impact of prevailing wind direction through bearing) and it also clearly shows the effect that distance between source and receptor has on the magnitude of the (T_{ijs}). Specifically, county receptors that are impacted most by emissions from the western Gulf are located relatively nearby to the source. The impact on air quality declines in nearly concentric distance bands from the source location.

Finally, the bottom right panel of Figure 3 shows the impact of an emission from a source in the eastern GOM. The greatest impact of discharges from this location are in Florida and the impact spreads northeast over other receptors in the southeastern United States. This panel, like the others in Figure 3, shows the influence of both bearing and distance on the (T_{ijs}).

Table 2 reports the results of the regression model applied to estimate the T_{ijs} corresponding to emissions of SO_2 and the resulting impact on concentrations of SO_2 and emissions of NO_x and the resulting impact on concentrations of NO_x. Note the distinction with Table 1. In Table 1, the transfer coefficients reflect the impact of emissions on resulting concentrations of $PM_{2.5}$.

Table 2 indicates that the impact of distance on the (T_{ijs}) is similar for both NO_x and SO_2; namely, the linear and cubic distance terms have a negative impact on the (T_{ijs}) whereas the quadratic term increases the (T_{ijs}). Also, the fitted coefficients in the NO_x are roughly an order of magnitude larger than the fitted coefficients for SO_2. Bearing has an increasing effect on the (T_{ijs}) for NO_x through the linear and cubic forms and a negative impact through the quadratic term. The orientation of this relationship is reversed for $SO_{2.}$ The linear and cubic terms are negative while the quadratic term is positive. Hence, the impact of bearing for both SO_2 and NO_x on (T_{ijs}) is quite similar to the relationship reported in Table 1.

Table 1 Regression Analysis Results for Primary and Secondary Particulate Matter (PM2.5). Dependent Variable: Log T_{jis}.

VARIABLES	(1) NO_x – $PM_{2.5}$	(2) $PM_{2.5}$	(3) SO_2 – $PM_{2.5}$	(4) VOC TC
Distance	-4.76e-03***	-5.87e-03***	-4.65e-03***	-5.87e-03***
	(7.34e-06)	(8.07e-06)	(7.00e-06)	(8.07e-06)
$Distance^2$	3.22e-06***	3.93e-06***	3.08e-06***	3.93e-06***
	(6.96e-09)	(7.65e-09)	(6.64e-09)	(7.65e-09)
$Distance^3$	-7.37e-10***	-8.85e-10***	-6.92e-10***	-8.85e-10***
	(1.88e-12)	(2.07e-12)	(1.80e-12)	(2.07e-12)
Bearing	8.55e-03***	5.60e-03***	-6.08e-04***	5.60e-03***
	(4.82e-05)	(5.30e-05)	(4.60e-05)	(5.30e-05)
$Bearing^2$	-9.17e-05***	-7.11e-05***	2.77e-05***	-7.11e-05***
	(3.07e-07)	(3.37e-07)	(2.92e-07)	(3.37e-07)
$Bearing^3$	1.080e-07***	-1.45e-07***	-7.15e-08***	-1.45e-07***
	(5.62e-10)	(6.17e-10)	(5.36e-10)	(6.17e-10)
Constant	-14.79***	-14.04***	-14.80***	-14.04***
	(2.97e-03)	(3.26e-03)	(2.83e-03)	(3.26e-03)
Observations	8,512,743	8,511,952	8,511,952	8,511,952
R^2	0.183	0.189	0.162	0.189

Ordinary Least Squares
Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 2 Regression Analysis Results for NO_x to NO_x and SO_2 to SO_2. Dependent Variable: Log T_{jis}.

VARIABLES	(1) $NO_x – NO_x$	(3) $SO_2 – SO_2$
Distance	-1.14e-02***	-6.00e-03***
	(1.83e-05)	(1.00e-05)
$Distance^2$	1.17e-05***	3.91e-06***
	(2.22e-08)	(1.08e-08)
$Distance^3$	-3.31e-09***	-7.65e-10***
	(7.42e-12)	(3.27e-12)
Bearing	1.38e-02***	-1.23e-02***
	(9.65e-05)	(5.70e-05)
$Bearing^2$	-9.72e-05***	1.01e-04***
	(6.23e-07)	(3.60e-07)
$Bearing^3$	1.71e-07***	-1.99e-07***
	(1.14e-09)	(6.53e-10)
Constant	-13.06***	-13.84***
	(5.56e-03)	(3.57e-03)
Observations	2,194,075	6,500,105
R^2	0.191	0.172

Ordinary Least Squares
Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Figure 1 The Effect of Distance on T_{jis}.

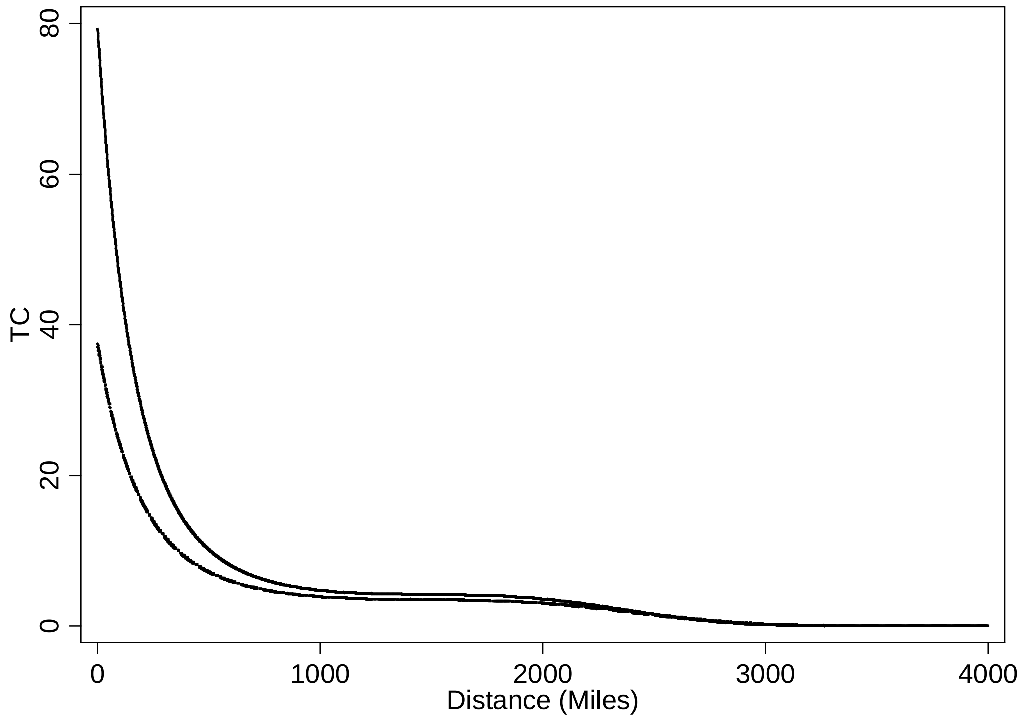

Figure 2 The Effect of Direction (Bearing) on T_{jis}.

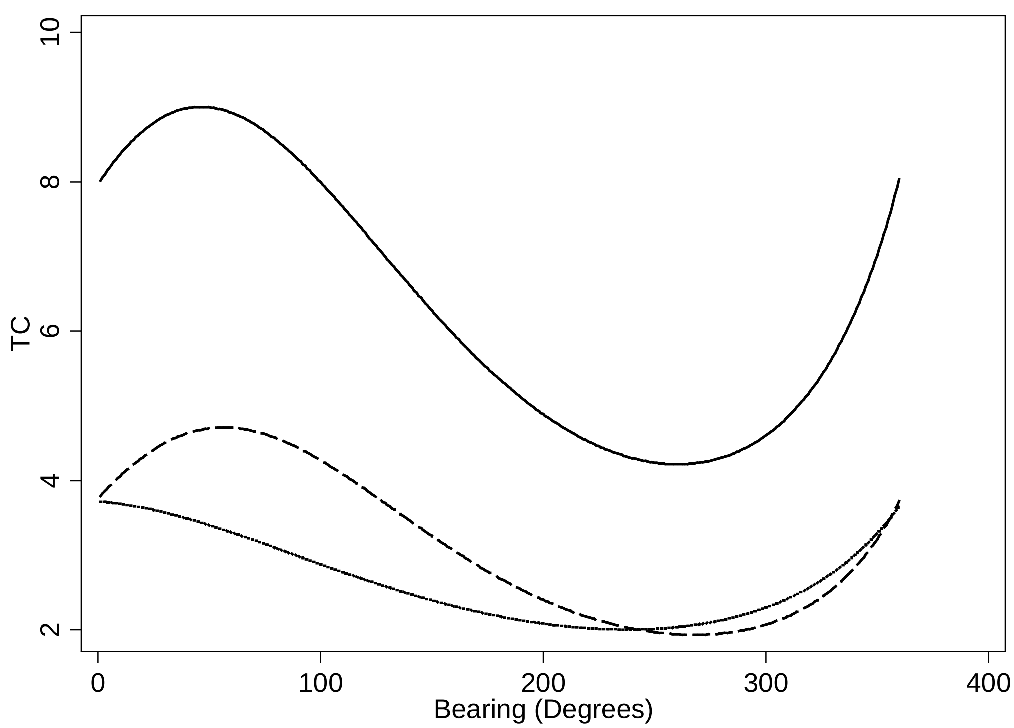

Figure 3 Transfer Coefficients: *Tijs* for Primary PM2.5*

* Locations of offshore emission sources are for illustrative purposes only.

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APPENDIX D: PHYSICAL EFFECTS AND VALUATION ESTIMATES FOR THE OECM AIR QUALITY MODULE

As described in the main body of this document, the assessment of air quality impacts in the OECM relies upon estimates of monetized impacts per ton of offshore emissions. Estimated by the Air Pollution Emission Experiments and Policy (APEEP) model, these dollar-per-ton estimates reflect human health effects, changes in agricultural productivity, and damage to manmade materials. Building upon the methods discussion presented in the main body of this document, this appendix provides additional detail on the methods used to quantify and monetize these effects on a per ton basis. Specifically, we describe (1) the data used to assess exposure to increased pollutant concentrations, (2) the dose-response functions employed for each impact category, and (3) valuation information.

Exposure Assessment

To estimate air pollution exposure, APEEP relies upon county-level estimates of receptor populations for the contiguous United States. These receptors vary by impact category based on the exposure metrics used in the dose-response literature. Because the magnitude of damages associated with air pollution changes over time as receptor populations increase or decrease in size, the APEEP runs for the OECM include receptor projections for those receptor categories for which projections are available. The receptor information included in APEEP for each major impact category is as follows.

> *Human Health:* To assess exposures for human health effects, APEEP uses population projections from EPA's BenMAP model by county and age group.[48] EPA has used BenMAP to assess the human health impacts of air pollution for several regulatory impact analyses, all of which have undergone extensive review with the Office of Management and Budget. Based on the BenMAP population data, APEEP estimates health effects for individuals of different ages. This is critical for correctly assessing the incidence of those health endpoints where the epidemiological literature shows differing levels of vulnerability to pollution across age groups. To allow for the estimation of dollar-per-ton values that vary over time, APEEP includes population projections for every fifth year (e.g., 2010, 2015, etc.) in the 50-year time horizon of the OECM.
>
> We note that BenMAP's county- and age-specific population projections cover the years 2010 through 2030. Population projections by county and age group beyond 2030 are not available from the U.S. Census or other sources. In the absence of such projections, we hold post-2030 population and age demographics constant at 2030 levels.[49] To the

[48] BenMAP is available for download at http://www.epa.gov/air/benmap/.

[49] As an alternative to holding population and demographics constant at 2030 levels, we explored different approaches for extrapolating population by age group and county beyond 2030 based on projected population growth for the 2020s. Over several decades, however, the extrapolation of the trends projected for the 2020s by age group and county yields population projections that do not appear credible. For example, in cases where the county-level population projections for 2029 and 2030 show a significant increase in population for the 25-29 age group in a given county, extrapolation of this trend through 2075 might suggest that most of the county's 2075 population is in the 25-29 age group, even though the individuals in this group in 2029 and 2030 are no longer between the ages of 25 and 29 in 2075.

extent that the U.S. population grows significantly after 2030, this leads to underestimation of impacts.

Agriculture: APEEP estimates exposure for agriculture based on county-level yield estimates for corn, cotton, peanuts, dry edible beans, grain sorghum, soybeans, spring wheat, and tobacco from U.S. Department of Agriculture's (USDA) 2002 Census of Agriculture.[50] APEEP uses these yield estimates for each year in the OECM's analytic time horizon.

Materials Damage: For materials damage, APEEP assesses exposure based on inventories of infrastructure, commercial buildings, and residential buildings constructed from materials susceptible to pollution-related damage, as indicated in the dose-response literature (*i.e.*, galvanized steel, painted wood surfaces, and carbonate stone). For infrastructure materials, APEEP uses inventories developed from methods outlined in National Acid Precipitation Assessment Program (NAPAP) (1991). NAPAP reports the estimated surface area of galvanized and carbon steel, focusing on bridges, transmission towers, railroads, and guardrails, for select areas of the country. We developed an inventory for other areas of the United States by applying the ratios of exposed surface area to land area from the NAPAP study to states and regions not covered by the original NAPAP surveys.

To develop inventories for commercial and residential buildings, we use an inventory previously developed from the Department of Energy's (DOE) Commercial Buildings Energy Consumption Survey and Residential Energy Consumption Survey, as well as the Census Bureau's Annual Housing Survey.[51] These surveys report the number of buildings by region (for the DOE sources) or by state (for the Census Bureau survey). To develop county-level estimates, the inventory distributes the regional/state values to the counties within each region/state in proportion to population. The extent of pollution-related materials damage to these buildings depends on the surface area of their exterior walls. While the DOE data provide regional estimates of the average square footage per building, they do not provide the average exterior wall area or the average number of floors per building). Thus, to estimate exterior area, the inventory employs the simplifying assumption that each building is cubic in shape with two stories of living/working space. Under this assumption, the exterior wall space of a building is twice its floor space.

After estimating the number and size of buildings by county, the inventory calculates the amount of painted wood, etc,. used on exterior walls based on data from the DOE commercial and residential surveys. Based on the DOE data, it is possible to directly estimate the percentage of buildings with exterior walls constructed from each material. The inventory applied these percentages to the estimated exterior wall area of each county to generate county-level estimates of vulnerable material, by material type.

[50] Data from the 2002 Census of Agriculture are available at http://www.agcensus.usda.gov/Publications/2002/index.asp.

[51] This inventory was developed for EPA's ongoing benefit-cost analysis of the Clean Air Act Amendments of 1990. See US EPA (2010b).

Dose-Response Functions

To estimate the physical effects of air pollution for exposed populations, APEEP will use a series of impact-specific dose-response (D-R) functions that relate changes in ambient pollutant concentrations to changes in the risk or probability of a given effect. As detailed below, these D-R relationships are derived from several analyses in the peer-reviewed literature.

Human Health

The epidemiological literature includes several studies that examine the relationship between air pollutant exposure and the risk of various adverse health effects. Based upon reviews of this literature conducted by the National Research Council and the EPA's Science Advisory Board (SAB), EPA has relied upon many studies from this literature to develop regulatory impact analyses (RIA) for proposed and final air rules. To ensure that the OECM reflects the advice of the SAB and National Academy of Sciences' expert reviewers, the APEEP runs conducted for the development of the OECM used the same dose-response (D-R) functions used by EPA in recent RIAs.

For many health endpoints, the peer-reviewed literature includes multiple studies that estimate the statistical relationship between exposure and risk. To incorporate the results of multiple studies into a single estimate of the D-R relationship, we developed a pooled estimate of this relationship based on the pooling procedures outlined in Abt Associates (2008). In effect, a pooled estimate of multiple D-R coefficients (β's) is a weighted average of the β values estimated in different studies. Weights may be assigned subjectively (*e.g.*, assigning equal weight to all studies) or through more formal methods, such as fixed effects weighting and random effects weighting. Under fixed effects weighting, it is assumed that one true parameter value for β exists and that differences in β estimates across studies reflect sampling error. Given that the variance of each β value is an indicator of the certainty of the estimate, fixed effects pooling weights each β value based on the inverse of its variance.[52] Under this approach, estimates with small variance (*i.e.*, estimates with relatively low uncertainty) receive large weights and estimates with large variance receive small weights.

An alternative to fixed effects pooling is random effects pooling. Unlike fixed effects pooling, which assumes one true value of β, random effects pooling allows for the possibility that multiple values for β may exist. For example, the β value for particulate matter (PM) mortality may vary geographically due to differences in the characteristics of PM in different locations. To account for the possibility of multiple β values, random effects pooling weights each β based on both within-study variance (like fixed effects weighting) and the variance between studies.[53]

[52] If the variance of the β estimate in a study is represented by v_i and the weight assigned to that study is w_i, then

$$w_i = \frac{1/v_i}{\sum 1/v_i}$$

[53] Under random effects pooling, the weights assigned to a given β are based on the sum of within-study variance (v_i), as specified as in the previous footnote, and between study variance (η^2), as specified in Abt Associates (2008). More specifically, the random effects weights are based on v_i^*, which is the sum of v_i and η^2. Given v_i^*, the weight (w_i^*) assigned to a given β is specified as follows:

To pool the β values for a given health endpoint, the functional form used in the underlying studies must be consistent. For example, if one study uses a log-linear functional form to estimate the relationship between pollutant concentrations and risk and another uses a logistic functional form, it would be inappropriate to pool the β values from these studies because they do not represent parameter estimates for the same health impact function. Due to such differences in functional form, our pooled β estimates for some health endpoints exclude a limited number of studies from the epidemiological literature.

Table 1 summarizes the human health dose-response information incorporated into APEEP to develop dollar-per-ton values for the OECM. For each health endpoint, the table identifies the study(s) used and describes how the studies for a given endpoint were pooled (where applicable).

We note that the health effects incorporated into APEEP, as detailed in Table 1, include most, but not all, of the health impacts typically included in EPA RIAs. For some health effects, the epidemiological literature specifies impacts using a metric of air quality that is inconsistent with the metric used by APEEP. In particular, the health impact functions for many PM-related endpoints are based on the 24-hour average $PM_{2.5}$ concentration, rather than the annual average concentration estimated by APEEP. These endpoints include nonfatal myocardial infarction, respiratory hospital admissions, cardiovascular hospital admissions, asthma-related emergency room visits, acute bronchitis, lower respiratory symptoms, upper respiratory symptoms, asthma exacerbation, minor restricted activity days[54], and work loss days. The exclusion of these health endpoints from the dollar-per-ton impact values estimated by APEEP has minimal impact on the magnitude of these estimates, as the mortality effects of PM and ozone make up the vast majority of the monetized health impacts associated with air pollution.[55] Both PM- and ozone-related mortality are reflected in the dollar-per-ton values generated by APEEP.

The dose-response functions employed in the studies listed in Table 1 use the baseline incidence rate of each respective health endpoint as a variable in estimating changes in health impacts associated with air pollution. Table 2 presents the baseline incidence rates assumed in developing the dollar-per-ton values for the OECM.

Agriculture

To estimate changes in crop yield associated with changes in ozone concentrations, APEEP uses dose-response functions from the National Crop Loss Assessment Network (Lesser *et al.*, 1990). These functions are specified as follows.

(1) $$CY^* = \left(1 - e^{-\left(\frac{O_3}{\sigma}\right)^{\gamma}}\right) \times CY^b$$

where CY^* = crop yield following emissions perturbation
CY^b = baseline crop yield (1996)

$$w_i^* = \frac{1/v_i^*}{\sum 1/v_i^*}$$

[54] We included minor restricted activity days associated with ozone exposure in APEEP for this analysis. Exposure to $PM_{2.5}$ also increases the risk of experiencing minor restricted activity days, but this change in risk related to $PM_{2.5}$ was not incorporated into APEEP for this analysis.

[55] As indicated in many RIAs published by EPA, PM- and ozone-related mortality dominates the estimates of monetized human health impacts. See U.S. EPA (2010c), U.S. EPA (2008), U.S EPA (2006), and U.S. EPA (1999).

O_3 = 7 or 12-hour daily mean ozone concentrations (parts per million by volume)
γ = statistically estimated shape parameter
σ = statistically estimated parameter

Based on this equation, APEEP derives the change in crop yield associated with a given emissions scenario.

Table 1 Summary of Human Health Dose-Response Information Reflected in Dollar Per Ton Estimates for Air Quality Impacts

POLLUTANT	HEALTH EFFECT	LITERATURE SOURCES FOR D-R FUNCTIONS	D-R COEFFICIENT INCORPORATED INTO APEEP	FUNCTIONAL FORM	NOTES
$PM_{2.5}$	Premature mortality (age 29 and older)	Mean of a Weibull distribution of dose-response coefficients under which the dose-response coefficient from Pope *et al.* (2002) is the 25th percentile and the dose-response coefficient from Laden *et al.* (2006) is the 75th percentile.	0.0106	Log-linear	• Recent EPA RIAs present separate estimates of the mortality impacts of $PM_{2.5}$ based upon both the Pope *et al.* (2002) and Laden *et al.* (2006) D-R functions.[1] • This approach for the OECM is based upon input from the Health Effects Subcommittee of the SAB Advisory Council for Clean Air Compliance Analysis, which recommended that EPA define a distribution of possible D-R coefficients with the 25th percentile equal to the Pope *et al*. (2002) estimate, the 75th percentile equal to the Laden *et al.* (2006) estimate, and the mean approximately equal to the mean of these two values (EPA HES 2010).
	Infant mortality (age <1 year)	Woodruff *et al.* (1997)	0.003922	Logistic	• EPA has estimated infant mortality based on the Woodruff *et al*. (1997) study in several RIAs.[2]
	Chronic bronchitis (ages 27 and older)	Abbey *et al.* (1995)	0.013185	Logistic	• Few studies have examined the impact of air pollution on new cases of chronic bronchitis. Abbey *et al*. (1995) provides evidence that long-term $PM_{2.5}$ exposure gives rise to the development of chronic bronchitis among U.S. populations.

POLLUTANT	HEALTH EFFECT	LITERATURE SOURCES FOR D-R FUNCTIONS	D-R COEFFICIENT INCORPORATED INTO APEEP	FUNCTIONAL FORM	NOTES
Ozone	Premature mortality (all ages)[3]	Pooled estimate of D-R coefficients, using equal weighting, from the following studies: • Ito *et al.* (2005) • Bell *et al.* (2004)	0.000717	Log-linear	• EPA's RIA for the reconsideration of the ozone National Ambient Air Quality Standards (NAAQS) (U.S. EPA, 2010c) estimates changes in ozone-related mortality based on both of these studies and based on Schwartz (2005), Bell *et al*. (2005), Levy *et al*. (2005), and Huang *et al*. (2005). Three of these studies (Bell et al., 2004; Huang et al., 2005; and Schwartz, 2005) are based upon the National Morbidity, Mortality, and Air Pollution Study (NMMAPS) data set, and the other three (Bell et al., 2005; Ito et al., 2005; and Levy et al, 2005) are meta-analyses of data from other studies. Because of differences in functional specification across studies (i.e., log-linear versus logistic functional form) and differences in the type of mortality estimated in each study (i.e., all-cause, non-accidental, and cardiopulmonary mortality), it would not be appropriate to pool the dose-response coefficients across all six of these studies. We pooled the Ito *et al.* (2005) and Bell *et al.* (2004) dose-response coefficients because (1) they have the same functional specification, (2), they reflect the same type of mortality (i.e., non-accidental), and (3) they reflect both the NMMAPS data set and the meta-analyses referenced above. • Because EPA RIAs have presented separate estimates of mortality impacts based on each mortality study, we use equal weighting rather than fixed effects or random effects weighting for ozone mortality.

POLLUTANT	HEALTH EFFECT	LITERATURE SOURCES FOR D-R FUNCTIONS	D-R COEFFICIENT INCORPORATED INTO APEEP	FUNCTIONAL FORM	NOTES
Ozone (continued)	Respiratory hospital admissions (adults aged 65 and older)	Pooled estimate of city-specific dose-response coefficients from the following studies, using the random effects pooling procedure described in Abt Associates (2008): • Schwartz (1995): New Haven • Schwartz (1995): Tacoma	0.002994	Log-linear	• The Schwartz (1995) assessments for New Haven and Tacoma examined respiratory hospital admissions associated with all respiratory disease. • EPA RIAs have also used results from the Moolgavkar *et al.* (1997) Minneapolis and Schwartz (1994) Detroit studies. Because each of these studies estimate separate D-R coefficients for multiple respiratory conditions that may lead to hospitalization (*i.e.*, they estimate D-R functions for multiple types of respiratory hospital admissions), it was not possible to pool the D-R coefficients from these studies with those from the New Haven, Tacoma, and Minneapolis studies, each of which estimates just one D-R coefficient. • EPA RIAs have also estimated changes in respiratory hospital admissions based on Schwartz (1994). This study estimates pneumonia-related hospital admissions rather than admissions associated with all respiratory disease. Therefore, it would not be appropriate to pool the dose-response coefficient from this study with those from Schwartz (1995).
	Respiratory hospital admissions (age <2 years)	Burnett *et al.* (2001)	0.008177	Log-linear	• Several recent EPA regulatory impact analyses relied upon the Burnett *et al.* study to estimate ozone-related changes in respiratory hospital admissions among children less than two years old.[4]
	Asthma-related ER visits (all ages)	Pooled estimate of dose-response coefficients from Peel *et al.* (2005) and Wilson *et al.* (2005), using random effects pooling procedure described in Abt Associates (2008)	0.001320	Log-linear	• This is consistent with the dose-response functions employed in U.S. EPA (2010c).
Ozone (continued)	Minor restricted activity days (ages 18-64)	Pooled estimate (using fixed effects weighting) of year-specific dose-response coefficients estimated in Ostro and Rothschild (1989)	0.002596	Log-linear	• Ostro and Rothschild (1989) estimate separate dose-response parameter values for the years 1976 through 1981. Consistent with several EPA RIAs, we use the weighted average of these values, using the inverse of the variance of each parameter estimate as weights.[4]

POLLUTANT	HEALTH EFFECT	LITERATURE SOURCES FOR D-R FUNCTIONS	D-R COEFFICIENT INCORPORATED INTO APEEP	FUNCTIONAL FORM	NOTES
	School Loss Days (children age 5 to 17)	Chen *et al.* (2000)	0.015763	Linear	• Chen *et al*. (2000) focused on children between the ages of 6 and 11. Based upon recommendations issued by the National Research Council (2002) and the Health Effects Subcommittee of the EPA Science Advisory Board's Advisory Council on Clean Air Compliance Analysis (2004), APEEP estimates changes in school absences for all school-aged children given the biological similarities between children aged 5 to 17. • Recent EPA RIAs have developed pooled estimates of school loss days based on both Chen *et al.* (2000) and Gilliland *et al.* (2001). It was not possible to pool the dose-response coefficients from these two studies because Chen *et al.* (2001) uses a linear specification while Gilliland *et al.* (2001) uses a log-linear specification.

Notes:

1. Examples of EPA regulatory impact analyses that have used both the Pope et al. (2002) and Laden et al. (2006) dose-response functions include U.S. EPA (2010a), U.S. EPA (2010c), U.S. EPA (2008), and U.S. EPA (2006).
2. For example, see U.S. EPA (2008) and U.S. EPA (2006).
3. The ozone mortality studies referenced here use the 24-hour or 1-hour maximum ozone levels as metrics of exposure. Neither of these metrics, however, is the most relevant for characterizing population-level exposure. Because most people tend to be outdoors only during daylight hours, which is when ozone concentrations are highest, the 24-hour metric is not appropriate. In addition, the 1-hour maximum ozone metric is inconsistent with that used for the current ozone NAAQS. The most biologically relevant metric is the 8-hour maximum standard, which has been used in the ozone NAAQS since 1997. For this analysis, we therefore converted the ozone health impact functions that use a 24-hour average or 1-hour maximum ozone metric to maximum 8-hour average ozone concentrations using the procedure described in Abt Associates (2008).
4. For example, see U.S. EPA (2010c) and U.S. EPA (2008).

Table 2 Summary of Baseline Incidence Rates for Human Health Effects

Endpoint		Notes/Source	Rate per 100 people per year by Age Group <1	<2	<18	18–24	25–29	30-34	35-44	45-54	55-64	65-74	75-84	85+
Mortality (all causes)		CDC Compressed Mortality File, accessed through CDC Wonder (1996–1998)			0.045	0.093	0.119	0.119	0.211	0.437	1.056	2.518	5.765	15.16
Mortality (non-accidental)					0.025	0.022	0.057	0.057	0.15	0.383	1.006	2.453	5.637	14.859
Infant Mortality (all causes)		Derived from 2002 mortality data from CDC Multiple Cause-of-Death Public-Use Data Files	0.7037											
Chronic Bronchitis		Abbey et al. (1993, Table 3), for ages 27+					0.378							
Respiratory Hospital Admissions (all respiratory, ages 65 and older)		1999 NHDS public use data files										5.2		
Respiratory Hospital Admissions (all respiratory, ages 0 and 1)	West	1999 NHDS public use data files		6.059										
	South			5.709										
	Northeast			4.785										
	Midwest			4.938										
Asthma ER Visits		2000 NHAMCS public use data files; 1999 NHDS public use data files			1.011	1.087	0.751		0.438	0.352	0.425	0.232		
Minor Restricted Activity Days		Ostro and Rothschild (1989, p. 243)				780								
School Loss Days		National Center for Education Statistics (1996)			990									

Notes: Northeast - Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania
Midwest - Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, Kansas
South - Delaware, Maryland, District of Columbia, Virginia, West Virginia, North Carolina, South Carolina, Georgia, Florida, Kentucky, Tennessee, Alabama, Mississippi, Arkansas, Louisiana, Oklahoma, Texas
West - Montana, Idaho, Wyoming, Colorado, New Mexico, Arizona, Utah, Nevada, Washington, Oregon, California, Alaska, Hawaii
*Blank cells indicate that no value was necessary, as the dose-response function for that health end point applies only to a limited number of age groups.

Man-made Materials

APEEP uses dose-response functions for man-made materials from two sources: the NAPAP studies (Atteraas, Haagenrud, 1982; Haynie, 1986) and the International Cooperative Programme on Effects on Materials (ICP, 1998). These studies specify separate dose-response functions for (1) galvanized steel, (2) painted surfaces, and (3) carbonate stone surfaces.

Atteraas and Haagenrud (1982) estimate a linear dose-response function relating ambient concentrations of SO_2 to the corrosion of galvanized steel. This function is based on an analysis of mass loss data from 22 field sites in Norway and is specified as follows:

(2) $$\Delta M = (\beta_0 SO_2 + \beta_1) M_b$$

where: ΔM = mass loss of material,

β_0, β_1 = statistically estimated parameters (6.05 and 0.22, respectively, as estimated in Atteraas and Haagenrud (1982),

SO_2 = ambient concentration of SO_2, and

M_b = existing material quantity

For painted surfaces, APEEP relies upon the dose-response relationship estimated by Haynie *et al.* (1986), which was developed from erosion data for painted specimens exposed to both SO_2 and moisture. This function is specified as follows:

(3) $$\Delta M_C = R_C \beta_0 \left(10^{-pH} - 10^{-5.2}\right) + \beta_1 SO_{2C} F_C$$

where: ΔM_c = mass loss of material,

β_0, β_1 = statistically estimated parameters

SO_{2c} = ambient concentration of SO_2,

pH = average pH by region, as measured by the National Atmospheric Deposition Program (NADP),

F_c = frequency exposed surface area is wet by county (c), and

R_c = annual rainfall.

The model predicts the increase in erosion relative to a baseline under which pH is 5.2 and the SO_2 concentration is zero (representative of a clean environment).

APEEP uses the dose-response function from ICP (1998) to estimate the effect of ambient SO_2 on carbonate stone surfaces. The ICP's dose-response function is based upon an extensive field exposure program in which data on materials corrosion, gaseous pollutants, precipitation, and climate parameters were collected at 39 exposure sites in 12 European countries, the U.S., and Canada. The dose-response function estimated from these data is as follows:

(4) $$\Delta S = \left(\beta_0 SO_2^{\kappa}\right) \exp^{\gamma T_C} + \left(\beta_1 R_C\right) H^{+}$$

where: ΔS= surface recession of material,

β_0, β_1,γ,κ = statistically estimated parameters ,

SO_2 = ambient concentration of SO_2,

T_c = ambient temperature,

R_c = annual rainfall, and

H^+ = hydrogen concentration of precipitation.

In using the ICP dose-response function, APEEP holds ambient temperature, annual rainfall, and the hydrogen concentration of precipitation constant.

Valuation

To estimate the value of the health, agricultural, and materials impacts outlined above, APEEP uses a combination of market price data, willingness to pay values estimated in the peer-reviewed literature, and (for certain health impacts) cost of illness estimates derived from studies of treatment costs. We describe these values below by major impact category.

Health Effects

To assess the value of the adverse health effects associated with increased pollutant concentrations, APEEP relied upon two types of valuation estimates: willingness-to-pay (WTP) values and cost-of-illness (COI) estimates. In economic terms, the value of avoiding an adverse health effect is the dollar amount necessary such that a person would be indifferent between avoiding the effect and receiving the compensation. In most cases, the dollar amount required to compensate a person for exposure to an adverse effect is roughly the same as the dollar amount a person is willing to pay to avoid the effect. Therefore, in economic terms, WTP is the appropriate measure of the value of avoiding an adverse effect. Where possible, APEEP used WTP values derived from the peer-reviewed literature to estimate the value of the adverse health effects associated with changes in ambient pollutant concentrations.

For some health effects (*e.g.*, hospital admissions), WTP estimates are not available from the peer-reviewed literature. In these cases, APEEP used the cost of treating or mitigating the effect as a primary estimate. These COI estimates generally understate the true value of reducing the risk of a health effect, because they reflect the direct expenditures related to treatment, but not the value of avoided pain and suffering (Harrington and Portney, 1987; Berger, 1987).

For both WTP and COI estimates, we rely upon valuation studies employed by EPA for numerous regulatory impact analyses of air pollution policy. These studies have undergone extensive peer review and are widely accepted as the state of the science.

Economic theory maintains that individuals' willingness to pay for goods, including the avoidance of an adverse health effect, increases as real income increases. Given that incomes are likely to increase during the 50-year analytic time horizon of the OECM, APEEP (where possible) uses income-adjusted valuation estimates to assess the value of the adverse health effects associated with changes in ambient pollutant concentrations. The model made these adjustments only for those health effects for which we used WTP valuation estimates. We did not adjust COI estimates because the cost of treating an illness is not dependent upon income.

To develop income-adjusted estimates, we use income elasticities from EPA's BenMAP model that represent the percentage change in WTP associated with a one percent change in real income (Abt Associates, 2008). We will applied these elasticity values to Gross Domestic Product (GDP) per capita, as projected in the DOE's Annual Energy Outlook (AEO) 2010. The DOE data cover the years 2010 through 2035. To extend the income adjustments through the end of the OECM's analytic time horizon, we assume that DOE's projected growth rates for GDP and population in 2035 apply to later years as well. The main body of this document presents our valuation estimates for each health endpoint for the years 2015 and 2065, with information on the source for each value. Tables 3a and 3b contain estimates for the intervening years.

Table 3a Income Adjusted Values Per Statistical Case, by Health Endpoint: 2010-2040 (2006$)

HEALTH ENDPOINT	2010	2015	2020	2025	2030	2035	2040
Premature mortality	$8,200,000	$8,600,000	$8,900,000	$9,200,000	$9,500,000	$9,800,000	$10,000,000
Chronic bronchitis	$450,000	$470,000	$490,000	$510,000	$530,000	$550,000	$570,000
Respiratory hospital admissions (65+)	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000
Respiratory hospital admissions (<2)	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000
Asthma-related emergency room visits	$370	$370	$370	$370	$370	$370	$370
Minor restricted activity days	$61	$62	$63	$64	$65	$66	$66
School loss days	$89	$89	$89	$89	$89	$89	$89

Table 3b Income Adjusted Values Per Statistical Case, by Health Endpoint: 2045-2075 (2006$)

HEALTH ENDPOINT	2045	2050	2055	2060	2065	2070	2075
Premature mortality	$10,000,000	$11,000,000	$11,000,000	$12,000,000	$12,000,000	$12,000,000	$13,000,000
Chronic bronchitis	$590,000	$610,000	$630,000	$660,000	$680,000	$700,000	$730,000
Respiratory hospital admissions (65+)	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000
Respiratory hospital admissions (<2)	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000
Asthma-related emergency room visits	$370	$370	$370	$370	$370	$370	$370
Minor restricted activity days	$67	$68	$69	$70	$70	$71	$72
School loss days	$89	$89	$89	$89	$89	$89	$89

Agriculture

To estimate the economic value of changes in crop yield, APEEP will use crop pricing data from the USDA, as summarized in Table 4.

Table 4 Summary of Crop Prices (2006$)

CROP	PRICE
Corn	$4.08 per bushel
Cotton	$0.59 per pound
Peanut	$0.20 per pound
Grain Sorghum	$7.08 per hundredweight
Soybeans	$9.82 per bushel
Spring Wheat	$7.31 per bushel
Tobacco	$1.65 per pound
Source: USDA/NASS (2009)	

Materials Damage

APEEP values materials damage as the change in the present value of future maintenance costs. Under baseline emission conditions, APEEP assumes a five-year maintenance schedule for man-made materials. Based on this maintenance schedule, the model calculates the present value of materials maintenance costs using the following formula:

(5) $M_{rb} = \delta \times (RC_{rb}(e^{-rt})/(1 - e^{-rt})$

where: M_{rb} = annual maintenance costs in county (r), baseline SO_2,

δ = market interest rate

RC_{rb} = replacement costs in receptor county (r), baseline SO_2, and

t= time of repairs (5,10,15,...,T).

As materials decay due to increased air pollution, regularly scheduled maintenance will occur more frequently. APEEP calculates the increased frequency of maintenance activities based on the ratio of the materials inventory after the emission change (I_p) to the materials inventory before the change (I_b). This ratio characterizes the extent to which a change in emissions enhances or mitigates materials decay rates. If the emission change increases pollution, then $I_p < I_b$, and the optimal maintenance schedule will occur earlier than every five years. To estimate the amended maintenance schedule, APEEP multiplies the ratio of I_p to I_b by the baseline five-year maintenance schedule, as shown in Equation 6:

(6) $t^* = 5 \times (I_p/I_b)$

To estimate the present value of maintenance costs under this new maintenance schedule, APEEP incorporates the modified maintenance schedule into the materials maintenance cost equation (Equation 5). The change in the present value of the maintenance schedules extending into the future constitutes the monetary impact of an emission change on materials damage.

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