

**Forecasting Environmental and Social  
Externalities Associated with Outer Continental  
Shelf (OCS) Oil and Gas Development –  
Volume 1:**

**The 2015 Revised Offshore Environmental Cost  
Model (OECM)**

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# **Forecasting Environmental and Social Externalities Associated with Outer Continental Shelf (OCS) Oil and Gas Development – Volume 1:**

## **The 2015 Revised Offshore Environmental Cost Model (OECM)**

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# 1 INTRODUCTION

The Bureau of Ocean Energy Management (BOEM) is charged with assisting the U.S. Secretary of the Interior in carrying out the mandates of the Outer Continental Shelf (OCS) Lands Act (Act), which calls for expedited exploration and development (E&D) of the OCS to, among other goals, “reduce dependence on foreign sources and maintain a favorable balance of payments in world trade.” The Act also requires that BOEM prepare forward-looking five year schedules of proposed OCS lease sales that define as specifically as possible the size, timing, and location of the OCS territory(ies) to be offered for lease. As part of the development of these “Five Year Programs,” BOEM completes an analysis of the environmental and social costs attributable to the exploration, development, production, and transport of oil and natural gas anticipated to result from the Program proposal, net of the environmental and social costs attributable to the No Action Alternative (NAA) (i.e., the costs associated with energy production from sources that would substitute for OCS production in the absence of the Program) and net of any benefits (measured as “negative costs”) attributable to OCS oil- and natural gas-related activities.

To estimate the anticipated environmental and social costs attributable to oil and natural gas E&D activities on the OCS, as specified in an E&D scenario,<sup>1</sup> BOEM utilizes the Offshore Environmental Cost Model (OECM). An updated Microsoft (MS) Access-based version has been developed in conjunction with development of the 2017-2022 Program. This guide presents 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:

1. Recreation: The loss of consumer surplus that results when oil spills interfere with recreational offshore fishing and beach visitation.
2. Air quality: Emissions—by pollutant, year, and planning area—and the monetary value of the human health and environmental damage caused by these emissions.
3. Property values: Impacts of the visual disamenity caused by offshore oil and natural gas platforms and losses in the economic rent of residential properties caused by oil spills.
4. Subsistence harvests: The estimated replacement cost for marine subsistence organisms killed by oil spills.
5. Commercial fishing: The costs of fishing area pre-emption caused by the placement of oil and natural gas infrastructure (platforms and pipelines).
6. Ecological: Restoration costs for habitats and biota injured by oil spills.

The OECM also is programmed to enable consideration of any benefits that might be attributable to OCS activity (e.g., the recreational or ecological benefits associated with platforms that become artificial reefs after oil or natural gas production has ceased). A discussion of key potential benefit categories is

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<sup>1</sup> An E&D scenario defines the incremental level of OCS exploration, development, production, and decommissioning activity anticipated to occur within planning areas expected to be made available for leasing in the BOEM Five Year OCS Oil and Gas Leasing Program. Elements of an E&D scenario include the number of exploration wells drilled, the number of platforms installed, the number of development wells drilled, miles of new pipeline constructed, anticipated aggregate oil and gas production, and the number of platforms removed.

provided at the end of this document. The current version of the model does not, however, include any benefit calculations due to a lack of data that would support a credible and consistent assessment across all BOEM planning areas.

While the six categories of impacts identified above capture most of the environmental and social costs associated with E&D activities, they do not reflect all of these costs. Because the OEEM was designed to capture the most significant costs associated with OCS exploration and development, BOEM considers additional non-monetized costs and benefits qualitatively in the supplemental document *Economic Analysis Methodology for the OCS Oil and Gas Leasing Program for 2017-2022*.<sup>2</sup> Categories of impacts not captured in the OEEM include the following:

- (a) **Select oil spill impacts.** While the OEEM quantifies spill-related costs associated with animal mortality and habitat loss using restoration costs for interim losses as an indicator of monetized damages, the model does not quantify any values above the restoration cost at which society may value the damaged resource. As described in Appendix G, estimating these values would require more detailed data than are currently available. Further, the OEEM does not include ecological costs associated with the use of dispersants. This would require detailed data on the likelihood of their use on a given spill and the likely impacts associated with their use, both of which are highly uncertain. Finally, the OEEM does not estimate air quality costs associated with response vessel activity in the event of an oil spill. For most oil spills, which involve limited volumes of oil, emissions from vessel activity are not likely to be substantial.
- (b) **Ecological damage from exploration and development operations.** As discussed in detail in this document, the OEEM monetizes ecological damages associated with oil spills but does not monetize impacts to marine resources from general exploration and development operations. For example, the model does not capture costs to habitats or organisms from waste cuttings or drilling muds deposited on the ocean floor near offshore structures during their construction, operation, or removal. Similarly, the OEEM does not estimate water quality impacts associated with produced water discharged from wells or non-oil discharges from platforms and vessels. For each of these impact categories, key information that would be required to quantify and monetize impacts are not readily available (e.g., sediment damage to benthic communities per well drilled). The OEEM also does not capture auditory and vessel strike impacts to marine mammals. These impacts are unlikely to be substantial, and the data required for their estimation are not currently available (e.g., relationship between seismic surveying and marine mammal reproduction).
- (c) **Impacts from development of onshore infrastructure.** With one exception, the OEEM does not quantitatively address environmental impacts related to the construction and operation of onshore infrastructure to support OCS activities. The model includes air quality impacts from onshore pipeline construction associated with development in the Chukchi Sea planning area, but does not capture changes in air quality, impacts from reductions in coastal marshland, the value of the ecosystem services lost (e.g., flood protection), or impacts to water quality associated with onshore infrastructure construction. The estimation of these impacts would require information on the level of onshore infrastructure development required under individual E&D scenarios that is not currently available.

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<sup>2</sup> A draft version of the *Economic Analysis Methodology* paper will be published with the 2017-2022 Proposed Program and a final version will be published with the 2017-2022 Proposed Final Program.

- (d) **Greenhouse gas impacts.** The OECM estimates greenhouse gas emissions under program scenarios and the NAA. While greenhouse gases contribute to ocean acidification and eutrophication, the OECM does not monetize these impacts as they relate to greenhouse gases under program scenarios and the NAA because the marginal impact of OCS greenhouse gas emissions on ocean acidification and eutrophication is likely to be minimal.
- (e) **Other impacts.** Further, although certain passive-use values, such as bequest value, option value, existence value, and altruistic value can exist for stakeholders under both an E&D scenario and the NAA, they are not included in the OECM, as the monetization of these impacts would require detailed survey data specific to the resources affected by a given exploration and development scenario.

Just as there are non-monetized environmental impacts under program scenarios, there are also non-monetized impacts associated with the NAA. These costs not captured relate to increased onshore energy production, including the environmental costs associated with new infrastructure construction. The NAA analysis does not account for the ecological costs associated with increased terrestrial oil spills or pollution from produced water discharges associated with increased onshore oil and gas production; increased emissions and increased oil spill risk associated with transporting onshore oil; air emissions associated with the production of biomass energy sources; or ecosystem and health damages related to releases from coal and uranium mines. For most of these impacts, either the data required for their monetization are not available or their magnitude of impacts is likely to be small.

In addition to these broad categories of impacts not captured in the OECM, the model does not estimate the impacts of catastrophic spills, impacts to unique resources such as endangered species, or the broader regional economic impacts of oil and natural 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). With respect to catastrophic events and impacts to unique resources, the rarity of such events and resources makes it problematic to develop statistical representations of impacts comparable to the estimated impacts of other environmental effects included in the OECM.

This document represents an update to the original June 2012 documentation of the Offshore Environmental Cost Model (OECM).<sup>3</sup> The original version of the document presents the methods and data incorporated into the OECM for the purpose of developing BOEM's Five Year Outer Continental Shelf (OCS) Oil and Gas Leasing Program for 2012-2017 ("Program" or "Five Year Program"), and it corresponds to the Decision Document for the Program. This update to the OECM documentation reflects refinements to the methods and data in the model since publication of the June 2012 model documentation. The OECM was revised for the purpose of developing BOEM's Five Year Outer Continental Shelf (OCS) Oil and Gas Leasing Program for 2017-2022. These changes include the following:

- Revisions to air emissions factors for the Alaska OCS Region to reflect emission data specific to Arctic Alaska (the Chukchi Sea and Beaufort Sea Planning Areas) versus non-Arctic Alaska. These updates are reflected in the emission factor discussion in Chapter 4 and Appendix E, the latter of which details the estimation of Alaska-specific emission factors.

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<sup>3</sup> See U.S. Department of the Interior, Bureau of Ocean Energy Management, Forecasting Environmental and Social Externalities Associated with OCS Oil and Gas Development: The Revised Offshore Environmental Cost Model, OCS Study BOEM 2012-025, June 2012.

- Updated emissions factors for onshore oil, gas, and coal production to reflect updated data for these activities.
- Addition of FPSO installation and removal as emissions-generating activities.
- Expansion of the OECM to capture air impacts associated with constructing an onshore pipeline connecting the Chukchi Sea planning area to the Trans-Alaska pipeline.
- Descriptions of the model time horizon were modified to reflect its 75-year projection horizon. The model previously assessed impacts over a 50-year period.
- Refinements to the model's assumptions regarding the spatial allocation of oil and gas imported to the U.S. via tanker.
- A minor correction to the OECM's regression equations for oil spill effects in the Chukchi Sea planning area (see below for description of these regression equations).

A principal goal of this guide is to aid the user in navigating the details contained within the revised model. During that process, users should be aware of the following:

- Many of the impacts that the model estimates are associated with the possibility of oil spills from pipelines, tankers, and OCS platforms. Estimating the costs of these impacts depends on the output from the SIMAP fate and transport model developed by Applied Science Associates. Running SIMAP many times to reflect a range of oil spill types, locations, and environmental conditions enables the development of regression equations that relate, by planning area, a particular effect (e.g., meters of oiled beach) to an estimated volume of oil produced in a particular scenario.<sup>4</sup> The regression equations and coefficients are the only elements of this part of the analysis that are stored within the OECM. More complete descriptions of SIMAP and the process for developing the regression equations are provided in Appendix A (Oil Spill Modeling for the Offshore Environmental Cost Model).
- Users similarly are limited in their ability to view or modify the calculations associated with the air quality and commercial fishing categories. In both cases, the model incorporates the results of analyses completed outside of the OECM. However, complete descriptions of these external analyses, and how their results are incorporated into the model, are presented in this guide. For the air quality analysis, the user does have the ability to view and edit one of the key calculation drivers: air emission factors.

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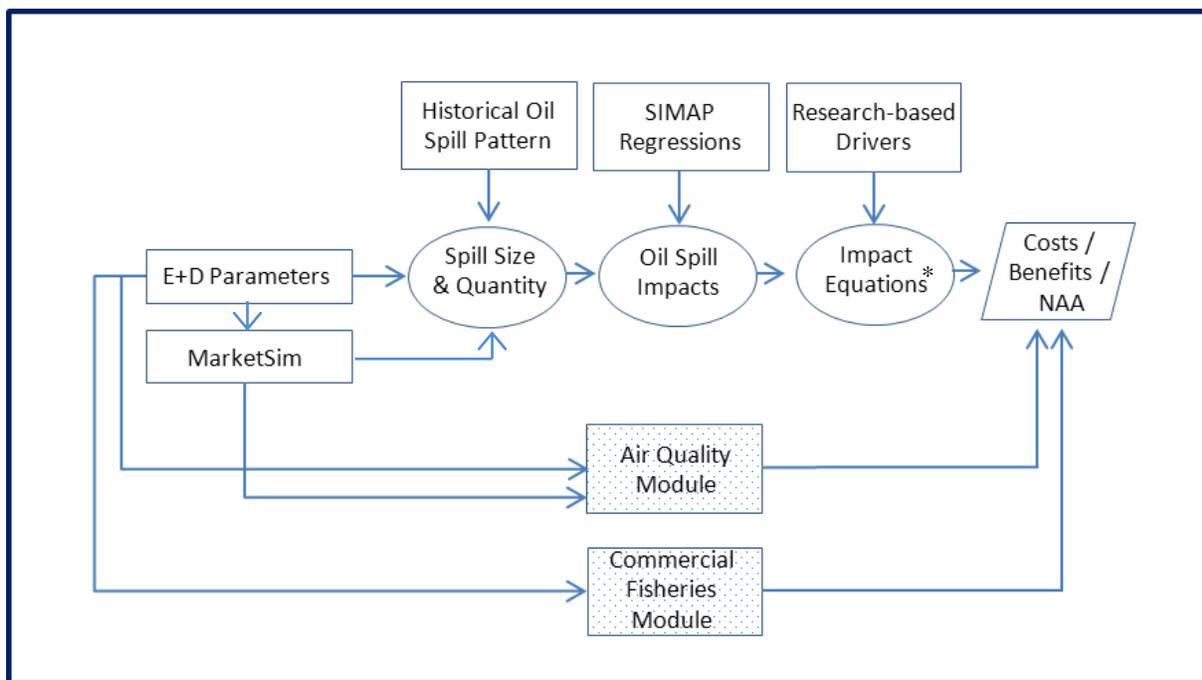
<sup>4</sup>SIMAP modeling covers the range of spill volumes that historically have resulted from "routine" exploration, development, and production activity. SIMAP results are *not* meant to be scaled to low probability/potentially high consequence events. As a result, OECM results do not reflect the costs that might be associated with such events.

## 2 MODEL DESCRIPTION

The OECM is built on an MS Access 2003 platform and is compatible with MS Access 2010. As defined in the E&D scenario worksheet, 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
- 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.<sup>5</sup>



\*Impact equations apply to recreation, property values, subsistence, and ecological effects.

<sup>5</sup> 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 above. 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 sectors 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 calculations used in the general cost and benefit calculations that occur within the OECM. A discussion of the calculations associated with the energy sources that would serve as substitutes for forgone OCS production under the NAA also is provided.

## 2.1 GENERAL COST AND BENEFIT CALCULATIONS

The following describes the 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.<sup>6</sup>

### *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).<sup>7</sup> 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: (1) platforms, (2) pipelines, (3) OCS supply vessels, and (4) tankers; and three oil types: (1) crude and condensate, (2) heavy fuel oil, and (3) 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).<sup>8</sup> 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*

---

<sup>6</sup> Note that the calculations for 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.

<sup>7</sup> 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.

<sup>8</sup> For OCS platforms, wells, pipelines, and service vessels, the OECM uses mean spill sizes for five size classes. For tankers, the model uses mean spill sizes for six size classes.

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:

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

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.<sup>9</sup> SIMAP-generated impacts include:

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

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 OCS platforms, pipelines, and supply vessels, the OECM assumes that the spill occurs at the location of the platform. For tanker spills, the OECM assumes 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

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<sup>9</sup> 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.

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.

*Step 5. Multiply regression outputs by the number of 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. Because the Secretary of the Interior must be able to view costs and benefits from a national perspective and also be able to attribute them to specific program options he or she could select, the OECM's national allocation 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 natural gas production under the E&D scenario. For example, if 35 percent of oil and natural gas production under an E&D scenario occurs in the Western Gulf of Mexico, the OECM assigns 35 percent of NAA 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 tanker spills to the planning area where oil is brought to shore, and the remainder (OCS platforms, pipelines, vessels, and one-half of tanker spills) are attributed to the planning area of production.<sup>10</sup> This approach acknowledges the uncertainty regarding the location of 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 Five Year Program activity (i.e., the Secretary decides not to hold any lease

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<sup>10</sup> Although environmental and social costs are not confined to (offshore) planning areas, their attribution to planning areas under the regional allocation is a convenient way to provide decision makers with a general idea of where such costs are likely to be incurred, especially given the extent to which actual conditions could affect specific results. Attribution to planning areas also provides some consistency for comparisons between results obtained with the national allocation and those obtained with the regional allocation.

sales during the five year period of analysis). The absence of program activity is referred to as the No Action Alternative (NAA). The process for calculating these costs begins with the application of the *Market Simulation Model (MarketSim)* to an E&D scenario. *MarketSim* produces an estimate of the energy markets' response to the forgone production that would have occurred as a result of the program proposal or other program options. *MarketSim* results may show an overall reduction in energy demand due to slightly higher prices, but the primary response will be substitution across various segments of the energy sector. Three specific responses are considered important enough to measure and evaluate in the absence of the program production forecasted in the E&D scenario: (1) an increase in the quantity of oil delivered into the U.S. market via overseas tanker; (2) the quantity of natural gas imported into the United States via tanker; and (3) an increase in the onshore production of oil, natural gas, and coal within the United States.<sup>11</sup> These responses are assumed to be the most significant in terms of potential environmental effects and resulting 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 liquefied natural gas [LNG]); and (3) the incremental emissions associated with onshore oil, natural gas, and coal production. Other potential costs are not included in the model due to the combination of the lack of reliable data and limited importance to the results. For example, potential impacts associated with the waste water generated through onshore oil and gas production 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.

The OECM's estimates of the net environmental and social costs of a program scenario also reflect the impacts avoided due to conservation under the NAA. Relative to the impacts estimated under an E&D scenario, the avoidance of impacts under the NAA represents a benefit of the NAA. Because conservation involves no production of substitutes for OCS oil and natural gas, the OECM assumes that the impacts associated with conservation are nil. Thus, when OECM nets NAA impacts from E&D impacts, the impacts of conservation are reflected in these calculations (i.e., as a value of \$0 among the other NAA impacts). Put differently, for the small fraction of OCS production displaced by conservation, the *net* impact of an E&D scenario is the same as the *gross* impact associated with the E&D scenario itself (i.e., an estimated impact of \$0 is netted out of the estimated impact associated with the E&D scenario).<sup>12</sup>

## 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 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 in the regional allocation of the model, 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 Scenarios. Specifically, users may adjust the distribution of imports displaced by production in a given region. The approach for deriving default values is presented in Appendix F.

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<sup>11</sup> 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 natural gas imports from Canada may change under the NAA, no impacts are estimated for these specific changes in imports.

<sup>12</sup> The OECM does not isolate impacts for the portion of the E&D scenario displaced by conservation under the NAA. This comparison in the main text is provided for illustrative purposes only.

- To estimate costs associated with the transportation of OCS oil to shore and, in the case of Alaska, to the continental United States, the model includes user-specified assumptions regarding where and how OCS oil is transported. Model users can view and adjust assumptions with respect to the method of shipping oil to shore (i.e., via tanker, barge, or pipeline) in the Exploration and Development (E&D) spreadsheet used to develop scenarios for analysis in the OECM. In addition, on the Regional Allocation of Costs page under Manage Data, OECM users may specify the percentage of Alaskan OCS oil that stays in the State and the percentage that is transported to the contiguous United States. The OECM's assessment of both oil spill and air quality impacts accounts for changes in these assumptions.
- 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 it 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.<sup>13</sup>
- 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 NAA: one approach for tanker imports of oil and natural gas and a second methodology for increased onshore production of oil, natural gas, and coal.

- For oil and natural gas tanker imports, the model applies emissions factors from the literature to various tanker activities, including (1) tanker cruising, (2) unloading, (3) Volatile Organic Compound (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), the OECM assumes that emissions are distributed across an entire planning area. In contrast, emissions released at port (unloading and ballasting emissions) are distributed uniformly 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 displaced by production in a given region.
- 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, natural 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

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<sup>13</sup> The oil spill rates used within the OECM are outlined in Appendix A.

Policy (APEEP) analysis model (see Appendix C). For a given pollutant, the dollar-per-ton values applied depend on the location of displaced OCS production (see Appendix F).

### 3 RECREATION

#### 3.1 OVERVIEW

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

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 off Alaska. The Gulf of Alaska, Cook Inlet, and Kodiak 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 OCS 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 following 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 (U.S. DOI, 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: (a) 50 percent – Eastern Gulf of Mexico, (b) 25 percent – South Atlantic, and (c) 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 it only accounts for 90 percent of the total, reflecting a concentration of activity in and adjacent to three planning areas: (a) Gulf of Alaska – 45 percent, (b) Cook Inlet – 40 percent, and (c) 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 one; they are not included in the model based on an assumption that activity at this scale cannot reasonably be 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<sup>2</sup>.

### 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, searches of the economics and social science literature were conducted. Specifically, the 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). The review was restricted to recently published studies 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, the existing range of values was retained, the high and low was inflated to current dollars, and the resulting average value of \$42 was assigned 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 following equation.

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

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 areas, 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 (U.S. EPA, 2009). 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 Reach Addressing Database. The total length of public beach in each planning area is the sum of state-level beach lengths across the states (or parts of states) that correspond to the planning areas.

### **3.5.3 Length of beach closure**

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  $1 \text{ g/m}^2$ .

### **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, the economics and social science literature were reviewed to identify relevant studies published since the previous update, again restricting the search to recently published studies 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, the existing range of values is retained, and the high and low values are inflated to current dollars. The resulting average value of \$14 is assigned as the oil spill-related per-day-loss for beach use.

### **3.6 REFERENCES – RECREATION**

- Roach, B., W. Wade, and J. Plater. 2001. Forecasting Environmental and Social Externalities Associated with OCS Oil and Gas Development: The Offshore Environmental Cost Model, Volume 2, Determinants of Environmental and Social Costs. Minerals Management Service (MMS) OCS Study 2001-018. Herndon, VA: U.S. DOI, MMS, Environmental Studies Branch.
- U.S. Department of the Interior (U.S. DOI), Fish and Wildlife Service. 2006. 2006 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation.
- U.S. Environmental Protection Agency (U.S. EPA). 2009. BEACH Act: Beaches National Geospatial Dataset.

## 4 AIR QUALITY

### 4.1 OVERVIEW

Exploration and development of the OCS will lead to emissions of sulfur dioxide (SO<sub>2</sub>), oxides of nitrogen (NO<sub>x</sub>), volatile organic compounds (VOCs), particulate matter (PM)<sup>14</sup>, and other air pollutants that may adversely affect human populations and the environment. To account for these effects, the revised OEEM includes an air quality module that estimates the emissions—by pollutant, year, and planning area—associated with a given E&D scenario and 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 United States, converts these values to monetized damages using a modified version of the APEEP model 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<sup>2</sup> in size, as illustrated in Figure 1.

The specific air pollution impacts that the OEEM examines include:

- adverse human health effects associated with increases in ambient PM<sub>2.5</sub> and ozone concentrations,
- changes in agricultural productivity caused by changes in ambient ozone concentrations, and
- damage to physical structures associated with increases in SO<sub>2</sub>.

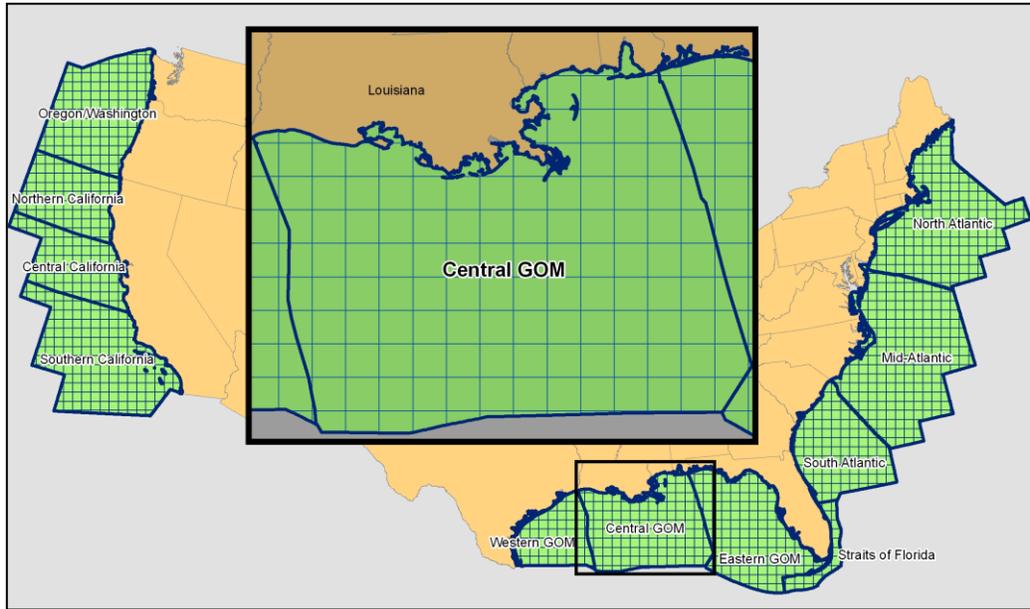
Emissions from OCS development also may affect visibility, forest productivity, and recreational activity (e.g., visits to National Parks). The OEEM does not include these effects, however, as the limited data on these impacts in the peer-reviewed literature are not amenable to the streamlined air quality modeling framework included in the APEEP model. Because human health effects generally dominate the results of more detailed air pollution impact analyses,<sup>15</sup> excluding emissions-related changes in visibility, forest productivity, and recreational activity from the OEEM is unlikely to have a significant impact on the model's results.

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<sup>14</sup> The PM estimates emissions of both fine particulate matter (PM<sub>2.5</sub>) and coarse particulate matter (PM<sub>10</sub>).

<sup>15</sup> See U.S. EPA (2011).

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  $G$

$F_{P,A}$  = Emissions 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 natural gas extraction, and platform removal). The model also uses a series of activity-specific assumptions to specify the location of OCS emissions. For example, 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:

$I_{P,Y,G}$  = Monetized impacts from emissions of pollutant  $P$  in year  $Y$  in grid cell  $G$

$\sum_G \sum_A E_{P,Y}$  = 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, caissons, and FPSOs installed, by year;
- production platforms, caissons, and FPSOs in operation, by year;
- transport of oil produced on the OCS, by year<sup>16</sup>;
- miles of pipeline laid, by year;
- production platforms decommissioned, by year; and
- for the NAA, changes in onshore energy production and tanker imports of oil and natural 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 natural gas platform operations, (2) exploration and delineation well activity, (3) floating production storage and offloading (FPSO) vessel activity<sup>17</sup>, (4) development and production well activity, (5) helicopter trips, (6) pipe-laying vessels, (7) platform installation and removal, (8) support vessels, (9) survey vessels, and (10)

<sup>16</sup> All natural gas is assumed to be shipped via pipeline, with no emissions.

<sup>17</sup> Absent emissions data specific to FPSOs, the OECM assumes that the emissions factors for exploration wells also apply to FPSOs.

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).<sup>18</sup> Table 1 summarizes the emission factors for each of these activities. For planning areas along the contiguous United States, the values in the figure for OCS exploration and development activities are based upon emissions data provided by BOEM staff for oil and natural gas operations in the Gulf of Mexico. These emission factors are applied to all OCS regions adjacent to the contiguous United States under the assumption that oil and natural gas operations in these areas would not differ significantly from operations in the Gulf of Mexico.<sup>19</sup> The emission factors for Alaska planning areas are, where possible, based on Alaska-specific emissions data. For those activities for which Alaska-specific data were not readily available (e.g., helicopter trips), the OECM uses the emission factors derived from Gulf of Mexico emission data. Appendix E includes more detailed information on the derivation of emission factors for Alaska planning areas.

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 natural 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 production:* Criteria pollutant emission factors for onshore oil production for the contiguous United States were based on the Western Regional Air Partnership's (WRAP's) 2002 emissions inventory for oil and gas activities in 12 Western States: Alaska, Arizona, California, Colorado, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, and Wyoming (WRAP, 2009).<sup>20</sup> Excluding oil and natural gas operations in the coastal States of Alaska and California that were included in the WRAP inventory, emission factors for onshore oil production were developed by dividing the emissions estimates from the WRAP inventory (with some adjustments) by U.S. Department of Energy (U.S. DOE) estimates of onshore oil production in the 10 States analyzed. These States accounted for approximately 14 percent of onshore crude oil production in 2002. More detailed information on the derivation of the onshore oil emission factors for criteria pollutants is available in Appendix B.

The greenhouse gas emission factors for oil production were derived from an analysis published by the National Energy Technology Laboratory (U.S. DOE NETL, 2014). The NETL analysis provides estimates of greenhouse gas emissions, expressed as CO<sub>2</sub> equivalents (CO<sub>2</sub>e), for five categories of oil production in 2013: enhanced oil recovery, tight oil, other onshore oil, offshore, and Alaska. For the purposes of deriving emission factors, enhanced oil recovery and tight oil were considered "unconventional" oil production, whereas other onshore oil was considered conventional oil production.<sup>21</sup> To estimate greenhouse gas emissions factors for unconventional oil production, the CO<sub>2</sub>e emissions for the enhanced oil recovery and tight oil categories combined were divided by total production for these categories in 2013 as reported in the 2015

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<sup>18</sup> Note that the model allows users to specify how oil is distributed across three modes of transportation to shore in non-Alaska OCS regions: (1) pipeline (assumed not to cause emissions), (2) tanker, and (3) 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.

<sup>19</sup> 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.

<sup>20</sup> WRAP also includes the States of Washington and Idaho, but they did not produce crude oil or natural gas in 2002, so these two States were not considered in this analysis.

<sup>21</sup> Because the offshore and Alaska categories include offshore production, the emissions data for these categories were not used.

Annual Energy Outlook (AEO) (U.S. DOE EIA, 2015). Similarly, for conventional production, the NETL estimates of CO<sub>2</sub>e emissions for other onshore oil were divided by production for this category reported in the 2015 AEO. The CO<sub>2</sub>e emissions per barrel of conventional and unconventional production were distributed to individual greenhouse gases—CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O—based on (1) the distribution of the oil sector’s emissions of these pollutants, as reported in the U.S. Greenhouse Gas Emissions and Sinks Inventory (U.S. EPA, 2015) and (2) the global warming potential of each pollutant.

- *Onshore natural gas production:* The OECM contains separate emission factors for conventional and unconventional natural gas production, drawing from data published by the NETL (2012), the U.S. EPA (2012b), and the World Resources Institute (WRI, 2013). Focusing on the year 2010, NETL (2012) estimates the emissions, by pollutant, of onshore natural gas production across multiple production methods and sources. These include shale gas, coal bed methane, tight gas, associated gas, and onshore conventional production. For the purposes of distinguishing between conventional and unconventional onshore gas production, unconventional natural gas production is assumed to include tight gas, shale gas and coal bed methane production. All other methods, including associated gas production, are considered conventional. To estimate emissions per billion cubic feet of gas production, pollutant-specific emissions for conventional and unconventional sources as reported by NETL were divided, respectively, by conventional and unconventional production in 2010, as obtained from EIA (2012).

Because the 2010 emissions estimates published in NETL (2012) reflect emissions in 2010, they do not account for the impact of EPA’s 2012 New Source Performance Standards (NSPS) for the oil and gas industry. These standards are projected to lead to substantial reductions in VOC and CO<sub>2</sub>e emissions and slight increases in CO and NO<sub>x</sub> emissions. To capture these changes, the emissions factors for conventional and unconventional gas production described in the previous paragraph were adjusted based on information published in EPA’s 2012 regulatory impact analysis (RIA) for the NSPS (2012) and a WRI report that examined the emissions impacts of the standards (WRI, 2013). EPA’s RIA presents the aggregate changes in emissions, by pollutant, expected under the NSPS but does not distinguish between changes from conventional and unconventional production sources. WRI (2013) provides an estimate of the distribution between methane emissions reductions from conventional gas production versus unconventional under the NSPS. This distribution is assumed to apply to other pollutants as well. While the NSPS examined in the EPA and WRI documents cover both the oil and gas sectors, information in both documents make clear that the standards are primarily aimed at reducing emissions from gas production. This is consistent with EPA’s Greenhouse Gas Emissions and Sinks Report, which includes emissions reductions related to the NSPS for the natural gas sector but not for the oil sector (EPA, 2015). Adjustments for the NSPS were therefore made to the natural gas emission factors only.

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

EMISSIONS FACTORS: <sup>1</sup>		PLANNING AREA	NO <sub>x</sub>	SO <sub>2</sub>	PM <sub>10</sub>	PM <sub>2.5</sub>	CO	VOC	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O
Oil and Natural Gas Platform Operations (tons/platform/yr) <sup>2</sup>		All planning areas	75.65	2.87	0.75	0.75	63.25	23.8	10035.5	117.88	0.33
Caisson Operations (tons/caisson/yr) <sup>2</sup>		All planning areas	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.42	0.00
Exploration and Delineation Wells (tons/well, by water depth)	0-60 m	All, except for Alaska planning areas <sup>3</sup>	58.37	1.602	1.85	1.79	11.21	1.73	5,221.9	0.06	0.005
	60-800 m		102.69	2.84	3.24	3.14	19.60	3.08	9,244.00	0.11	0.00
	800-1600 m		264.54	6.00	9.69	9.40	59.37	4.79	19,556.35	0.15	0.89
	>1600 m		518.55	11.37	19.38	18.80	118.98	8.48	37,081.20	0.26	1.54
	All depths <sup>4</sup>	Cook Inlet	50.89	0.1254	1.441	1.304	9.793	4.518	5,309	0.00	0.00
		Beaufort and Chukchi	242.3	0.3787	12.24	11.04	90.33	18.68	5,309	0.00	0.00
		Other Alaska	50.89	0.1254	1.441	1.304	9.793	4.518	5,309	0.00	0.00
Development and Production Wells (tons/well, by water depth)	0-60 m	All, except for Alaska planning areas <sup>3</sup>	58.37	1.6	1.85	1.79	11.21	1.73	5,221.9	0.06	0.005
	60-800 m		102.69	2.84	3.24	3.14	19.6	3.08	9,244	0.11	0.000
	800-1600 m		264.54	6.00	9.69	9.40	59.37	4.79	19,556.35	0.15	0.89
	>1600 m		518.55	11.37	19.38	18.80	118.98	8.48	37,081.20	0.26	1.54
	All depths <sup>4</sup>	Cook Inlet	50.89	0.1254	1.441	1.304	9.793	4.518	5,309	0	0
		Beaufort and Chukchi	242.3	0.3787	12.24	11.04	90.33	18.68	5,309	0	0
		Other Alaska	50.89	0.1254	1.441	1.304	9.793	4.518	5,309	0	0
Helicopters (tons/platform/yr) <sup>2</sup>		All planning areas	0.27	0.04	0.01	0.01	.78	.59	58.07	0.004	0.004
Pipe-laying Vessels (tons/mile of pipe) <sup>2</sup>		All planning areas	20.31	0.25	0.75	0.72	4.55	0.27	1305.99	0.010	0.039
Platform Construction/Removal (tons/platform or caisson, by water depth)	<300 ft	All, except for Alaska planning areas <sup>3</sup>	8.74	0.18	0.33	0.32	2.06	0.12	601.73	0.004	0.03
	300-600 ft		25.86	0.55	0.97	0.94	6.10	0.37	1779.50	0.01	0.08
	>600 ft		226.60	4.78	8.53	8.27	53.46	3.22	15,594.87	0.09	0.71
	All depths <sup>4,5</sup>	Cook Inlet	307.5	31.4	6.7	6.3	49.7	12.5	13,910	0.103	0.576
		Beaufort and Chukchi	800.9	32.1	34.1	30.8	263.3	48.1	13,910	0.103	0.576

EMISSIONS FACTORS: <sup>1</sup>		PLANNING AREA	NO <sub>x</sub>	SO <sub>2</sub>	PM <sub>10</sub>	PM <sub>2.5</sub>	CO	VOC	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O
Subsea Construction (tons/subsea/year)	0-197 ft	All, except for Alaska planning areas <sup>3</sup>	58.37	1.60	1.85	1.79	11.21	1.73	5,221.9	0.06	0.005
	197-2625 ft		102.69	2.84	3.24	3.14	19.60	3.08	9,244	0.11	0.00
	2625-5248 ft		264.54	6.00	9.69	9.40	59.37	4.79	19,556.35	0.15	0.89
	>5248 ft		518.55	11.37	19.38	18.80	118.98	8.48	37,081.2	0.26	1.54
	All depths <sup>4</sup>	Cook Inlet	50.89	0.13	1.44	1.3	9.79	4.52	5,308.77	0.00	0.00
		Beaufort and Chukchi	242.28	0.38	12.24	11.04	90.33	18.68	5,308.77	0.00	0.00
		Other Alaska	50.89	0.13	1.44	1.3	9.79	4.52	5,308.77	0.00	0.00
FPSO Operation (tons/FPSO/year) <sup>6</sup>	0-60 m	All planning areas	39.52	0.35	0.38	0.38	51.25	30.19	2,759.35	147.92	0.05
	60-800 m		84.66	2.95	0.98	0.98	76.12	74.22	9,964.10	285.79	0.24
	800-1600 m		626.64	60.81	5.15	5.13	177.24	57.03	144,970.15	261.17	2.63
	>1600 m		1275.9	61.16	11.40	11.37	393.68	151.63	320,304	637.18	5.11
FPSO Construction, installation activity at site (tons/FPSO) <sup>6</sup>		All planning areas	145.78	0.054	1.56	1.51	42.88	1.18	5591.11	0.03	0.27
FPSO Construction, <i>en route</i> to site (tons per mile per FPSO) <sup>6</sup>		All planning areas	0.196	0.025	0.004	0.004	0.055	0.005	6.78	0.00006	0.0003
FPSO Removal, removal activity at site (tons/FPSO) <sup>6</sup>		All planning areas	69.16	0.03	0.74	0.72	20.34	0.56	2652.36	0.02	0.13
FPSO Removal, <i>en route</i> to site (tons per mile per FPSO) <sup>6</sup>		All planning areas	0.196	0.025	0.004	0.004	0.055	0.005	6.783	0.00006	0.0003
Support Vessels (tons/platform/yr)		All, except for Alaska planning areas <sup>2</sup>	147.40	1.81	5.40	5.24	29.96	3.37	10,916.96	0.06	0.32
		Cook Inlet <sup>2</sup>	147.40	1.81	5.40	5.24	29.96	3.37	10,916.96	0.06	0.32
		Beaufort and Chukchi <sup>4,5</sup>	2,096.8	15.8	110.8	98.9	873.1	139.7	5,247	0.033	0.249
		Other Alaska <sup>2</sup>	147.40	1.81	5.40	5.24	29.96	3.37	10,916.96	0.06	0.32
Survey Vessels (tons/platform or caisson/yr) <sup>2</sup>		All planning areas	6.59	0.08	0.24	0.24	1.48	0.09	423.77	0.002	0.01
Tugs Pulling Barges, Non-Alaska OCS Regions <sup>5</sup>	Cruising emissions (tons/BBO/mile)	All planning areas	183.5	22.2	2.78	2.78	15.2	2.78	9,063	0.0557	0.430
	Idling emissions during loading (tons/BBO)	All planning areas	5,087	863.8	192.0	192.0	1,056	12,473	344,084	2,171	14.9

EMISSIONS FACTORS: <sup>1</sup>		PLANNING AREA	NO <sub>x</sub>	SO <sub>2</sub>	PM <sub>10</sub>	PM <sub>2.5</sub>	CO	VOC	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O
	Idling emissions during unloading (tons/BBO)	All planning areas	5,087	863.8	192.0	192.0	1,056	6,332	344,084	1,087	14.9
Oil Tankers, Non-Alaska OCS Regions <sup>5</sup>	Cruising emissions (tons/BBO/ mile)	All planning areas	62.7	7.61	0.9511	0.9511	5.23	0.9512	3,101	0.190	0.1474
	Idling emissions during loading (tons/BBO)	All planning areas	1,740	295.5	65.7	65.7	361.2	12,346	117,717	2,304	5.1
	Idling emissions during unloading (tons/BBO)	All planning areas	1,740	295.5	65.7	65.7	361.2	6,206	117,717	1,085	5.1
Oil Tankers (Alaska OCS Region) <sup>5</sup>	Cruising emissions (tons/BBO/mile)	All planning areas	22.8	2.77	0.346	0.346	1.905	18.7	1,129	3.246	0.054
	Idling emissions during loading (tons/BBO)	All planning areas	633.7	107.6	23.9	23.9	131.5	12,363	42,867	2,178	1.9
	Idling emissions during unloading (tons/BBO)	All planning areas	633.7	107.6	23.9	23.9	131.5	6,194	42,867	1,089	1.9
LNG Tankers <sup>7</sup>	Cruising emissions (tons/tillion cubic feet (ft <sup>3</sup> ) of gas/ mile)	All planning areas	0.434	1.4	0.095	0.068	0.098	0.006	244.4	NA	NA
	Loading emissions (tons/tillion ft <sup>3</sup> of gas)	All planning areas	NA	NA	NA	NA	NA	NA	19,080	NA	NA
	Unloading emissions (tons/tillion ft <sup>3</sup> of gas)	All planning areas	55.4	136.0	9.6	6.5	15.6	0.982	772.3	NA	NA
Onshore Oil Production – Contiguous United States (tons/million barrels) <sup>8</sup>		All planning areas	5.0	15.0	0.003	0.001	4.5	209.6	8,609.5	1,446.4	0.00
Onshore Pipeline (tons/pipeline mile) <sup>9</sup>		Chukchi Sea	0.64	0.00158	0.03	0.04	0.28	0.05	0.01	0.00	0.00
Onshore Gas Production (Conventional) – Contiguous United States (tons/trillion ft <sup>3</sup> ) <sup>10</sup>		All planning areas	89,070	50	1,280	1,280	8,710	108,100	5,352,900	533,300	70
Onshore Gas Production (Unconventional) – Contiguous United States (tons/trillion ft <sup>3</sup> ) <sup>10</sup>		All planning areas	80,000	830	760	760	7,390	64,860	3,499,620	352,910	120
Onshore Coal Production – Contiguous United States (tons/million short tons) <sup>11</sup>		All planning areas	335.56	153.13	191.34	33.10	80.20	164.76	36,853	3184.26	0.72
Production of Oil Imported via Pipeline (tons/million barrels) <sup>12</sup>		All planning areas	0.00	0.00	0.00	0.00	0.00	0.00	66,074	0.00	0.00
Production of Oil Imported via Tanker (tons/million barrels) <sup>12</sup>		All planning areas	0.00	0.00	0.00	0.00	0.00	0.00	40,259	0.00	0.00
Production of Gas Imported via Pipeline (tons/trillion ft <sup>3</sup> ) <sup>13</sup>		All planning areas	0.00	0.00	0.00	0.00	0.00	0.00	5,709,250	0.00	0.00
Production of Gas Imported via Tanker (tons/trillion ft <sup>3</sup> ) <sup>13</sup>		All planning areas	0.00	0.00	0.00	0.00	0.00	0.00	954,958	0.00	0.00

EMISSIONS FACTORS: <sup>1</sup>	PLANNING AREA	NO <sub>x</sub>	SO <sub>2</sub>	PM <sub>10</sub>	PM <sub>2.5</sub>	CO	VOC	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O
<p>Sources/Notes:</p> <ol style="list-style-type: none"> <li>1. The emissions listed in this table are nitrogen oxides (NO<sub>x</sub>), sulfur dioxide (SO<sub>2</sub>), particulate matter up to 10 micrometers in size (PM<sub>10</sub>), particulate matter up to 2.5 micrometers in size (PM<sub>2.5</sub>), carbon monoxide (CO), volatile organic compounds (VOC), carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O).</li> <li>2. Emissions factors from Wilson et al, 2014.</li> <li>3. Emissions factors from Eastern Research Group, Inc. 2012.</li> <li>4. Emissions factors from EPA, 2010b Statement of Basis for Frontier Discoverer in Chukchi and EPA AP-42.</li> <li>5. Emissions factors from Eric Wolvovsky of BOEM, May 1, 2012, and Billings et al. (2012).</li> <li>6. Emissions factors from Billings et al. (2015a and 2015b).</li> <li>7. Emissions factors from Jaramillo et al. (2007) and Afon and Ervic (2008).</li> <li>8. CAPs derived from WRAP (2009). GHGs derived from NETL (2014).</li> <li>9. Derived from the emissions estimates for pipeline construction associated with two of the alternatives (alternatives A and D2) considered in the Environmental Impact Statement for Greater Mooses Tooth One Development Project proposed by ConocoPhillips Alaska, Inc. These alternatives pertain to the development of oil and gas leases on land managed by the Bureau of Land Management (BLM) in the National Petroleum Reserve in Alaska. See U.S. Department of the Interior, Bureau of Land Management (2013, 2014).</li> <li>10. Derived from NETL, 2012. "Role of Alternative Energy Sources: Natural Gas Technology Assessment".</li> <li>11. Emissions factors from Argonne National Laboratory (2014).</li> <li>12. Emissions factors from U.S. Department of Energy, NETL (2009).</li> <li>13. Emissions factors from Advanced Resources International, Inc. and ICF International (2008)</li> </ol>										



- *Onshore coal production:* Emissions per unit production of coal were derived using the Argonne National Laboratory's GREET Model (U.S. DOE ANL, 2014), which is a widely used national database for life cycle emissions estimates. The emissions factors are based on the mix of coal consumed in the United States. Because 99 percent of coal consumed in the U.S. is produced domestically, the data in GREET provide a reasonable representation of the emissions associated with U.S. coal production.
- *Oil imports:* The OECM also estimates emissions associated with oil imported into the United States. Given the global effects of green house gas (GHG) emissions, the model treats these emissions from imports separately from NO<sub>x</sub>, SO<sub>2</sub>, PM, CO, and VOCs. More specifically, the OECM estimates GHG emissions associated with both the production and transport of this oil. The model estimates GHG emissions for the full roundtrip journey from the country of production to the U.S. and back. For NO<sub>x</sub>, SO<sub>2</sub>, PM, CO, and VOCs, the OECM's estimation of tanker emissions is limited to tanker travel in U.S. waters. For oil shipped into the United States by tanker, the OECM estimates tanker emissions on a roundtrip basis only in U.S. waters using the same emission factors as are used for tankers transporting crude oil from Alaska to the West coast of the contiguous 48 States.

The OECM estimates GHG emissions associated with the production of oil imported into the United States based on non-U.S. greenhouse gas emission factors published by the National Energy Technology Laboratory (U.S. DOE, NETL, 2009). According to these data, Canadian oil production is more GHG-intensive than oil production in other countries that supply oil to the United States. Because Canada represents the most significant source of U.S. pipeline imports, the OECM uses the Canada-specific GHG emission factors from NETL (2009) for pipeline oil imports. For the production of oil imported via tanker, the OECM uses a weighted average of the GHG emission factors reported in NETL (2009) for other countries that supply oil to the United States, using country-specific exports of oil to the United States as weights. The OECM does not estimate NO<sub>x</sub>, SO<sub>2</sub>, PM, CO, and VOC emissions associated with the production of oil imported into the United States.

- *Natural gas imports:* Similar to its treatment of oil imports, the OECM estimates GHG emissions associated with the production of natural gas imported into the United States and GHG, NO<sub>x</sub>, SO<sub>2</sub>, PM, CO, and VOCs associated with the transportation of natural gas shipped to the United States by tanker. For tanker transport, the OECM's emission factors for LNG tankers (expressed as emissions per trillion cubic feet) are based on LNG tanker emission information (e.g., power rating, average speed, etc.) obtained from Jaramillo et al. (2007) and Afon and Ervin (2008). The OECM applies these emission factors on a roundtrip basis, though the model's emissions estimates for NO<sub>x</sub>, SO<sub>2</sub>, PM, CO, and VOCs reflect LNG tanker travel only in U.S. waters. For GHGs, the OECM estimates tanker emissions associated with the full roundtrip journey.

The OECM's estimation of production-related emissions for natural gas imports is limited to GHGs. To estimate these emissions, the OECM applies separate emission factors to natural gas pipeline imports from Canada and imports shipped to the United States via tanker. GHG emission factors for both were obtained from Advanced Resources International, Inc. and ICF International (2008). Similar to the emission factors for non-U.S. oil production, the emission factors for non-U.S. natural gas production indicate that natural gas production in Canada is more GHG intensive than in other countries that supply natural gas to the United 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.

Table 2. Crosswalk between Emissions Drivers and Emissions Category.

EMISSIONS DRIVERS	EMISSIONS CATEGORIES
Number of operational platforms	Platform operations Helicopters Support vessels Survey vessels <sup>1</sup>
Number of operational caissons	Caisson operations Survey vessels <sup>1</sup>
Number of operational FPSOs	FPSO operations
Number of platforms and caissons over the life of the program	Platform construction Platform removal
Number of FPSOs over the life of the program	FPSO construction FPSO 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 subseas	Subsea construction
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
Trillion cubic feet miles traveled for imported natural gas (e.g., 2 trillion cubic feet of gas traveling 100 miles is 200 trillion cubic feet miles traveled)	LNG tanker cruising emissions
Trillion cubic feet of natural gas imported	LNG tanker unloading emissions
Barrels of onshore oil production	Emissions from onshore oil production
Trillion cubic feet of onshore natural gas production	Emissions from onshore natural gas production
Tons of onshore coal production	Emissions from onshore coal production
Notes: 1. Survey vessel emissions are estimated based on the total number of operational platforms and caissons.	

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 E&D activities is uncertain. The location of emissions associated with the NAA is similarly uncertain. For example, if domestic onshore natural 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, the following approaches were employed 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, caisson, and FPSO operations; (2) exploration and delineation wells; (3) platform, caisson, and FPSO installation and removal (excluding *en route* emissions for FPSO installation and removal), (4) subseas, (5) and survey vessel activity. For these E&D activities, emissions for a given platform group were allocated 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, emissions were allocated 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, pipe-laying vessels, and vessels traveling for FPSO installation or removal also are likely to operate over the full distance between platform groups and shore. To account for this wider geographic scope of activity, emissions for these activities were allocated 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*: 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 OECM allocates onshore oil and gas production under the No Action Alternative based on (1) the regions of the country likely to be served by OCS production and (2) the sources of domestic crude and natural gas that serve these regions. Appendix F contains more detailed information on this approach. For onshore coal production, the model does not allocate production to specific locations within the United States. Instead, it applies the same dollar-per-ton values to all onshore production of coal. These dollar-per-ton values reflect the geographic distribution of onshore coal production across the contiguous United States as derived from U.S. DOE production data. Thus, for coal, the OECM implicitly assumes that the geographic distribution of onshore 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: the North Atlantic, Mid-Atlantic, South Atlantic, Central Gulf of Mexico, and Western Gulf of Mexico Planning Areas.
	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 that will be discussed first below, and a second approach for planning areas in the Alaska OCS Region.

The dollar-per-ton values included in the revised OECM for the non-Alaska planning areas are derived from a modified version of the APEEP model, which is a reduced-form integrated air quality assessment model designed to estimate county-level dollar-per-ton estimates of the damages associated with PM<sub>2.5</sub>, VOC, NO<sub>x</sub>, and SO<sub>2</sub> emissions.<sup>22</sup> To generate dollar-per-ton values for the OECM, the APEEP model

<sup>22</sup> The approach described in this section is based on the approach applied in Muller (2014).

follows a three-step analytic chain consistent with the methods employed in U.S. EPA regulatory impact analyses of air pollution impacts:

1. *Air quality*: First, the APEEP model 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, the APEEP model 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*: The APEEP model 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, the APEEP model generates dollar-per-ton impact estimates for emissions of NO<sub>x</sub>, SO<sub>2</sub>, PM<sub>2.5</sub>, and VOCs. Each of these steps is described in more detail below.

### Air quality

The air quality modeling module within the APEEP model originally was 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 the APEEP model to assess how *offshore* emissions affect onshore air quality. The 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, the APEEP model 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. Using these data, a regression analysis was conducted 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, the emissions-air quality transfer coefficients for each offshore grid cell were estimated. To develop these estimates, the distance and directional relationship between each offshore grid cell and each (onshore) county in the contiguous United States was entered 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 contiguous U.S. county.

Using the transfer coefficients developed from this methodology, the changes in onshore pollutant concentrations associated with changes in offshore emissions were assessed. 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 the APEEP model. 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, the APEEP model estimates the number of receptors exposed to changes in air pollution and employs a series of peer-reviewed dose-response (D-R) 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 the APEEP Model 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 (age <1 year)	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 <sub>2</sub>	Damage to galvanized steel, painted surfaces, and carbonate stone surfaces	Atteraa (1982), Haynie (1986), and ICP (1998)

### Valuation

To estimate the value of the health, agricultural, and materials impacts outlined above, the APEEP model 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.

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	<ul style="list-style-type: none"> <li>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 (2010a).</li> </ul>
Chronic bronchitis	\$470,000	\$680,000	WTP	<ul style="list-style-type: none"> <li>WTP to avoid a case of pollution-related CB is calculated as <math>WTP_x = WTP_{13} \cdot e^{-\beta(13-x)}</math>, where <math>x</math> is the severity of an average CB case; <math>WTP_{13}</math> is WTP for a severe case of CB; and <math>\beta</math> 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).</li> </ul>
Respiratory hospital admissions (age 65+)	\$25,000	\$25,000	COI	<ul style="list-style-type: none"> <li>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 COI values for income growth.</li> </ul>
Respiratory hospital admissions (age <2 years)	\$10,000	\$10,000		
Asthma-related emergency room visits	\$370	\$370	COI	<ul style="list-style-type: none"> <li>Simple average, adjusted for income, of estimates from Smith et al. (1997) and Stanford et al. (1999).</li> </ul>
Minor restricted activity days	\$62	\$70	WTP	<ul style="list-style-type: none"> <li>Median WTP estimate to avoid one minor restricted activity day from Tolley et al. (1986).</li> </ul>
School loss days	\$89	\$89	COI	<ul style="list-style-type: none"> <li>Point estimate is based on (1) the probability that, if a school child stays home from school, a parent will have to stay 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, Inc. (2008).</li> </ul>

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 (galvanized steel and paint) – Morici (2005) Materials (stone) – Masonry Advisory Council, 2009-2010 Masonry Cost Guide, <a href="http://www.maconline.org/tech/estimating/cost/cost.html">http://www.maconline.org/tech/estimating/cost/cost.html</a>		

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, the APEEP model 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, the APEEP model 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’ 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 75-year analytic time horizon of the OECM, the APEEP model (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.

#### Damages per ton in Alaska planning areas

As outlined above, the air quality analysis for the Atlantic, Pacific, and Gulf of Mexico OCS Regions relies on the existing APEEP modeling framework to monetize the air quality impact of offshore emissions. A similar model for Alaska, however, is not readily available. Moreover, no studies in the literature were identified 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, dollar-per-ton values for grid cells off the coast of Alaska were derived by scaling values generated by the APEEP model for the Washington/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 model results presented in Appendix C for the Atlantic, Pacific, and Gulf of Mexico 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 the scaling procedure, Alaska and Washington/Oregon grid cells were grouped 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, average dollar-per-ton values, by pollutant and year, were developed for each band of grid cells in the Washington/Oregon Planning Area. These band-specific values form the basis of 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, the corresponding 50-km band of grid cells was identified in the Washington/Oregon Planning Area. To develop dollar-per-ton estimates for a given Alaska grid cell, dollar-per-ton values for the corresponding Washington/Oregon distance band were multiplied 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. The 750-mile cutoff around each grid cell was based on the APEEP model 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

Figures 2a through 2d display the damages (\$/ton) due to emissions of PM<sub>2.5</sub>, SO<sub>2</sub>, NO<sub>x</sub>, and VOCs corresponding to all of the nearly 1,500 offshore source locations for the lower 48 States. The figures show several patterns that are important in determining damages. First, sources closer to land cause greater damage per ton than sources farther from shore in any region. Second, sources located near 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 U.S. Northeast coast 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 PM<sub>2.5</sub>-related damages between \$15,000 and \$25,000 (shown in crimson) do not extend far off the East coast.

In contrast, examine sources in the Gulf of Mexico. This top damage class for PM<sub>2.5</sub> encompasses sources that extend far out into the Gulf. Yet, nearby populations that would be exposed to emissions from sources in the Gulf must be smaller than the populations near 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 cities in the southeastern United States. Similarly, sources off the East coast also have their emissions directed to the northeast. However, in marked contrast, the major population centers in the Northeast lie to the west of these sources, so 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.

Figures 2b through 2d show a similar pattern for emissions of SO<sub>2</sub>, NO<sub>x</sub>, and VOCs. In the Gulf of Mexico, the transition from high- to low-impact grid cells is much more gradual than in the Northeast.

Figure 2a. Damages Due to PM<sub>2.5</sub> Emissions.

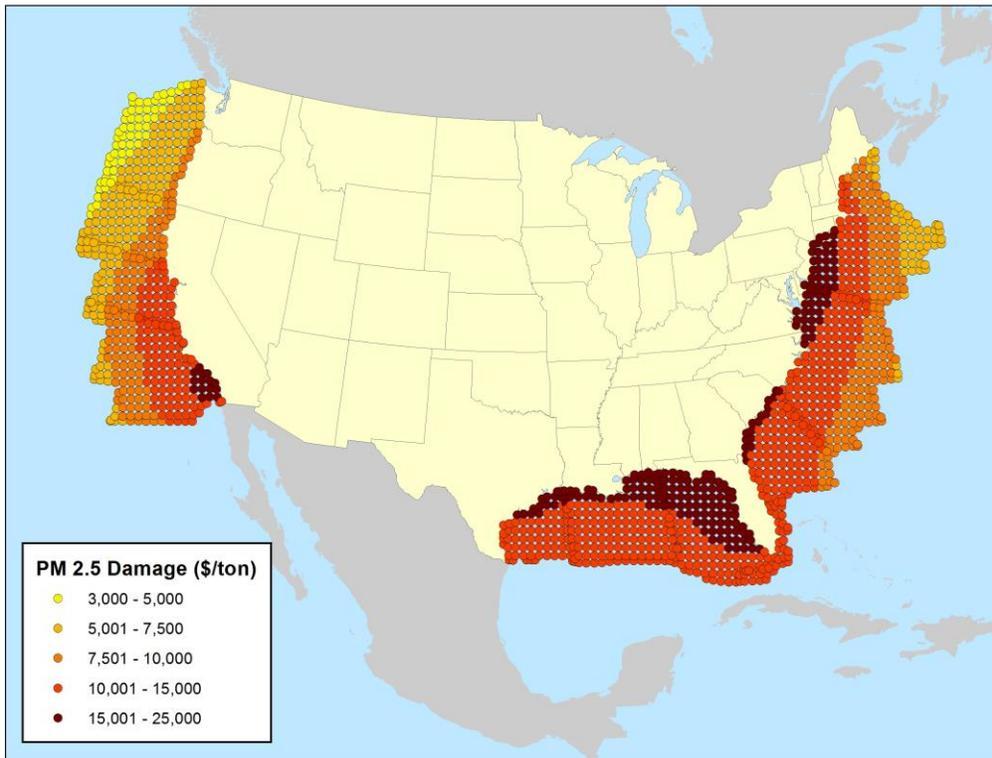


Figure 2b. Damages Due to SO<sub>2</sub> Emissions.

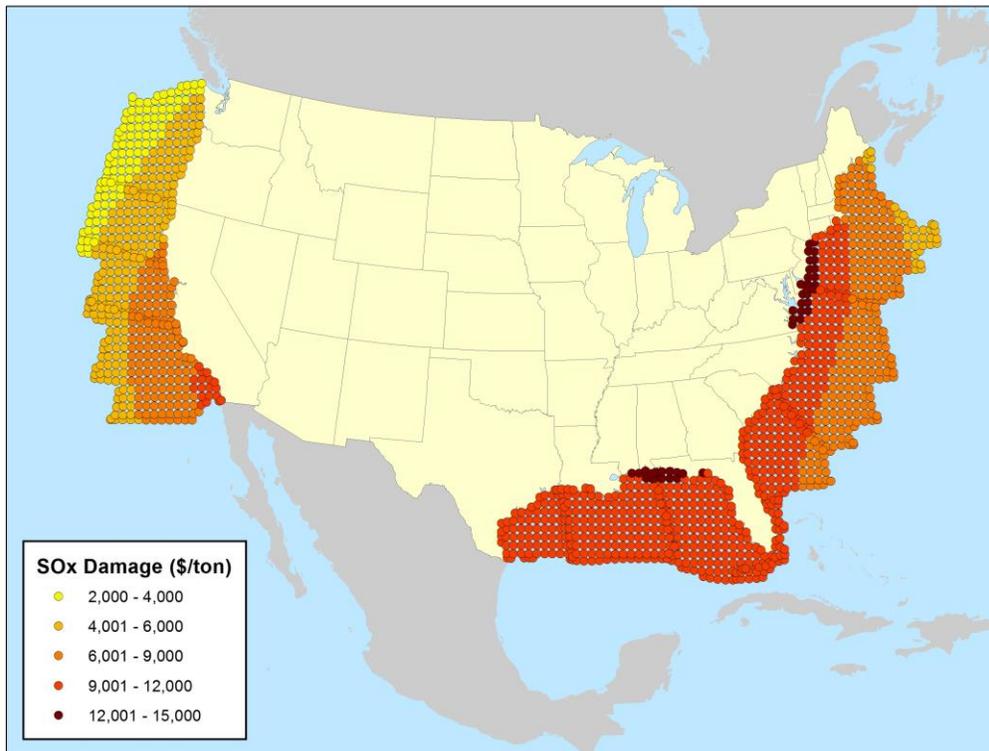


Figure 2c. Damages Due to NO<sub>x</sub> Emissions.

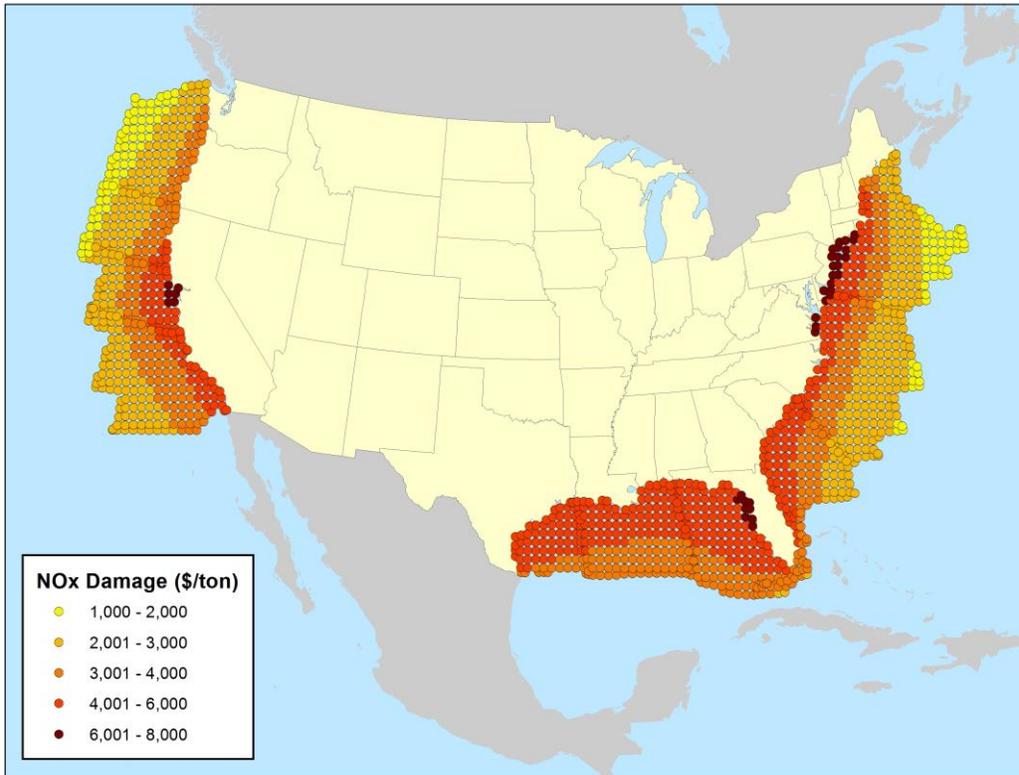
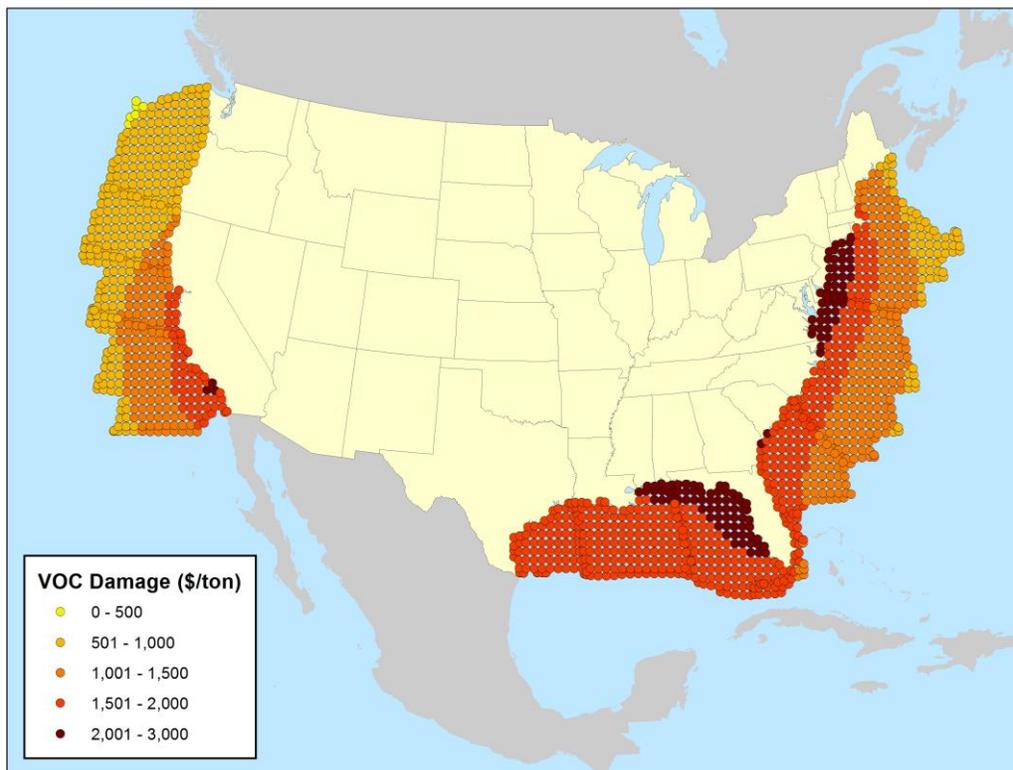


Figure 2d. Damages Due to VOC Emissions.



## 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, natural 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. The APEEP model produces these values at the county level, but the change in onshore energy production for the NAA is specified only at the national level. Therefore, two sets of weighted average dollar-per-ton values were developed, one for oil and natural gas and a second set of estimates applied to emissions from onshore coal production. For oil and natural gas, weighted average values were developed based on county-level employment data for the oil and natural gas sector from the U.S. Census Bureau's 2008 County Business Pattern data. County-level coal production published in the U.S. DOE's (2010) *Annual Coal Report 2009*, was used to develop weighted average dollar-per-ton values for coal production.

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

## 4.6 DOLLAR-PER-TON VALUES FOR ALASKA ONSHORE PIPELINE CONSTRUCTION

As described above, most of the air quality impacts associated with a given E&D scenario result from emissions occurring offshore. The production of oil in the Chukchi Sea planning area, however, would require the construction of an onshore pipeline connecting the Chukchi Sea to the Trans-Alaska Pipeline System (TAPS).<sup>23</sup> The construction of this pipeline would result in air emissions and would potentially lead to impacts associated with onshore oil spills (if the pipeline were to leak), visual disamenity, and potential erosion impacts from the clearing of land. Of these, air emissions represent the only impact category that can be measured and monetized credibly in the OECM. The other categories of impacts are likely to be small in monetized terms, and data that would enable the monetization of these other impacts in the OECM are not readily available. To quantify the onshore emissions associated with the construction of the pipeline, the OECM assumes that the pipeline would transport Chukchi Sea oil 284 miles from Wainwright to Pump Station 1 of the TAPS near Prudhoe Bay and that its construction would occur during the two years immediately preceding production in the Chukchi Sea.<sup>24</sup>

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<sup>23</sup> The OECM assumes that no additional pipelines would be necessary for oil produced in the Beaufort Sea or Cook Inlet Planning Areas. A recent expansion for the Point Thompson Development has extended a pipeline all the way to the western border of ANWR near the eastern edge of existing Beaufort Sea Planning Area leases. Future oil production from the Beaufort Planning Area could tie into this line and minimize new pipeline installation. In the Cook Inlet Planning Area, produced oil would be stored at Nikiski, where smaller tankers could load up for transport to the U.S. west coast. Some produced oil would also be processed at the local refinery in Nikiski and converted into fuel products for local use.

<sup>24</sup> At the time of publication, BOEM assumed that any connection from producing blocks in the Chukchi Sea to TAPS would be completed to transport production from existing leases, prior to any production resulting from the new Five Year Program. However, the costs of this new pipeline construction are being estimated to assure that they are not omitted should earlier development not be sufficient to complete that pipeline connection.

Similar to the OECM's monetization of offshore emissions in the Alaska OCS Region, the model monetizes these *onshore* emissions by scaling the onshore dollar-per-ton values generated by the APEEP model for Washington and Oregon. The specific steps involved in this scaling process are as follows:

1. *Population within 750 miles:* Estimate the population located within 750 miles of North Slope Borough County, Alaska (where the pipeline would be located) and within 750 miles of each county in Washington and Oregon. As noted above, the APEEP results presented in Appendix C suggest that the effect of distance on air quality levels off at approximately 750 miles.
2. *Scale the county-level dollar-per-ton values for Washington and Oregon:* For each county in Washington and Oregon, the dollar-per-ton values generated by APEEP were scaled in proportion to the ratio of North Slope Borough County's population to the population of each county in Washington and Oregon.
3. *Average the scaled dollar-per-ton values:* For each pollutant, the scaled dollar-per-ton values estimated in Step 2 were averaged to create the values applied to North Slope Borough County.

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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 natural 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 of the 23 planning areas that are within visible distance from land. 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; Hoehn et al., 2011).
- 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, therefore, is 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, 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 (\$) 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 coastlines, and it includes residential property values from assessor and census data at the census block group level (DataQuick, 2007-2009; U.S. Census Bureau, 2000b). The coastline is split into the 23 planning areas using a BOEM shapefile, and then it is further split by census block group using a census shapefile (U.S. Census Bureau, 2000a). 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 Bureau, 2000b). 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, 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 A.T. Kearney, Inc., et al., 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 Gulf of Mexico, the assumption is 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.

- 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\$)
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 of between 4.20 and 4.45 percent in each of the planning areas. 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 of 5.94 percent (Freddie Mac, 2010). The Federal tax rate at the median household income of \$50,300 is 25 percent (U.S. Census Bureau, 2009b; 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:  $(\text{Pre-Tax Rate}) - (\text{Pre-Tax Rate}) * [(\text{Federal Tax Rate}) + (\text{State Tax Rate}) * (1 - \text{Federal Tax Rate})]$ . 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. Visibility by region is known to vary due to haze. Based on visibility data from national parks and wilderness areas from 1992 through 2004, visibility on the Pacific coast is generally superior (IMPROVE, 2007). As such, visibility (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

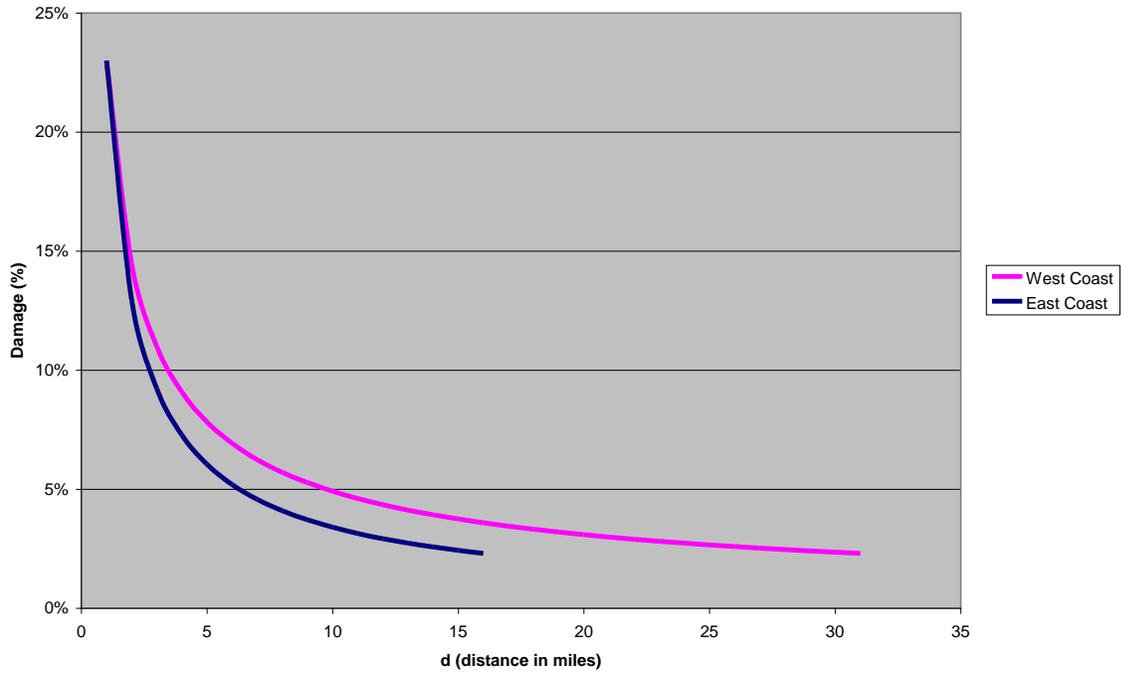
The parameter  $m$  is the maximum percentage impact of a visual disturbance on residential property values. Based on previous studies, the maximum loss in property values resulting from a visual disturbance ranges from 21 to 25 percent, so an estimate of 23 percent is used here (Hoen et al., 2011; Des 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 1 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 of 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.



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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.

$$Impact_t_p = Value_p * i_{ap} * (d_p/365) * l_p$$

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 (m)

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

$i_{ap}$  = After-tax discount rate in each planning area

$i_{ppp}$  = Pre-tax discount rate in each planning area

$t_f$  = Marginal Federal tax rate (25 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 adjacent to the coastlines. In order to solve for this parameter, residential property values from assessor and census data are used at the census block group level (DataQuick, 2007-2009; U.S. Census Bureau, 2000b). The coastline is split into the 23 planning areas using a BOEM shapefile, and then it is further split by census block group using a census shapefile (U.S. Census Bureau, 2000a). 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 lower 48 States (DataQuick, 2007-2009). Otherwise, data from the 2000 census are used (U.S. Census Bureau, 2000b). Table 8 provides an overview of the total residential property value per 1-meter wide by 242-foot long (the length of an average property) area of coastline within each planning

area based on assessor and census data.<sup>25</sup> From both sources, 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 1-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

<sup>25</sup> 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 potentially could 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 of between 4.20 and 4.45 percent in each of the planning areas. This value is the adjusted after-tax current residential mortgage rate (cost of capital) for the average national 30-year fixed interest loan rate between 2005 and 2009 of 5.94 percent (Freddie Mac, 2010). The Federal tax rate at the median household income of \$50,300 is 25 percent (U.S. Census Bureau, 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:  $(\text{Pre-Tax Rate}) - (\text{Pre-Tax Rate}) * [(\text{Federal Tax Rate}) + (\text{State Tax Rate}) * (1 - \text{Federal Tax Rate})]$ . 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<sup>2</sup>.

## 6.4 ASSUMPTIONS

Several assumptions are made in determining the driver values for each planning area, including:

- coastal property values are equivalent to average property values over the extent of a coastal block group;
- 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, assuming that this average parcel is square (ERS, 2002; U.S. Census Bureau, 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. This assumes 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 programmatic Environmental Impact Statement (EIS), strongly suggests that seismic and drilling activities do have an effect on the subsistence harvest of whales and other marine mammals. The EIS, however, also indicates that thresholds above which specific changes can be expected to occur do not exist in the literature. Thus, there is no empirical basis for modeling an adverse change in subsistence harvest success rates.
- *Onshore infrastructure.* The development of coastal infrastructure to support OCS activity (oil and natural gas processing facilities, water treatment plants, pipelines, etc.) 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 also is limited to the impact of OCS oil and natural gas activities on subsistence harvests in Alaska planning areas, reflecting the significance of this issue in Alaska relative to other regions and the availability of Alaskan subsistence harvest data. Alaska planning areas that do not include a 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 updated to incorporate assessments of any impact OCS oil and natural 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 ( $\text{km}^2$  of oiled surface area above an impact threshold for whales and other marine mammals;  $\text{m}^3$  for marine invertebrates and fish)

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

$D_i$  = Replacement cost for biological group  $i$  ( $\$/\text{kg}$ )

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 2 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 2 percent.

### 7.3.2 Area or volume of water in which spill impact occurs

SIMAP 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 SIMAP.

### 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, and 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 in the ADFG database.<sup>26</sup>

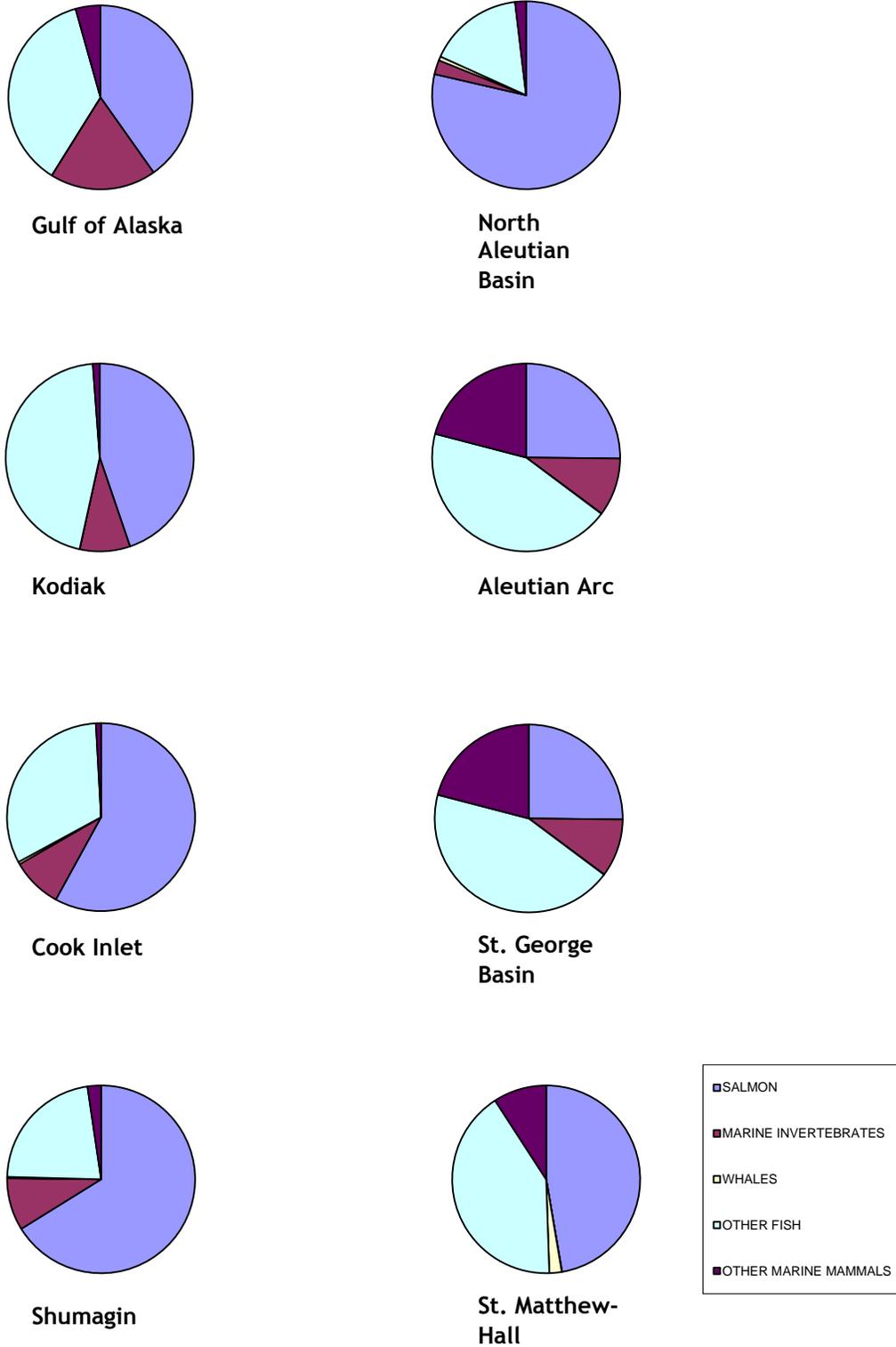
### 7.3.4 Replacement cost

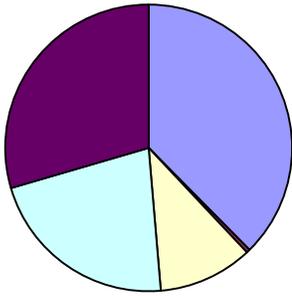
Subsistence use of natural resources includes a cultural element that is not well-addressed in the economics literature. The standard methods for deriving estimates of economic value are limited in their ability to capture the full value associated with subsistence-use activities, as it is very difficult to include cultural and other intangible values that would necessarily be part of a total value measure. Replacement cost is one method that is commonly used as a substitute measure of value. However, here, too, data related to subsistence use are limited. In the model, replacement cost is used as a proxy for the lost subsistence harvest and provides some level of compensation for the lost cultural value. The cultural and social impacts associated with the loss of the subsistence harvest are difficult to quantify and may not be fully reflected in this measure. The model currently utilizes a single per kilogram (kg) replacement cost derived from the BP Exploration Good Neighbor Policy for its Northstar Project in the Beaufort Sea (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. 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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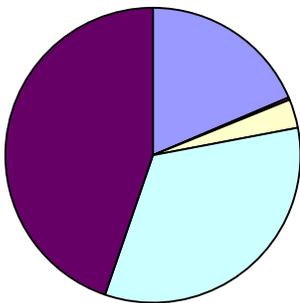
<sup>26</sup> The planning areas in which whale harvest losses can be calculated are Cook Inlet, North Aleutian Basin, St. Matthew Hall, Norton Basin, Hope Basin, Chukchi Sea, and Beaufort Sea.

Figure 4. Marine Harvest Profiles for Alaska Planning Areas.

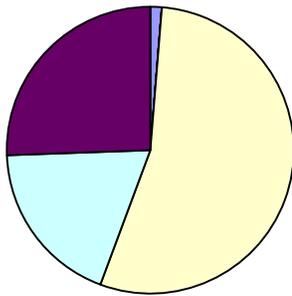




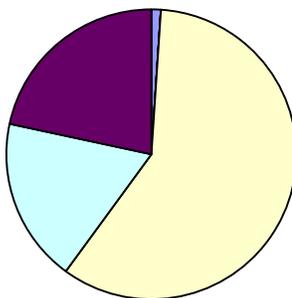
Norton Basin



Hope Basin



Chukchi Sea



## 7.4 REFERENCES – SUBSISTENCE

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## 8 COMMERCIAL FISHING

### 8.1 OVERVIEW

The Commercial Fisheries Impact (CFI) Model measures the costs of fishing area preemption caused by the placement of oil and natural gas infrastructure (platforms and pipelines) in the OCS.<sup>27</sup> The model assumes that there will be buffer zones around platforms that decrease the area of the ocean available for fishing. In most cases, these buffer zones will be a circle with a radius of 805 meters (0.5 miles). 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 redistributed 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 natural gas infrastructure is placed in an area where little or no fishing takes place, the preemption 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 natural 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.<sup>28</sup>

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, Norway, and elsewhere around the world indicates that unburied pipe also is unlikely to affect fish harvesting, with the exception of dredges used to harvest scallops and clams.<sup>29</sup> The model for the North Atlantic and Mid-Atlantic Planning Areas includes preemption impacts of unburied pipelines on the scallop fisheries and quahog fisheries that occur in waters deeper than 60 meters.

This CFI model is significantly different than the CFI 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 preempted by oil and natural gas infrastructure. Thus, if there were 10,000 square miles in a planning area and

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<sup>27</sup> The CFI 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.

<sup>28</sup> There do not appear to be significant concerns that platforms cause negative impacts on the biomass of commercial fish species. In fact, there is considerable debate about whether platforms actually may increase fishable biomasses of certain species. In this case, the decision was to err on the conservative side of the issues and assume for the purpose of the model that additional platforms will not increase biomass levels of commercial fish species.

<sup>29</sup> In the research for this model, conversations were held on April 25, 2010 with 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 absence of specific information regarding potential impacts of pipelines on crab migrations, the decision was not to speculate, but note that there may be additional impacts beyond those reflected in the model.

platforms and pipelines preempted 100 square miles, then fish harvests were assumed to be reduced by 1 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 OEMCM does not currently estimate the impact of oil spills on commercial fishing. While spills attributable to OCS activity may 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 exploration and development scenario is constrained by a number of factors. Producing a credible prediction of spill-related costs would require assumptions such as the spill's biological impact, if any, on future stocks; the relative impact of a spill on different commercial species; the timing of a spill and whether it would occur during a period when commercial activity is occurring at a particular location; and a spill's influence on consumer behavior (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 effort to date. Also note that the most significant costs would result from low probability/high consequence events that the model is not intended to address.

Focusing on potential impacts associated with temporary fishery closures, such impacts are unlikely to be significant in the areas included in the Five Year Program. Because most fisheries are managed through catch limits, temporary closure of a fishery still would give the industry ample opportunity to reach the catch limit for the season. Although the industry may not be able to completely make up for the catch losses associated with the temporary closure, historical experience suggests that the industry is able to make up for a significant portion of these losses by increasing their catch later in the season. For example, data on the impact of the 1987 Glacier Bay spill on the Cook Inlet salmon fishery show that catch for drift net fishermen increased in late July and early August to make up for the reduction in catch in the immediate aftermath of the spill in mid-July.<sup>30</sup> If a spill occurs near the end of the season, fisheries management authorities typically have the flexibility to extend the season to minimize catch losses.

## 8.2 BASIC CALCULATION

This section provides a summary of the methodology used to estimate preemption impacts of oil and natural 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 the National Oceanic and Atmospheric Administration (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

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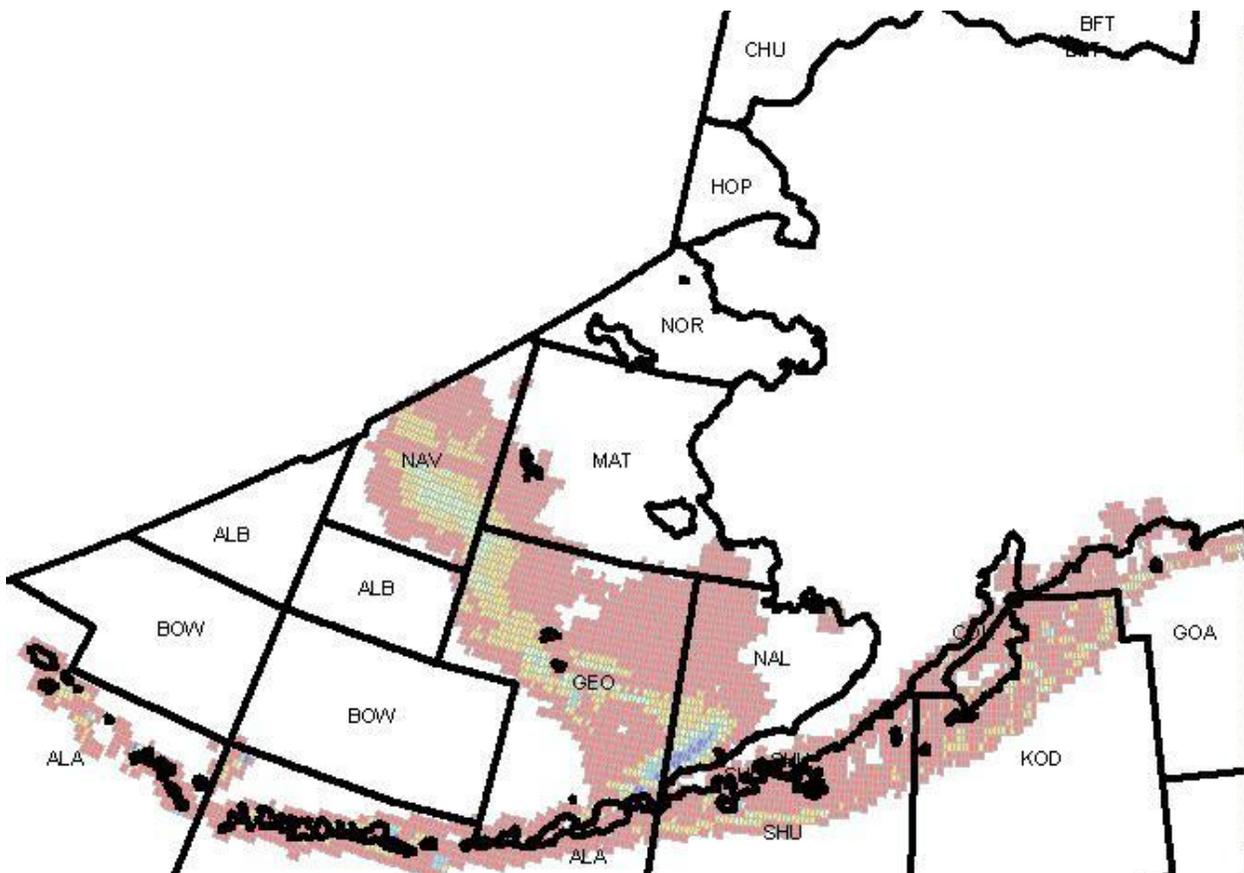
<sup>30</sup> See MMS (1990).

- 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. 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 natural 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 is similar.

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



Source: Developed for the OEM by Alaska Map Company from data supplied by NMFS.

Preemption 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 CFI 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  $10 \times 10$  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, and
- Group 2: 7 platforms with average depth of 55 meters

The model randomly assigns platforms to 12 different  $10 \times 10$  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 ( $BRc$ )  $\times$  (Cell area – buffer zone)  $\div$  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 the 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 ( $FRc$ ) =  $PRc \times \sum IRc \div \sum PRc$

Once fishery values are redistributed 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.<sup>31</sup>

In order to estimate the cost impact of grounds preemption, 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 preempted due to oil and natural 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 preemption 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 located in cells

<sup>31</sup>The following formulation will be used to estimate the fishing cost differential across  $10 \times 10$  cells:

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

$dCp_c$  = 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

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. Coefficients incorporated in this version of the OEM result from regressions on thousands of simulation iterations<sup>32</sup> 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.<sup>33</sup> 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 also can 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 terms of impacts.<sup>34</sup>

### 8.3 REGRESSION COEFFICIENTS

The OEM, 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 with estimated regression 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  $i$ . Regression coefficients are included 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 is 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, 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 are placed in the ranges with negative coefficients for the un-squared term. Because it is doubtful that displacing fishing effort will result in overall cost reductions, the model returns a zero value for any negative cost results.

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<sup>32</sup> For most planning areas, over 20,000 simulation iterations were generated. Exceptions were the North and Mid-Atlantic for which 10,000 simulation iterations were run.

<sup>33</sup> Because of the large number of  $10 \times 10$  cells in each planning area, the spreadsheets used to calculate results are quite large. For example, the spreadsheet used to interactively calculate the 250 location configurations in the St. Matthew Hall Planning Area (with 1,447 cells) is over 23 megabytes in size. Increasing the number of iterations to 1,000 would make the estimate of 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.

<sup>34</sup> This last set of regression coefficients has not been included with this version of the OEM, but it potentially could be added at a later date.

In part because of the fact that negative coefficients for the un-squared terms occur, but also because fewer interactions are likely between depth ranges when all platforms are located in a single depth range, a second set of regression coefficients 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 still is one instance of a negative coefficient. This occurs in the Bowers Basin Planning Area off Alaska, 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 fishery data inputs and 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. St. George Basin is home to some of the most prolific fishing grounds in Alaska.

Table 9 summarizes the data by depth range used to develop the impact model for St. George Basin. The table shows:

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

Notes:

HA M is millions of hectares,

Real \$ M is millions of real dollars.

Table 10 summarizes the regression coefficients that result from the thousands of simulations run through the St. George Basin Planning Area model. The table contains two independent sets of regression 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 of cells that exist in the depth range. For most areas, it would be more likely that the number of platforms would be relatively small, and therefore potential scenarios in the range from zero to nine platforms were over-sampled.

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 reduced significantly. Simulations were run 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 numbered 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 5 percent generally are considered significantly different than zero. The fact that both coefficients for platforms in D1 are negative implies that additional platforms in this depth range will dampen the negative impacts of platforms in other depth ranges (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 D3 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 preemption cost impacts of 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, 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 coefficient for the number of platforms in D1 is 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		<i>P</i> -values (Significant if <5%)	
		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: Regression 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 zero, 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 D1 and five platforms will be placed in D2. In this case,  $x_1 = 3$  and  $x_2 = 5$ . The annual fishery impacts would be estimated as  $Y = (-0.6107 \times 2) + (-0.0199 \times 2^2) + (6.5774 \times 5) + (-0.0083 \times 5^2) = 31.3785$ .

Example 2: Assume an E&D scenario for the St. George Basin in which two platforms will be placed in D2 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 Gulf of Mexico 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  $10 \times 10$  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  $10 \times 10$  cells for all of Alaska for the years 2006-2009 (Lewis, 2010). NMFS Alaska 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  $10 \times 10$  cell, as long as more than three vessels contributed harvests to the landings; otherwise, the landings were considered confidential. NMFS also provided 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 cells with more harvesters.

Therefore, 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 platforms.

In addition to groundfish, crab and halibut also are 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 2006-2009. In Alaska, crab landings are reported by statistical areas covering one-half of a degree of latitude and one degree of longitude. Given that these statistical areas are already geographically based, it was a straightforward process to subdivide the landings by stat-area into  $10 \times 10$  cells, with each cell receiving a portion of the landings equal to its share of the water in the stat-area. The CFEC also reported total landings by fishery and year. The amount of crab landings that were considered confidential were inferred from these data. Confidential harvests were assigned to statistical areas that were adjacent to statistical areas 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 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 2006-2009 (Kong, 2010). In the Bering Sea, halibut landings are reported using the same geographically-defined statistical areas. In the Gulf of Alaska, statistical areas specifically for halibut are used. In general, essentially the same process was used to assign harvests to  $10 \times 10$  cells with one important twist. It was assumed that within a statistical area, halibut harvested were distributed to  $10 \times 10$  cells in proportion to the amount of water area in each cell. In the case of halibut, however, information from IPHC indicated that harvests of halibut generally are limited to water less than 500 fathoms (914 meters) of depth. Thus, halibut harvests were not assigned 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, average ex-vessel harvest values by species and year were assigned independently. Ex-vessel values were adjusted to account for inflation to 2009 dollars using the U.S. Bureau of Labor Statistics producer price index (PPI) for unprocessed and packaged.<sup>35</sup> 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 salmon harvests were not included in the Alaska data. While salmon fisheries are very important in Alaska, accounting for roughly one-third of the ex-vessel value (Hiatt et al., 2009), the vast majority of harvests take place inside State waters and therefore would not be directly affected by the placement of 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  $10 \times 10$  cells for 2006-2009 from two sources. Harvests in the offshore Pacific whiting fishery were provided from observer data by NMFS Northwest Fishery Science Center through a special request (Tuttle, 2010). Estimates of harvests of shorebased trawl by  $10 \times 10$  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 for calculation of data that

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<sup>35</sup> PPI obtained from <http://data.bls.gov:8080/PDQ/outside.jsp?survey=wp>.

had been withheld for confidentiality. Confidential harvest amounts then were 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, 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 INPFC has been dissolved, INPFC statistical 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 Exclusive Economic Zone (EEZ) off the Pacific Coast. Harvest data from INPFC Areas are reported by PacFIN on an annual basis (PacFIN, 2010a and 2010b).

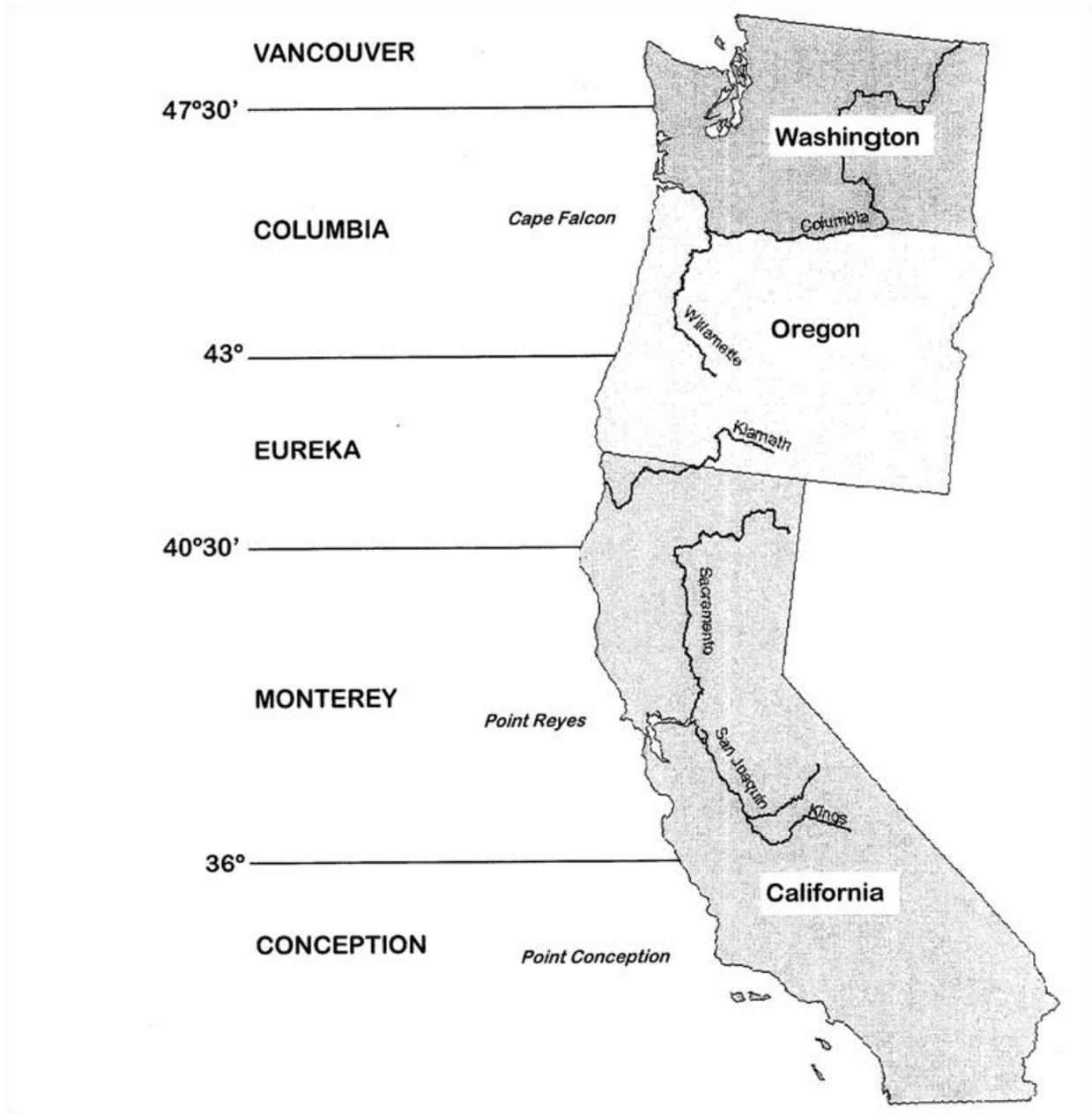
For non-trawl landings of groundfish, primarily sablefish and rockfish, landings data by INPFC Areas were combined with fishery specific landings data for  $10 \times 10$  cells for trawls and assigned non-trawl landings to  $10 \times 10$  cells in each INPFC Area in proportion to the landings those 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  $10 \times 10$  cells that had rockfish trawl landings. In this case, areas of high abundance of particular species presumably 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  $10 \times 10$  data with which to associate non-trawl landings. In this case, estimates were made of the proportion of landings by depth in areas north of the Conception INPFC Areas for those fisheries that occur inside the Conception Area. Harvests then were assigned 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, salmon, and shrimp trawl fisheries. Both 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 CFI 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 farther out into the EEZ. Based on this information, landings data by INPFC Areas from PacFIN were assigned to  $10 \times 10$  cells in these depth ranges in proportion to water area.

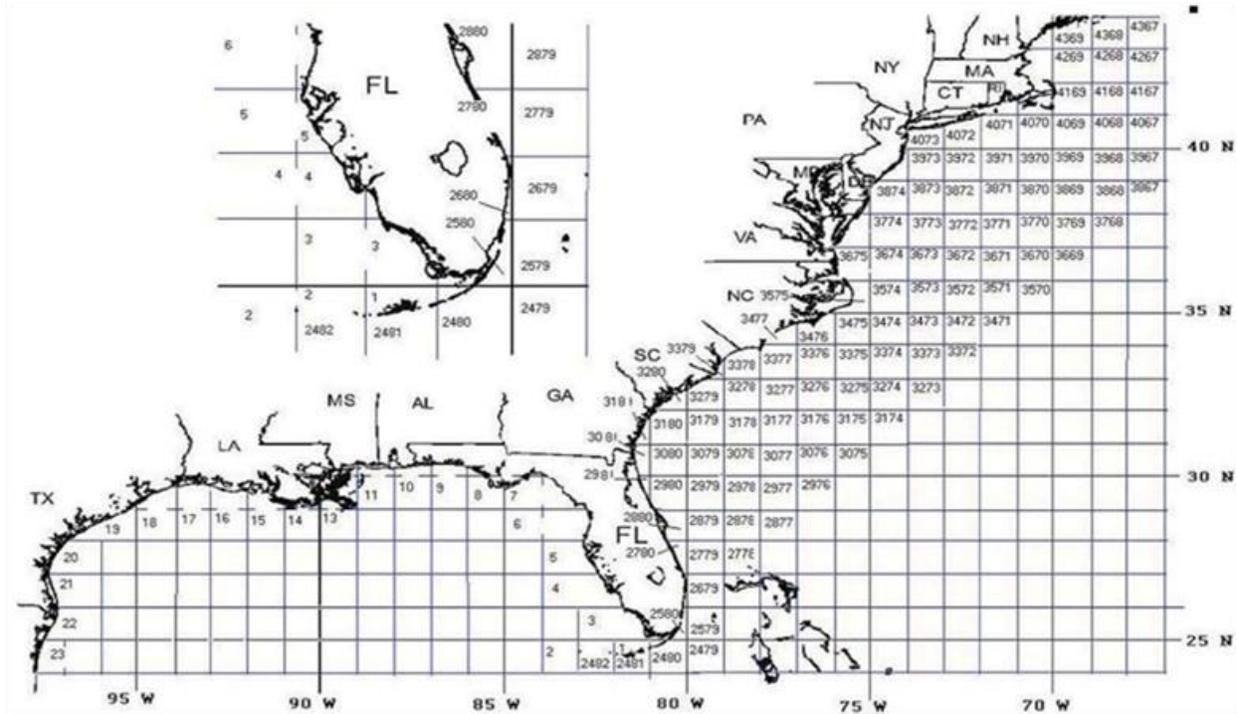
Figure 6. International North Pacific Fishery Commission (INPFC) Statistical Areas.



### 8.5.3 Gulf of Mexico and South Atlantic

Information on commercial fish harvests for the Gulf of Mexico and for the South Atlantic were the 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 statistical areas in general use throughout the region. The statistical 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 SEFSC as part of the BOEM data request (Jamir, 2010).

In the Gulf of Mexico there are 23 statistical areas. Areas 19-23 and 1-7 extend in east-west directions outward from the coastline until they meet the statistical 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, statistical areas are linked to specific geographic coordinates. Each statistical area covers one degree of longitude and one degree of latitude and is designated based on the coordinates of the lower right corner.

NMFS 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

Note that the sizes of many of the statistical areas, particularly in the Gulf of Mexico, are quite large. Therefore, in order to provide more realistic geographic distributions of harvests, the determination was made that 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 at <http://www.aquamaps.org/>. Table 12 shows the maximum cell depth to which landings were allocated for each of the fisheries within statistical areas. For example, if there were 1,000 metric tons of reeffish landings reported for Statistical Area 12 in the Gulf of Mexico, then only those cells in the statistical area that had depths of 540 meters or less would be assigned reeffish landings. The cells with depths greater than 540 meters would not be assigned reeffish harvests. In general, fisheries to be harvested were not constrained in cells with depths greater than some minimum. The exception to this rule was for Golden Crab. For that fishery, cells had to have a minimum depth of 250 meters to receive an allocation.

Table 12. Maximum Cell 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 that are not federally managed. In the Gulf of Mexico, 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 within three miles of shore, and therefore that they would not be displaced by new 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 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 prices to landings and as a means to assign harvests to cells for which fishery-specific data were noted as confidential. While the data provided 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 three miles also were excluded, such as blue crab.

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 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. It is believed that these fisheries could be affected by OCS platforms; therefore, alternative sources of information were found. Estimates of commercial fisheries harvest volumes and values by state compiled by the NMFS Office of Science and Technology for 2006-2009 were used as source data for lobster and large pelagics in the North and Mid-Atlantic (NMFS, 2010).

Estimated harvests by state were allocated to  $10 \times 10$  cells by latitude. For example, cells with latitude of 43 degrees and higher were assigned to Maine, while cells from 41.6 degrees to 42.9 degrees were assigned to Massachusetts and New Hampshire. Lobster landings reported in the NMFS database for Maine were assigned to the  $10 \times 10$  cells in Maine in proportion to each cell's water area. It should be noted that a maximum depth limit was added 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 the NMFS commercial fisheries harvest database (NMFS, 2010). In this case, harvests were not constrained to specific depths and 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 Alaska planning area. Note that there are no commercial fisheries in Federal waters in Hope Basin or Chukchi and Beaufort Seas, 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

Notes:

HA M is millions of hectares.

Real \$ M is millions of real dollars.

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

Depth Band	Depth Range	Regression Coefficients		P-values (Significant if <5%)	
		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 zero, 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

Notes:

HA M is millions of hectares.

Real \$ M is millions of real dollars.

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

Depth Band	Depth Range	Regression Coefficients		P-values (Significant if <5%)	
		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 zero, 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

Notes:

HA M is millions of hectares.

Real \$ M is millions of real dollars.

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

Depth Band	Depth Range	Regression Coefficients		<i>P</i> -values (Significant if <5%)	
		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 zero, then no impacts are estimated for platforms in the depth range.

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

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

Notes:

HA M is millions of hectares.

Real \$ M is millions of real dollars.

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

Depth Band	Depth Range	Regression Coefficients		<i>P</i> -values (Significant if <5%)	
		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 zero, 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

Notes:

HA M is millions of hectares.

Real \$ M is millions of real dollars.

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

Depth Band	Depth Range	Regression Coefficients		<i>P</i> -values (Significant if <5%)	
		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 zero, 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

Notes:

HA M is millions of hectares.

Real \$ M is millions of real dollars.

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

Depth Band	Depth Range	Regression Coefficients		<i>P</i> -values (Significant if <5%)	
		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 zero, 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

Notes:

HA M is millions of hectares.

Real \$ M is millions of real dollars.

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

Depth Band	Depth Range	Regression Coefficients		<i>P</i> -values (Significant if <5%)	
		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 zero, 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

Notes:

HA M is millions of hectares.

Real \$ M is millions of real dollars.

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

Depth Band	Depth Range	Regression Coefficients		P-values (Significant if <5%)	
		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 zero, 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

Notes:

HA M is millions of hectares.

Real \$ M is millions of real dollars.

Table 31. Commercial Fishing Modeling: Fishery Impact Coefficients for Shumagin.

Depth Band	Depth Range	Regression Coefficients		<i>P</i> -values (Significant if <5%)	
		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 zero, 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

Notes:

HA M is millions of hectares.

Real \$ M is millions of real dollars.

Table 33. Commercial Fishing Modeling: Fishery Impact Coefficients for Kodiak.

Depth Band	Depth Range	Regression Coefficients		<i>P</i> -values (Significant if <5%)	
		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 zero, 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

Notes:

HA M is millions of hectares.

Real \$ M is millions of real dollars.

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

Depth Band	Depth Range	Regression Coefficients		<i>P</i> -values (Significant if <5%)	
		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 zero, 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

Notes:

HA M is millions of hectares.

Real \$ M is millions of real dollars.

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

Depth Band	Depth Range	Regression Coefficients		P-values (Significant if <5%)	
		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 zero, 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 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

Notes:

HA M is millions of hectares.

Real \$ M is millions of real dollars.

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

Depth Band	Depth Range	Regression Coefficients		P-values (Significant if <5%)	
		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 zero, 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

Notes:

HA M is millions of hectares.

Real \$ M is millions of real dollars.

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

Depth Band	Depth Range	Regression Coefficients		P-values (Significant if <5%)	
		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 zero, 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

Notes:

HA M is millions of hectares.

Real \$ M is millions of real dollars.

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

Depth Band	Depth Range	Regression Coefficients		P-values (Significant if <5%)	
		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 zero, 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

Notes:

HA M is millions of hectares.

Real \$ M is millions of real dollars.

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

Depth Band	Depth Range	Regression Coefficients		P-values (Significant if <5%)	
		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 zero, 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 Gulf of Mexico 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

Notes: HA M is millions of hectares.  
Real \$ M is millions of real dollars.

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

Depth Band	Depth Range	Regression Coefficients		<i>P</i> -values (Significant if <5%)	
		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 zero, 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

Notes:

HA M is millions of hectares.

Real \$ M is millions of real dollars.

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

Depth Band	Depth Range	Regression Coefficients		P-values (Significant if <5%)	
		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 zero, 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

Notes:

HA M is millions of hectares.

Real \$ M is millions of real dollars.

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

Depth Band	Depth Range	Regression Coefficients		P-values (Significant if <5%)	
		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 zero, 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- and North Atlantic differ from models for other regions in that they assume that unburied pipelines can occur in D2 and D3 (from 60-300 m) and 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

Notes:

HA M is millions of hectares.,

Real \$ M is millions of real dollars.

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

Depth Band	Depth Range	Regression Coefficients		P-values (Significant if <5%)	
		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 zero, then no impacts are estimated for platforms in the depth range.

Table 54. Commercial Fishing Modeling: Data Summary for 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

Notes:

HA M is millions of hectares.

Real \$ M is millions of real dollars.

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

Depth Band	Depth Range	Regression Coefficients		<i>P</i> -values (Significant if <5%)	
		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 zero, then no impacts are estimated for platforms in the depth range.

Table 56. Commercial Fishing Modeling: Data Summary for 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

Notes:

HA M is millions of hectares.

Real \$ M is millions of real dollars.

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

Depth Band	Depth Range	Regression Coefficients		P-values (Significant if <5%)	
		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 zero, then no impacts are estimated for platforms in the depth range.

Table 58. Commercial Fishing Modeling: Data Summary for 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

Notes:

HA M is millions of hectares.

Real \$ M is millions of real dollars.

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

Depth Band	Depth Range	Regression Coefficients		P-values (Significant if <5%)	
		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 zero, 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 natural gas development, the 2001 version of the OECM employed a habitat equivalency analysis (HEA)-based, restoration cost approach to determining dollar damages. The revised OECM uses a similar approach. However, it updates (1) the restoration cost data used in the OECM, and (2) 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 the willingness to pay (WTP) for their protection and/or enhancement. Changes in the quality or quantity of these services, 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 natural 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.

Among valuation approaches, stated preference methods are the only tools available for eliciting non-use values (i.e., economic value that is not associated with direct use of a resource) from the public. The strength of stated-preference methods is the ability to pose to a respondent any hypothetical scenario; the method is not limited to observing behaviors under limited actual conditions. However, given the national 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. Stated preference methods also remain controversial when applied to elicit values.<sup>36</sup> As noted in the U.S. EPA’s guidance document for preparing economic analyses:

Concerns about the reliability of value estimates that come from CV [contingent valuation] studies have dominated debates about the methodology, since research has shown that bias can be introduced easily into these studies, especially if they are not carefully done. In particular, the concern that CV surveys do not require respondents to make actual payments has led critics to argue that responses to CV surveys are biased because of the hypothetical nature of the good. Reliability tests on the data that conform to expectations from both economic and psychological theory can enhance the credibility of a CV survey. Surveys without these tests should be suspect; surveys whose results fail the tests may be discredited. (U.S. EPA, 2000, page 83)

This limitation also applies to benefits transfers that apply existing valuation estimates from the stated preference literature.

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<sup>36</sup> The application of survey-based approaches for use-values, such as understanding how, and how often, members of a community use a resource, is generally accepted, especially when issues such as recall bias and strategic responses are addressed.

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.<sup>37</sup> Restoration costs also can be viewed as costs for which 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 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, an important strength of HEA relative to the economic valuation techniques outlined above is that HEA may be broadly applied to large areas with relative ease. Although the cost of restoration projects depends on factors such as the existing condition of the area to be restored, these costs do not vary significantly between different areas. In addition, because HEA provides a lower bound estimate of WTP, there is less uncertainty in the directional bias of HEA-based estimates than from estimates derived from primary economic valuation methods or benefits transfer.

It is important to note that economic valuation and equivalency-based approaches both require a detailed understanding of the underlying ecological injury and changes in service flows. That is, these approaches are not a substitute for sound injury determination and injury quantification. They are a distinct means, however, to establishing the scale of restoration, since they involve valuation of service losses, or at least economic tradeoffs. While habitat and resource equivalency do not involve valuation, they ultimately involve the development of restoration cost estimates.

The types of assessment approaches that are required to apply economic valuation of ecological changes and/or value equivalency approaches are different than those used for habitat and resource equivalency. They might include benefits transfer (i.e., application of values from the published literature), or primary research involving focus groups and stated preference surveys of the public. As noted above, the cost of applying primary economic techniques can be substantial, and these studies can take significant time to complete.

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<sup>37</sup> 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, oil spills are assumed to naturally degrade over time or are cleaned up such that adverse impacts resolve within 3 to 5 years (French-McCay, 2009).

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 natural 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 natural 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<sup>38</sup> 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 that accounts 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 replace similar wildlife through restocking) presented in a variety of documents, but they rely heavily on NOAA’s “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](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 NRDAM/CME-output estimates of habitat or wildlife injured per BBO spilled on a regional basis. Damages are expressed as either low or high

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<sup>38</sup> 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.

by applying the low or high restoration costs, respectively, and they are expressed on a per-BBO-produced basis when used in OECM calculations.

- Resultant damages are increased by 9 percent to account for NRDA administrative costs; a percentage calculated based on cost components from six NRDAAs.<sup>39</sup>

### 9.3 MODIFICATIONS TO THE 2001 MODEL

In general, an HEA and REA/restoration cost-based approach for assessing ecological damages from offshore 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
  - 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.

As in the 2001 model, the revised OECM addresses only those adverse ecological impacts caused by oil spills. Although other adverse ecological effects likely occur as a result of offshore development (for example, adverse effects from noise and vibration and wildlife kills related to collisions with offshore structures have been evaluated in the context of programmatic EISs), reliable methods to quantify such impacts on a planning area basis currently are unavailable. The OECM does not assess any impacts related to onshore construction and development-related projects.<sup>40</sup> The model considers only the ecological costs of exploration, development, and transportation of OCS resources to shore, as these activities are within Department of the Interior jurisdiction. The development of any new onshore infrastructure beyond existing infrastructure would be analyzed through future permitting-related activities and, given the uncertainties about the scope of onshore infrastructure construction required under program scenarios, are not incorporated into the OECM. Finally, estimation of ecological costs in

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<sup>39</sup> Note that this calculation is made *ex post facto*, on a regional basis, outside of the actual OECM.

<sup>40</sup> The OECM does include the air emissions resulting from the development of an onshore pipeline to transport oil produced in the Chukchi Sea. This is discussed in Chapter 4.

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:
  - a. Numbers of individual wildlife organisms killed are calculated from wildlife abundance in sea and shoreline areas oiled above mortality thresholds.
  - b. 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 that is 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 by 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 macro-invertebrates 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

### Area or volume of water in which spill impact occurs

SIMAP 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.

### 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 of 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, 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
- *Polar bears* (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 (debit or loss side of the analysis) are quantified when saltmarsh, mangrove, rocky shore, gravel and sand beaches, and mudflat habitats are oiled with sufficient oil to adversely affect invertebrates associated with the intertidal habitat. A greater than 0.1 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 to 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 3 percent.

The area (m<sup>2</sup>) of salt marsh requiring restoration per m<sup>2</sup> 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<sup>2</sup>) of marsh restored.

This HEA calculation was performed for habitat types in which a benthic invertebrate injury would occur, such as 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 salt marsh restored per m<sup>2</sup> 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, REA restoration factors, which are derived using a combined REA-trophic web model, are used 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 initially were 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 also have been used in several other cases, as well as in 23 successful claims submitted by the Florida Department of Environmental Protection to the U.S. Coast Guard, National Pollution Funds 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), with primary production used to measure the benefits of the restoration. However, in this case, the transfer of production up the food web is taken into consideration. Specifically, 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, 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 (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 kilogram of injury divided by ecological efficiency, which 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 3 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
- Project lifetime (years the restored habitat will provide services)

In this case, it is assumed that marsh creation or restoration is performed, that the marsh requires 15 years to reach full function (based on LA DEQ et al., 2003) and 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  $\text{m}^{-2} \text{yr}^{-1}$ . In addition, benthic microalgal production provides another 105 g dry weight  $\text{m}^{-2}$  (Van Raalte et al., 1976). Thus, estimated total primary production rate in salt marshes in this region is 605 g dry weight  $\text{m}^{-2} \text{yr}^{-1}$ .
- Gulf of Mexico and South Atlantic: Above-ground primary production rates of salt marsh cord grasses in Georgia were used as estimated by Nixon and Oviatt (1973), based on Teal (1962), as 1,290 g dry weight  $\text{m}^{-2} \text{yr}^{-1}$ . In addition, benthic microalgal production provides another 105 g dry weight  $\text{m}^{-2}$  (Van Raalte et al., 1976). Thus, estimated total primary production rate in salt marshes in this region is 1,395 g dry weight  $\text{m}^{-2} \text{yr}^{-1}$ .
- Northern, Central, and Southern California: Above-ground primary production rates of salt marshes in the Central California coast were used as estimated by Continental Shelf Associates (CSA) (1991) as 3,666 g dry weight  $\text{m}^{-2} \text{yr}^{-1}$ . In addition, benthic microalgal production provides another 312 g dry weight  $\text{m}^{-2}$  (CSA, 1991). Thus, estimated total primary production rate in salt marshes in this region is 3,978 g dry weight  $\text{m}^{-2} \text{yr}^{-1}$ .
- Washington and Oregon: Above-ground primary production rates of salt marshes on the Oregon coast were used as estimated by CSA (1991) as 2,636 g dry weight  $\text{m}^{-2} \text{yr}^{-1}$ . In addition, benthic microalgal production provides another 375 g dry weight  $\text{m}^{-2}$  (CSA, 1991). Thus, estimated total primary production rate in salt marshes in this region is 3,011 g dry weight  $\text{m}^{-2} \text{yr}^{-1}$ .
- Gulf of Alaska: Above-ground primary production rates of salt marshes 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  $\text{m}^{-2} \text{yr}^{-1}$ . In addition, benthic microalgal production over a 6-month growing season provides another 1,488 g dry weight  $\text{m}^{-2}$  (CSA, 1991). Thus, estimated total primary production rate in salt marshes in this region is 2,170 g dry weight  $\text{m}^{-2} \text{yr}^{-1}$ .

- Northern Alaska: Above-ground primary production rates of salt marshes 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  $\text{m}^{-2} \text{yr}^{-1}$ . In addition, benthic microalgal production over a 6-month growing season provides another 744 g dry weight  $\text{m}^{-2}$  (CSA, 1991). Thus, estimated total primary production rate in salt marshes in this region is 1,085 g dry weight  $\text{m}^{-2} \text{yr}^{-1}$ .

For the injured resources, all weights are as wet weight; dry weight is assumed to be 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, data from a meta-analysis of wetland restoration costs by Louis Berger & Associates, Inc. (1997) is combined 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). All costs are updated to 2009 dollars.

The Louis Berger study presents cost data for two sets of projects. The first set includes 65 restoration and creation projects for several wetland types in the States of New York, Rhode Island, Maine, Massachusetts, Connecticut, and New Hampshire. Data from the subset of 11 estuarine wetland restoration and two creation projects were applied.<sup>41</sup> Presented costs included three components of planning, construction, and monitoring. All three cost components were used to 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, costs from a subset of 15 that involve estuarine wetland restoration, include complete construction costs, and comprise substantial restoration were applied. Because data provided for the Connecticut projects do not include monitoring costs, calculation and application of a ratio of monitoring to planning and construction costs based on data from Louis Berger (1997) were used to estimate monitoring costs for these projects.

These selected cost data from Louis Berger were combined with data on seven coastal marsh creation projects provided by Mr. Carl Alderson (2010) to populate a restoration costs database of 26 restoration projects and nine creation projects. Based on these data, average per-acre restoration and average per-

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<sup>41</sup> Costs from one coastal wetland restoration project (Boston's Logan Airport) were determined to be excessive and were not used in the calculations. In addition, data from two combination restoration and creation projects were excluded.

acre creation costs for coastal marsh habitat in the Northeast were created.<sup>42</sup> The midpoint of the restoration cost and creation cost averages was applied as the per-acre cost estimate for the Northeast.

In order to account for the variability of restoration costs in different regions of the United States, ELI data on wetland compensatory restoration costs for 38 cities and regions in the United States were used. 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, planning area-specific ratios of restoration costs were created based on ELI (2007) data. Specific ratios of restoration costs were created for each planning area, relative to restoration costs in the North Atlantic Planning Area.<sup>43</sup> To establish planning area-specific cost estimates for use in calculating ratios, data presented for coastal cities in a given planning area were averaged. In instances where data are not available from such cities, the average of neighboring planning areas was used.

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 from ELI (2007) data. This determines planning area-specific per-acre coastal marsh restoration costs for application in the OECM.<sup>44</sup>

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<sup>42</sup> 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), other data clearly suggest that wetland creation costs greatly exceed wetland restoration costs.

<sup>43</sup> Per-acre restoration costs from New England and New York are averaged to determine a baseline restoration cost for the North Atlantic Planning Area.

<sup>44</sup> Note that per-acre restoration costs are converted to units of dollars per m<sup>2</sup>.

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## 10 Benefits of OCS Oil and Natural Gas Activity

### 10.1 OVERVIEW

As with the cost categories considered for inclusion in the OECM, assessing benefits associated with OCS oil and natural gas activity would include: (1) defining an appropriate quantification metric, (2) using that metric as a basis for quantitative analysis of the impact of a specific E&D scenario, and (3) translating the results of the quantitative analysis into a monetary estimate of a change in social welfare value. One potential benefit is the enhancement of recreational fishing and diving opportunities in the vicinity of exploration and production platforms, absent access restrictions.

### 10.2 RECREATIONAL BENEFITS

Recreational fishing combines both private boat fishing and commercial charter or party boat operations that engage in fishing for sport or competition. Commercial charter and party boat operations involve vessels with licensed captains and crew. Charter operations generally consist of pre-formed groups of fishermen, while party boats combine several groups on the same trip and vessel. Recreational diving similarly encompasses private, charter, and party trips, but because these trips are comparatively less common than fishing trips, there are few data to support reporting statistics in narrower categories.

The most detailed study of the economic impacts of recreational fishing and diving in relation to offshore structures is a 2002 Minerals Management Service (MMS)<sup>45</sup> study, *Economic Impact of Recreational Fishing and Diving Associated with Offshore Oil and Gas Structures in the Gulf of Mexico*. This study used a combination of in-person and telephone surveys of marinas in the Central and Western Gulf of Mexico to estimate the total annual expenditures in 1999 on recreational fishing and diving trips from respondents' self-reported survey responses. Survey estimates were then scaled up to the full population values of expenditures using NMFS's Marine Recreational Fishery Statistics Survey's estimates of recreational fishing and diving in the survey areas. Further, in order to extend the analysis from direct expenditures on fishing and diving trips to the full direct, indirect, and induced economic impacts of that activity, the study used IMPLAN (IMPact analysis for PLANning) input-output modeling to estimate total output, employment, and value added impacts.

The 2002 MMS study found significant use of offshore oil and natural gas structures for recreational fishing and diving trips. The percentages of trips to within 300 feet of an offshore or oil/natural gas structure for recreational fishing and recreational diving were 21.9 percent and 93.6 percent, respectively. These trips accounted for a total economic output of \$324.6 million in the coastal counties of the states in the study. Private boating accounted for the highest proportion of this amount with a total of \$255.2 million, followed by charter fishing at \$45.4 million, recreational diving with \$13.6 million, and finally party boats with the smallest economic impact at \$10.4 million.<sup>46</sup>

Recognizing the economic and environmental benefits of the artificial reefs created by offshore structures, all five Gulf States have instituted artificial reef programs to facilitate permitting, navigational requirements, and liability transfer for decommissioned and reefed rigs. These artificial reef programs aim to continue the economic and environmental benefits of offshore structures through their productive

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<sup>45</sup> Predecessor agency to BOEM.

<sup>46</sup> No party boat trips were sampled in Alabama and Mississippi. Follow-up interviews were not performed for recreational diving in Texas. These categories of expenditures, therefore, are missing from the economic impacts analyses.

stages and post-abandonment. For example, in the Louisiana Artificial Reef Program, designations of “artificial reef planning areas” incorporate input from recreational as well as commercial fishermen, recreational divers, and shrimpers. These designations steer reefing activities towards locations that tend to decrease burdens on navigation and commercial fishing, while increasing the likelihood that they are attractive sites for recreational use.

While the economic impact study in the Gulf provides evidence of calculable recreational benefits associated with offshore structures, existing studies and data are insufficient for quantification, across all planning areas, of the benefit of a specific change in offshore activity. Even within the four Gulf States in the 2002 MMS survey, there was a considerable amount of disparity in not only the mode but also the impacts of the recreational use of offshore structures, making it difficult to support extrapolating from the Gulf of Mexico planning areas to other regions.<sup>47</sup> Additionally, the effect that artificial reef programs have on decommissioning cost decision-making, and hence on extending the period of time during which recreational benefits accrue for a given structure, adds a level of unpredictability to the quantification of recreational benefits. There are few data with which to model the comparative costs of decommissioning options, especially considering geographic differences in decommissioning costs and individual States’ specific artificial reef programs. Further, the 2002 MMS study specifically describes the difficulty in identifying the characteristics that make certain sites more attractive for recreational use.

### **10.3 ENERGY SECURITY BENEFITS**

The pursuit of energy security has a long history, having gained worldwide impetus after the tripling of the international price of crude oil in October 1973. One of the consequences of this price shock “was to put energy security and, more specifically, security of oil supply at the heart of the energy policy agenda of most industrialized nations” (LaCasse and Plourde, 1995). The run-up in oil prices in recent years has again raised the profile of energy security policies. During the first year of the 111<sup>th</sup> Congress (2009/2010), more than 90 bills were introduced with the term “energy security” in the bill text; more than 200 such bills were introduced during the 110<sup>th</sup> Congress.

Since the 1970s, macroeconomists and energy economists have viewed large changes in the price of oil as a contributing source of economic fluctuations both domestically and globally. Policymakers’ interest in energy security often reflects this concern that sharp increases in oil prices can lead to economic downturns. Moreover, these oil price shocks are often attributed to deliberate attempts by oil-producing countries to hold back supply or to supply disruptions caused by geopolitical events in those countries. It therefore is argued that reduced import dependence or diversification in the sources of supply would insulate oil-importing nations from this source of economic instability. On this basis, a complete accounting of the net benefits (costs) attributable to a Five Year Program would include the value attributable to the increase in energy security provided by the program-related domestic production activity.

The OECM does not currently provide a quantified estimate of energy security benefits, as there is not yet a single, widely accepted method for doing so. However, renewed interest among policymakers in the economic impacts of price shocks has coincided with a growing academic literature on the measurement and attainment of energy security.<sup>48</sup> Many papers seek to quantify the security of energy supplies for importing countries, using measures such as the degree of import dependence, the extent of diversification

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<sup>47</sup> Hiatt and Milon, pg. 78.

<sup>48</sup> Several recent books address the topic of energy independence, including Bryce (2008), Hakes (2008), and Sandalow (2008). See Loungani (2009) for a review of these books.

in sources of supply, and the distance between sources of supply and the point of consumption (Blyth and Lefevre, 2004; Le Coq and Paltseva, 2008, 2009; Gupta, 2008). This section offers an introduction to the issue by describing two approaches that might serve as a foundation for future modeling considerations.

LaCasse and Plourde (1995) provide a useful conceptual framework for analyzing energy security. They suggest that in the short run, energy security “*can be identified with the physical availability of [energy] supplies.*” Over longer time horizons, energy security is a function not only of the availability of supplies but the likelihood of sustained run-ups in energy prices and the associated effects on the macroeconomy. LaCasse and Plourde argue that this macro response is not likely to be overly dependent on import reliance; instead, “*a country’s oil consumption, regardless of its origin, together with the magnitude of the price hike, jointly determine the severity of the effects of the shock.*” For long-run energy security, “*the focus of policymakers on import dependence leads down a false trail: the composition of demand is a minor issue compared to the use of [energy] as an input.*”

Casual empiricism suggests that diversification in sources of energy supply has been increasing. Bryce (2008) notes, for instance, that the United States buys crude oil and gasoline from over 40 countries and jet fuel from over 25 countries. Canada and Mexico have grown in importance as suppliers, whereas countries of the Persian Gulf now supply only about 10 percent of all the oil consumed in the United States.

The basic idea behind diversification is borrowed from portfolio theory in finance. Holding other things constant, the overall risk to a country’s energy supply is smaller if it has a diversified portfolio of suppliers. A diversified portfolio can reduce a country’s vulnerability to supply disruptions from a particular source. Moreover, even in the absence of supply disruptions, diversification reduces the market power of any one supplier, lowering the “risks of higher prices and/or inferior products and services” (Blyth and Lefevre, 2004, p. 18).

Another approach for measuring energy security approaches the issue from a welfare analytics perspective. Energy policymakers make decisions on both micro and macro levels. When developing oil (and natural gas) policy, they need to address a wide range of issues such as the impact of oil consumption on aggregate economic activity, the terms of trade for imported oil and petroleum products, the welfare effects due to pollution arising from the consumption of oil, and the vulnerability of U.S. economic activity to world oil supply disruptions. Brown and Huntington (2009) developed a welfare approach for addressing these analytical issues. Under their framework, energy security or vulnerability depends on expected losses in U.S. economic activity and increased transfers to foreign oil producers that are associated with oil supply disruptions. The welfare function associated with U.S. oil consumption can be represented as

$$Welfare = Y(O_C) - TC_D - PO_M - X_O + E(\Delta Y) - E(\Delta P)O_M$$

where domestic welfare (*Welfare*) depends on the six right-hand components. The first four are expressed in terms of domestic benefits and costs, and the last two are related to oil price shocks. Domestic GDP,  $Y$ , is a function of oil consumption ( $O_C$ ). The total cost of *domestic* oil production,  $TC_D$ , and the cost of imported oil (price of oil ( $P$ ), times the quantity imported ( $O_M$ ), and the environmental externalities as a result of oil consumption ( $X_O$ ), enter the welfare function negatively.  $E[\Delta Y]$  is the expected GDP loss associated with price increases resulting from oil supply disruptions, and  $E[\Delta P] \cdot O_M$  is the expected increase in oil import costs associated with the expected oil supply disruptions.

While the two approaches described above for quantifying energy security have potential application within the OECM or *MarketSim* framework, incorporating the data that would be necessary to do so (e.g., changes in oil or natural gas imports by country of origin or the change in GDP associated with increased oil or natural gas prices) is beyond the scope of the current model development effort.

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

by

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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 natural 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 OECM as oil spill model-derived algorithms that relate quantity and location of spilled oil (forecast separately) to bio-physical consequence metrics. 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 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, 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 OECM;
- Within OECM, multiply the areas, shore lengths and volumes affected by receptor densities and/or costs in the locations of concern; and
- Allow 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,

$$\textit{Spill risk} = \textit{probability of spill} \times \textit{impacts of spill}$$

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 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. OECM 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. Sub-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 a 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 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 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 (USDOI) 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<sup>th</sup> percentile value for each impact category, location, and oil type. These 99<sup>th</sup> 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<sup>th</sup> 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.**

<b>Spill Volume (gallons)</b>	<b>Duration of release (hours)</b>
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
<b>Total</b>	<b>17</b>		<b>230</b>			

## 2.2 Model Input Data

Detailed descriptions of input data for each location modeled are provided in Sub-appendix A. 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 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<sup>2</sup>/sec for floating oil and 1 m<sup>2</sup>/sec for surface and deep waters. The vertical diffusion (randomized mixing) coefficient is assumed as 0.0001 m<sup>2</sup>/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 Sub-appendix A for a detailed description of currents for each location).

### 2.2.4 Oil Properties and Toxicity

The spilled oil used in OECM consisted of a variety of types, including various crude oils, heavy fuel oil (HFO), and diesel. Physical and chemical data on these oils are summarized in Sub-appendix 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 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 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 OECM, a number of impact measures were evaluated, as described in Table 4 and the following sections. All regressions used the 99<sup>th</sup> percentile value for each oil type, spill volume, and impact measure.

**Table 4. Impact measures used to estimate consequences.**

<b>Consequence</b>	<b>Impact Measure</b>	<b>Impact Threshold</b>
Impact to wildlife: seabirds, waterfowl, marine mammals, and sea turtles	Water surface area exposed to floating oil	10 g/m <sup>2</sup> (French et al., 1996; French McCay, 2009)
Impact to wildlife: shorebirds and waders	Shore area exposed	100 g/m <sup>2</sup> (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 <sup>2</sup> )
Shoreline cleanup	Shore area exposed	Sheen (1 g/m <sup>2</sup> )
Boating/shipping	Water surface area exposed to floating oil	Sheen (1 g/m <sup>2</sup> )
Water surface cleanup	Water surface area exposed to floating oil	Sheen (1 g/m <sup>2</sup> )

### 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 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 Department of the Interior in support of the CERCLA NRDA regulations (French et al., 1996); these data sets are included in the OECM and provided in Sub-appendix 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<sup>2</sup> 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<sup>2</sup> (from the Type A model) by the probability of oiling for that species' behavior group (Table 5) to estimate the number killed per km<sup>2</sup>. 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<sup>2</sup> by the mean weight per individual of each species to calculate the kilograms killed per km<sup>2</sup>. This information is summarized for each location in the enclosed digital sub-appendix (Sub-appendix 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.**

<b>Wildlife Behavior Group</b>	<b>Probability</b>
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<sup>2</sup> 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<sup>2</sup> (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<sup>2</sup>. We also multiplied the number killed per km<sup>2</sup> by the mean weight per individual of each species to calculate the kilograms killed per km<sup>2</sup>. This information is summarized for each location in the enclosed digital sub-appendix (Sub-appendix 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 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 Sub-appendix 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:

$$\text{Volume Killed} = (\text{Average Dose})/(\text{Lethal Threshold}) * (\text{Volume exceeding 1ppb})$$

Regressions were then developed for the water volume killed as a function of the spill volume. In 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 99<sup>th</sup> 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 sub-appendix (Sub-appendix 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<sup>2</sup>. 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<sup>2</sup>. 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,  $1 \text{ g/m}^2$ . Regressions were developed of water surface area exposed versus spill volume for each oil type.

## 3. HABITAT EQUIVALENCY ANALYSIS (HEA)

In Natural Resource Damage Assessments in the U.S., 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 OECM is provided as Sub-appendix C.

## 4. SPILL RATE AND VOLUME ANALYSIS

As part of the OECM analysis, Environmental Research Consulting used in-house databases, including data provided by BOEM, 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 Sub-appendix D.<sup>1</sup>

---

<sup>1</sup> Subsequent to the completion of this analysis, BOEM instructed the project team to apply the rates reported in Sub-Appendix F, which are based on BOEM's own data and analysis, to spills associated with pipelines, platforms, and non-tanker vessels. As its data source, BOEM used the file named "All Petroleum Spills  $\geq 1$  Barrel from OCS Oil & Gas Activities by Size, Category and Year, 1964 to 2010," which is on the BSEE website at <http://www.bsee.gov/Inspection-and-Enforcement/Accidents-and-Incidents/Spills---Statistics-and-Summaries-1996-2011.aspx> (accessed September 15, 2011). OCS production since 2000 is available at:

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

<http://www.boemre.gov/stats/OCSproduction.htm>. OCS oil production for the period through 1999 was obtained from BOEM queries of its internal Technical Information Management System (TIMS). OECM continues to use the tanker spill rates reported in Sub-appendix D. Subsequent to the incorporation of the aforementioned spill rates from the databases cited above, BOEM instructed us to use the spill rates and analysis included in the Five Year Programmatic EIS. These spill rates and sizes for the 1996-2010 period are obtained from source data supporting Table 16. U.S. OCS Petroleum Spills, Overall Spill Size Characterization By Spill Source, 1996 – 2010 from the Anderson (2012) paper listed in Sub-appendix F (alternative).

## 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 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, ULCCs) 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 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 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)**

## **SUB-APPENDIX 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 NOS 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.

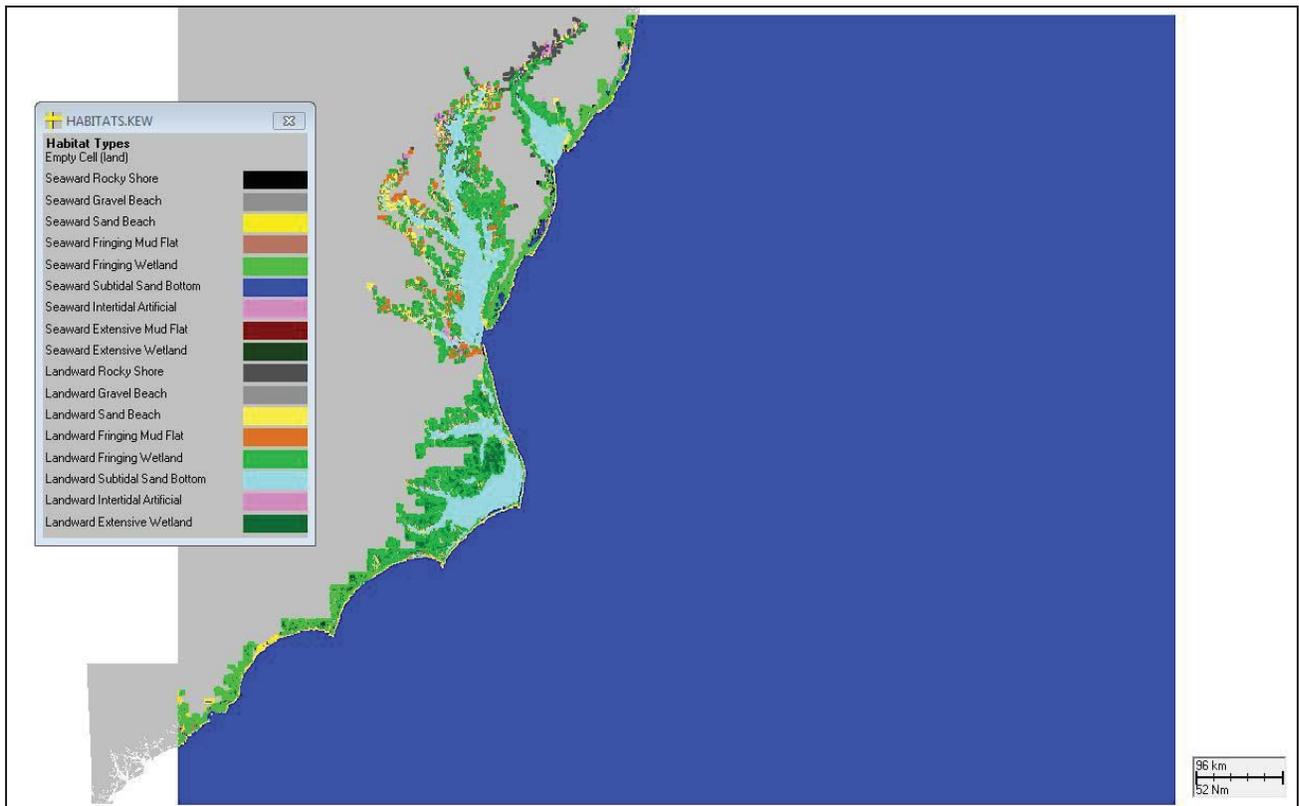


Figure A-1. Habitat grid developed for the Mid-Atlantic region.

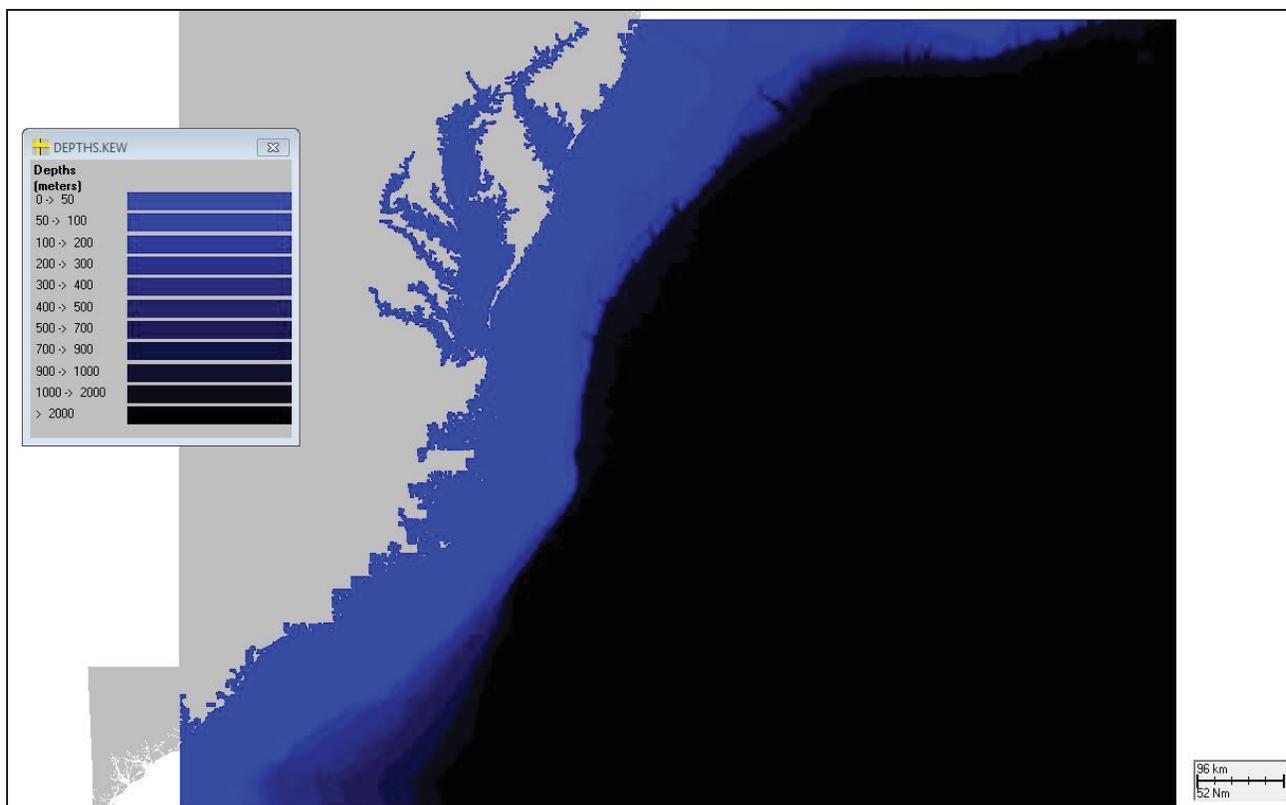


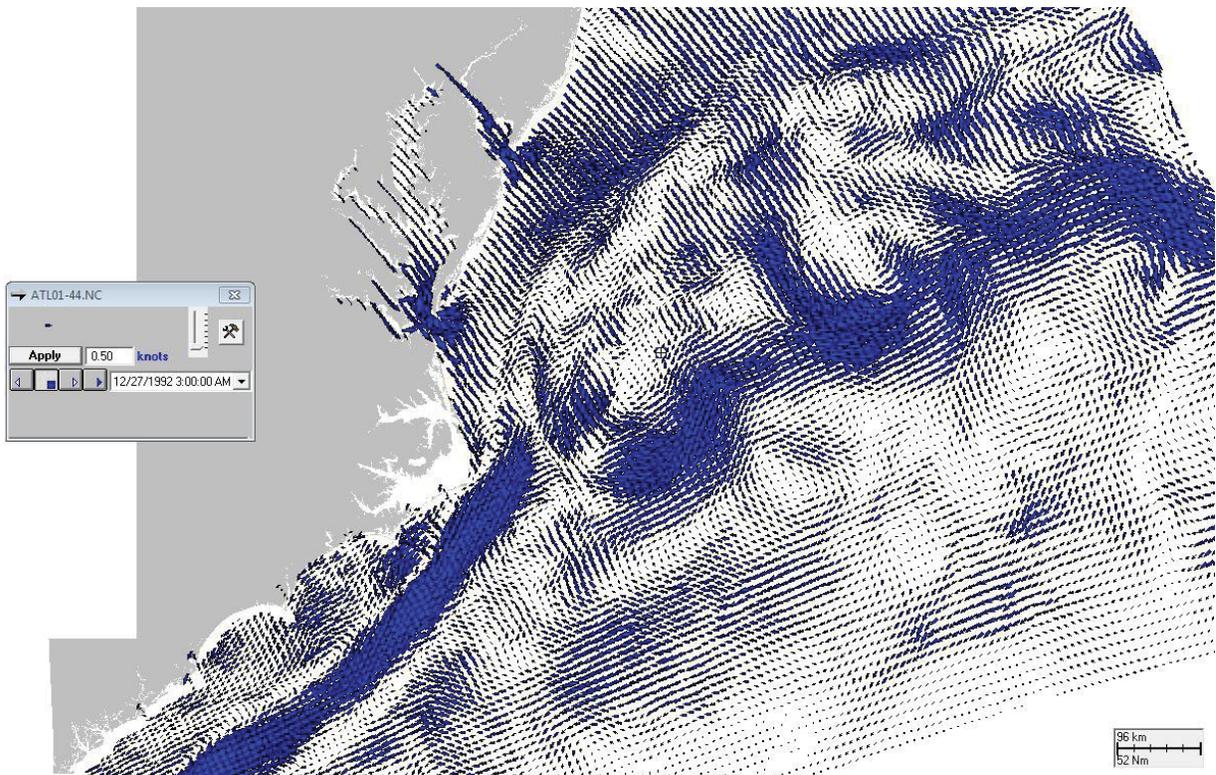
Figure A-2. Depth grid developed for the Mid-Atlantic region.

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 <sup>2</sup> )	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.



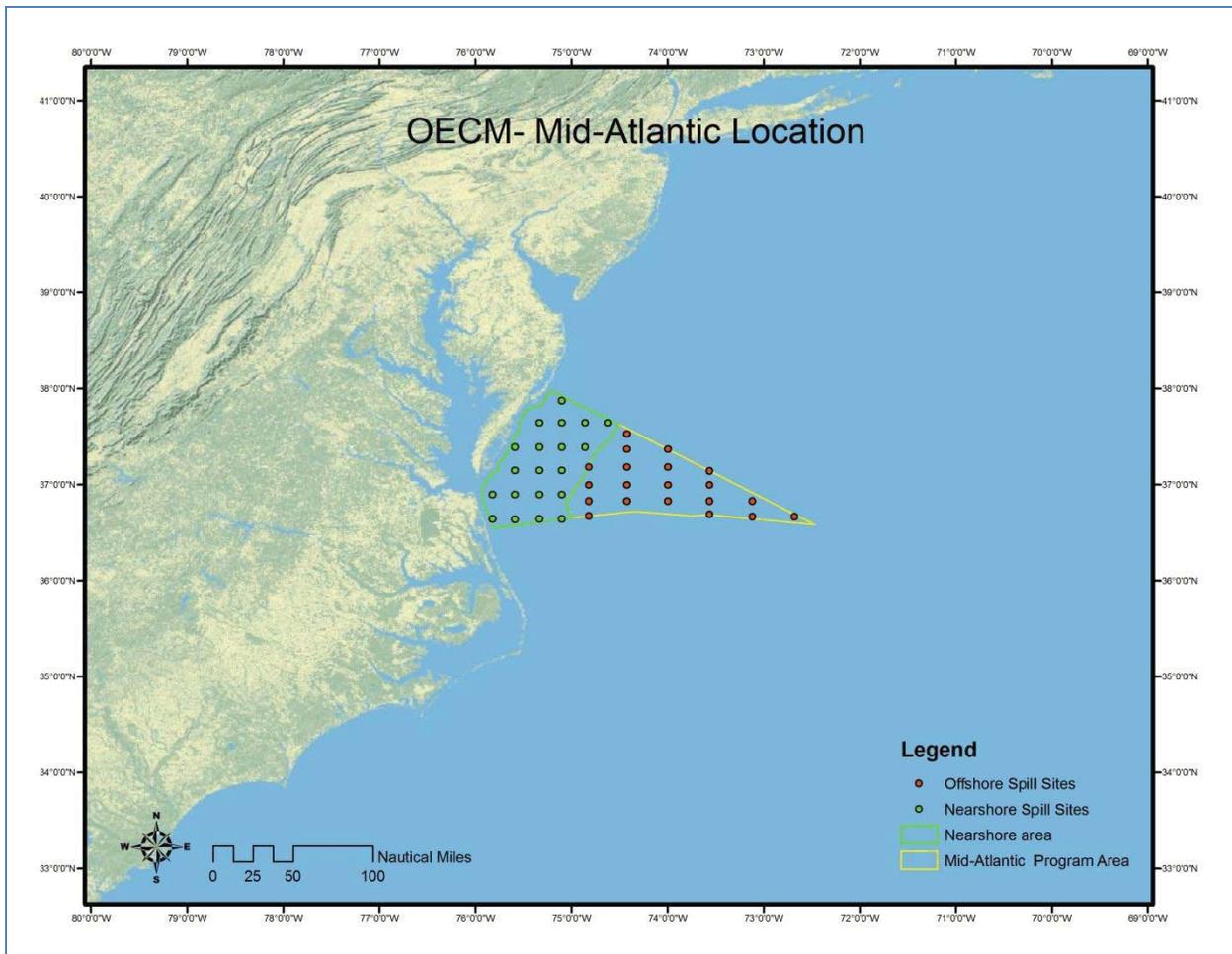
**Figure A-3. Example of current component data used in modeling for the Mid-Atlantic region. Vector length indicates speed in the indicated direction.**

## Winds

Standard meteorological data were acquired from the National Data Buoy Center 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.

## Spill Sites

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.**

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
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
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.**

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
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

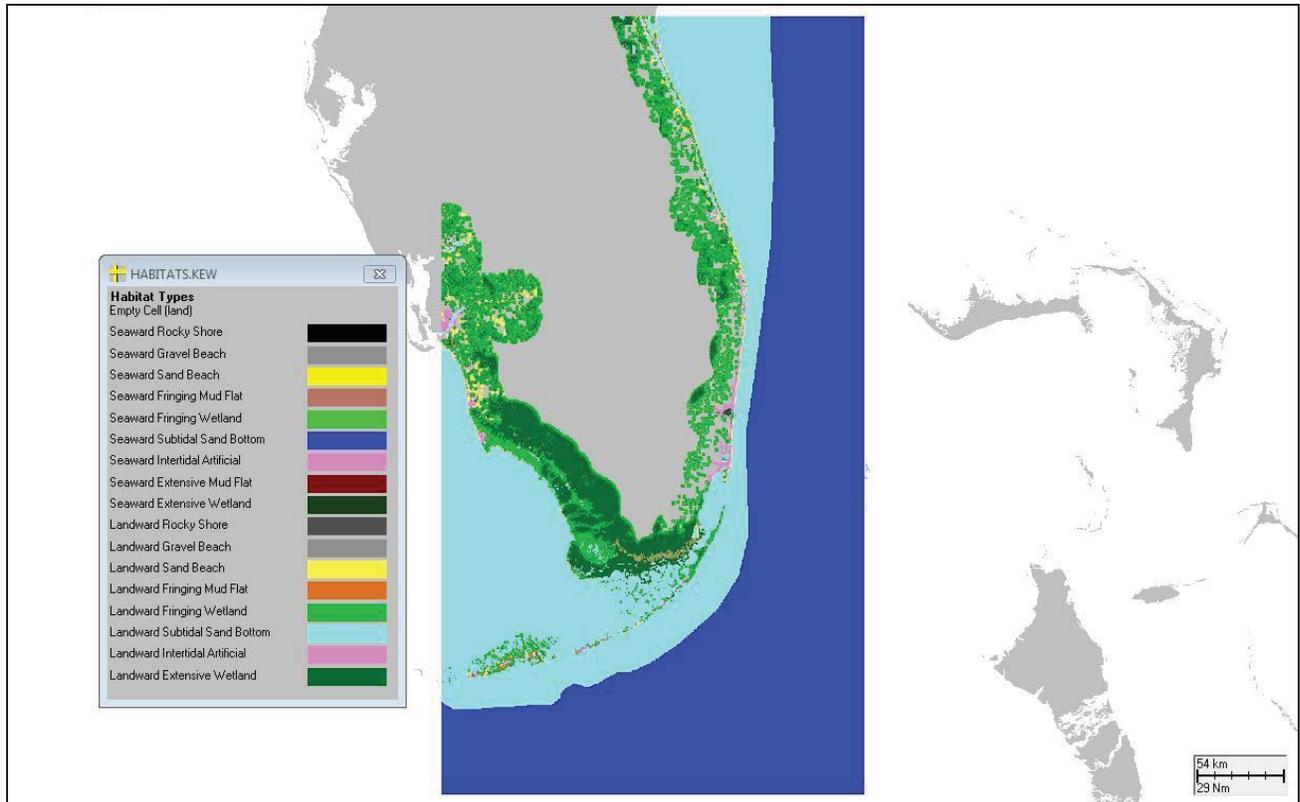
## Straits of Florida

### Habitat Grid

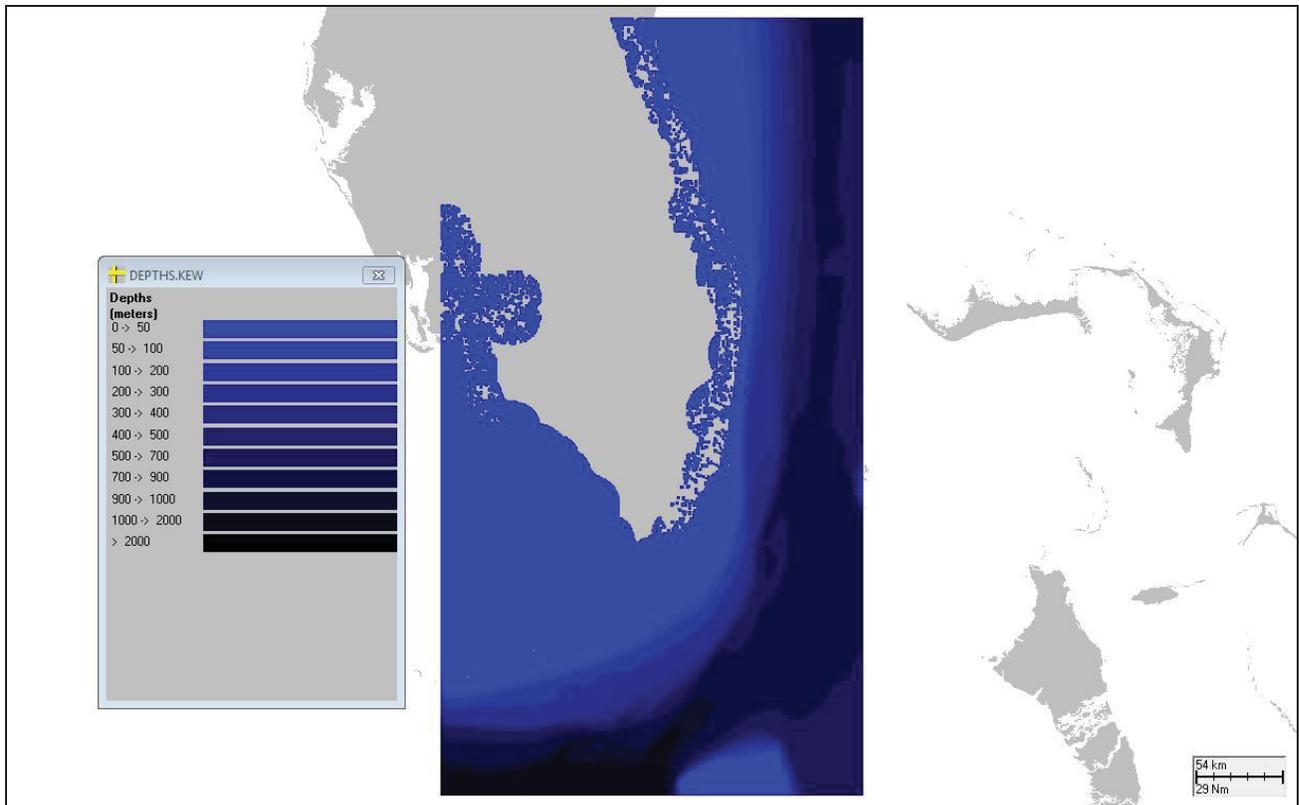
The digital shoreline, shore type, and habitat mapping for the Straits of Florida were obtained from the Florida Environmental Sensitivity Index (ESI) Atlas database compiled for the state of Florida by the Florida and Wildlife Institute (FWRI).

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.**



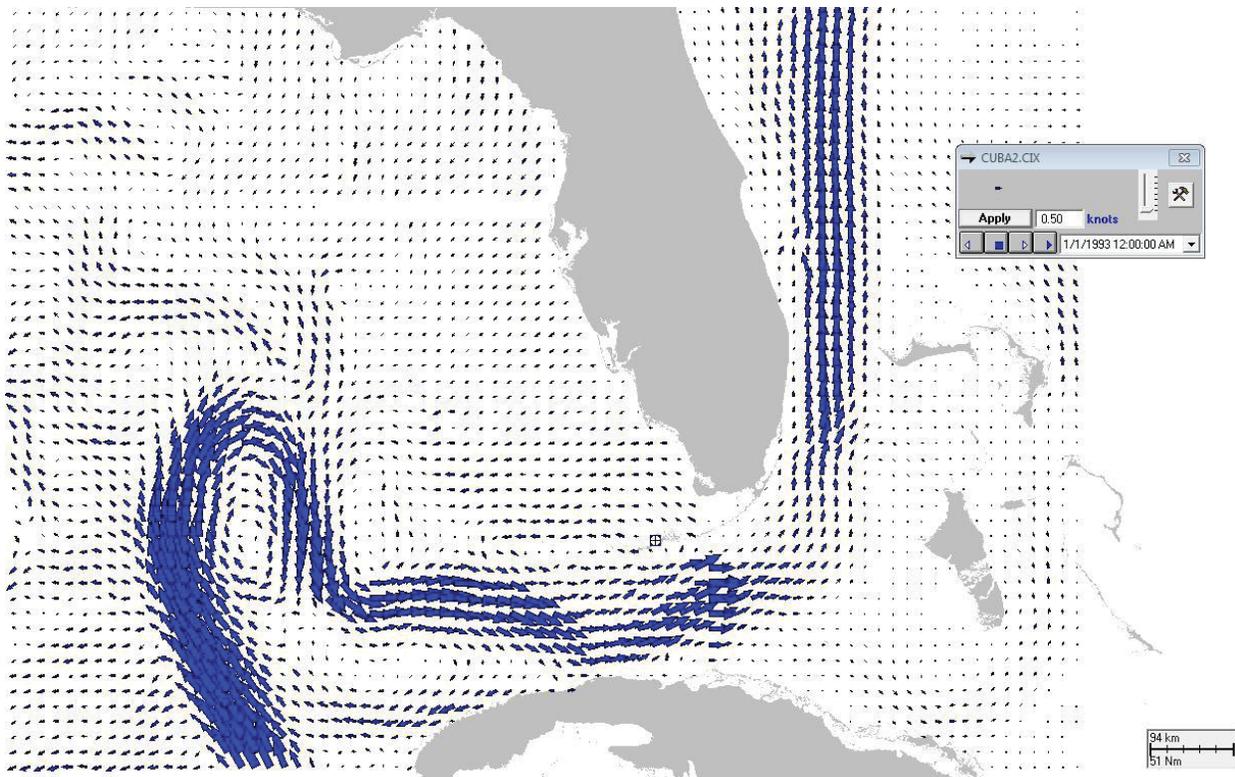
**Figure A-6. Depth grid developed for the Straits of Florida region.**

**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 <sup>2</sup> )	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.



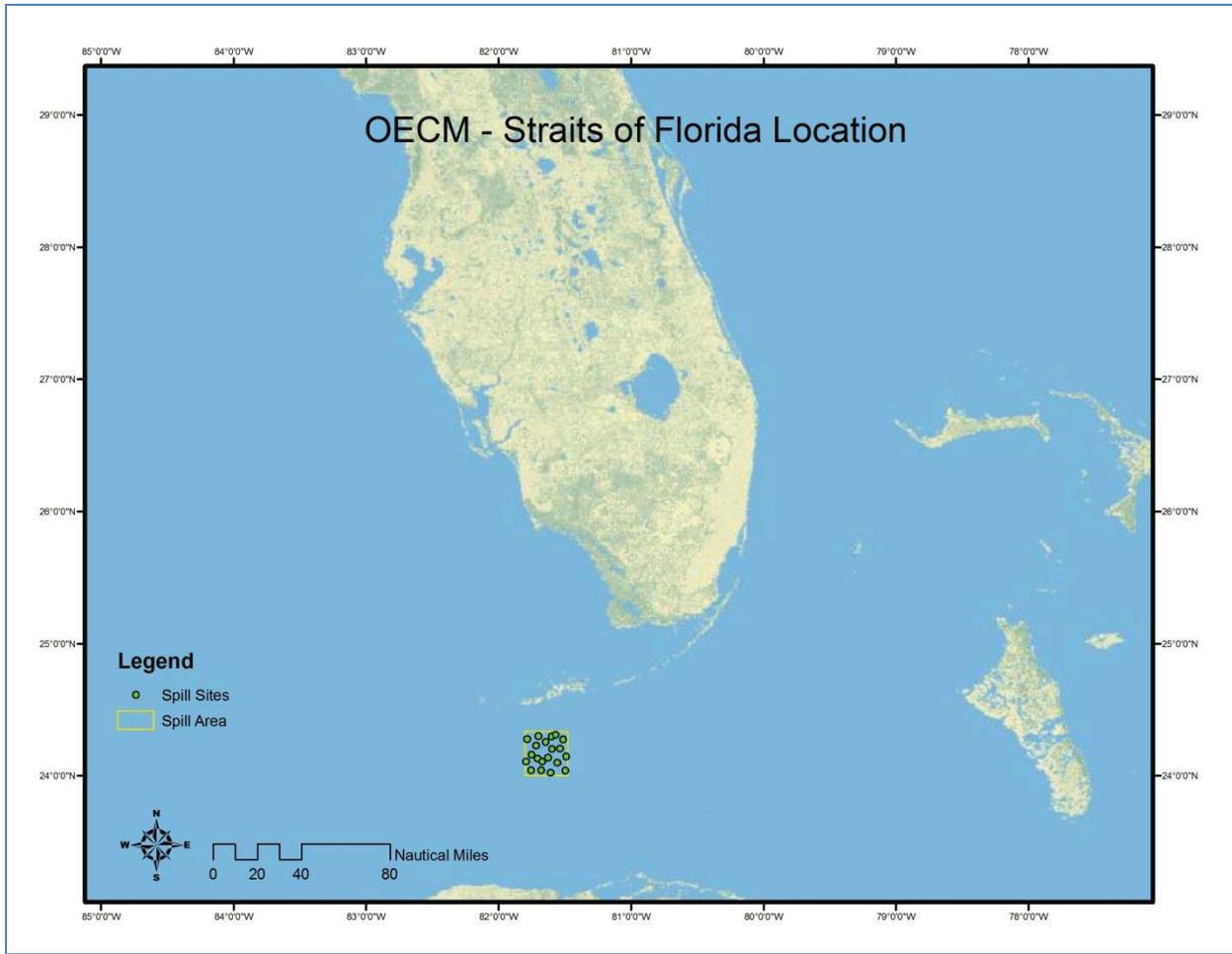
**Figure A-7. Example of current component data used in modeling for the Straits of Florida region. Vector length indicates speed in the indicated direction.**

## Winds

Standard meteorological data were acquired from the National Data Buoy Center 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.

## Spill Sites

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.**

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
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
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

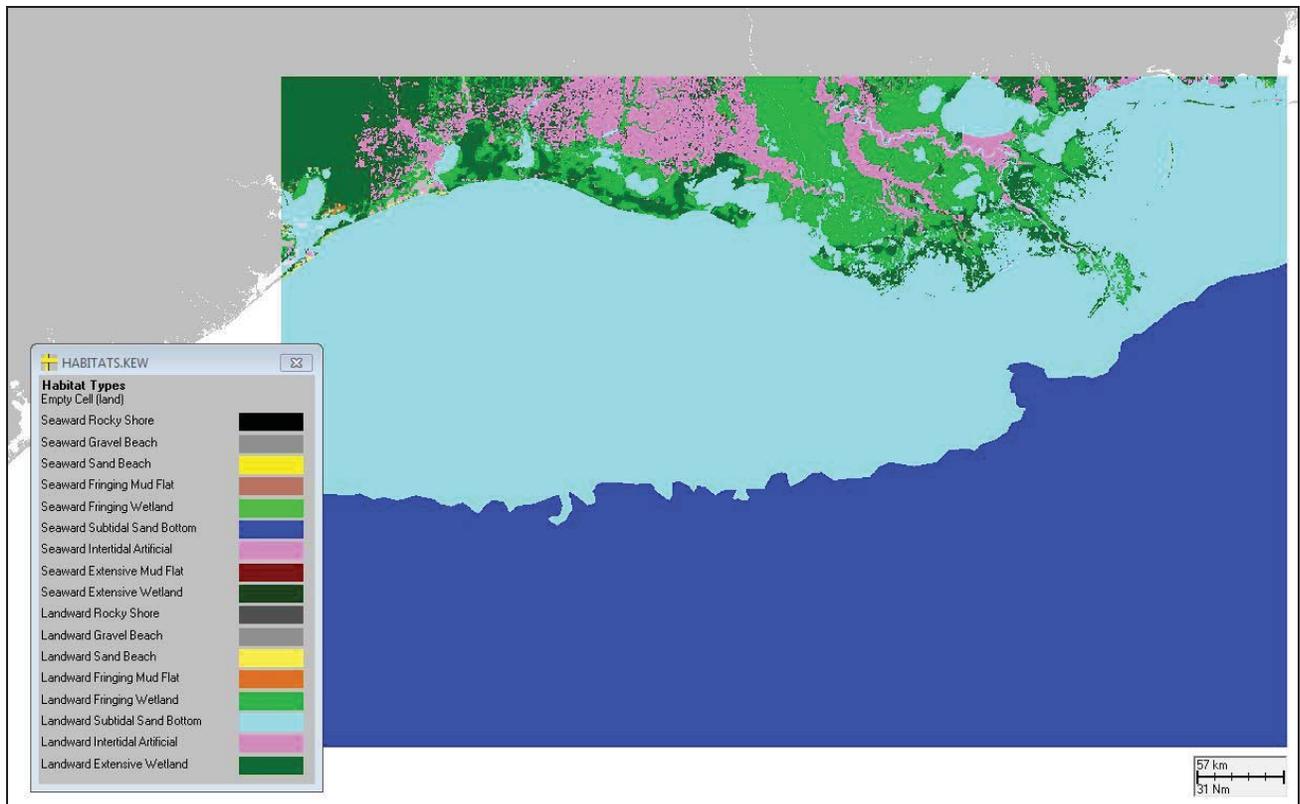
## Gulf of Mexico

### Habitat Grid

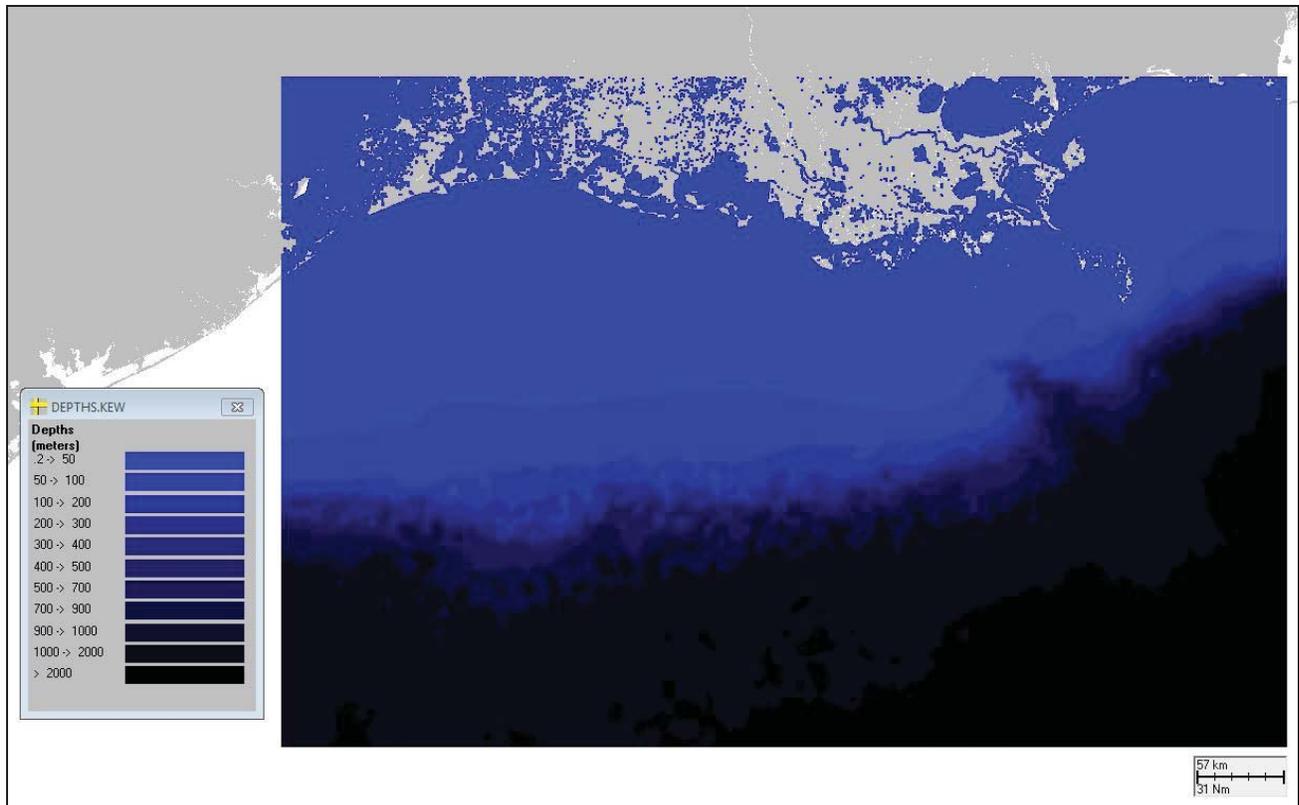
The digital shoreline used to create the habitat grid was the “Land and Water Interface of the Louisiana Coastal Region” from LOSCO, published in 2000. Although, there is a more recent shoreline from LOSA published in the year 2002, the 2000 shoreline was a better fit to the other habitat GIS data that 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 (MMS) and the U.S. Geological Survey (USGS) Land Cover Institute (LCI).

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.**



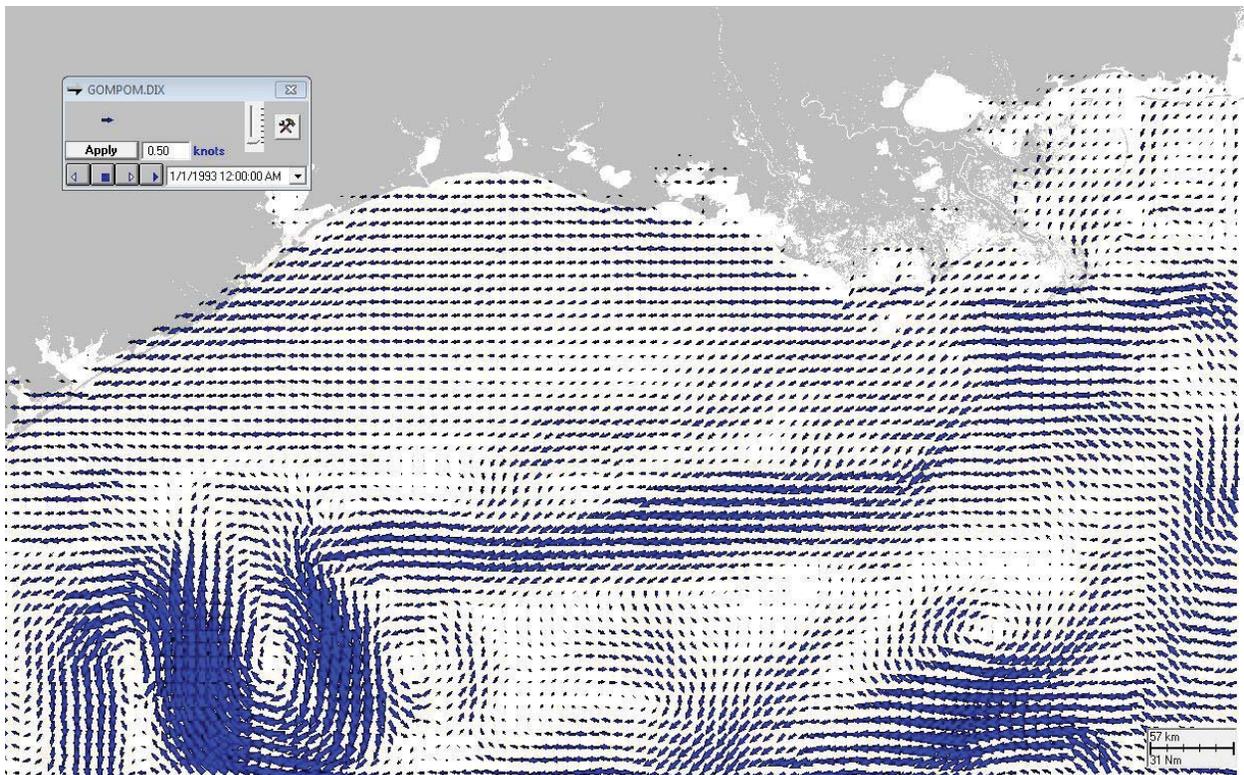
**Figure A-10. Depth grid developed for the Gulf of Mexico region.**

**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 <sup>2</sup> )	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 (CASE). 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).



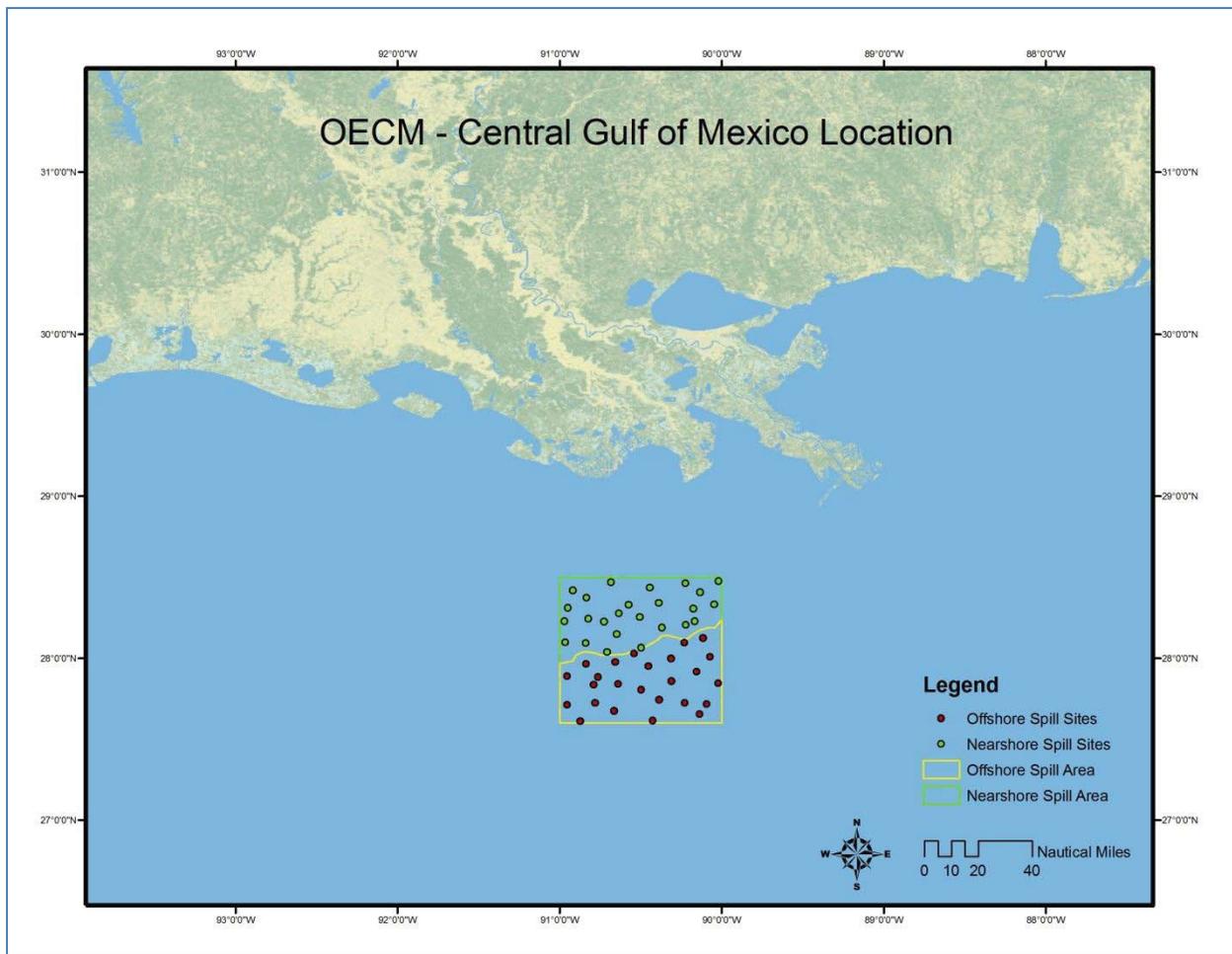
**Figure A-11. Example current component data used in modeling for the Gulf of Mexico region. Vector length indicates speed in the indicated direction.**

## Winds

Standard meteorological data were acquired from the National Data Buoy Center 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.**

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
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.**

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
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
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 Environmental Sensitivity Index (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.

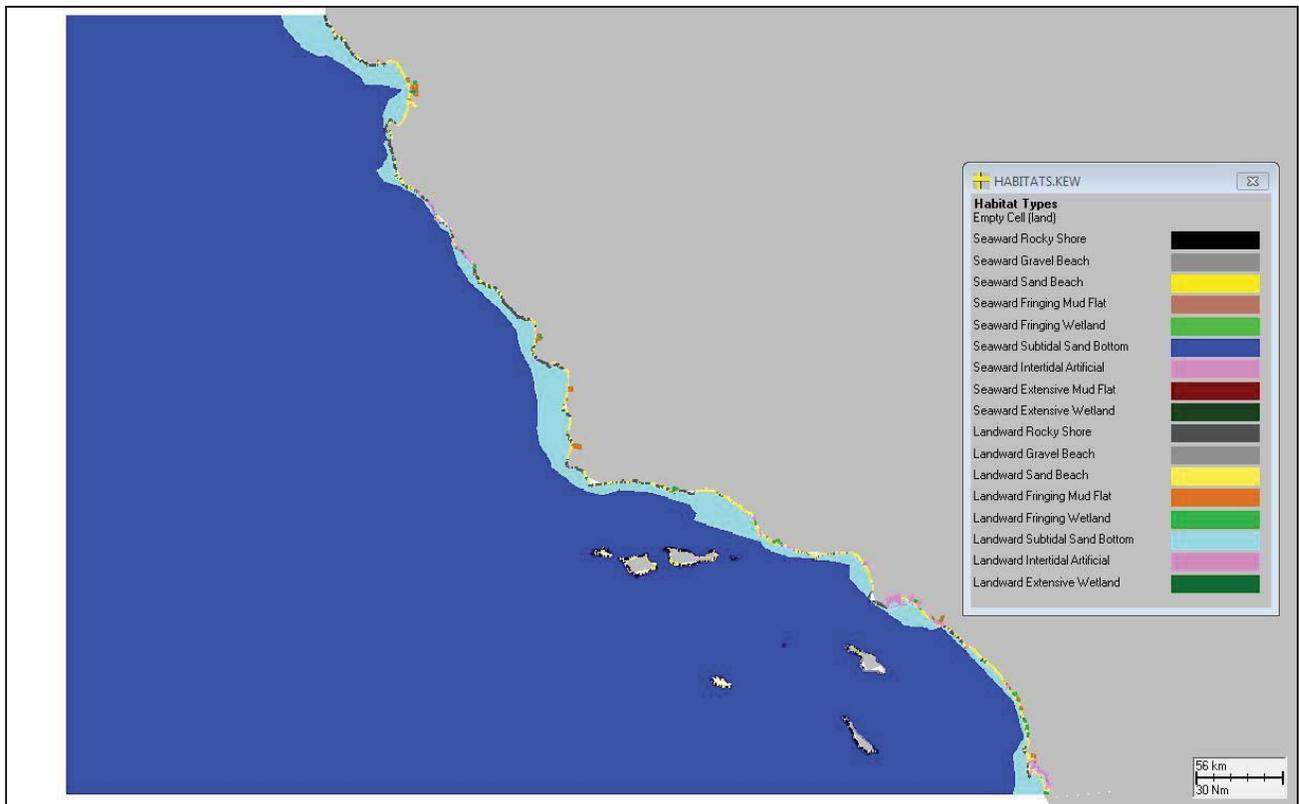
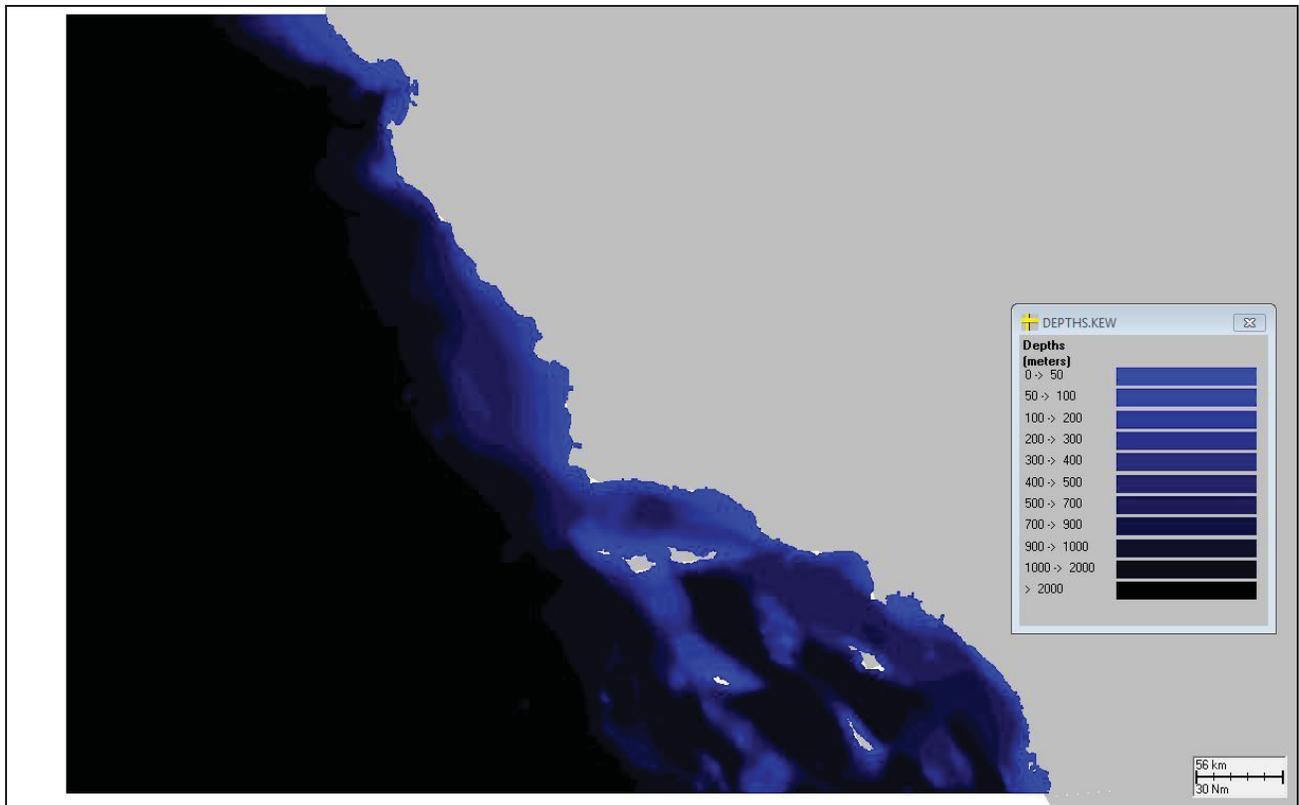


Figure A-13. Habitat grid developed for the Southern California region.



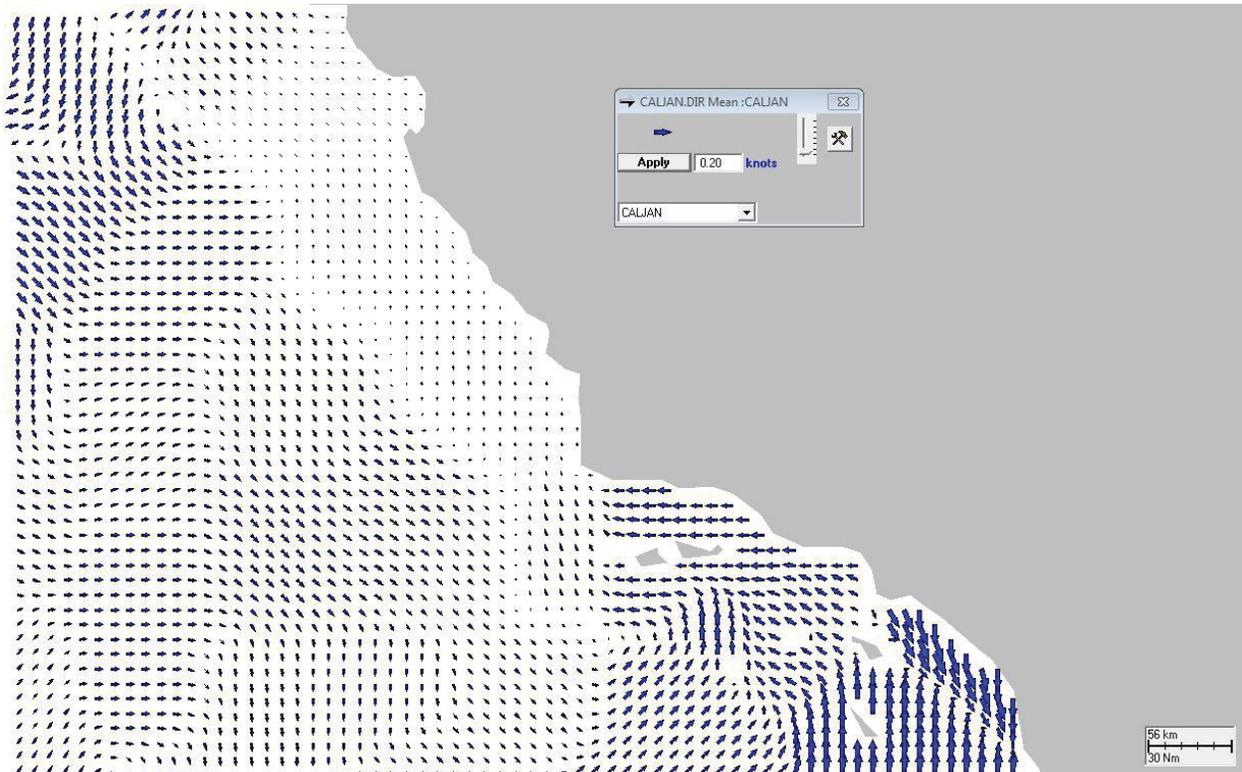
**Figure A-14. Depth grid developed for the Southern California region.**

**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° 18.873' W
Grid S edge	32° 33.413' N
Cell size (° longitude)	0.0073° W
Cell size (° latitude)	0.0073° 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 <sup>2</sup> )	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

## Currents

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  $\pm 5$  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.**

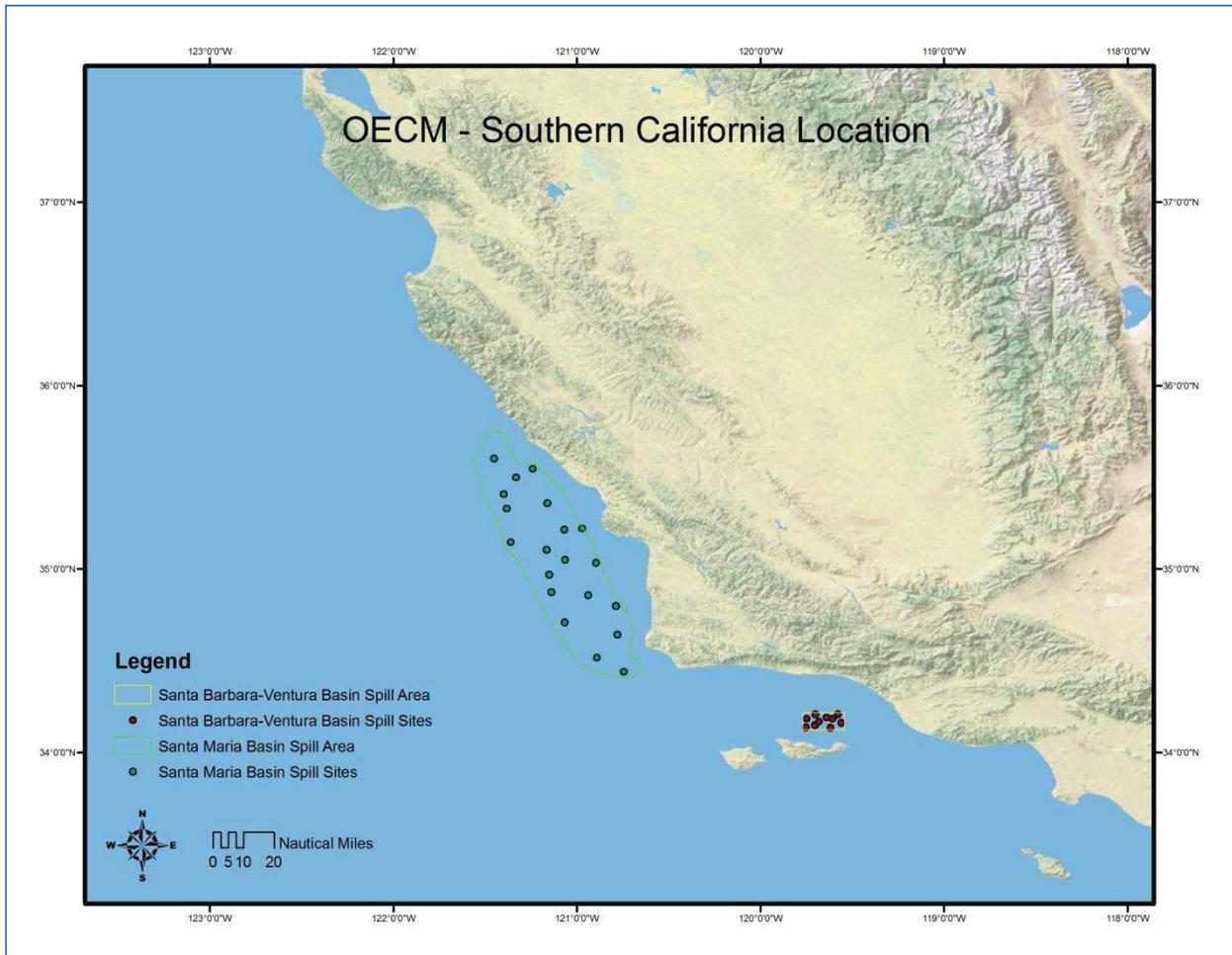
## Winds

Standard meteorological data were acquired from the National Data Buoy Center 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), and a representative portion of the Santa Barbara-Ventura Basin Draft Proposed Program Area (2010-2015) (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.**

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
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
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.**

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
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

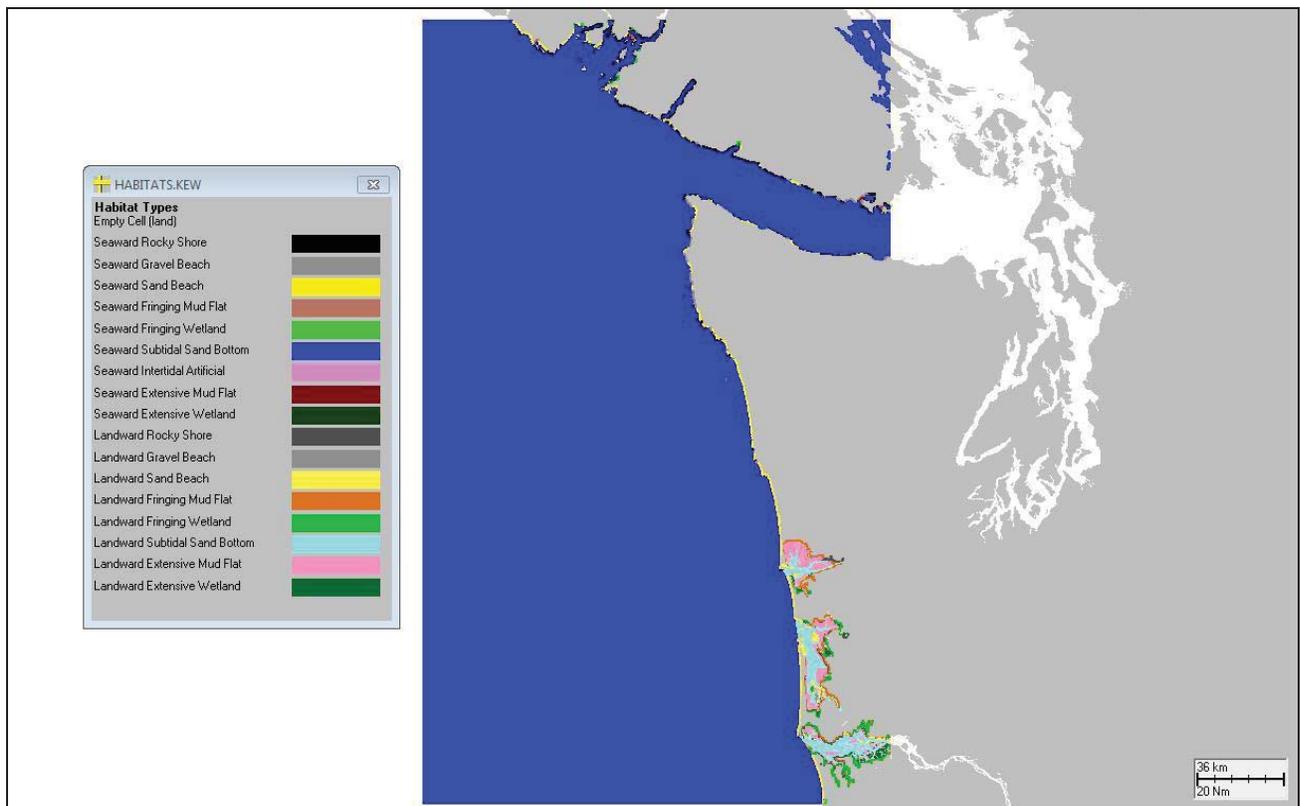
## Washington/Oregon

### Habitat Grid

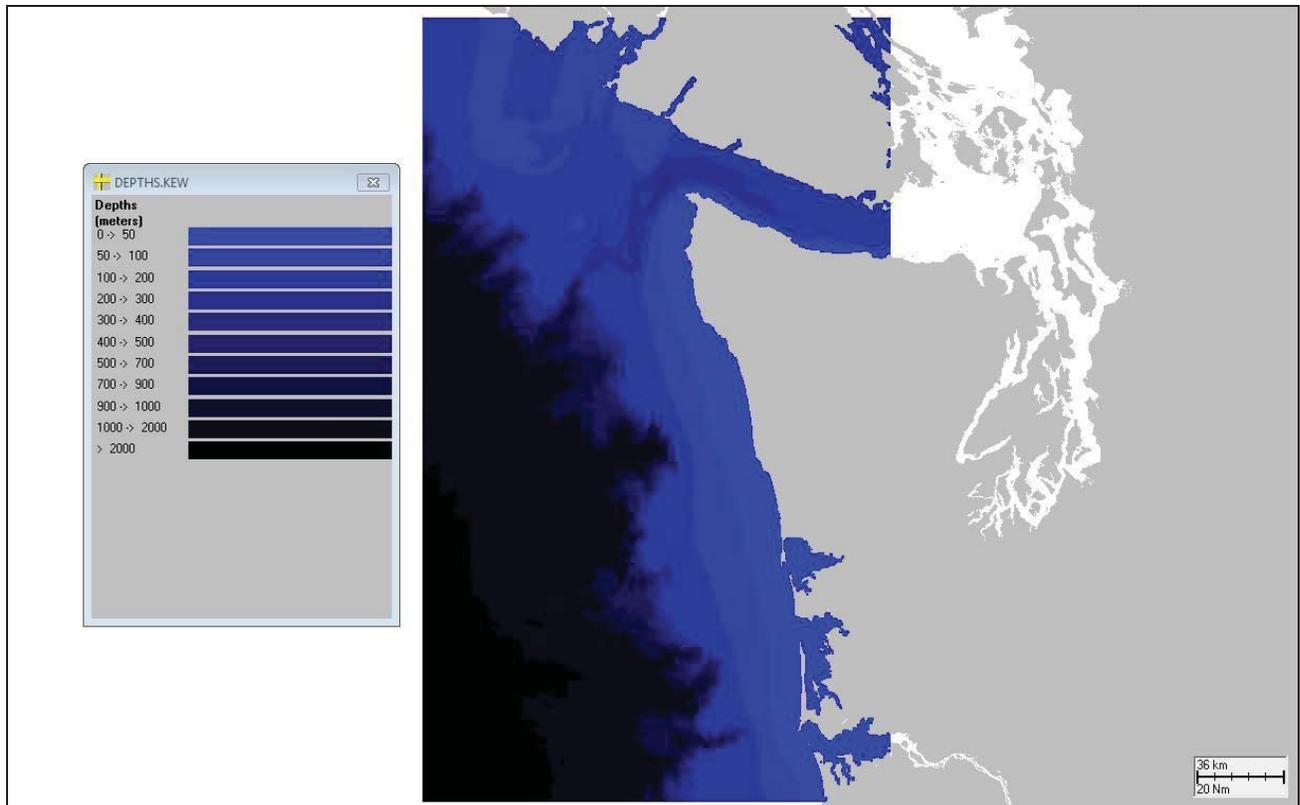
The digital shoreline, shore type, and habitat mapping for the outer coast of Washington and the Columbia River were obtained from Environmental Sensitivity Index (ESI) Atlas database compiled for the area by Research Planning, Inc. (RPI). These data are distributed by NOAA Hazmat (Seattle, WA).

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.**

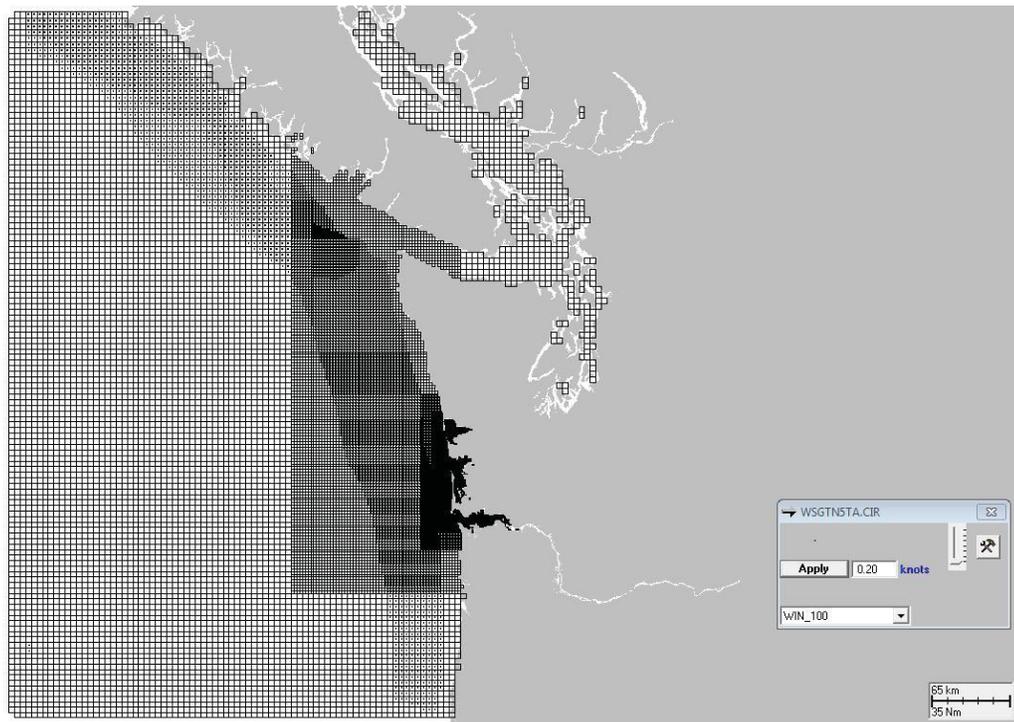
**Table A-12. Dimensions of the habitat grid cells used to compile statistics for Washington/Oregon model runs.**

Habitat grid	OC_SL_HAB-DEPTH.HAB
Grid W edge	126° 13.958'W
Grid S edge	46° 0.085' N
Cell size (° longitude)	0.0031° W
Cell size (° latitude)	0.0031° 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 <sup>2</sup> )	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

## Currents

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).



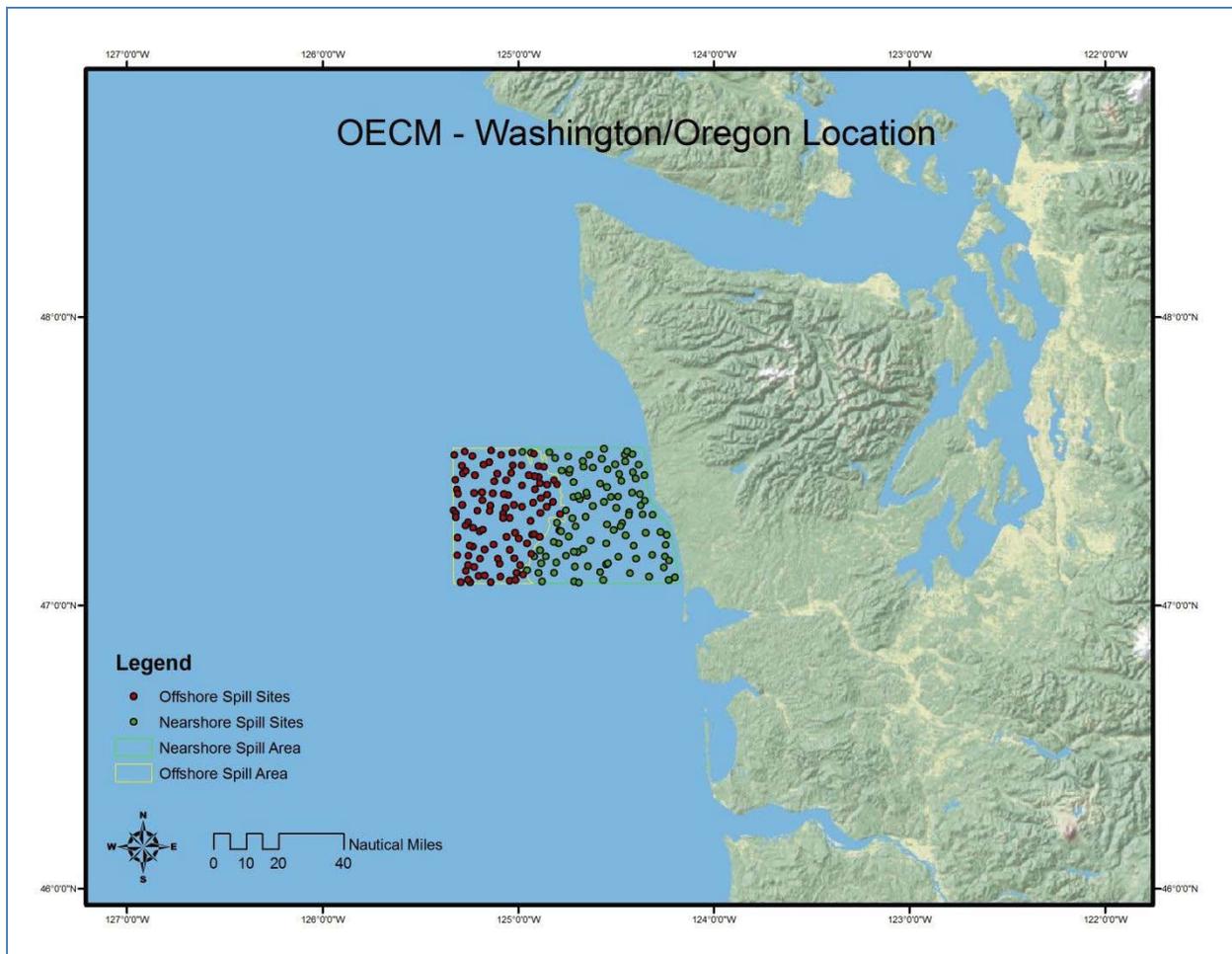
**Figure A-19. Extent of current data used in modeling for the Washington/Oregon region.**

## Winds

Standard meteorological data were acquired from the National Data Buoy Center 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.

## Spill Sites

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.**

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
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

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
46	47.44336	-124.40071
47	47.17141	-124.91648
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

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
93	47.36500	-124.35267
94	47.11463	-124.89561
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.**

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
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

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
36	47.39183	-125.13110
37	47.38879	-125.07291
38	47.10170	-125.08943
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

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
83	47.32093	-125.31789
84	47.37445	-124.88461
85	47.45945	-125.10720
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

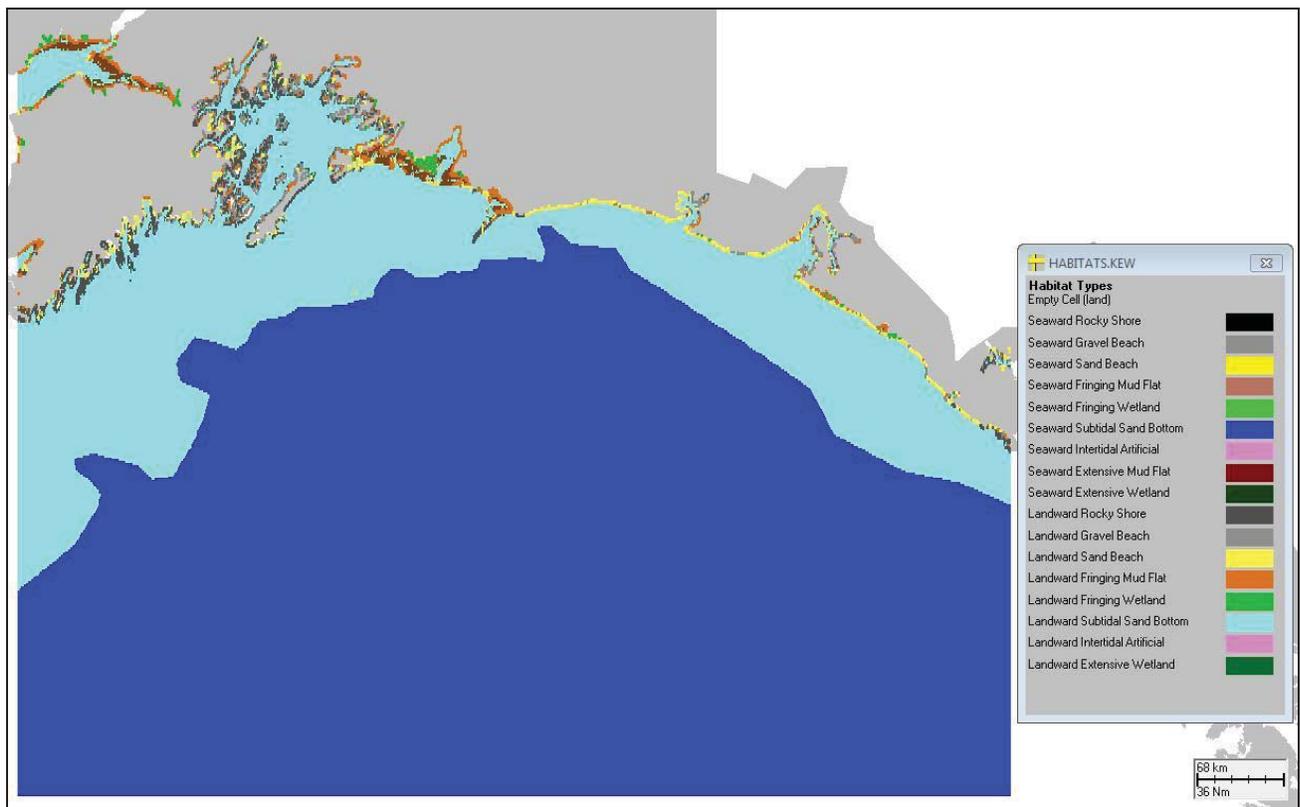
## Gulf of Alaska

### Habitat Grid

The digital shoreline, shore type, and habitat mapping for the Gulf of Alaska region were obtained from the Environmental Sensitivity Index (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.**

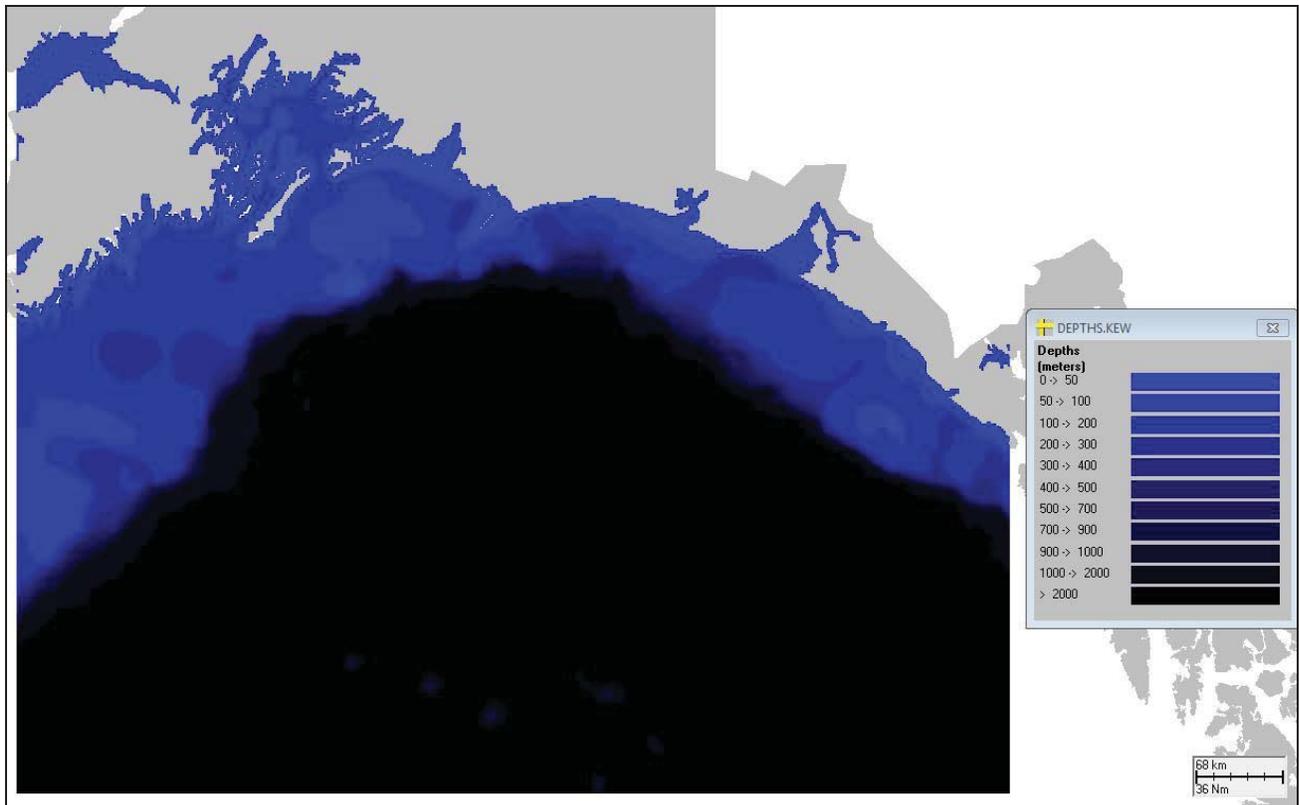


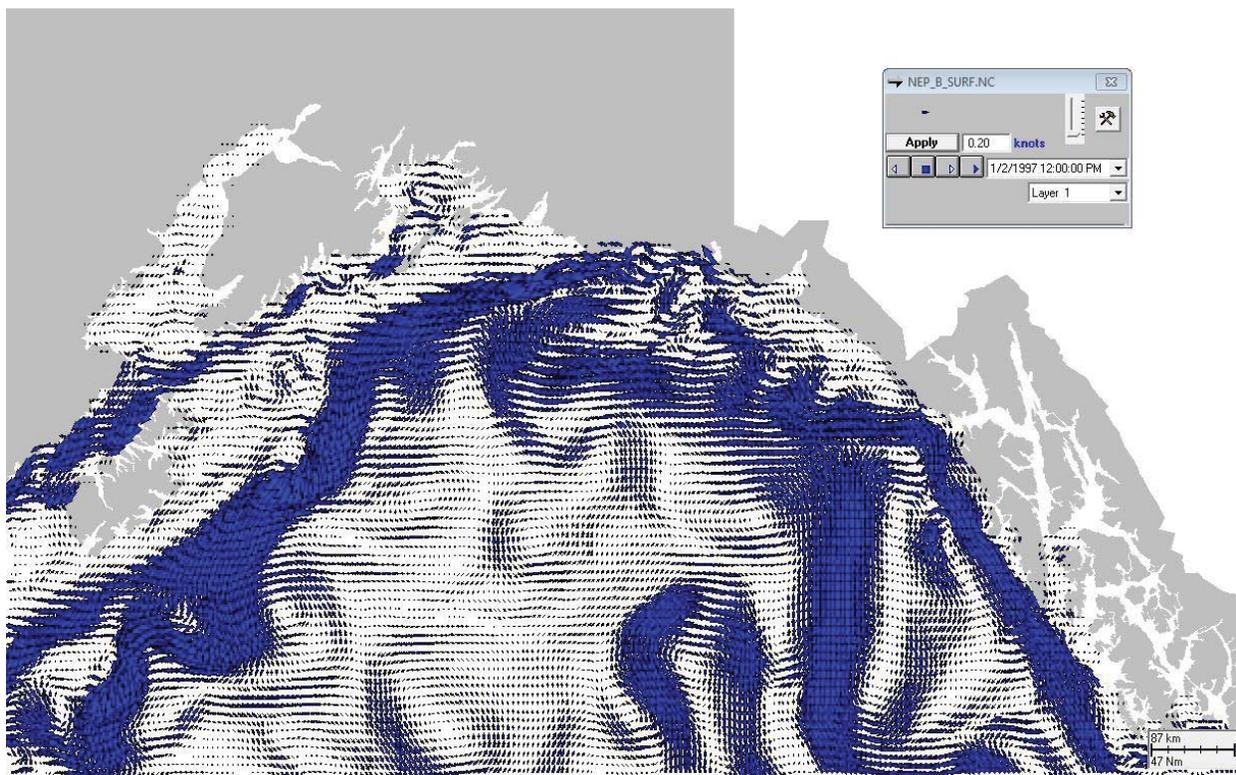
Figure A-22. Depth grid developed for the Gulf of Alaska region.

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 <sup>2</sup> )	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 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-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 National Data Buoy Center 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.

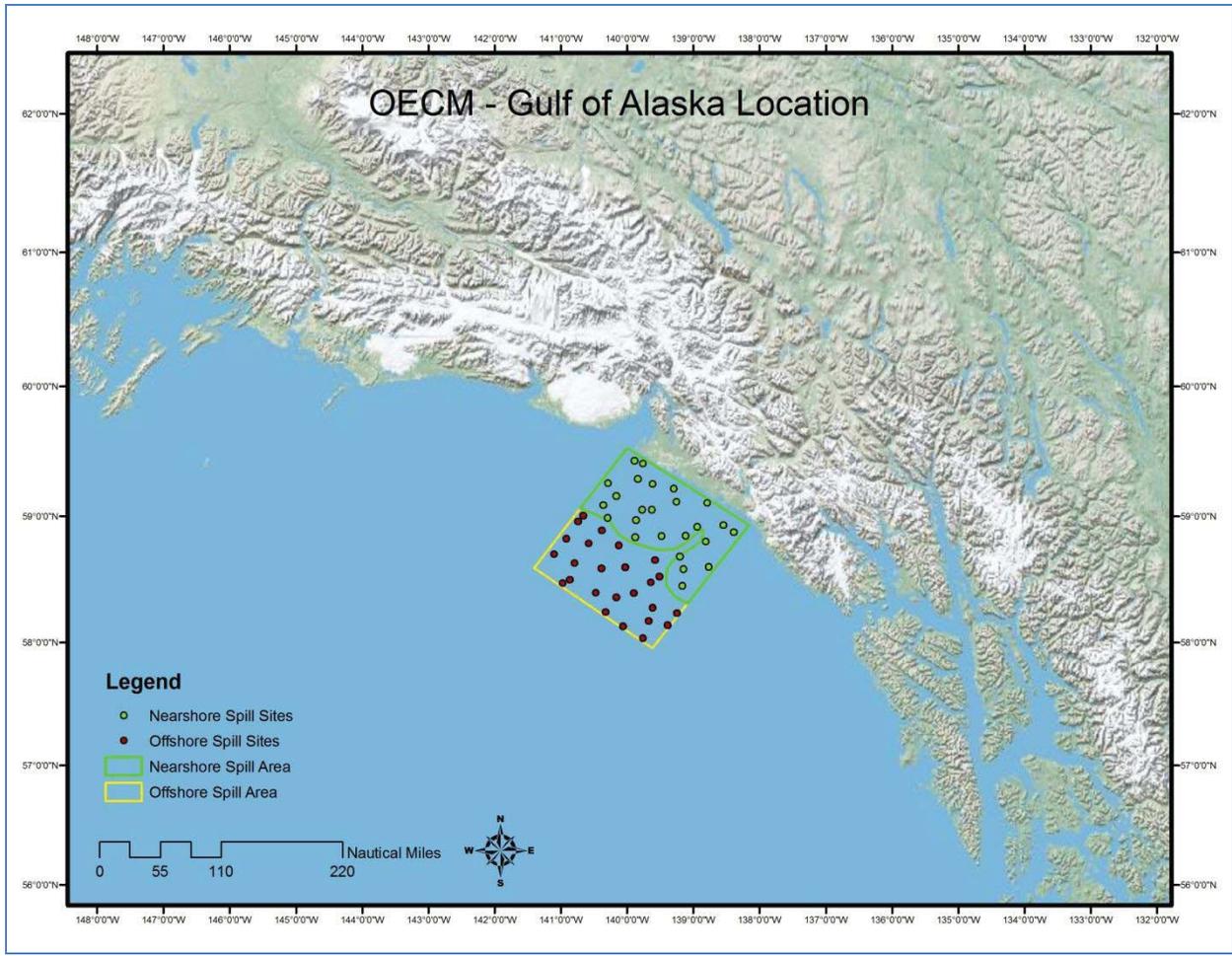
For station 46001, hourly mean wind speed and direction for the time period 6/1/1997 to 5/31/2003 were compiled in the SIMAP model input file format. The other three stations used for this location had sufficient wind records, but did not have data for all the years encompassed by the time-stamped currents 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.**

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
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

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
16	58.83876	-139.87945
17	58.91929	-138.93752
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.**

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
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

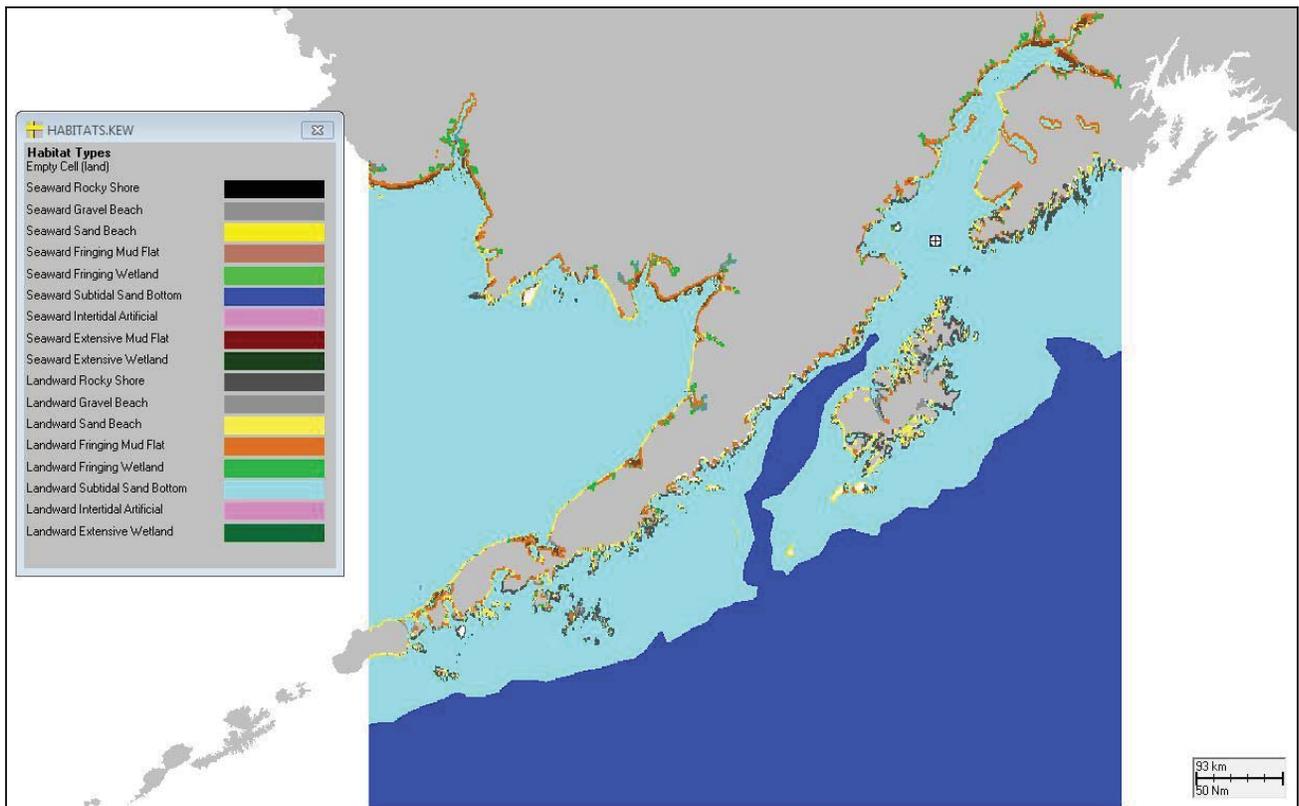
## Cook Inlet/Shelikof Strait

### Habitat Grid

The digital shoreline, shore type, and habitat mapping for the Cook Inlet/Shelikof Strait region were obtained from the Environmental Sensitivity Index (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.**

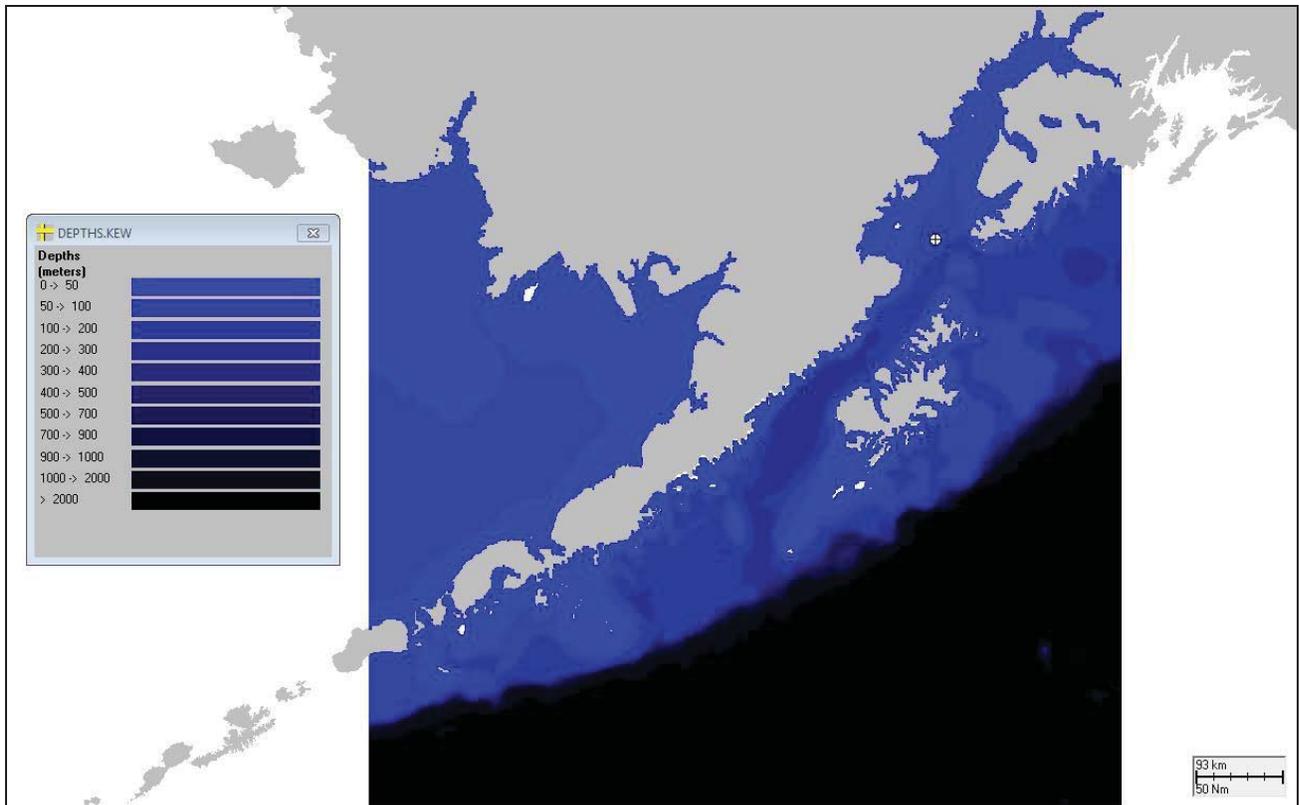


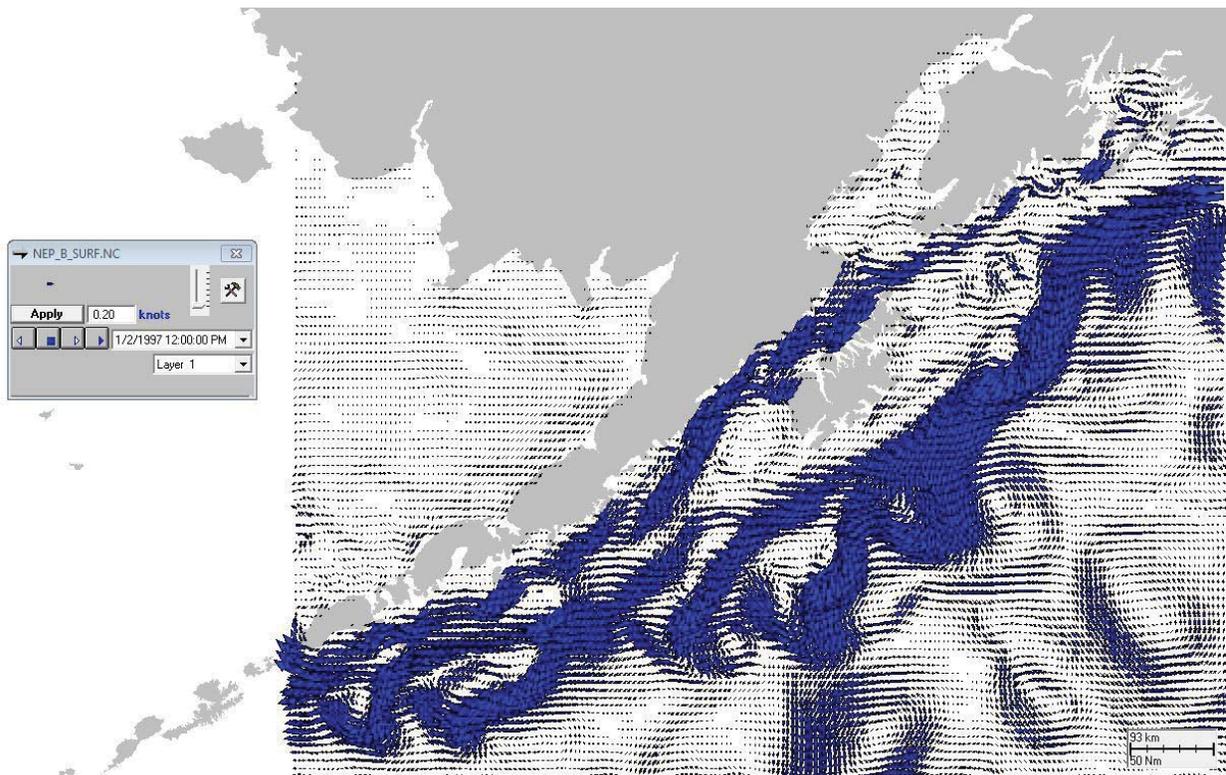
Figure A-26. Depth grid developed for the Cook Inlet/Shelikof Strait region.

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° 11.938'W
Grid S edge	52° 47.926' N
Cell size (° longitude)	0.0154° W
Cell size (° latitude)	0.0154° 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 <sup>2</sup> )	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

## Currents

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.**

## Winds

Standard meteorological data were acquired from the National Data Buoy Center 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

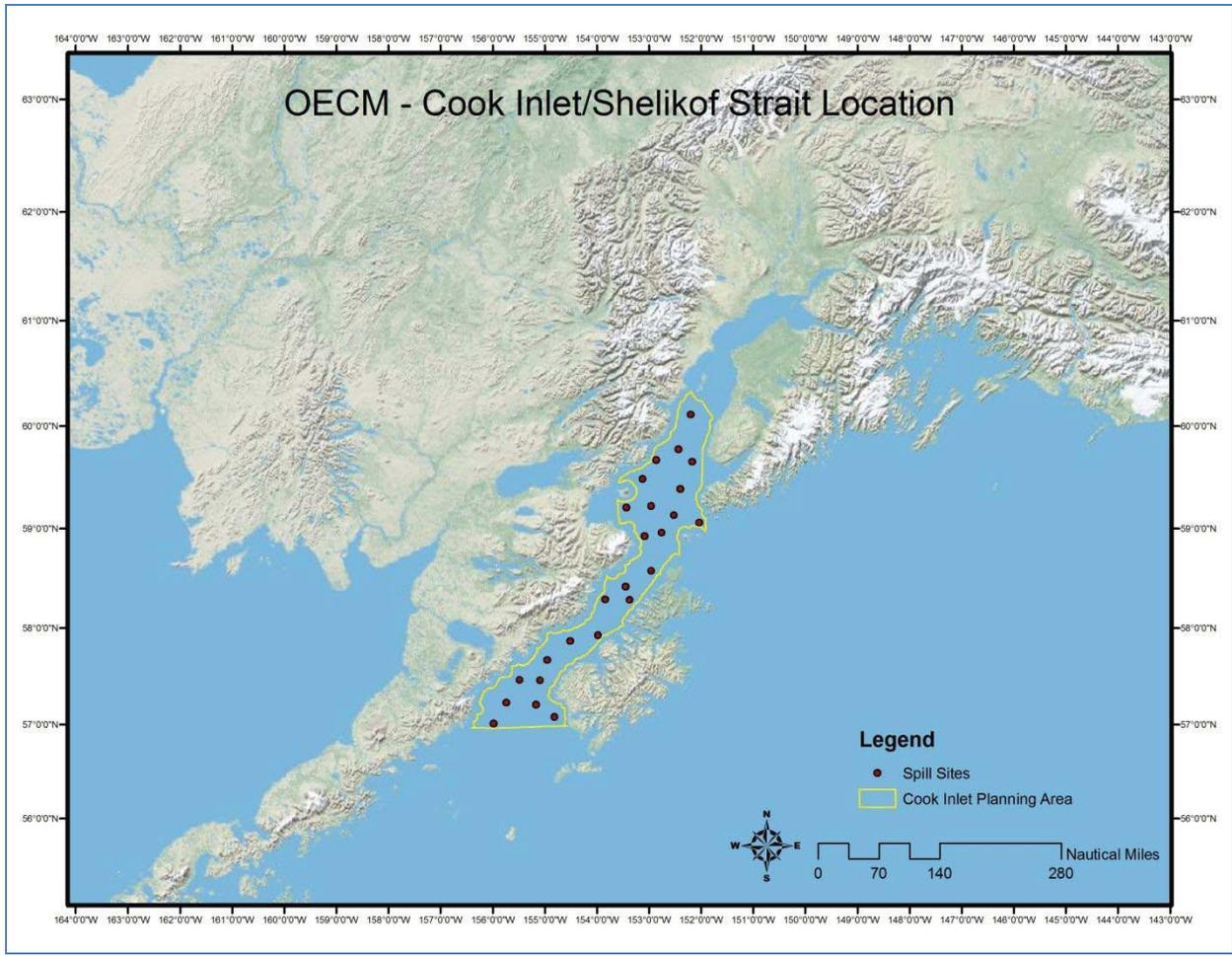
match the currents, we used data from later years as a proxy for the missing earlier years, as described below.

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

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
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

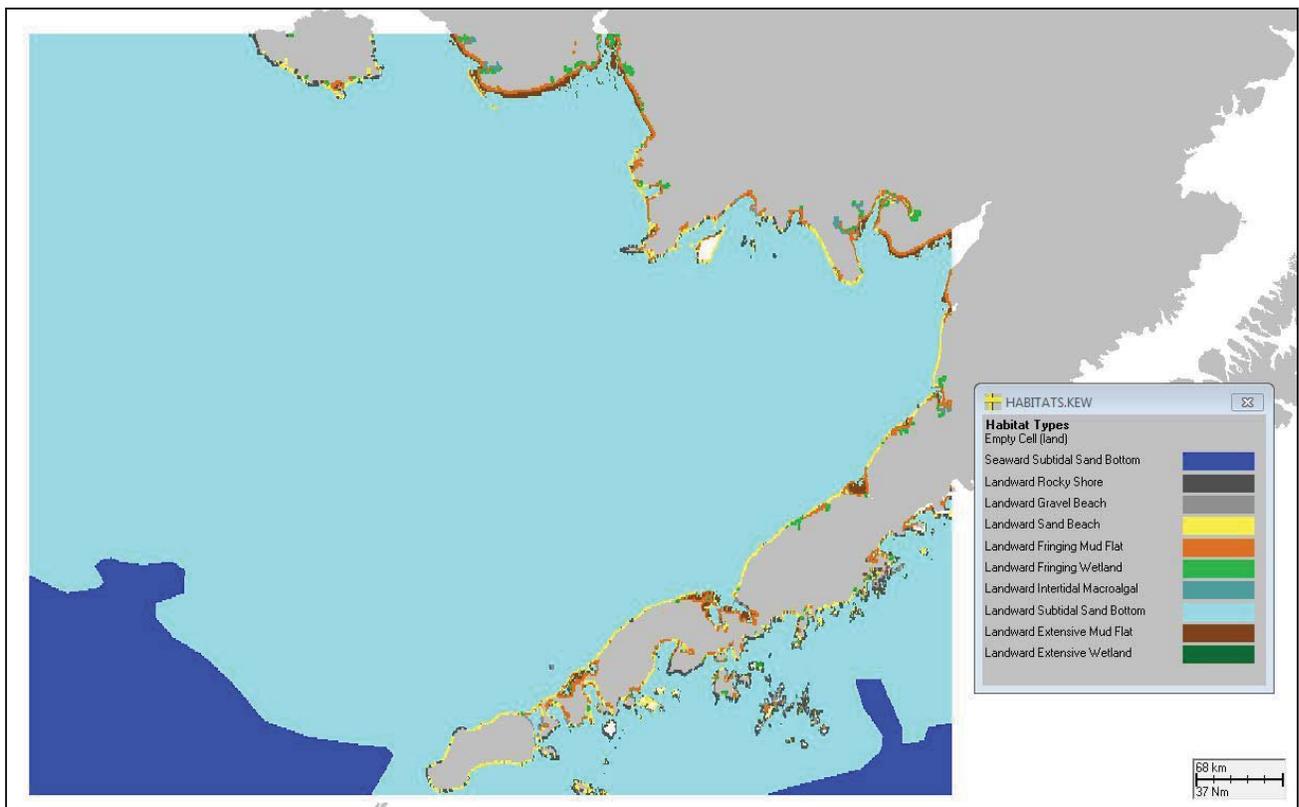
## Bering Sea

### Habitat Grid

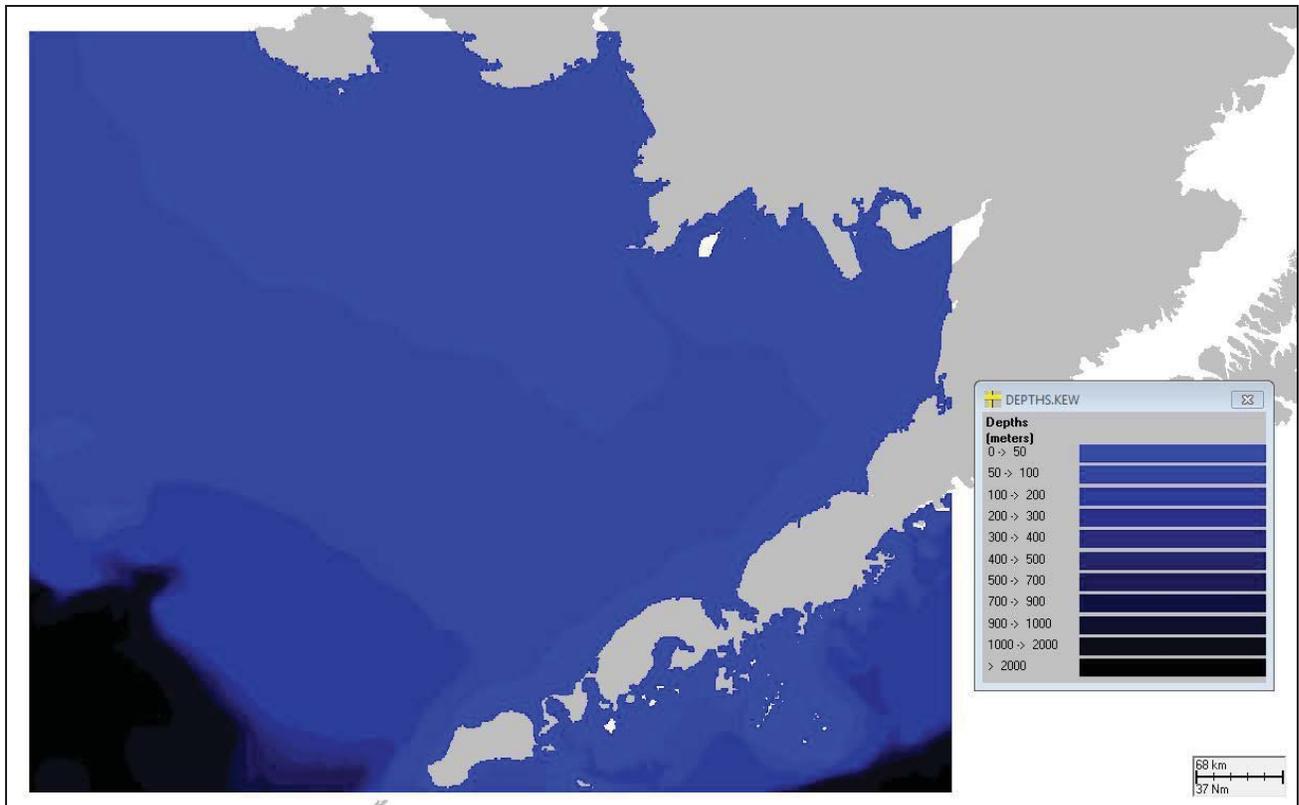
The digital shoreline, shore type, and habitat mapping for the Bering Sea region were obtained from the Environmental Sensitivity Index (ESI) Atlas databases for Aleutians, Bristol Bay and Western Alaska compiled for the state of Alaska by Research Planning, Inc. (RPI). These data are distributed by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



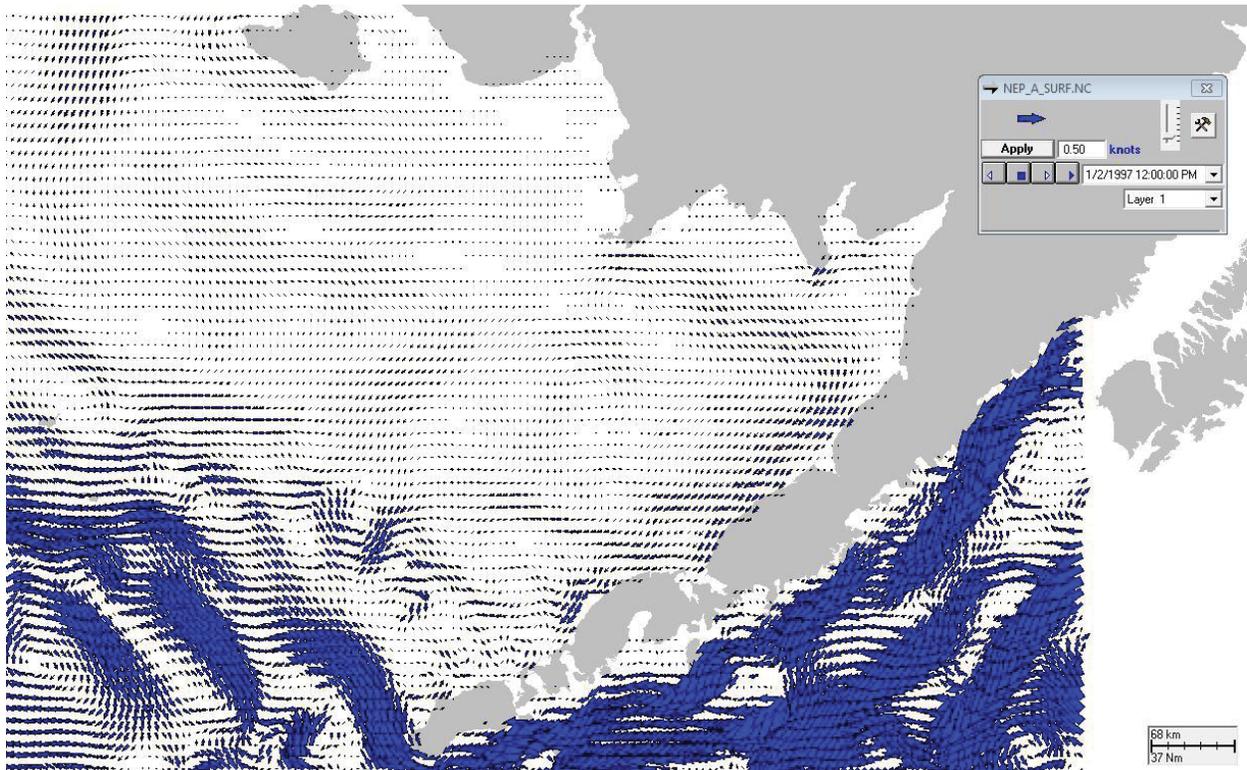
**Figure A-30. Depth grid developed for the Bering Sea region.**

**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° 35.380' W
Grid S edge	54° 22.155' N
Cell size (° longitude)	0.0132° W
Cell size (° latitude)	0.0132° 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 <sup>2</sup> )	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

## Currents

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.



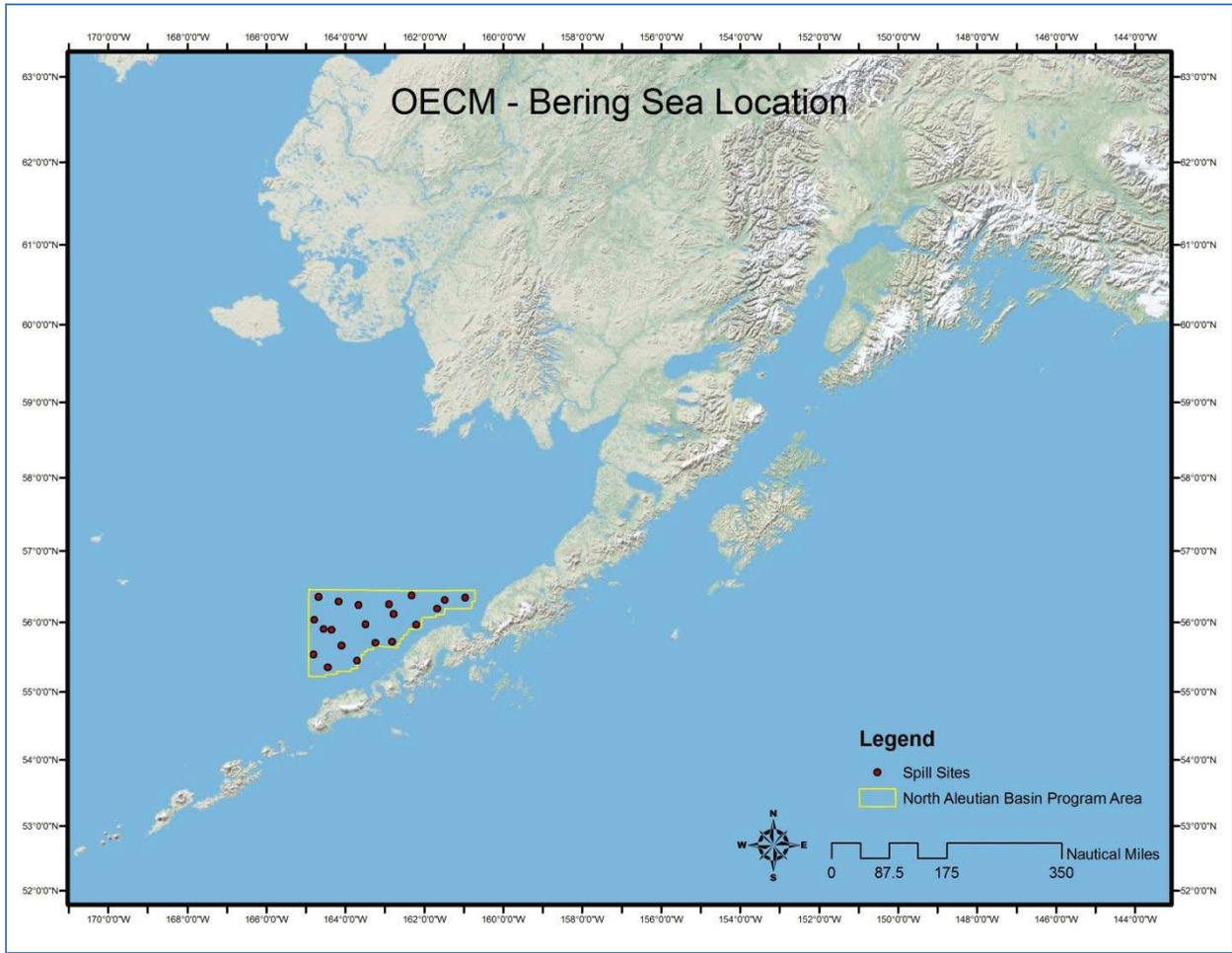
**Figure A-31. Example current component data used in modeling for the Bering Sea region. Vector length indicates speed in the indicated direction.**

## 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.**

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
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
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

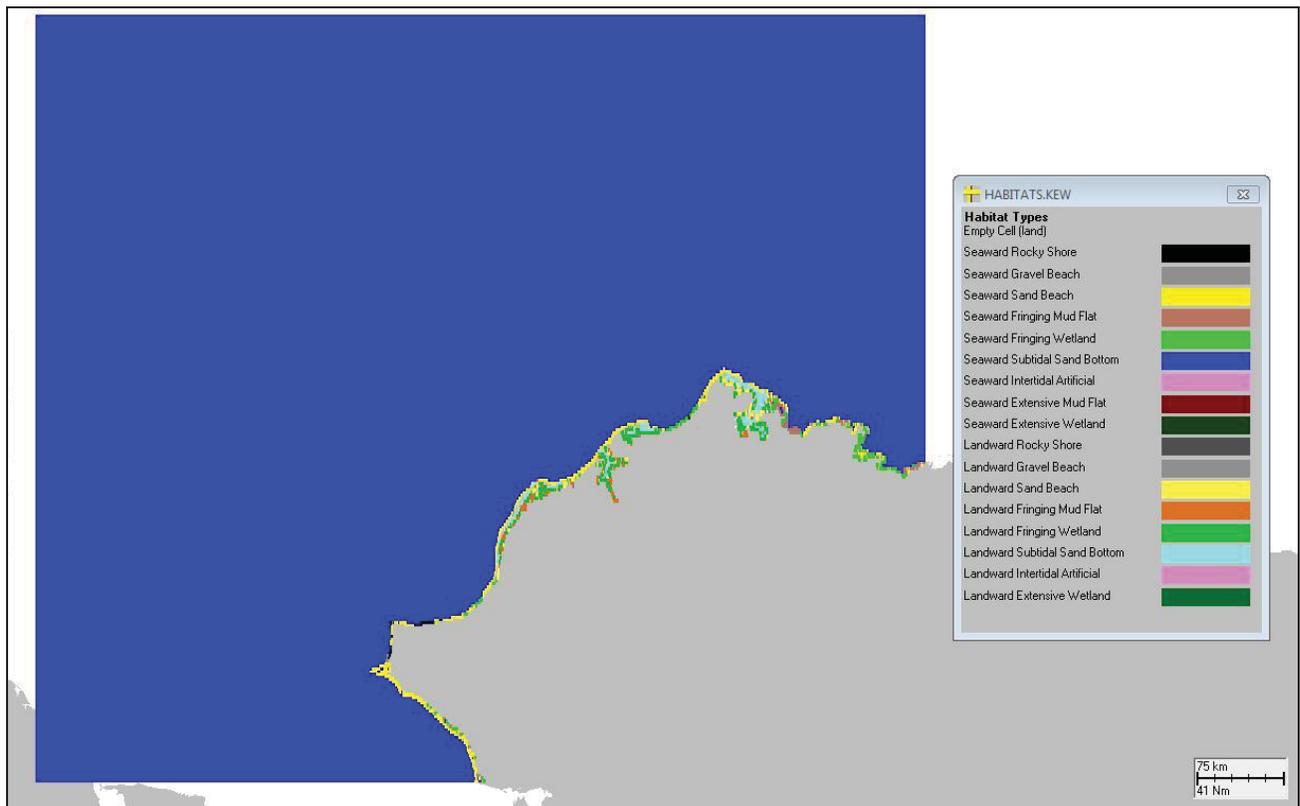
## Chukchi Sea

### Habitat Grid

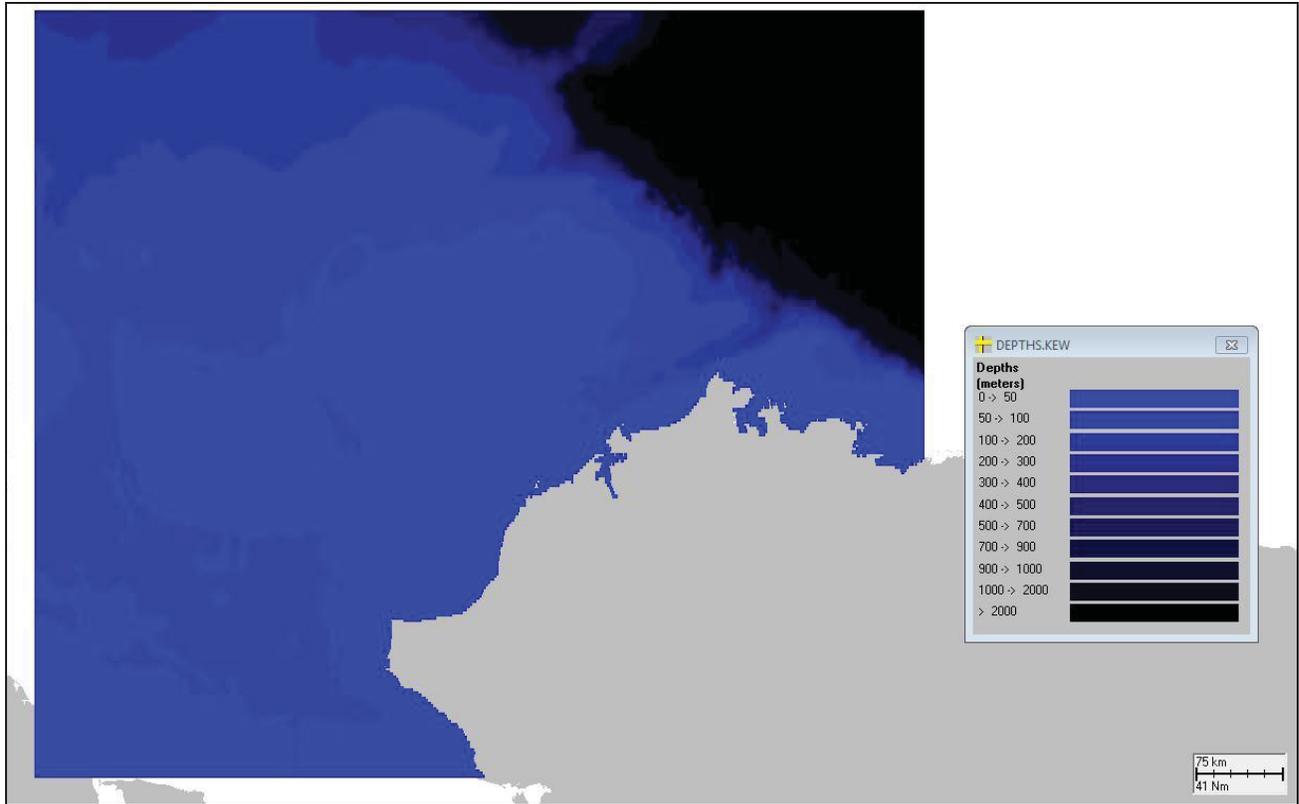
The digital shoreline, shore type, and habitat mapping for the Chukchi Sea region were obtained from the Northwest Arctic and North Slope Environmental Sensitivity Index (ESI) Atlas databases compiled for the state of Alaska by Research Planning, Inc. (RPI). These data are distributed by NOAA Hazmat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



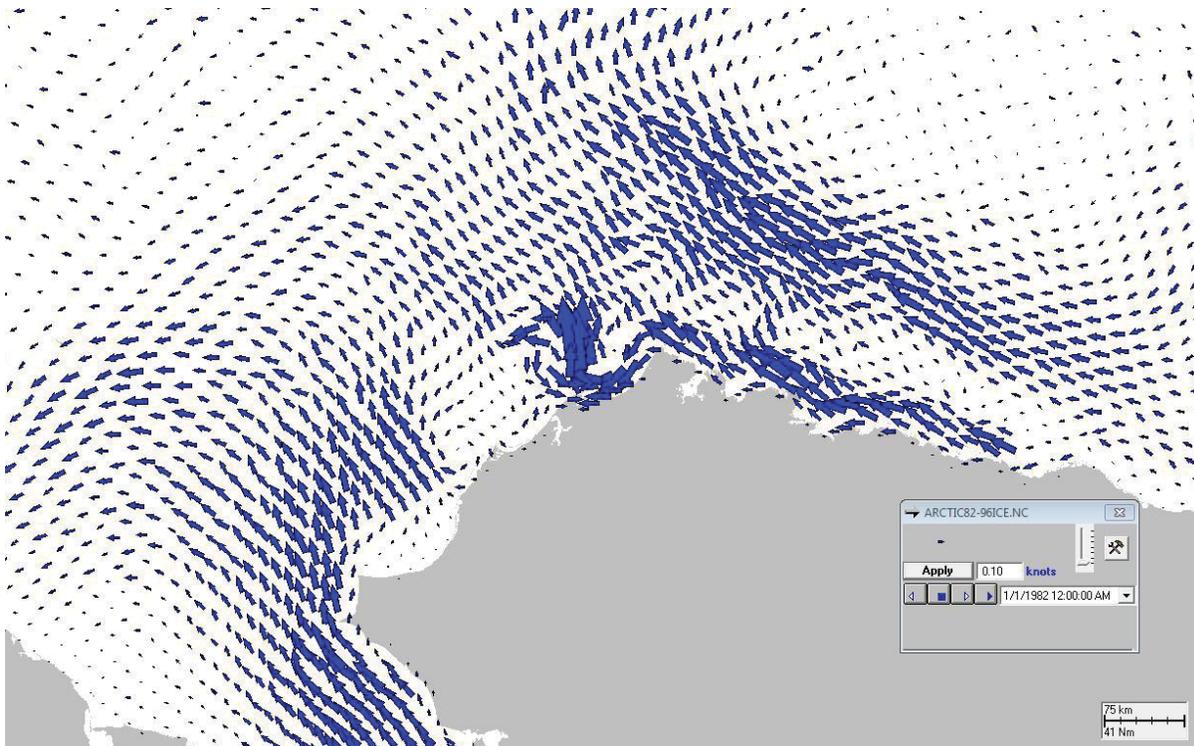
**Figure A-34. Depth grid developed for the Chukchi Sea region.**

**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 <sup>2</sup> )	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

## Currents

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.**

Ice

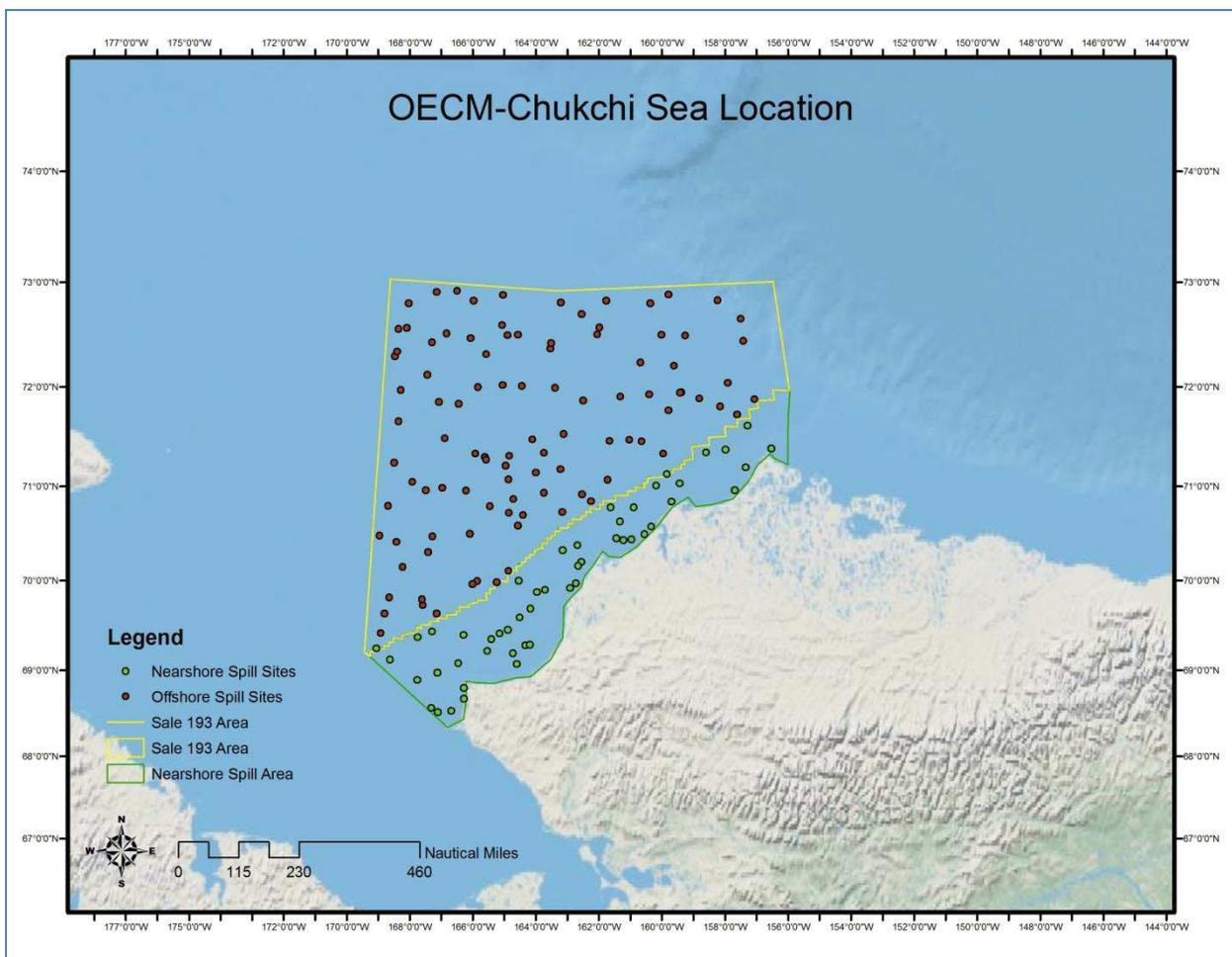
As mentioned above, ice distribution was included in the model analysis and was treated in the same manner as current velocities. The program host provided the model outputs in original binary format. ASA subsequently converted them in to NetCDF format for SIMAP model usage.

### 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 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.**

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
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

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
47	69.99947	-164.54262
48	69.19607	-164.71789
49	69.07496	-164.60936
50	69.24981	-169.06530

**Table A-24. Chukchi Sea offshore spill sites.**

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
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

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
40	70.41722	-168.42607
41	71.88031	-157.05767
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

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
87	70.70016	-164.39985
88	69.98332	-165.24292
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

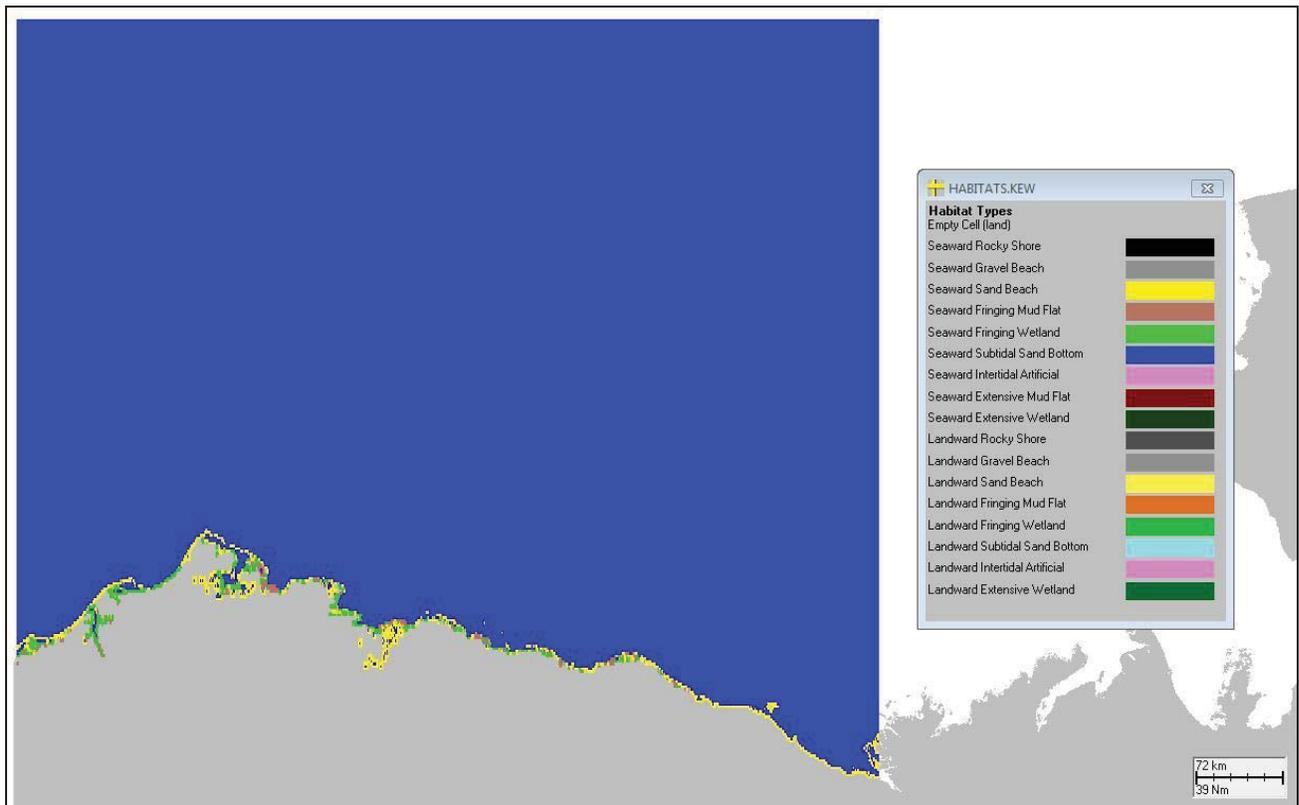
## Beaufort Sea

### Habitat Grid

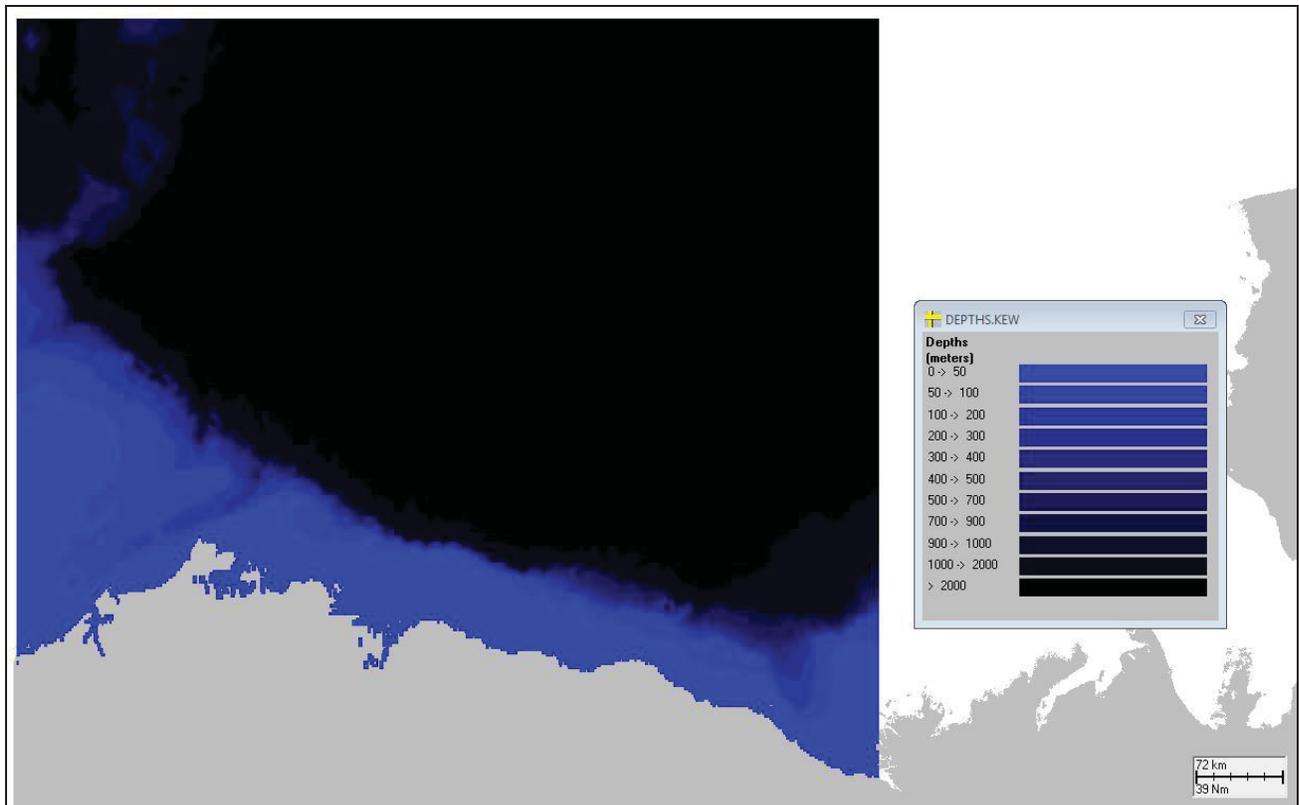
The digital shoreline, shore type, and habitat mapping for the Beaufort Sea region were obtained from the North Slope Environmental Sensitivity Index (ESI) Atlas database compiled for the state of Alaska by Research Planning, Inc. (RPI). These data are distributed by NOAA Hazmat (Seattle, WA).

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.**



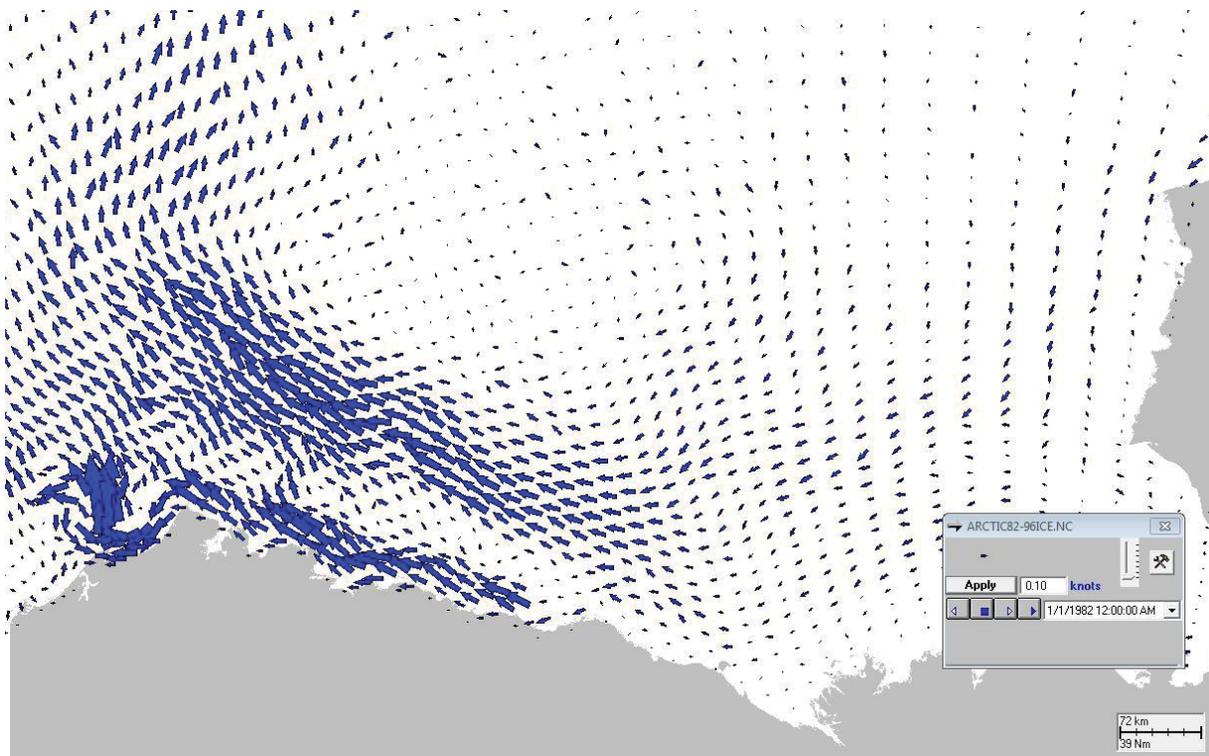
**Figure A-38. Depth grid developed for the Beaufort Sea region.**

**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 <sup>2</sup> )	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 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-39. Example current component data used in modeling for the Beaufort Sea region. Vector length indicates speed in the indicated direction.**

Ice

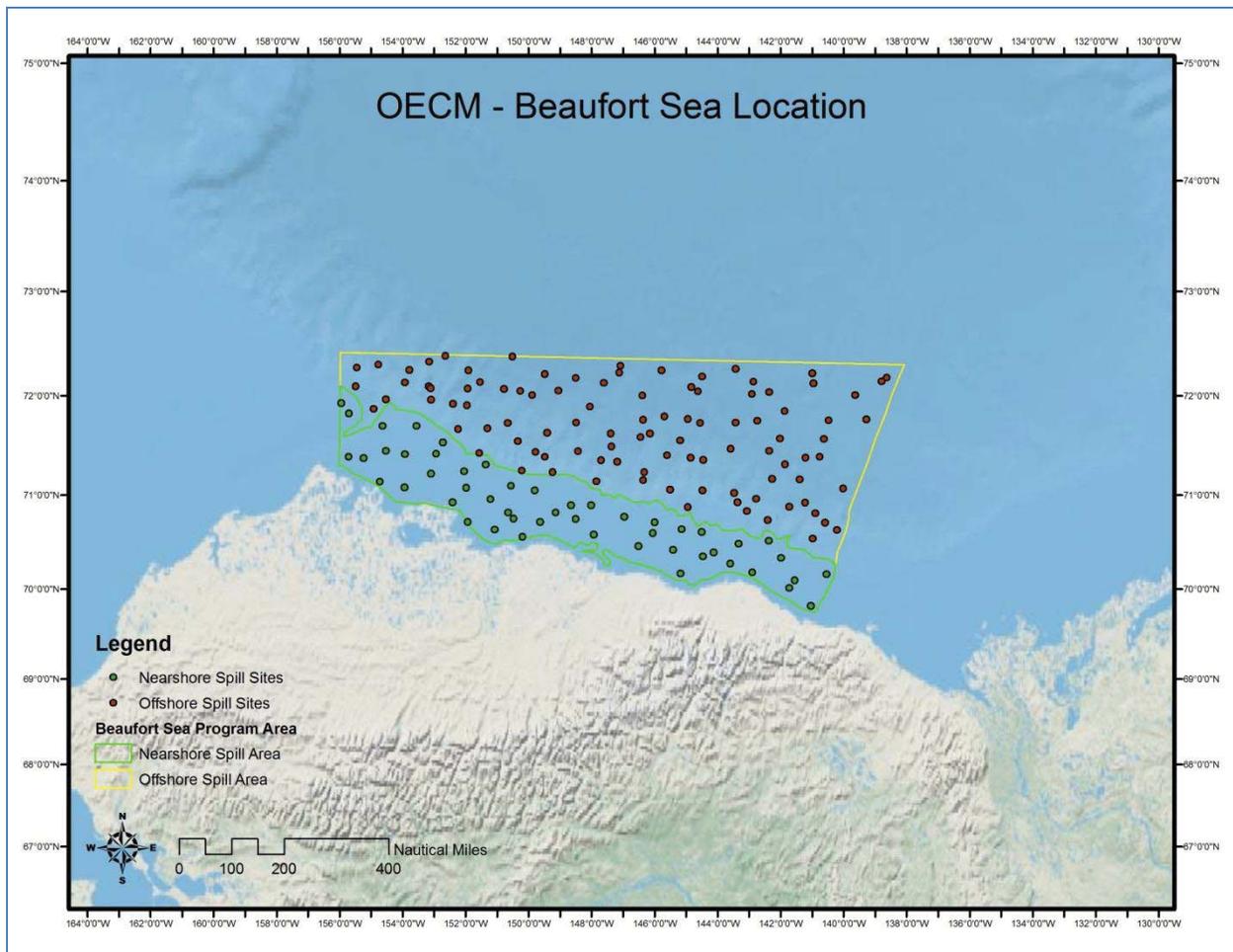
As mentioned above, ice distribution was included in the model analysis and was treated in the same manner as current velocities. The program host provided the model outputs in original binary format. ASA subsequently converted them in to NetCDF format for SIMAP model usage.

### 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 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.**

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
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

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
43	70.27678	-143.59203
44	70.71670	-145.99497
45	70.01231	-141.73111
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.**

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
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

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
36	71.39158	-140.75832
37	72.01116	-139.62887
38	71.73580	-148.48504
39	71.36116	-144.46177
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

<b>Spill Site #</b>	<b>Latitude</b>	<b>Longitude</b>
83	71.77527	-144.94114
84	72.03951	-142.36495
85	72.04944	-150.25811
86	70.80993	-140.89805
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)**

## **SUB-APPENDIX B**

### **Properties of Oils used in SIMAP Modeling**

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

<b>Property</b>	<b>Value</b>	<b>Reference</b>
Density @ 25 deg. C (g/cm <sup>3</sup> )	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°C	0.16522	Jokuty et al. (1999)*
Fraction Non-Aromatics: boiling point 180-264°C	0.185839	Henry (1997)
Fraction Non-Aromatics: boiling point 264-380°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.**

<b>Property</b>	<b>Value</b>	<b>Reference</b>
Density @ 25 deg. C (g/cm <sup>3</sup> )	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°C	0.139429	Environment Canada (2004)
Fraction Non-Aromatics: boiling point 180-264°C	0.167188	Environment Canada (2004)
Fraction Non-Aromatics: boiling point 264-380°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.**

<b>Property</b>	<b>Value</b>	<b>Reference</b>
Density @ 25 deg. C (g/cm <sup>3</sup> )	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°C	0.20408	Environment Canada (2004)
Fraction Non-Aromatics: boiling point 180-264°C	0.121224	Environment Canada (2004)
Fraction Non-Aromatics: boiling point 264-380°C	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.**

<b>Property</b>	<b>Value</b>	<b>Reference</b>
Density @ 0 deg. C (g/cm <sup>3</sup> )	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°C	0.104772	Environment Canada (2009)
Fraction Non-Aromatics: boiling point 180-264°C	0.091787	Environment Canada (2009)
Fraction Non-Aromatics: boiling point 264-380°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.**

<b>Property</b>	<b>Value</b>	<b>Reference</b>
Density @ 25 deg. C (g/cm <sup>3</sup> )	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°C	0.008181	Jokuty et al. (1999)*
Fraction Non-Aromatics: boiling point 180-264°C	0.045206	Jokuty et al. (1999)*
Fraction Non-Aromatics: boiling point 264-380°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.**

<b>Property</b>	<b>Value</b>	<b>Reference</b>
Density @ 25 deg. C (g/cm <sup>3</sup> )	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°C	0.042207	Jokuty et al. (1999)*
Fraction Non-Aromatics: boiling point 180-264°C	0.335825	Jokuty et al. (1999)*
Fraction Non-Aromatics: boiling point 264-380°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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# **Oil Spill Modeling for the Offshore Environmental Cost Model (OECM)**

## **SUB-APPENDIX 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 1.

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

<b>Consumer</b>	<b>Prey/food</b>	<b>% Efficiency</b>
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 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 2 Composite ecological efficiency relative to benthic invertebrate production by trophic group.**

<b>Species Category</b>	<b>Trophic Level</b>	<b>Ecological Efficiency Relative to Benthic Detritivores (%)</b>
<i>Fish and Invertebrates:</i>		
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
<i>Birds:</i>		
Waterfowl	bottom feeders	2
Seabirds	piscivores	0.4
Waders	piscivores	0.4
Shorebirds	bottom feeders	2
Raptors	piscivores	0.4
Kingfishers	piscivores	0.4
<i>Other wildlife:</i>		
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 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  $\text{m}^{-2} \text{yr}^{-1}$ . In addition, benthic microalgal production provides another 105 g dry weight  $\text{m}^{-2}$  (Van Raalte, et al., 1976). Thus, estimated total primary production rate in saltmarshes in this region is 605g dry weight  $\text{m}^{-2} \text{yr}^{-1}$ .

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  $\text{m}^{-2} \text{yr}^{-1}$ . In addition, benthic microalgal production provides another 105 g dry weight  $\text{m}^{-2}$  (Van Raalte, et al., 1976). Thus, estimated total primary production rate in saltmarshes in this region is 1,395g dry weight  $\text{m}^{-2} \text{yr}^{-1}$ .

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 (1991) as 3,666 g dry weight  $\text{m}^{-2} \text{yr}^{-1}$ . In addition, benthic microalgal production provides another 312 g dry weight  $\text{m}^{-2}$  (Continental Shelf Associates, 1991). Thus, estimated total primary production rate in saltmarshes in this region is 3,978 g dry weight  $\text{m}^{-2} \text{yr}^{-1}$ .

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

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 Continental Shelf Associates (1991). The daily rates were applied to a 6-month growing season, with the annual total being 681 g dry weight  $\text{m}^{-2} \text{yr}^{-1}$ . In addition, benthic microalgal production over a 6-month growing season provides another 1,488 g dry weight  $\text{m}^{-2}$  (Continental

Shelf Associates, 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 Continental Shelf Associates (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  $m^{-2}$  (Continental Shelf Associates, 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 (> 0.1mm thickness results in invertebrate injuries). Benthic invertebrate production rates for each habitat type are taken into account when determining injury (Tables 3 to 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 0.1mm thick is calculated as a factor of daily production rate, as a function 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 3. Benthic invertebrate production rates by habitat type for Mid-Atlantic location.**

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

<sup>1</sup> Nixon and Oviatt, 1973; VanRaale et al., 1976

<sup>2</sup> Raymond, 1980

[12.5 g wet weight/g C, Odum, 1971; dry weight is 22% of wet weight, Nixon and Oviatt, 1973]

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

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

<sup>1</sup> Teal, 1962; Van Raalte et al., 1976

<sup>2</sup> Raymond, 1980

[12.5 g wet weight/g C, Odum, 1971; dry weight is 22% of wet weight, Nixon and Oviatt, 1973]

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

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

<sup>1</sup> Teal, 1962; Van Raalte et al., 1976

<sup>2</sup> Flint, 1985

<sup>3</sup> Raymont, 1980

<sup>4</sup> Muscatine, 1980

[12.5 g wet weight/g C, Odum, 1971; dry weight is 22% of wet weight, Nixon and Oviatt, 1973]

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

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

<sup>1</sup> Continental Shelf Associates, Inc., 1991

<sup>2</sup> Raymont, 1990

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

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

<sup>1</sup> Greeson et al., 1979

<sup>2</sup> Raymont, 1990

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

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

<sup>1</sup> Greeson et al., 1979

<sup>2</sup> Raymont, 1990

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

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

<sup>1</sup> Continental Shelf Associates, Inc., 1991

<sup>2</sup> Raymont, 1990

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

<b>Habitat Injured</b>	<b>Natural Recovery Time (years)</b>
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 11 provides a summary for HEA information for all OECM locations.

**Table 11. Summary of HEA Information used in the OECEM.**

OECEM Location Code	Area (m <sup>2</sup> ) of Saltmarsh Restored per kg of Injury, by OECEM Location										
	ATL	SFL	CGM	SCA	WAS	GOA	CIS	BER	CHU	BEA	
<i>Birds:</i>											
Waterfowl	82.56	46.37	46.37	16.13	18.75	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	93.75
Wading Birds	412.82	231.87	231.87	80.63	93.75	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	18.75
Raptors	412.82	231.87	231.87	80.63	93.75	93.75	93.75	93.75	93.75	93.75	93.75
<i>Other Wildlife:</i>											
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	52.84
Pinnipeds	4,128.16	-	-	806.35	937.46	528.37	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	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	1,056.75
Polar Bears	-	-	-	-	-	-	-	52,837.31	52,837.31	52,837.31	52,837.31
Herbivorous Mammals	3,091.60	3,091.60	3,091.60	-	-	-	-	-	-	-	-
<i>Fish and Invertebrates:</i>											
Small Pelagic Fish	8.26	4.64	4.64	1.61	1.87	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	46.87
Demersal Fish	16.51	9.27	9.27	3.23	3.75	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	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	1.87
<b>Area (m<sup>2</sup>) of Saltmarsh Restored per Area (m<sup>2</sup>) Oiled, by OECEM Location</b>											
Intertidal Injury	9.375	15.514	0.725	0.757	2.616	0.378	0.480	0.597	2.243	1.765	1.765

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

## **SUB-APPENDIX D**

### **Spill Rate and Volume Data for OECM Modeling**

This sub-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 1], pipelines [Table 2], and from vessels servicing the platforms [Table 3]). The PDFs include:

- Crude oil spills from OCS platforms/wells (Table 1);
- Operational diesel spills from OCS platforms/wells (Table 1);
- Crude oil spills from offshore pipelines (Table 2);
- Diesel spills from offshore pipelines (Table 2); and
- Diesel spills<sup>2</sup> from offshore supply or service vessels (Table 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 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;<sup>3</sup>
- Bunker fuel spills<sup>4</sup> for tankers transporting crude oil and petroleum products; and
- Diesel fuel spills<sup>5</sup> 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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<sup>2</sup> The smaller vessels that service the offshore platforms are fueled by diesel rather than heavy fuel oil.

<sup>3</sup> Petroleum products will be represented by diesel fuel in the modeling scenarios.

<sup>4</sup> Heavy fuel oil

<sup>5</sup> Tankers in the future will most likely be fueled with diesel rather than heavy fuel oil to meet air pollution standards.

Table 1. Spill rates and spill size distributions for spills associated with OCS platforms and wells, and are based upon all OCS spills from 1964-2010 excluding the catastrophic Deepwater Horizon (DWH) event.

Oil Source	Oil Type <sup>6</sup>	Spill Rate (bbl spilled per bbl produced)	Size Class	Spill Size Range (bbl)	Mean bbl <sup>7</sup>	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%
	Heavy crude	0.0000038	Very Large	10,001 – 100,000	47,937	20,000	0.51%
			Very Small	1 – 10	4	3.5	75.56%
			Small	11 – 100	29	21	15.85%
			Medium	101 – 1,000	334	262	5.89%
	Medium crude	0.0000038	Large	1,001 – 10,000	3,312	3,500	2.18%
			Very Large	10,001 – 100,000	47,937	20,000	0.51%
			Very Small	1 – 10	4	3.5	75.56%
			Small	11 – 100	29	21	15.85%
Diesel	0.0000009	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%	
		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%		

<sup>6</sup> No heavy fuel oil spills would be expected from platforms.

<sup>7</sup> Mean spill volume within the spill range.

Table 2. Spill rates and spill size distributions for spills associated with OCS pipelines.

Oil Source	Oil Type <sup>8</sup>	Spill Rate (bbl spilled per bbl produced)	Size Class	Spill Size Range (bbl)	Mean bbl <sup>9</sup>	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%
			Very Small	1 – 10	4	3	67.9%
	Heavy crude	0.00000162	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%
			Very Small	1 – 10	4	3	67.9%
			Small	11 – 100	28	18	17.6%
Medium crude	0.00000162	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%	
		Very Small	1 – 10	4	3	67.9%	
		Small	11 – 100	28	18	17.6%	
		Medium	101 – 1,000	404	323	9.0%	
Diesel	0.00000003	Large	1,001 – 10,000	3,734	3,700	4.7%	
		Very Large	10,001 – 100,000	16,351	15,574	0.8%	
		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%

<sup>8</sup> No heavy fuel oil spills would be expected from pipelines.

<sup>9</sup> Mean spill volume within the spill range.

Table 3. Spill rates and spill size distributions for spills associated with OCS service vessels.

Oil Source	Oil Type <sup>10</sup>	Spill Rate (bbl spilled per bbl produced)	Size Class	Spill Size Range (bbl)	Mean bbl <sup>11</sup>	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	-	-	-
	Heavy crude	0	Very Large	10,001 – 100,000	-	-	-
			Very Small	1 – 10	-	-	-
			Small	11 – 100	-	-	-
			Medium	101 – 1,000	-	-	-
	Medium crude	0	Large	1,001 – 10,000	-	-	-
			Very Large	10,001 – 100,000	-	-	-
			Very Small	1 – 10	-	-	-
			Small	11 – 100	-	-	-
Diesel	0.00000136	Medium	101 – 1,000	-	-	-	
		Large	1,001 – 10,000	-	-	-	
		Very Large	10,001 – 100,000	-	-	-	
		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	- <sup>12</sup>	-	-

<sup>10</sup> No crude or heavy fuel oil spills would be expected from offshore supply vessels. Minor spills of other oils (lubricating oil) might occur.

<sup>11</sup> Mean spill volume within the spill range.

<sup>12</sup> Theoretical worst-case discharge 3,570 bbl.

Table 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	-	-	-	

Data sources:

1. *All Petroleum Spills  $\geq$  1 Barrel from OCS Oil & Gas Activities by Size Category and Year, 1964 to 2010* (<http://www.boemre.gov/incidents/Excel/PetroleumSpillsBySizeCatYearSourceFourTabs.xls>)
2. Accessed from <http://www.bsee.gov/Inspection-and-Enforcement/Accidents-and-Incidents/Spills---Statistics-and-Summaries-1996-2011.aspx> [Accessed September 15, 2011]
3. OCS oil production since 2000 obtained from: <http://www.boemre.gov/stats/OCSproduction.htm>
4. 1999 and prior OCS oil production obtained from BOEM queries of Technical Information Management System (TIMS)

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

## **SUB-APPENDIX 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 Sub-appendix as digital files (\*.xlsx).

Contained in this Sub-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 1. Region Codes**

<b>Code</b>	<b>Region</b>
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 2. Offshore/Nearshore Location Codes**

<b>Code</b>	<b>Region</b>
OFF	Offshore
ON	Onshore (nearshore)
SBVB*	Santa Barbara-Ventura Basin
SMB*	Santa Maria Basin

\*Applies to Southern California region only

**Table 3. Oil Type Codes**

<b>Code</b>	<b>Region</b>
ALC	Arab Light Crude
DFO	Diesel Fuel Oil
HC	Heavy Crude
HFO	Heavy Fuel Oil
LC	Light Crude
MC	Medium Crude

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

## **SUB-APPENDIX F**

### **Alternative Spill Rate and Volume Data for OECM Modeling Provided by BOEM\***

\* BOEM considers the recently developed rates for platform and pipeline spills using historical data from 1996-2010 to best reflect the improved technology and safety procedures in use today. Hence, these are the rates used in the Five Year Programmatic EIS. To maintain consistency with the PEIS, the OECM (which is not designed to estimate the effects of catastrophic events) now also uses the BOEM rates shown in this appendix for spills from platforms and pipelines.

The oil spill rates and spill sizes (other than tanker spills) used in the OECM model runs for the 2012-2017 Five Year Proposed Final Program are the following 1996-2010 rates from Anderson 2012.

<b>Platform Spills</b>			
<b>Size Class</b>	<b>Spill Range</b>	<b>Mean bbl</b>	<b>% of Spills</b>
Very Small	1-10	3	63.13%
Small	10-100	34	26.84%
Medium	100-1000	240	9.73%
Large	1000-10,000	2,000	0.29%
Very Large	10,000-100,000	n/a	0.00%

<b>Cumulative Oil Production (bbl)</b>	8,000,000,000
<b>Years</b>	1996-2010
<b>Spilled (bb)</b>	13,666
<b>Spill Rate/bbl</b>	0.0000017083
<b>Spill Rate/MMbbl</b>	1.70827500

<b>Platform <u>Diesel</u> Spills</b>			
<b>Size Class</b>	<b>Spill Range</b>	<b>Mean bbl</b>	<b>% of Spills</b>
Very Small	1	1	22.22%
Small	2-10	4	43.83%
Medium	11-100	37	28.40%
Large	101-1,000	390	4.32%
Very Large	1,001-3,600	1,533	1.23%

<b>Cumulative Oil Production (bbl)</b>	8,000,000,000
<b>Years</b>	1996-2010
<b>Spilled (bbl)</b>	7,781
<b>Spill Rate/bbl</b>	0.0000009726
<b>Spill Rate/MMbbl</b>	0.97257750

<b>Pipeline Spills</b>			
<b>Size Class</b>	<b>Spill Range</b>	<b>Mean bbl</b>	<b>% of Spills</b>
Very Small	1-10	4	67.98%
Small	10-100	31	20.69%
Medium	100-1000	383	7.88%
Large	1000-10,000	2,771	3.45%
Very Large	10,000-100,000	n/a	0.00%

<b>Cumulative Oil Production (bbl)</b>	8,000,000,000
<b>Years</b>	1996-2010
<b>Spilled (bbl)</b>	27,320
<b>Spill Rate/bbl</b>	0.0000034150
<b>Spill Rate/MMbbl</b>	3.41497875

<b>Pipeline Diesel Spills</b>			
<b>Size Class</b>	<b>Spill Range</b>	<b>Mean bbl</b>	<b>% of Spills</b>
Very Small	1	1	25.00%
Small	2-10	3	75.00%
Medium	11-100	n/a	0.00%
Large	101-1,000	n/a	0.00%
Very Large	1,001-10,000	n/a	0.00%

<b>Cumulative Oil Production (bbl)</b>	8,000,000,000
<b>Years</b>	1996-2010
<b>Spilled (bbl)</b>	11
<b>Spill Rate/bbl</b>	0.0000000013
<b>Spill Rate/MMbbl</b>	0.00134125

<b>Vessel Spills</b>			
<b>Size Class</b>	<b>Spill Range</b>	<b>Mean bbl</b>	<b>% of Spills</b>
Very Small	1	1	20.59%
Small	2-10	5	44.12%
Medium	11-100	42	32.35%
Large	101-1,000	430	2.94%
Very Large	1,001-10,000	n/a	0.00%

<b>Cumulative Oil Production (bbl)</b>	8,000,000,000
<b>Years</b>	1996-2010
<b>Spilled (bbl)</b>	975
<b>Spill Rate/bbl</b>	0.0000001218
<b>Spill Rate/MMbbl</b>	0.12183750

## References

Anderson, Cheryl McMahon, Melinda Mayes, and Robert LaBelle. 2012 Update of Occurrence Rates for Offshore Oil Spills, BOEM 2012-069, Bureau of Ocean Energy Management and Bureau of Safety and Environmental Enforcement, Herndon, VA. June, 2012

[http://www.boem.gov/Environmental-Stewardship/Environmental-Assessment/Oil-Spill-Modeling/Oil-Spill-Occurrence-Rate-for-Oil-Spill-Risk-Analysis-\(OSRA\).aspx](http://www.boem.gov/Environmental-Stewardship/Environmental-Assessment/Oil-Spill-Modeling/Oil-Spill-Occurrence-Rate-for-Oil-Spill-Risk-Analysis-(OSRA).aspx)

## **APPENDIX B: DERIVATION OF CRITERIA POLLUTANT EMISSION FACTORS FOR ONSHORE OIL PRODUCTION**

To provide additional documentation of the data and methods incorporated into the OECM, this appendix provides a detailed description of the data and methods employed to derive the criteria pollutant emission factors for onshore oil production.<sup>49</sup> These emission factors serve as inputs into the NAA in the OECM and help assess the environmental impacts of energy production displaced by production on the OCS.

Before describing the approach in detail, note that there are two main challenges to estimating emissions associated with onshore oil production. The first is the need to distinguish between onshore and offshore oil 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 natural gas production to either oil production or natural gas production, given that oil and gas are often jointly produced. Some emissions-producing activities, such as drilling wells, are integral to the production of both crude oil and natural gas at the same well, 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 production made it necessary 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, an estimate of the rate of emissions associated with each unit of onshore crude oil produced nationwide was developed. That is, each emission factor was estimated as the ratio of oil-related emissions to oil production in the states analyzed.

The remainder of this appendix proceeds as follows.

1. The first section describes the data sources used to obtain estimates of crude oil production and associated emissions from both point and nonpoint sources.
2. This appendix then outlines the methods followed, first, to identify emissions associated with the production of oil and natural gas (because the two are often jointly produced), and second, to apportion these emissions between oil production and natural gas production.
3. Finally, estimates of NO<sub>x</sub>, SO<sub>2</sub>, VOC, CO, PM<sub>2.5</sub>, and PM<sub>10</sub> emissions for area and point sources associated with production of crude oil are presented. Using these values, emissions per unit of crude oil produced onshore were calculated.

### **Data Sources**

In order to develop a per-unit estimate of the emissions caused by onshore production of oil, it was necessary to obtain data on the quantity of oil produced and the emissions from point and area sources associated with oil production.

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<sup>49</sup> While the data sources described in this appendix would allow for the estimation of emission factors for onshore gas production, gas-specific emission factors are developed with more up-to-date data sources, as documented in Chapter 4, and are not presented in this appendix.

## Onshore oil production

Data on onshore oil production were obtained from databases of domestic energy production maintained by the DOE's Energy Information Administration (EIA). EIA's databases include production data from 1967 through 2014 and distinguish between onshore production and offshore production. From these databases, annual onshore crude oil production data by state were obtained.<sup>50</sup> These totals are presented in Table 1. Note that the data presented in Table 1 are specific to the year 2002 to be consistent with the emissions data obtained for the oil sector. With the significant increase in unconventional oil production over the past decade, the distribution of onshore oil production has shifted significantly since 2002, with sharp increases in market share for North Dakota and Texas and decreases in California, Alaska, and Louisiana.

Table 1. Onshore Crude Oil Production in 2002.

STATE	2002 ONSHORE PRODUCTION OF CRUDE OIL (THOUSAND BARRELS)
Alabama	8,631
Alaska <sup>1</sup>	359,335
Arizona <sup>1</sup>	63
Arkansas	7,344
California <sup>1</sup>	258,010
Colorado <sup>1</sup>	17,734
Florida	3,656
Illinois	12,051
Indiana	1,962
Kansas	32,721
Kentucky	2,679
Louisiana	93,477
Maryland	0
Michigan	7,219
Mississippi	18,015
Missouri	95
Montana <sup>1</sup>	16,855
Nebraska	2,779
Nevada <sup>1</sup>	553
New Mexico <sup>1</sup>	67,041
New York	165
North Dakota <sup>1</sup>	30,993
Ohio	6,004
Oklahoma	66,642
Oregon <sup>1</sup>	0
Pennsylvania	2,233
South Dakota <sup>1</sup>	1,214
Tennessee	275
Texas	411,985
Utah <sup>1</sup>	13,676

<sup>50</sup> Crude oil production data were obtained at [http://tonto.eia.doe.gov/dnav/pet/pet\\_crd\\_crpdn\\_adc\\_mbb1\\_a.htm](http://tonto.eia.doe.gov/dnav/pet/pet_crd_crpdn_adc_mbb1_a.htm).

STATE	2002 ONSHORE PRODUCTION OF CRUDE OIL (THOUSAND BARRELS)
Virginia	22
West Virginia	1,382
Wyoming <sup>1</sup>	54,717
Total Onshore Production	1,499,528
WRAP States (minus California and Alaska)	202,846
Source: Department of Energy's Energy Information Administration databases. Crude oil production values were taken from <a href="http://tonto.eia.doe.gov/dnav/pet/pet_crd_crdn_adc_mbb1_a.htm">http://tonto.eia.doe.gov/dnav/pet/pet_crd_crdn_adc_mbb1_a.htm</a> .	
Note:	
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 production. Emissions from smaller field equipment involved in oil production usually fall below EPA's permitting thresholds and are therefore underrepresented in the NEI. Consequently, emissions information was sought from sources that improved on the NEI by adding information about area sources related to the production of oil.

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 an Oil and Gas Emissions Workgroup tasked with developing a more complete inventory of emissions from oil and natural gas production.<sup>51</sup> To develop this inventory, WRAP solicited review of the 2002 NEI from individual states, corrected errors, and added an oil and natural gas field operations area source inventory. This analysis uses the final version of the 2002 emissions inventory developed by WRAP's Stationary Sources Joint Forum, which includes point-source and area-source emissions data for NO<sub>x</sub>, SO<sub>2</sub>, VOC, CO, PM<sub>10</sub>, and PM<sub>2.5</sub>.<sup>52</sup> Because of reliance on WRAP emissions inventory, the scope of the analysis is limited to the states that belong to 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 they were not considered in this analysis. In addition, Alaska and California were excluded from consideration, because both states engaged in onshore as well as offshore oil production, and it was not possible to identify which emissions were associated only with onshore production. As shown in Table 1, the remaining ten WRAP states produced over 200 million barrels of crude oil in 2002. These totals represent about 14 percent of total onshore crude oil production in 2002. 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.

<sup>51</sup> "Oil & Gas Emissions Workgroup: About." Accessed at <http://www.wrapair.org/forums/ogwg/index.html>.

<sup>52</sup> Both area-source and point-source emissions were obtained at <http://www.wrapair.org/forums/ssif/pivot.html>.

### **Methodology for emissions estimates**

Emissions estimates for both point sources and area sources were obtained from the WRAP emissions inventory discussed above. For each source category, emissions associated with oil and natural gas production first were identified and then divided between oil production and natural gas production.

### **Emissions data for area sources**

The area source emissions database obtained from WRAP presents emissions at the State level, organized by Standard Classification Code (SCC). To identify emissions associated with oil and/or natural gas production, all emissions from the SCCs for “Industrial Processes-Oil and Gas Production” were selected. The full list of SCCs used to identify area-source emissions from oil and natural gas production can be found in Table 2.

Table 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

SCC descriptions also were used to determine which emissions were attributable to oil production and which to natural gas production. As Table 2 shows, most SCC descriptions indicate whether the emissions source is associated with either crude petroleum or natural gas. Using this process, about 85 percent of total NO<sub>x</sub> emissions, 99 percent of VOC emissions, and 92 percent of CO emissions, but less than one percent of SO<sub>2</sub> emissions, were allocated to area sources specific to oil or natural gas production. 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, it would not be appropriate to fully allocate emissions from drill rigs to either category. Instead, these emissions were divided between oil and natural gas production according to the division of emissions from all other SCCs. In the case of SO<sub>2</sub> emissions, some states did not have emissions from any sources other than drill rigs. In those states, SO<sub>2</sub> emissions from drill rigs were divided in proportion to the division of NO<sub>x</sub> emissions from other sources.

### **Emissions data for point sources**

As with emissions from area sources, all emissions from SCCs for “SCCs for Industrial Processes\_Oil and Gas Production” first were selected. Based on communications with the WRAP Air Quality Project Manager, however, it was determined that sources with those SCCs did not account for all emissions from activities associated with oil and natural gas production.<sup>53</sup> 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, 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, information from the 2002 NEI was used 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, scaling factors were developed by state, pollutant, and SCC, which allowed for estimation of the emissions in the WRAP database attributable to oil and natural gas production. These scaling factors were estimated using the following three steps.

1. Four NAICS codes were identified and assumed to be associated with oil and natural gas production, presented in Table 3.
2. Then emissions sources in the WRAP database were matched to sources 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, matching sources with NAICS codes were identified for 39,620, or about 75 percent.
3. For this sample of point sources from the WRAP database, determinations were made by state, SCC, and pollutant, of the percent of total emissions that come from facilities with oil and natural gas production NAICS codes (listed in Table 3). As an example, for the facilities from the

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<sup>53</sup> Personal communication with Lee Gribovicz, WRAP Air Quality Project Manager, February 24, 2010.

WRAP database with matches in the NEI database, it is estimated that 71.1 percent of NO<sub>x</sub> emissions from natural gas-fired industrial internal combustion engines in Colorado were associated with oil and natural gas production.

These state-, SCC-, and pollutant-specific scaling factors were used to estimate emissions associated with oil and natural gas production. The full list of SCCs for which point source emissions were estimated related to onshore oil and natural gas production is presented in Table 4.

Table 3. NAICS Codes Associated with Crude Oil and Natural Gas Production.

NAICS CODE	NAICS DESCRIPTION
211111	U.S. national industry classification for crude petroleum and natural gas extraction
211112	U.S. national industry classification for natural gas liquid extraction
213111	U.S. national industry classification for drilling oil and natural gas wells
213112	U.S. national industry classification for support activities for oil and natural gas operations

Table 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
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

Table 4. Point-Source SCCs.

SCC CODE	SCC DESCRIPTION	OIL OR GAS
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, the same approach was followed initially as described above for area sources. However, a large portion of emissions – particularly VOC emissions – remained uncategorized. For these remaining emissions, it was 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 assignment of all but 3.5 percent of VOC emissions to either natural gas production or crude oil production. Finally, all remaining uncategorized emissions were divided between oil and natural gas production according to the division of emissions from all other SCCs, as with area source emissions

## Results

In this section, estimates of state-level NO<sub>x</sub>, SO<sub>2</sub>, VOC, CO, PM<sub>10</sub>, and PM<sub>2.5</sub> emissions from point and nonpoint sources associated with onshore oil production in 2002 are presented. Table 5 presents emissions from area sources associated with oil production, while Table 6 presents emissions from point sources. Total emissions from both point and area sources are presented in Table 7. Finally, Table 8 presents total production of crude oil for the 10 states for which emissions were estimated, together with emissions rates for each of the seven pollutants. The totals in Table 8 represent estimates of the nationwide emissions rates associated with onshore oil production.

Table 5. 2002 Area Source Emissions from Onshore Oil Production.

STATE NAME	EMISSIONS (TONS)					
	NO <sub>x</sub>	SO <sub>2</sub>	VOC	CO	PM <sub>10</sub>	PM <sub>2.5</sub>
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.						

Table 6. 2002 Point Source Emissions from Onshore Oil Production.

STATE NAME	EMISSIONS (TONS)					
	NO <sub>x</sub>	SO <sub>2</sub>	VOC	CO	PM <sub>10</sub>	PM <sub>2.5</sub>
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.

Table 7. Total 2002 Emissions from Onshore Oil Production.

STATE NAME	EMISSIONS (TONS)					
	NO <sub>x</sub>	SO <sub>2</sub>	VOC	CO	PM <sub>10</sub>	PM <sub>2.5</sub>
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.

Table 8. Tons of Emissions Per Thousand Barrels of Onshore Oil Production.

STATE NAME	PRODUCTION (THOUSAND BARRELS)	EMISSIONS PER UNIT (TONS PER THOUSAND BARRELS)					
		NO <sub>x</sub>	SO <sub>2</sub>	VOC	CO	PM <sub>10</sub>	PM <sub>2.5</sub>
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

# 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, the APEEP analysis model (Muller and Mendelsohn, 2007 and 2009; Muller et al., 2011) was used 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. These particular source locations reflect possible locations of offshore oil and natural gas exploration and extraction sites. In past applications, the APEEP model'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 the APEEP model (denoted as  $T_{ijs}$ ), 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 U.S. county 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. The APEEP model has been used in prior analyses to connect emissions from onshore sources to onshore consequences (Muller and Mendelsohn, 2007 and 2009; Muller et al., 2010). Hence, the APEEP model currently is 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 the APEEP model is derived from the Gaussian Plume model (Turner, 1994). As such, the APEEP model contains a series of source-receptor matrices that are comprised of transfer coefficients that depict the relationship between emissions in source location ( $i$ ) and receptor location ( $j$ ), denoted  $T_{ijs}$ . Note that ( $s$ ) corresponds to pollution species. Hence, the APEEP model 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*).  $T_{ijs}$  values 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 the APEEP model 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 Formulas (1) and (2) below.

The distance in miles ( $D_{ij}$ ) between offshore source (*i*) and receptor county (*j*) is computed using Formula (1).

Formula (1):

$$D_{ij} = (((\text{Lat}_i - \text{Lat}_j)^2 \times 69) + ((\text{Lon}_i - \text{Lon}_j)^2 \times 53))^{0.5} \times (\cos(\text{Lat}_j/57.3))$$

where:  $\text{Lat}_i$  = latitude in source grid cell (*i*)  
 $\text{Lon}_i$  = 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 Formula (2)

Formula (2):

$$\theta_{ij} = (\text{atan2}(\sin(\text{Lon}_j - \text{Lon}_i) * \cos(\text{Lat}_j), \cos(\text{Lat}_j) * \sin(\text{Lat}_j) - \sin(\text{Lat}_i) * \cos(\text{Lat}_j) * \cos(\text{Lon}_j - \text{Lon}_i)))$$

In order to convert the resultant  $\theta_{ij}$  to degrees,  $\theta_{ij}$  is multiplied by  $180/\Pi$ , or 57.3. Finally, since (2) produces values on the interval  $-180^\circ, 180^\circ, 360^\circ$  is added to  $\theta_{ij}$  and the modulus function applied to derive the bearing ( $B_{ij}$ ) between each source (*i*) and receptor (*j*). This is shown in Formula (3).

Formula (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 Formula (4). Note that  $T_{ijs}$  is constructed as a function of distance and bearing between (*i*) and (*j*).

Formula (4):

$$T_{ijs} = \beta_{0s} + \beta_{1s}D_{ij} + \beta_{2s}B_{ij} + \beta_{3s}D_{ij}B_{ij} + \epsilon_{ijs}$$

Empirically, this procedure employs the transfer coefficients in the source-receptor matrices in the APEEP model, as the  $T_{jis}$  in (4). 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 Formula (4) forms the basis of a fitted regression model in which transfer coefficients are regressed on distance and compass bearing for all of the ground-level county-to-county transfer coefficients in the APEEP model. This estimation procedure results in a set of parameter estimates ( $\beta_{ks}$ ) for each pollutant species ( $s$ ), which describe  $T_{ijs}$  as a function of distance and bearing. The estimated parameters from Formula (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 U.S. counties, 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  $T_{ijs}$  reflects 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 the APEEP model 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 the APEEP model and calculated in each onshore receptor location. Hence, when modeling an emission of  $SO_2$ , for example, from an offshore source, the estimated ( $T_{ijs}$ ) predicts 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 ozone ( $O_3$ ) levels, offshore emissions of  $NO_x$  and VOCs are linked to ambient concentrations of  $NO_x$  and VOCs 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 the APEEP model (Muller and Mendelsohn, 2007). Specifically, a reduced-form model translates ambient levels of  $NO_x$  and VOCs 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 Formula (4), by pollutant species ( $s$ ). Although there is not a necessarily preferred functional form for Formula (4), a third-order approximating polynomial is used 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 VOCs on ambient concentrations of  $PM_{2.5}$ . The results shown are ordinary least squares (OLS) estimates. First, the large number of observations (>8 million) results in hypothesis tests with high statistical power; note that most of the OLS 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 at first steeply declining as distance between source and receptor increases. At approximately 750 miles, the effect of distance mitigates and  $T_{ijs}$  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  $\text{NO}_x$ ,  $\text{PM}_{2.5}$ , and VOCs, the linear terms are positive, while the quadratic terms are negative. For  $\text{NO}_x$ , the cubic term also is positive. In contrast, for  $\text{PM}_{2.5}$  and VOCs the cubic term is negative. Bearing appears to have a somewhat different impact on the  $T_{ijs}$  corresponding to  $\text{SO}_2$ . Specifically, the linear and cubic terms are negative while the quadratic term is positive. The nature of the functional forms for the relationship between bearing and the  $T_{ijs}$  for  $\text{PM}_{2.5}$ ,  $\text{NO}_x$ , VOCs, and  $\text{SO}_2$  is shown in Figure 2. This figure indicates that for  $\text{NO}_x$ , VOCs, and  $\text{PM}_{2.5}$ ,  $T_{ijs}$  maximizes at between approximately  $45^\circ$  and  $90^\circ$ . That is, if the receptor is located from the northeast to due east of the source, the  $T_{ijs}$  is 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  $\text{SO}_2$ , there is not a clear maximum before  $90^\circ$ . Rather, the  $T_{ijs}$  gradually declines from  $0^\circ$  to  $90^\circ$ .

Conversely, Figure 2 indicates that for each pollutant,  $T_{ijs}$  minimizes between approximately  $250^\circ$  and  $270^\circ$ . That is, if the receptor is located approximately due west of the source, the  $T_{ijs}$  is 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 ( $T_{ijs}$ ) for emissions of primary  $\text{PM}_{2.5}$  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 the effect is what Figure 2 implies since the transfer coefficients for primary  $\text{PM}_{2.5}$  emissions are greatest between  $45^\circ$  and  $90^\circ$  (northeast and due east).

The top right panel of Figure 3 shows ( $T_{ijs}$ ) for a source located off 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 Gulf of Mexico. 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 ( $T_{ijs}$ ). Specifically, county receptors that are impacted most by emissions from the western Gulf are located relatively near 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 Gulf of Mexico. 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 ( $T_{ijs}$ ).

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 where transfer coefficients reflect the impact of emissions on resulting concentrations of  $PM_{2.5}$ .

Table 2 indicates that the impact of distance on ( $T_{ijs}$ ) is similar for both  $NO_x$  and  $SO_2$ . Namely, the linear and cubic distance terms have a negative impact on ( $T_{ijs}$ ), whereas the quadratic term increases ( $T_{ijs}$ ). 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 ( $T_{ijs}$ ) 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 ( $PM_{2.5}$ ). Dependent Variable: Log  $T_{ijs}$ .

VARIABLES	(1) NO <sub>x</sub>	(2) PM <sub>2.5</sub>	(3) SO <sub>2</sub>	(4) VOC
Distance	-4.76e-03*** (7.34e-06)	-5.87e-03*** (8.07e-06)	-4.65e-03*** (7.00e-06)	-5.87e-03*** (8.07e-06)
Distance <sup>2</sup>	3.22e-06*** (6.96e-09)	3.93e-06*** (7.65e-09)	3.08e-06*** (6.64e-09)	3.93e-06*** (7.65e-09)
Distance <sup>3</sup>	-7.37e-10*** (1.88e-12)	-8.85e-10*** (2.07e-12)	-6.92e-10*** (1.80e-12)	-8.85e-10*** (2.07e-12)
Bearing	8.55e-03*** (4.82e-05)	5.60e-03*** (5.30e-05)	-6.08e-04*** (4.60e-05)	5.60e-03*** (5.30e-05)
Bearing <sup>2</sup>	-9.17e-05*** (3.07e-07)	-7.11e-05*** (3.37e-07)	2.77e-05*** (2.92e-07)	-7.11e-05*** (3.37e-07)
Bearing <sup>3</sup>	1.080e-07*** (5.62e-10)	-1.45e-07*** (6.17e-10)	-7.15e-08*** (5.36e-10)	-1.45e-07*** (6.17e-10)
Constant	-14.79*** (2.97e-03)	-14.04*** (3.26e-03)	-14.80*** (2.83e-03)	-14.04*** (3.26e-03)
Observations	8,512,743	8,511,952	8,511,952	8,511,952
R <sup>2</sup>	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<sub>x</sub> to NO<sub>x</sub> and SO<sub>2</sub> to SO<sub>2</sub>. Dependent Variable: Log T<sub>jis</sub>.

VARIABLES	(1) NO <sub>x</sub> – NO <sub>x</sub>	(2) SO <sub>2</sub> – SO <sub>2</sub>
Distance	-1.14e-02*** (1.83e-05)	-6.00e-03*** (1.00e-05)
Distance <sup>2</sup>	1.17e-05*** (2.22e-08)	3.91e-06*** (1.08e-08)
Distance <sup>3</sup>	-3.31e-09*** (7.42e-12)	-7.65e-10*** (3.27e-12)
Bearing	1.38e-02*** (9.65e-05)	-1.23e-02*** (5.70e-05)
Bearing <sup>2</sup>	-9.72e-05*** (6.23e-07)	1.01e-04*** (3.60e-07)
Bearing <sup>3</sup>	1.71e-07*** (1.14e-09)	-1.99e-07*** (6.53e-10)
Constant	-13.06*** (5.56e-03)	-13.84*** (3.57e-03)
Observations	2,194,075	6,500,105
R <sup>2</sup>	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  $T_{jis}$ .

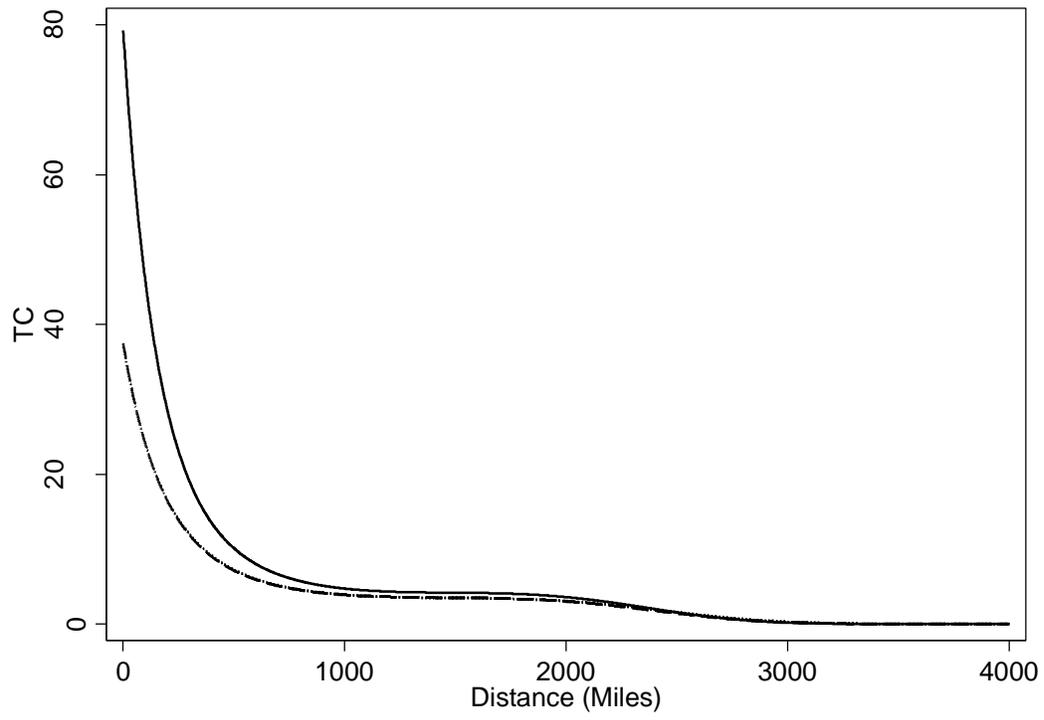


Figure 2. The Effect of Direction (Bearing) on  $T_{jis}$ .

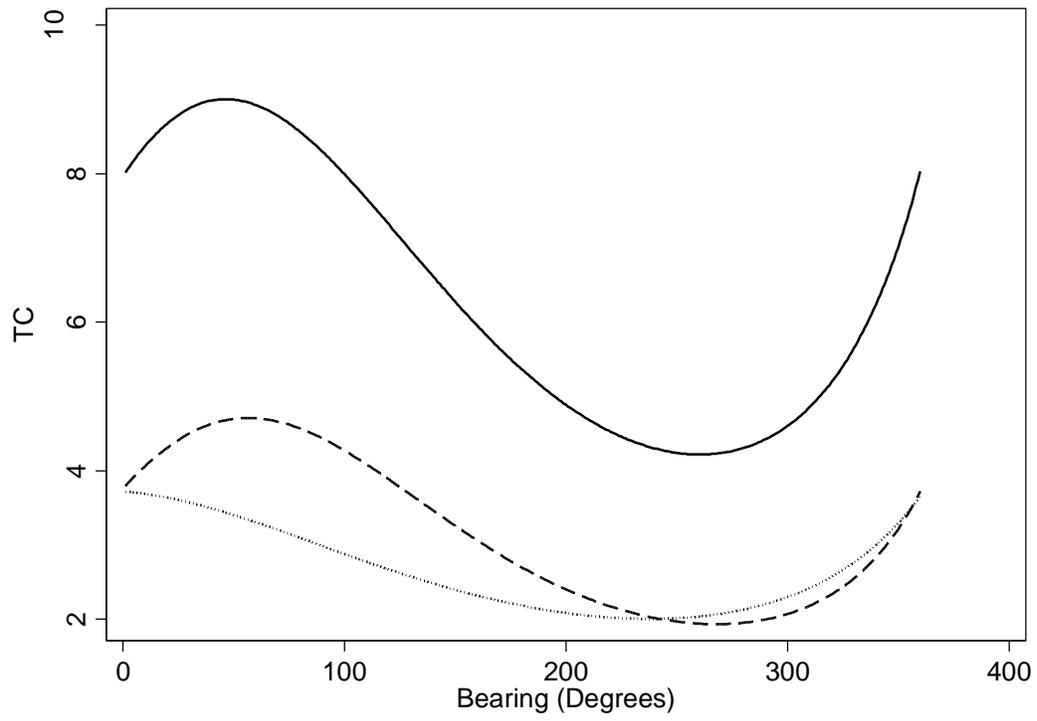
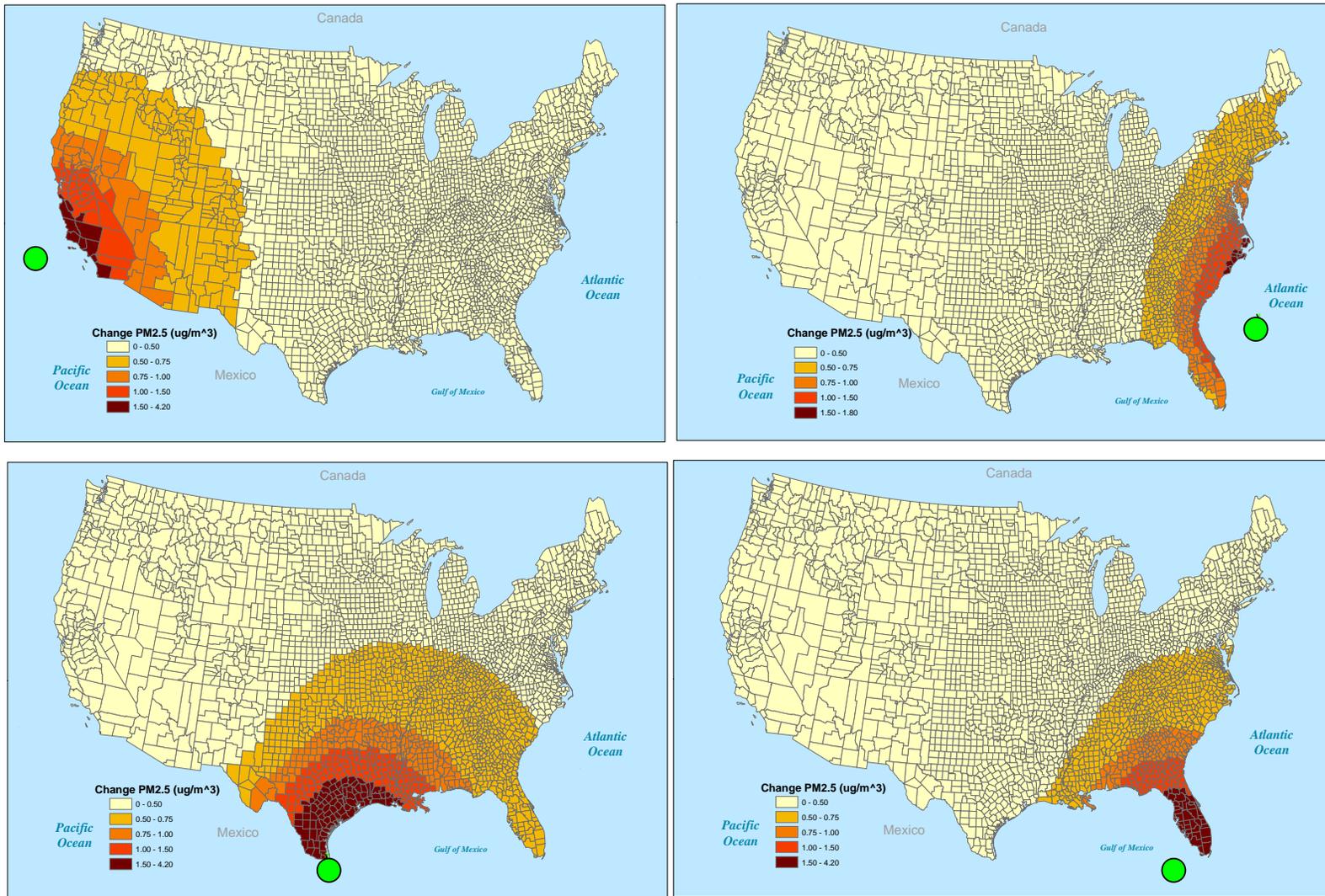


Figure 3. Transfer Coefficients:  $T_{ijs}$  for Primary  $PM_{2.5}$ .\*



\* 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 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, the data used to assess exposure to increased pollutant concentrations, the dose-response functions employed for each impact category, and valuation information are described.

### Exposure Assessment

To estimate air pollution exposure, the APEEP model 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 model-runs for the OECM include receptor projections for those receptor categories for which projections are available. The receptor information included in the APEEP model for each major impact category is as follows.

*Human Health:* To assess exposures for human health effects, the APEEP model uses population projections from the U.S. EPA's BenMAP model by county and age group.<sup>54</sup> The U.S. 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, the APEEP model 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, the APEEP model includes population projections for every fifth year (e.g., 2010, 2015, etc.) in the 75-year time horizon of the OECM.

Note that BenMAP's county- and age-specific population projections cover 2010 through 2030. Population projections by county and age group beyond 2030 are not available from the Census or other sources. In the absence of such projections, post-2030 population and age demographics are held constant at 2030 levels.<sup>55</sup> To the extent that the U.S. population grows significantly after 2030, this leads to underestimation of impacts.

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<sup>54</sup> BenMAP is available for download at <http://www.epa.gov/air/benmap/>.

<sup>55</sup> As an alternative to holding population and demographics constant at 2030 levels, different approaches were explored 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

*Agriculture:* The APEEP model 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 USDA's 2002 Census of Agriculture.<sup>56</sup> The APEEP model uses these yield estimates for each year in the OECM's analytic time horizon.

*Materials Damage:* For materials damage, the APEEP model 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, the APEEP model uses inventories developed from methods outlined in the National Acid Precipitation Assessment Program (NAPAP) (1991). The 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. An inventory was developed for other areas 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, an inventory previously developed from DOE's Commercial Buildings Energy Consumption Survey and Residential Energy Consumption Survey was used, as well as the Census Bureau's Annual Housing Survey.<sup>57</sup> 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.

## **Dose-Response Functions**

To estimate the physical effects of air pollution for exposed populations, the APEEP model 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.

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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.

<sup>56</sup> Data from the 2002 Census of Agriculture are available at <http://www.agcensus.usda.gov/Publications/2002/index.asp>.

<sup>57</sup> This inventory was developed for EPA's ongoing benefit-cost analysis of the Clean Air Act Amendments of 1990. See U.S. EPA (2010b).

## 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 (2002) and EPA's Science Advisory Board (SAB), the U.S. EPA has relied upon many studies from this literature to develop regulatory impact analyses (RIAs) for proposed and final air rules. To ensure that the OECM reflects the advice of the SAB and NAS expert reviewers, the APEEP model-runs conducted for the development of the OECM used the same D-R functions used by the U.S. 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, a pooled estimate of this relationship was developed based on the pooling procedures outlined in Abt Associates (2008). In effect, a pooled estimate of multiple D-R coefficients ( $\beta$ 's) is a weighted average of the  $\beta$  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  $\beta$  exists and that differences in  $\beta$  estimates across studies reflect sampling error. Given that the variance of each  $\beta$  value is an indicator of the certainty of the estimate, fixed effects pooling weights each  $\beta$  value based on the inverse of its variance.<sup>58</sup> Under this approach, estimates with small variance (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  $\beta$ , random effects pooling allows for the possibility that multiple values for  $\beta$  may exist. For example, the  $\beta$  value for PM mortality may vary geographically due to differences in the characteristics of PM in different locations. To account for the possibility of multiple  $\beta$  values, random effects pooling weights each  $\beta$  based on both within-study variance (like fixed effects weighting) and the variance between studies.<sup>59</sup>

To pool the  $\beta$  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  $\beta$  values from these studies because they do not represent parameter estimates for the same health impact function. Due to such differences in functional form, the pooled  $\beta$  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 the APEEP model to develop dollar-per-ton values for the OECM. For each health endpoint, the figure identifies the study(s) used and describes how the studies for a given endpoint were pooled (where applicable).

Note that the health effects incorporated into the APEEP model, as detailed in Table 1, include most, but not all, of the health impacts typically included in EPA's RIAs. For some health effects, the

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<sup>58</sup> If the variance of the  $\beta$  estimate in a study is represented by  $v_i$  and the weight assigned to that study is  $w_i$ , then

$$w_i = \frac{1/v_i}{\sum 1/v_i}$$

<sup>59</sup> Under random effects pooling, the weights assigned to a given  $\beta$  are based on the sum of within-study variance ( $v_i$ ), as specified as in the previous footnote, and between study variance ( $\eta^2$ ), 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  $\eta^2$ . Given  $v_i^*$ , the weight ( $w_i^*$ ) assigned to a given  $\beta$  is specified as follows:

$$w_i^* = \frac{1/v_i^*}{\sum 1/v_i^*}$$

epidemiological literature specifies impacts using a metric of air quality that is inconsistent with the metric used by the APEEP model. In particular, the health impact functions for many PM-related endpoints are based on the 24-hour average PM<sub>2.5</sub> concentration, rather than the annual average concentration estimated by the APEEP model. 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<sup>60</sup>, and work-loss days. The exclusion of these health endpoints from the dollar-per-ton impact values estimated by the APEEP model 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.<sup>61</sup> Both PM- and ozone-related mortality are reflected in the dollar-per-ton values generated by the APEEP model.

The D-R functions employed in the studies listed in Figure 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, the APEEP model uses D-R functions from the National Crop Loss Assessment Network (Lesser et al., 1990). These functions are specified as follows.

$$(1) \quad CY^* = \left( 1 - e^{-\left(\frac{O_3}{\sigma}\right)^\gamma} \right) \times CY^b$$

where:  $CY^*$  = crop yield following emissions perturbation

$CY^b$  = baseline crop yield (1996)

$O_3$  = 7- or 12-hour daily mean ozone concentrations (parts per million by volume)

$\gamma$  = statistically estimated shape parameter

$\sigma$  = statistically estimated parameter

Based on this equation, the APEEP model derives the change in crop yield associated with a given emissions scenario.

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<sup>60</sup> Minor restricted activity days associated with ozone exposure were included in the APEEP model for this analysis. Exposure to PM<sub>2.5</sub> also increases the risk of experiencing minor restricted activity days, but this change in risk related to PM<sub>2.5</sub> was not incorporated into the APEEP model for this analysis.

<sup>61</sup> 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).

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 <sub>2.5</sub>	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 25 <sup>th</sup> percentile and the dose-response coefficient from Laden et al. (2006) is the 75 <sup>th</sup> percentile.	0.0106	Log-linear	<ul style="list-style-type: none"> <li>Recent EPA regulatory impact analyses present separate estimates of the mortality impacts of PM<sub>2.5</sub> based upon both the Pope et al. (2002) and Laden et al. (2006) D-R functions.<sup>1</sup></li> <li>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 25<sup>th</sup> percentile equal to the Pope et al. (2002) estimate, the 75<sup>th</sup> percentile equal to the Laden et al. (2006) estimate, and the mean approximately equal to the mean of these two values (EPA 2010d).</li> </ul>
	Infant mortality (age <1 year)	Woodruff et al. (1997)	0.003922	Logistic	<ul style="list-style-type: none"> <li>EPA has estimated infant mortality based on the Woodruff et al. (1997) study in several RIAs.<sup>2</sup></li> </ul>
	Chronic bronchitis (ages 27 and older)	Abbey et al. (1995)	0.013185	Logistic	<ul style="list-style-type: none"> <li>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<sub>2.5</sub> exposure gives rise to the development of chronic bronchitis among U.S. populations.</li> </ul>

POLLUTANT	HEALTH EFFECT	LITERATURE SOURCES FOR D-R FUNCTIONS	D-R COEFFICIENT INCORPORATED INTO APEEP	FUNCTIONAL FORM	NOTES
Ozone	Premature mortality (all ages) <sup>3</sup>	Pooled estimate of D-R coefficients, using equal weighting, from the following studies: <ul style="list-style-type: none"> <li>• Ito et al. (2005)</li> <li>• Bell et al. (2004)</li> </ul>	0.000717	Log-linear	<ul style="list-style-type: none"> <li>• EPA’s regulatory impact analyses for the reconsideration of the ozone 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 D-R coefficients across all six of these studies. The Ito et al. (2005) and Bell et al. (2004) D-R coefficients were pooled 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.</li> <li>• Because EPA regulatory impact analyses have presented separate estimates of mortality impacts based on each mortality study, equal weighting is used rather than fixed effects or random effects weighting for ozone mortality.</li> </ul>

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 D-R coefficients from the following studies, using the random effects pooling procedure described in Abt Associates (2008): <ul style="list-style-type: none"> <li>• Schwartz (1995): New Haven</li> <li>• Schwartz (1995): Tacoma</li> </ul>	0.002994	Log-linear	<ul style="list-style-type: none"> <li>• The Schwartz (1995) assessments for New Haven and Tacoma examined respiratory hospital admissions associated with all respiratory disease.</li> <li>• EPA regulatory impact analyses also have used results from the Moolgavkar et al. (1997) Minneapolis and Schwartz (1994b) 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.</li> <li>• EPA regulatory impact analyses also have estimated changes in respiratory hospital admissions based on Schwartz (1994a). This study estimates pneumonia-related hospital admissions rather than admissions associated with all respiratory disease. Therefore, it would not be appropriate to pool the D-R coefficient from this study with those from Schwartz (1995).</li> </ul>
	Respiratory hospital admissions (age <2 years)	Burnett et al. (2001)	0.008177	Log-linear	<ul style="list-style-type: none"> <li>• 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.<sup>4</sup></li> </ul>
	Asthma-related emergency room visits (all ages)	Pooled estimate of D-R 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	<ul style="list-style-type: none"> <li>• This is consistent with the D-R functions employed in the U.S. EPA (2010c).</li> </ul>
Ozone (continued)	Minor restricted activity days (ages 18-64)	Pooled estimate (using fixed effects weighting) of year-specific D-R coefficients estimated in Ostro and Rothschild (1989)	0.002596	Log-linear	<ul style="list-style-type: none"> <li>• Ostro and Rothschild (1989) estimate separate D-R parameter values for the years 1976 through 1981. Consistent with several U.S. EPA regulatory impact analyses, the weighted average of these values was used, using the inverse of the variance of each parameter estimate as weights.<sup>4</sup></li> </ul>

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	<ul style="list-style-type: none"> <li>• 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 U.S. EPA Science Advisory Board's Advisory Council on Clean Air Compliance Analysis (2004), the APEEP model estimates changes in school absences for all school-aged children given the biological similarities between children aged 5 to 17.</li> <li>• Recent U.S. EPA regulatory impact analyses 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 D-R coefficients from these two studies because Chen et al. (2001) uses a linear specification while Gilliland et al. (2001) uses a log-linear specification.</li> </ul>
<p>Notes:</p> <ol style="list-style-type: none"> <li>1. Examples of EPA regulatory impact analyses that have used both the Pope et al. (2002) and Laden et al. (2006) D-R functions include U.S. EPA (2010a), U.S. EPA (2010c), U.S. EPA (2008), and U.S. EPA (2006).</li> <li>2. For example, see U.S. EPA (2008) and U.S. EPA (2006).</li> <li>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, the ozone health impact functions that use a 24-hour average or 1-hour maximum ozone metric to maximum 8-hour average ozone concentrations were therefore converted using the procedure described in Abt Associates (2008).</li> <li>4. For example, see U.S. EPA (2010c) and U.S. EPA (2008).</li> </ol>					

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 via 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, CDC multiple cause-of-death public-use data files	0.7037											
Chronic Bronchitis	Abbey et al. (1993), 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 Emergency Room 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)				780								
School Loss Days	National Center for Education Statistics (1996)			990									
<p>Notes:</p> <p>NHDS – National Hospital Discharge Survey, see <a href="ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHDS/">ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHDS/</a>.</p> <p>NHAMCS – National Hospital Ambulatory Medical Care Survey, see <a href="ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHAMCS/">ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHAMCS/</a>.</p> <p>Northeast - Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania</p> <p>Midwest - Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, Kansas</p> <p>South - Delaware, Maryland, District of Columbia, Virginia, West Virginia, North Carolina, South Carolina, Georgia, Florida, Kentucky, Tennessee, Alabama, Mississippi, Arkansas, Louisiana, Oklahoma, Texas</p> <p>West - Montana, Idaho, Wyoming, Colorado, New Mexico, Arizona, Utah, Nevada, Washington, Oregon, California, Alaska, Hawaii</p> <p>*Blank cells indicate that no value was necessary, as the D-R function for that health endpoint applies only to a limited number of age groups.</p>													

### *Man-made Materials*

The APEEP model uses D-R functions for man-made materials from two sources, the NAPAP studies (Atteraas and Haagenrud, 1982; Haynie, 1986) and the International Cooperative Programme on Effects on Materials (ICP, 1998). These studies specify separate D-R functions for (1) galvanized steel, (2) painted surfaces, and (3) carbonate stone surfaces.

Atteraas and Haagenrud (1982) estimate a linear D-R function relating ambient concentrations of SO<sub>2</sub> 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.

$$(1) \quad \Delta M = (\beta_0 SO_2 + \beta_1) M_b$$

where:  $\Delta M$  = mass loss of material,

$\beta_0, \beta_1$  = statistically estimated parameters (6.05 and 0.22, respectively, as estimated in Atteraas and Haagenrud (1982),

$SO_2$  = ambient concentration of SO<sub>2</sub>, and

$M_b$  = existing material quantity

For painted surfaces, the APEEP model relies upon the D-R relationship estimated by Haynie (1986), which was developed from erosion data for painted specimens exposed to both SO<sub>2</sub> and moisture. This function is specified as follows.

$$(2) \quad \Delta M_C = R_C \beta_0 (10^{-pH} - 10^{-5.2}) + \beta_1 SO_{2C} F_C$$

where:  $\Delta M_C$  = mass loss of material,

$\beta_0, \beta_1$  = statistically estimated parameters

$SO_{2C}$  = ambient concentration of SO<sub>2</sub>,

$pH$  = 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<sub>2</sub> concentration is zero or representative of a clean environment.

The APEEP model uses the D-R function from ICP (1998) to estimate the effect of ambient SO<sub>2</sub> on carbonate stone surfaces. 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 United States, and Canada. The D-R function estimated from these data is as follows.

$$(3) \quad \Delta S = (\beta_0 SO_2^k) \exp^{jT_C} + (\beta_1 R_C) H^+$$

where:  $\Delta S$  = surface recession of material,

$\beta_0, \beta_1, \gamma, \kappa$  = 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, the APEEP model 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, the APEEP model uses a combination of market price data, WTP values estimated in the peer-reviewed literature, and for certain health impacts, cost-of-illness (COI) estimates derived from studies of treatment costs. These values are described below by major impact category.

### *Health Effects*

To assess the value of the adverse health effects associated with increased pollutant concentrations, the APEEP model relied upon two types of valuation estimates: WTP values and 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, the APEEP model 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, the APEEP model 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 et al., 1987).

For both WTP and COI estimates, the APEEP model relies upon valuation studies employed by the U.S. EPA for numerous RIAs 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' 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 75-year analytic time horizon of the OECM, the APEEP model (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 WTP valuation estimates were used. Adjusted COI estimates were not used because the cost of treating an illness is not dependent upon income.

To develop income-adjusted estimates, income elasticities were used from EPA's BenMAP model that represents the percentage change in WTP associated with a 1 percent change in real income (Abt Associates, 2008). These elasticity values were then applied to GDP per capita, as projected in DOE's Annual Energy Outlook (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, DOE's projected growth rates for GDP and population in 2035 were presumed to apply to later years as well. The main body of this document presents the valuation estimates for each health endpoint for 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, the APEEP model will use crop pricing data from the U.S. Department of Agriculture, 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

The APEEP values materials-damage as the change in the present value of future maintenance costs. Under baseline emission conditions, the APEEP model assumes a 5-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.

$$(4) \quad M_{rb} = \delta \times (RC_{rb}(e^{-rt})/(1 - e^{-rt}))$$

where:  $M_{rb}$  = annual maintenance costs in county (r), baseline  $SO_2$ ,

$\delta$  = market interest rate

$RC_{rb}$  = replacement costs in receptor county (r), baseline  $SO_2$ , and

t = time of repairs (5,10,15,...)

As materials decay due to increased air pollution, regularly scheduled maintenance will occur more frequently. The APEEP model 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 5 years. To estimate the amended maintenance schedule, the APEEP model multiplies the ratio of  $I_p$  to  $I_b$  by the baseline five-year maintenance schedule, as shown in Equation 6.

$$(6) \quad t^* = 5 \times (I_p/I_b)$$

To estimate the present value of maintenance costs under this new maintenance schedule, the APEEP model 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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# APPENDIX E: DERIVATION OF ARCTIC AND NON-ARCTIC ALASKA EMISSION FACTORS

## Introduction and Overview

To provide additional documentation of the emission factors used in the OECM for planning areas off the coast of Alaska, this appendix provides a detailed description of the data sources and methods used to derive these values. Before presenting this information, it is important to note three challenges in estimating emissions associated with offshore oil and natural gas production in Alaska's offshore environment:

1. First, sea ice variability necessitates the presence of ice breaker vessels for OCS oil and gas activity in the Alaskan Arctic that must be captured in the emission factors for this area. For the purposes of estimating emission factors, it is assumed that ice breakers would be necessary in the Chukchi Sea and Beaufort Sea Planning Areas.
2. Under Section 432 of the omnibus spending bill enacted by Congress in December 2011, jurisdiction over air permitting on the OCS in the Arctic was transferred from the U.S. EPA to the U.S. Department of the Interior (DOI). Because the U.S. DOI is less likely to require best available control technology (BACT) than EPA, emission factors for Arctic Alaska are likely to be higher than those for the rest of Alaska's offshore environment, all else being equal.
3. Lastly, the limited availability of Alaska-specific emissions data complicates the derivation of emission factors for E&D activity in Alaska. Due to the limited availability of such data, a combination of Alaska-specific emissions data and emissions data for the Gulf of Mexico that the OECM applies to all planning areas along the contiguous 48 states is relied upon.

As noted above, this analysis used Alaska-specific emission factors where available. The following sources represent the most recently available data:

- U.S. EPA Region 10, Statement of Basis for Proposed Outer Continental Shelf Prevention of Significant Deterioration Permit No. R10OCS/PSD-AK-09-01, Shell Gulf of Mexico, Inc., Frontier Discoverer Drillship Chukchi Sea Exploration Drilling Program, January 8, 2010, and
- Shell Gulf of Mexico, Inc., The Revised Outer Continental Shelf Lease Exploration Plan, Chukchi Sea, Alaska. Appendix A: Outer Continental Shelf Information Form 137, May 2011.

In addition to these sources, this analysis also relied upon data from the following U.S. EPA sources to develop Alaska-specific emissions factors for CO<sub>2</sub>:

- U.S. EPA, AP-42, 3.4 Large Stationary Diesel and All Stationary Dual-fuel Engines, October 1996;
- U.S. EPA, AP-42, 3.3 Gasoline and Diesel Industrial Engines, October 1996; and
- U.S. EPA, AP-42, 1.4 Natural Gas Combustion, July 1998.

## Emission factors for exploration wells

Criteria pollutant emission factors for exploration wells drilled on the Alaska OCS were derived from the Statement of Basis for Shell's Frontier Discoverer exploration program, as referenced above. Appendix

A of this document (page A-1) provides a detailed accounting of the annual emissions associated with the Frontier Discover's exploration activity, including emissions for the Frontier Discover itself as well as associated fleets (ice breakers, resupply ship, and the oil-spill response fleet). The emissions data reported in the Statement of Basis are presented as tons of emissions per year and assume a drilling season of 168 days per year. The OEMCM, however, requires emission factors expressed as *tons per well*. To convert the Statement of Basis emissions data from tons per year to tons per well, the data were scaled under the assumption of 32 drilling days per well (i.e., the estimates were multiplied by 32/168).<sup>62</sup> Table 1 presents the resulting estimates.

The emissions data in Table 1 (and on page A-1 of the Statement of Basis) reflect the application of BACT to each Discoverer and associated fleets emissions source. As such, they are applicable to non-Arctic Alaska, given the December 2011 transfer of air permitting jurisdiction from U.S. EPA to U.S. DOI.<sup>63</sup> Under U.S. DOI authority, BACT will not always be required in Arctic Alaska. For the purposes of developing emission factors for the OEMCM, it is assumed that U.S. DOI would not require BACT controls for offshore emissions sources operating in the Arctic.

To estimate uncontrolled emissions per well, the values in Table 1 were scaled upward based on the control efficiency for each source/pollutant combination, as indicated in Appendix A of the Statement of Basis for Shell's Chukchi Sea exploration drilling program (referenced above). For example, the Statement of Basis indicates that the PM<sub>2.5</sub> control efficiency for BACT installed on generator engines is 50 percent. Uncontrolled PM<sub>2.5</sub> emissions from generator engines are therefore double the value for controlled engines. Based on this approach, Table 2 presents uncontrolled emissions per well for each of the vessels in the Statement of Basis document.

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<sup>62</sup> The estimate of 32 days per well was obtained from Shell Gulf of Mexico, Inc., The Revised Outer Continental Shelf Lease Exploration Plan, Chukchi Sea, Alaska. Appendix A: Outer Continental Shelf Information Form 137, May 2011.

<sup>63</sup> Although the Frontier Discoverer will operate in the Arctic, the Statement of Basis for the Frontier Discoverer permit includes estimates of *controlled* emissions because the document was completed prior to the December 2011 transfer of jurisdiction from the U.S. EPA to the U.S. DOI.

Table 1. Controlled Criteria Pollutant Emissions per Exploration Well in Alaska.

VESSEL	COMPONENT	UNITS	CONTROLLED EMISSIONS PER UNIT (TONS PER WELL)					
			NOX	SO2	PM10	PM2.5	CO	VOC
Frontier Discoverer	Generator Engine <sup>1</sup>	6	0.2952	0.0038	0.0762	0.0762	0.1067	0.0152
	Emergency Generator	1	0.0149	0.0000	0.0029	0.0029	0.0082	0.0016
	MLC Compressor	1	1.0229	0.0016	0.0248	0.0248	0.4762	1.0229
	HPU Engine	1	1.5581	0.0009	0.0305	0.0305	0.0476	0.0229
	Deck Crane	1	1.8095	0.0013	0.0133	0.0133	0.0381	0.0114
	Cementing Units and Logging Winches	1	2.2552	0.0011	0.0552	0.0552	0.1257	0.5733
	Heat Boiler <sup>1</sup>	2	0.6152	0.0049	0.0724	0.0724	0.2381	0.0038
	Incinerator	1	0.0114	0.0057	0.0190	0.0171	0.0743	0.0076
	Fuel Tanks	1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0019
	Supply Ship	1	0.0819	0.0000	0.0057	0.0057	0.0171	0.0057
	Drilling Mud System	1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0114
<b>Sub-total</b>			<b>9.7558</b>	<b>0.0433</b>	<b>0.7534</b>	<b>0.7515</b>	<b>1.9034</b>	<b>1.7577</b>
Associated Fleets	Ice Breaker #1		161.8819	0.1238	7.3200	6.4000	30.5714	6.8324
	Ice Breaker #2		13.5600	0.1295	2.2457	2.1238	45.1752	5.2743
	Resupply Ship		0.8076	0.0002	0.0610	0.0495	0.1067	0.0190
	OSR Ship -Nanuq		32.8286	0.0743	0.4781	0.3543	7.4552	2.5886
	OSR Ships Kvichak 1 & 2 w/ 3 work boats		7.5029	0.0076	0.1486	0.1486	0.3276	0.1524
<b>Total</b>			<b>226.3368</b>	<b>0.3787</b>	<b>11.0067</b>	<b>9.8277</b>	<b>85.5396</b>	<b>16.6244</b>
Notes:								
1. For those components where the number of units exceeds 1, the emission factors provided in this table reflect emissions for just one unit. For example, 0.2952 tons of NO <sub>x</sub> are emitted per well by each of the six generator engine units on the Frontier Discoverer. The emissions total, therefore, reflects 1.77 tons of NO <sub>x</sub> emissions from generator engines (6 × 0.2952).								

Table 2. Uncontrolled Criteria Pollutant Emissions per Exploration Well in Alaska.

VESSEL(S)	COMPONENT	UNITS	UNCONTROLLED EMISSIONS PER UNIT (TONS PER WELL)					
			NO <sub>x</sub>	SO <sub>2</sub>	PM <sub>10</sub>	PM <sub>2.5</sub>	CO	VOC
Frontier Discoverer	Generator Engine <sup>1</sup>	6	2.9524	0.0038	0.1524	0.1524	0.5333	0.0508
	Emergency Generator	1	0.0149	0.0000	0.0029	0.0029	0.0082	0.0016
	MLC Compressor	1	1.0229	0.0016	0.0495	0.0495	0.8985	1.9299
	HPU Engine	1	1.5581	0.0009	0.2032	0.2032	0.4762	0.2286
	Deck Cranes	1	1.8095	0.0013	0.0889	0.0889	0.3810	0.1143
	Cementing Units and Logging Winches	1	2.2552	0.0011	0.3683	0.3683	0.9678	0.6624
	Heat Boiler <sup>1</sup>	2	0.6152	0.0049	0.0724	0.0724	0.2381	0.0038
	Incinerator	1	0.0114	0.0057	0.0190	0.0171	0.0743	0.0076
	Fuel Tanks	1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0019
	Supply Ship	1	0.0819	0.0000	0.0057	0.0057	0.0171	0.0057
	Drilling Mud System	1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0114
<b>Sub-total</b>			<b>25.6987</b>	<b>0.0433</b>	<b>1.7966</b>	<b>1.7947</b>	<b>6.4992</b>	<b>3.2758</b>
Associated Fleets	Ice Breaker #1		161.8819	0.1238	7.3200	6.4000	30.5714	6.8324
	Ice Breaker #2		13.5600	0.1295	2.2457	2.1238	45.1752	5.2743
	Resupply Ship		0.8076	0.0002	0.0610	0.0495	0.1067	0.0190
	OSR Ship -Nanuq		32.8286	0.0743	0.6645	0.5233	7.6542	3.1263
	OSR Ships Kvichak 1 & 2 w/ 3 work boats		7.5029	0.0076	0.1486	0.1486	0.3276	0.1524
<b>Total</b>			<b>242.2797</b>	<b>0.3787</b>	<b>12.2363</b>	<b>11.0399</b>	<b>90.3344</b>	<b>18.6802</b>
Notes:								
1. For those components where the number of units exceeds 1, the emission factors provided in this table reflect emissions for just one unit. For example, 2.952 tons of NO <sub>x</sub> are emitted per well by each of the six generator engine units on the Frontier Discoverer. The emissions total therefore reflects 17.7 tons of NO <sub>x</sub> emissions from generator engines (6 × 2.952).								

Using the data in Tables 1 and 2, separate exploration well emission factors for Arctic Alaska (the Chukchi and Beaufort Sea Planning Areas) and non-Arctic Alaska (all other planning areas in the Alaska OCS region) were estimated. These emission factors are specified as follows:

- **Arctic Alaska:** For Arctic Alaska, the exploration well emission factors reflect *uncontrolled* emissions for all vessels and components reflected in Table 2. Thus, the “Total” row at the bottom of Table 2 represents the per-well emission factors incorporated into the OECM.
- **Non-Arctic Alaska:** Emission factors for Alaska planning areas outside the Arctic reflect *controlled* emissions, as presented in Table 1, for all vessels and components listed in the table with the exception of ice breakers. These vessels are assumed not to be necessary for exploration activity in non-Arctic planning areas.

Table 3 presents the estimated criteria pollutant emission factors for Arctic and non-Arctic Alaska based on the assumptions outlined above.

Table 3. Criteria Pollutant Emission Factors for Exploration Wells Drilled on the OCS in Alaska (Tons Per Well).

GEOGRAPHIC AREA	NO <sub>x</sub>	SO <sub>2</sub>	PM <sub>10</sub>	PM <sub>2.5</sub>	CO	VOC
Arctic Alaska	242.3	0.3787	12.24	11.04	90.33	18.68
Non-Arctic Alaska	50.89	0.1254	1.441	1.304	9.793	4.518

As suggested above, the data in the Statement of Basis document are limited to criteria pollutants and do not reflect emissions of greenhouse gases. To estimate CO<sub>2</sub> emissions per well, emission factors were obtained from EPA's AP-42 emissions documentation and these values were matched to the emissions sources included in Tables 1 and 2. The data that were used from AP-42 are as follows:

- **Large Stationary Diesel Engines:** AP-42 reports an emission factor of 165 pounds per million British thermal units (lbs/MMBtu) for these sources.<sup>64</sup> This value is applied to generator engines, the Frontier Discoverer supply ship, and the associated fleets' resupply ship.
- **Diesel Industrial Engines:** The CO<sub>2</sub> emission factor for these sources is an estimated 164 lb/MMBtu in AP-42.<sup>65</sup> This value is applied to the emergency generator, MLC compressor, HPU engine, deck cranes on the Discoverer, and the cementing units and logging winches.
- **Natural Gas Boilers:** AP-42 estimates CO<sub>2</sub> emissions of 120,000 pounds per million cubic feet for these sources.<sup>66</sup> To convert to lbs/MMBtu (making it consistent with the units used for the other two AP-42 values), it is assumed that natural gas has a heating value of 1,028 Btu per cubic foot. This converts the AP-42 value to 116 lbs/MMBtu. This value was applied to the heat boilers on the Frontier Discoverer.

Insufficient data were available to match the other emissions sources in Tables 1 and 2 with CO<sub>2</sub> emission factors in AP-42.

As noted above, the AP-42 emission factors are expressed as lbs/MMBtu. Equations 1 and 2 summarize the procedure that was followed for converting these values to tons per well. Equation 1 was applied to those sources for which the Statement of Basis provides a power rating expressed in terms of horsepower (i.e., all of the sources listed in the three bullets above except for heat boilers); equation 2 was applied to sources for which the Statement of Basis provides a power rating in terms of MMBtu per hour (i.e., heat boilers).

$$(1) \quad E = e \times h \times p \times 24 \times f \times d \div 2000$$

where:  $E$  = emission factor expressed as tons per well drilled;  
 $e$  = emission factor expressed as pounds per MMBtu;  
 $h$  = diesel heat rate, assumed to be 0.007 MMBtu/hp-hr, as presented in the Statement of Basis document;

<sup>64</sup> U.S. EPA, AP-42, 3.4 Large Stationary Diesel and All Stationary Dual-fuel Engines, October 1996.

<sup>65</sup> U.S. EPA, AP-42, 3.3 Gasoline and Diesel Industrial Engines, October 1996.

<sup>66</sup> U.S. EPA, AP-42, 1.4 Natural Gas Combustion, July 1998.

$p$  = power rating expressed in terms of horsepower;  
 24 = number of hours per day;  
 $f$  = operational factor indicating percent of hours during the day that the equipment is operational;  
 $d$  = number of days to drill a well (32 days); and  
 2000 = pounds per ton

$$(2) \quad E = e \times p_t \times 24 \times f \times d \div 2000$$

Where  $p_t$  = power rating expressed as MMBtu per hour; and  
 $E$ ,  $e$ ,  $f$ , and  $d$  are defined as above.

As indicated in Equations 1 and 2, estimation of the CO<sub>2</sub> emissions factor for each source requires information on its power rating and the percentage of the time that it operates. Both were obtained from the Statement of Basis document. Power ratings were obtained directly from the document, and  $f$  was estimated by dividing the maximum hours of daily operation by 24 hours per day. Table 4 summarizes these values.

Table 4. Power Rating and Operational Information for Select Sources.

EMISSIONS SOURCE	POWER RATING	PERCENT OF TIME OPERATIONAL
Generator Engine	1325 hp	100%
Emergency Generator	131 hp	8%
MLC Compressor	540 hp	100%
HPU Engine	250 hp	100%
Deck Cranes	365 hp	100%
Cementing Units and Logging Winches <sup>1</sup>	220 hp <sup>1</sup>	21% <sup>2</sup>
Heat Boiler	7.97 MMBtu/hr	100%
Supply Ship at Discoverer	292 hp	50%
Associated Fleets Resupply Ship	6,344 hp	17%
Source: Values derived from U.S. EPA Region 10, Statement of Basis for Proposed Outer Continental Shelf Prevention of Significant Deterioration Permit No. R10OCS/PSD-AK-09-01, Shell Gulf of Mexico, Inc., Frontier Discoverer Drillship Chukchi Sea Exploration Drilling Program, January 8, 2010.		
Notes: <ol style="list-style-type: none"> <li>The power rating for cementing units and logging winches represents the average of the values reported in Appendix A of U.S. EPA Region 10, Statement of Basis for Proposed Outer Continental Shelf Prevention of Significant Deterioration Permit No. R10OCS/PSD-AK-09-01, Shell Gulf of Mexico, Inc., Frontier Discoverer Drillship Chukchi Sea Exploration Drilling Program, January 8, 2010.</li> <li>Operational time value for cement units and logging winches based on the maximum hourly fuel use (in pounds) for each equipment unit reflected in this category and the maximum daily fuel use for the components combined (320 gallons per day), both of which are presented in the Statement of Basis document (see note 1 for full citation).</li> </ol>		

Applying the values in Table 4 to Equations 1 and 2, the CO<sub>2</sub> emission factors presented in Table 5 are estimated. Summing across the sources listed, it is estimated that there are 5,309 tons of CO<sub>2</sub> emissions per well. This value is applied to exploration wells in both Arctic and non-Arctic Alaska.

Table 5. CO<sub>2</sub> Emission Factors for Exploration Wells in Alaska.

EMISSIONS SOURCE	NUMBER OF UNITS	CO <sub>2</sub> EMISSIONS PER WELL (TONS)
Generator Engine	6	587.7
Emergency Generator	1	4.81
MLC Compressor	1	238.1
HPU Engine	1	110.2
Deck Cranes	1	160.9
Cementing Units and Logging Winches <sup>1</sup>	1	20.6
Heat Boiler	2	357.25
Supply Ship at Discoverer	1	64.75
Associated Fleets Resupply Ship	1	469.0
<b>TOTAL</b>		5308.8

It is noted that the approaches for estimating criteria pollutant and CO<sub>2</sub> emissions factors presented here for exploration wells implicitly assume that engines operate at full load (i.e., the load factor equals 1). In practice, engines typically would run below their capacity. The Statement of Basis, however, does not include load factors for the individual emissions sources used during exploration, as the intent of the document is to estimate the potential emissions of these sources. The emission factors presented here may therefore overestimate the emissions associated with exploration activity in the Alaska offshore environment.

### Emissions factors for development wells

Emissions data specific to development wells in the Alaska OCS region are not readily available. In the absence of such data, the emission factors for exploration wells presented above are used as an approximation of the emission factors for development wells. This is consistent with the approach used for planning areas not in the Alaska OCS region, as indicated by the emission factors presented in Chapter 4.

### Emissions factors for platform construction and removal

Similar to development wells, emissions data for platform construction and removal are not readily available for the Alaska OCS Region. Absent such information, emission factors for platform construction and removal in Alaska are developed based on the corresponding emission factors for planning areas offshore from the contiguous 48 states<sup>67</sup> and for the associated fleets (i.e., ice breakers,

<sup>67</sup> While the OECM uses the same emission factors for all planning areas along the contiguous U.S., we note that these emission factors are based on emissions data for the Gulf of Mexico.

resupply ship, and oil spill response vessels) emission factors for exploration activity in Alaska. These emission factors are developed separately for Arctic Alaska and non-Arctic Alaska as follows:

- **Arctic Alaska:** For each pollutant, the emission factor for platform construction and demolition in Arctic Alaska is estimated as the sum of (1) the corresponding emission factor for planning areas offshore from the contiguous U.S., and (2) modified versions of the associated fleet emissions factors presented above for uncontrolled emissions (i.e., without BACT). As indicated in Chapter 4, the OEEM uses platform construction/demolition emission factors for three depth categories in planning areas along the contiguous U.S. To minimize the risk of underestimating emissions in Alaska, it is assumed that the emissions factors for the deepest depth category (i.e., the highest emission factors of the three categories) are applicable to Alaska.

Emissions associated with ice breakers, a resupply ship, and oil-spill response vessels are added under the assumption that all would be necessary during platform construction.<sup>68</sup> However, the estimates presented in Table 2 above are based on 32 days of activity, consistent with the average time to drill an exploration well. For platform construction, these estimates are scaled to reflect the average time required to construct a platform. Based on input from BOEM, this is estimated to be 90 days.<sup>69</sup>

- **Non-Arctic Alaska:** To develop emission factors for platform construction/demolition in non-Arctic Alaska, this analysis follows the same approach as in Arctic Alaska with two exceptions. First, it is assumed that ice breakers are not required outside the Arctic. The associated fleet emissions for non-Arctic Alaska, therefore, reflect resupply ships and oil-spill response vessels only. Second, instead of using the uncontrolled emissions for these vessels, controlled emissions are used. Outside of the Arctic planning areas, the U.S. EPA has jurisdiction over air permitting and would be much more likely to require BACT.

Following this approach, this analysis estimates the emission factors presented in Table 6.

Table 6. Emission Factors for Platform Construction and Demolition in Alaska (Tons Per Platform)<sup>1</sup>.

	NO <sub>x</sub>	SO <sub>2</sub>	PM <sub>10</sub>	PM <sub>2.5</sub>	CO	VOC	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O
<b>Arctic Alaska</b>	800.9	32.1	34.1	30.8	263.3	48.1	13,910	0.103	0.576
<b>Non-Arctic Alaska</b>	307.5	31.4	6.7	6.3	49.7	12.5	13,910	0.103	0.576
Notes:									
1. The emission factors presented here are applied separately to platform construction and demolition.									
2. Although ice breakers are not required in the non-Arctic planning areas, the CO <sub>2</sub> , CH <sub>4</sub> , and N <sub>2</sub> O emission factors for non-Arctic Alaska are the same as the values for Arctic Alaska because insufficient data were available to estimate ice breaker emission factors for these gases.									

<sup>68</sup> Based on personal communication with Virginia Raps, BOEM, January 22, 2013.

<sup>69</sup> Personal communication with James Craig, BOEM, January 28, 2013.

## Emissions factors for support vessels

Comprehensive data on support vessel emissions for the Alaska OCS Region are not readily available. In the absence of these data, the support vessel emission factors (expressed as tons per platform) for the planning areas along the contiguous U.S.<sup>70</sup> are applied to both Arctic and non-Arctic Alaska. For the Arctic, however, the support vessel fleet will likely include ice breakers, which are not reflected in the emission factors for the contiguous U.S. To incorporate emissions from these vessels into the emission factor for Arctic Alaska, this analysis estimates ice breaker emissions per platform (without BACT for Arctic Alaska) by scaling the emission factors presented in Table 2. As noted above, the values in Table 2 reflect 32 days of operation per year. To estimate ice breaker emissions per platform, this analysis assumes 365 days of operation per year and scales the estimates in Table 2 (i.e., it is assumed that they must always be available). For example, to estimate annual NO<sub>x</sub> emissions per platform for ice breaker 1, the estimate of 161.9 tons in Table 2 is multiplied by 365/32, which yields 1,847 tons per year per platform. Following this approach, Table 7 presents the emission factors for support vessels in Alaska.

Table 7. Emission Factors for Support Vessels in Alaska (Tons Per Platform Per Year).

	NO <sub>x</sub>	SO <sub>2</sub>	PM <sub>10</sub>	PM <sub>2.5</sub>	CO	VOC	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O
<b>Arctic Alaska</b>	2,096.8	15.8	110.8	98.9	873.1	139.7	5,247	0.0332	0.2489
<b>Non-Arctic Alaska</b>	95.6	12.9	1.7	1.7	9.1	1.7	5,247	0.0332	0.2489

Note: CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O values are the same for Arctic and non-Arctic Alaska because insufficient data were available to estimate emission factors specific to these gases for the ice breakers reflected in the Arctic Alaska emission factors for other pollutants.

## Emission factors for other sources

The OECM estimates emissions for several other sources in Alaska, including, but not limited to, pipe-laying vessels, helicopters, survey vessels, and FPSOs. For these sources, the OECM uses the emission factors for sources in planning areas along the contiguous U.S.<sup>71</sup>

<sup>70</sup> Although the OECM uses the same emission factors for all planning areas along the contiguous U.S., note that these emission factors are based on emissions data for the Gulf of Mexico.

<sup>71</sup> As indicated in previous footnotes, the emission factors for all planning areas along the contiguous U.S. are based on emissions data from the Gulf of Mexico OCS Region.

## APPENDIX F: SPATIAL DISTRIBUTION OF OIL AND NATURAL GAS SUBSTITUTES UNDER THE NO ACTION ALTERNATIVE

Within the OECM, the No Action Alternative (NAA) represents the absence of Five Year Program activity (i.e., no lease sales are scheduled for the five year period).<sup>72</sup> To estimate the benefits and costs associated with this scenario, the model must account for the response of energy markets to forgone OCS production. The *Market Simulation Model (MarketSim)* provides the first step in this analysis. *MarketSim* calculates three primary impacts of the No Action Alternative on energy markets: (1) the increase in the quantity of crude oil shipped to the U.S. via tanker; (2) the increase in the quantity of natural gas shipped to the U.S. via tanker; and (3) the increase in domestic onshore production of oil, natural gas, and coal. The environmental consequences associated with these shifts in energy markets include: (1) oil spills from incoming tankers; (2) emissions from incoming tankers; and (3) emissions from increased onshore production.<sup>73</sup>

To quantify these impacts, the OECM must make assumptions about the geographic distribution of increased tanker imports and incremental onshore production. The version of the OECM used for the 2012-2017 Program assumed that incremental tanker imports of crude oil were distributed in proportion to the average annual fraction of crude tanker trips that arrived at each planning area and that incremental shipments of natural gas were also distributed in proportion to current patterns. Additionally, the model assumed that the geographic distribution of increased onshore production was consistent with the current distribution of onshore production. The costs of these onshore emissions were quantified using generic onshore emission factors and monetized using generic dollar per ton values that reflected the current distribution of onshore oil, gas, and coal production across the U.S.

The current version of the OECM described in this document improves upon the previous version by refining the model assumptions concerning the geographic distribution of impacts under the No Action Alternative. This appendix describes the methods used to develop the improved geographic data. Various data sets available from the U.S. Energy Information Administration (EIA) on production, refinement, imports, and transportation of oil and natural gas serve as the basis for this analysis. All EIA data on the transport of crude oil are reported at the level of Petroleum Administration for Defense Districts (PADDs).<sup>74</sup> The United States is divided into five PADDs: PADD 1 (East Coast), PADD 2 (Midwest), PADD 3 (Gulf of Mexico area), PADD 4 (Rocky Mountains), and PADD 5 (West Coast, AK, HI) (See Figure 1). PADDs 1, 3, and 5 all contain coastline with OCS planning areas located offshore. The Atlantic OCS planning areas are in PADD 1, the Gulf of Mexico OCS planning areas are in PADD 3, and the Pacific and Alaska planning areas are in PADD 5. Throughout this appendix, all regional production and transport data for oil are presented by PADD. In addition, although natural gas production and

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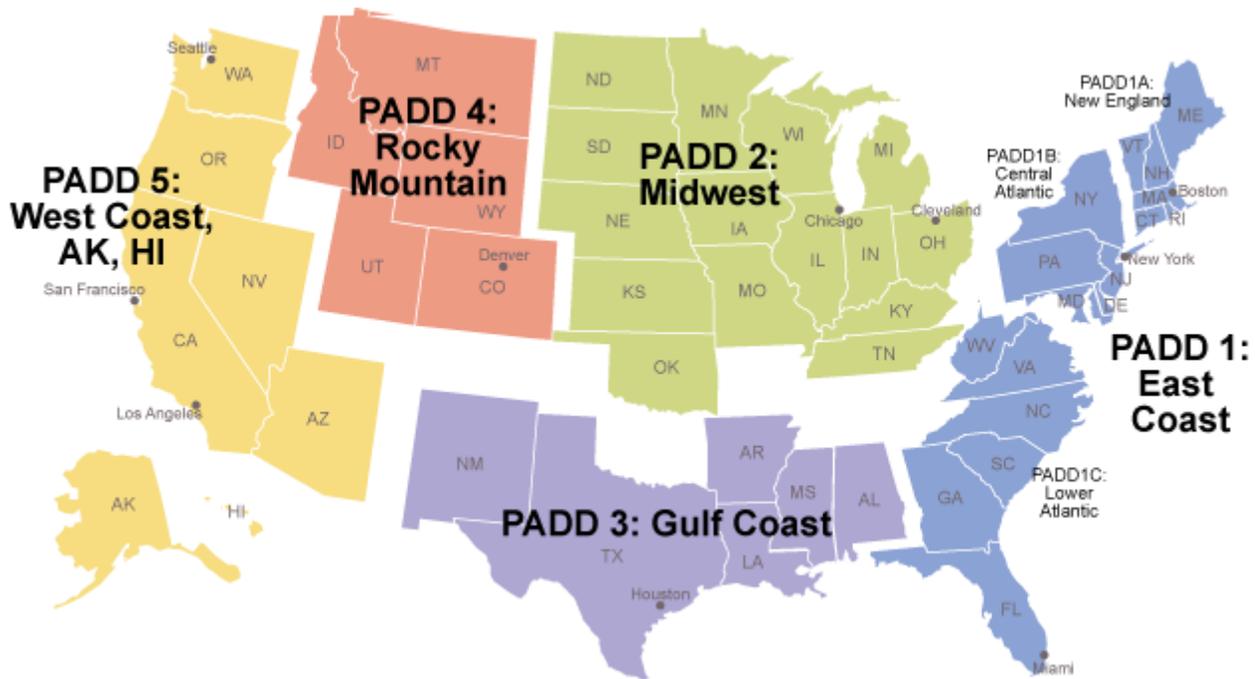
<sup>72</sup> In practice, Five Year Program decisions are made by planning area, and a “No Sale Option” is always available for each area. The models described in this report can be used for a full NAA (no lease sales for any areas) or to estimate the effects of selecting the No Sale Option for one or more areas. The models work the same way in either case.

<sup>73</sup> The OECM does not estimate other environmental and social costs that might result from increased onshore oil and gas (or coal) production, such as contamination of groundwater and rail car derailment. Similarly, it does not estimate costs that might result from pipeline transportation of oil and gas.

<sup>74</sup> While it is impossible to determine the ultimate destination of crude oil and gas, the availability of aggregate data on imports and flows between PADDs does allow for improvements to the OECM’s geographical allocation of incremental oil and gas production, importation, and transportation under the NAA.

transport data are not reported by PADD, these data are presented at the PADD level for consistency with the information presented on oil production and transportation.

Figure 1: Map of Petroleum Administration for Defense Districts



### Geographic distribution of incremental crude oil imports

The OECM’s assumptions regarding the geographic distribution of incremental imports under the NAA reflect the following two-step analysis described in greater detail below:

1. **Determine which regions of the U.S. are served by oil production in a given OCS planning area:** For a given PADD, the OECM makes this determination based on the portion of domestic crude production that is shipped to refineries in that PADD versus transported to other PADDs. For example, if 30 percent of production in PADD 3 is estimated to remain in PADD 3, the OECM assumes that 30 percent of the OCS production in the Central Gulf of Mexico is sent to refineries in the Gulf of Mexico region and that the remainder is sent to other PADDs (regions).
2. **For each area served by OCS production, identify the regions that supply crude oil to that area.** The different areas served by a given PADD have their own unique mix of crude oil imports. To varying degrees, each PADD relies in part on imports it receives directly from foreign sources and imports that arrive at ports in other PADDs but are then transported to that PADD.
3. **Integrate the information from Steps 1 and 2:** The information from Steps 1 and 2, when combined, provide the distribution of oil imports associated with the NAA. For example, for Step 1, assume that an E&D scenario includes OCS production in the Central Gulf of Mexico and that 30 percent of OCS oil in the planning area is assumed to be shipped to refineries in that planning

area and that the remaining 70 percent is shipped to refineries in the Atlantic region. Assume further that 50 percent of the oil imports sent to refineries in the Gulf of Mexico arrived at ports in that region and that 90 percent of imports processed in refineries in the Atlantic first arrive in the U.S. at Gulf of Mexico ports. Based on these assumptions, 78 percent ( $0.3 \times 0.5 + 0.7 \times 0.9$ ) of the oil imports that displace OCS production in the Central Gulf of Mexico would be replaced by imports to the Gulf of Mexico region

EIA data on crude oil movements between PADDs via pipeline, tanker, and barge serve as the basis for the estimates of inter-regional transport of crude.<sup>75</sup> These numbers were adjusted to account for two primary shortcomings in the EIA data: (1) the EIA does not track transport of crude by rail, and (2) the EIA does not differentiate between the transport of domestic and foreign crude. The approach for addressing these shortcomings is presented in the following sections. This appendix then turns to implementation of Steps 1 and 2 above.

### ***Crude by rail***

The first issue with the data on inter-PADD movements is that, at the time of this writing, the EIA does not track transport of crude via railroad, a method of growing importance in recent years. However, the EIA does compile information on refinery receipts of crude oil by rail for each PADD. Since the majority of shipments by rail originate from North Dakota's Bakken formation<sup>76</sup> (located in PADD 2), it is reasonable to infer that all refinery receipts of crude oil by rail represent deliveries from PADD 2.<sup>77</sup>

### ***Foreign versus domestic crude***

The second issue with EIA data on inter-PADD movements is that the data do not differentiate between transport of domestic and foreign crude. It is likely that domestic crude oil, including OCS production, follows a considerably different transport pattern than foreign oil.<sup>78</sup> As a result, this analysis parses out the foreign portion of inter-PADD deliveries to provide a more accurate estimate of the distribution of oil produced domestically.

EIA data on crude oil imports provide some insight into the movements of foreign crude. The EIA reports crude imports two different ways: (1) quantity of imports that enter each PADD and (2) quantity of

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<sup>75</sup> U.S. EIA. Movements by Pipeline between PAD Districts. Released September 29, 2014. Accessed October 20, 2014 at: [http://www.eia.gov/dnav/pet/pet\\_move\\_pipe\\_dc\\_R20-R10\\_mbbl\\_m.htm](http://www.eia.gov/dnav/pet/pet_move_pipe_dc_R20-R10_mbbl_m.htm)

U.S. EIA. Movements by Tanker and Barge between PAD Districts. Released September 29, 2014. Accessed October 20, 2014 at: [http://www.eia.gov/dnav/pet/pet\\_move\\_tb\\_dc\\_R20-R10\\_mbbl\\_m.htm](http://www.eia.gov/dnav/pet/pet_move_tb_dc_R20-R10_mbbl_m.htm)

<sup>76</sup> U.S. EIA. Crude-by-rail transportation provides Bakken Shale production access to major markets. June 10, 2014. Accessed December 2014 at: <http://www.eia.gov/todayinenergy/detail.cfm?id=16631#>

<sup>77</sup> Following the completion of the analysis presented in this appendix, the EIA released a dataset which tracks movements of crude oil by rail. While this analysis correctly inferred that the majority of crude oil moved by rail originates in PADD 2, the new EIA dataset indicates that this analysis underestimates total movements of crude by rail. Regardless, incorporation of the newly released data has only a minor impact on the estimated geographical allocation of incremental imports and onshore production presented in this appendix. The new dataset on movements of crude oil by rail can be accessed at: [http://www.eia.gov/dnav/pet/pet\\_move\\_rail\\_a\\_EPC0\\_RAIL\\_mbbl\\_a.htm](http://www.eia.gov/dnav/pet/pet_move_rail_a_EPC0_RAIL_mbbl_a.htm)

<sup>78</sup> The quality of crude oil ranges from light sweet oil that is volatile and easily refined into gasoline and other such high-value fuels to heavy sour crude, which is viscous and must be extensively refined. The equipment in each refinery is designed to most efficiently handle a specific range of crude quality, and refineries will blend the least expensive crudes to obtain that quality. Accordingly, the recent abundance of domestically produced light sweet crude has caused dramatic changes in the quality of crude imported. This likely has led to even greater differences in the transportation and use of domestic and imported crude oil by refineries.

imports that are processed in each PADD. Together these numbers indicate whether a PADD is, on net, receiving or delivering foreign crude to other PADDs (see Table 1).

Table 1: Imports of Crude Oil by PADD (Thousand Barrels, 2013).

PADD	IMPORTS INTO PADD	IMPORTS PROCESSED IN PADD	NET RECEIPTS OF FOREIGN CRUDE FROM OTHER PADDs
<b>PADD 1 (East Coast)</b>	283,040	287,076	4,036
<b>PADD 2 (Midwest)</b>	683,916	671,163	(12,753)
<b>PADD 3 (Gulf Coast)</b>	1,347,373	1,373,682	26,309
<b>PADD 4 (Rocky Mountains)</b>	107,879	90,009	(17,870)
<b>PADD 5 (West Coast)</b>	399,272	399,550	278
<b>Total</b>	2,821,480	2,821,480	-

Sources:

1. U.S. EIA. Crude Oil Imports by Area of Entry. Released September 29, 2014. Accessed October 22, 2014 at: [http://www.eia.gov/dnav/pet/pet\\_move\\_imp\\_a\\_epc0\\_im0\\_mbb1\\_a.htm](http://www.eia.gov/dnav/pet/pet_move_imp_a_epc0_im0_mbb1_a.htm)
2. U.S. EIA. Crude Oil Imports by Processing Area. Released October 30, 2014. Accessed November 3, 2014 at: [http://www.eia.gov/dnav/pet/pet\\_move\\_imp2\\_a\\_epc0\\_ip0\\_mbb1\\_a.htm](http://www.eia.gov/dnav/pet/pet_move_imp2_a_epc0_ip0_mbb1_a.htm)

Further inferences can be drawn from EIA data on U.S. imports by country of origin. In particular, the breakdown of imports from Canada versus other countries provides useful information (see Table 2). Because the landlocked PADDs (2 and 4) can only receive imports directly from Canada, any non-Canadian imports that are processed within PADD 2 or 4 must have been delivered from a coastal PADD. Similarly, PADD 3 cannot receive any crude oil directly from Canada by land, without the crude first passing through another PADD. Though PADD 3 receives a small amount of Canadian crude via oil tanker, the majority of all Canadian crude processed in PADD 3 must be delivered from PADD 2 or PADD 4. Data from the U.S. Army Corps of Engineers indicate that PADD 3 received approximately 890,000 barrels of crude from Canada via waterborne methods of transportation in 2012.<sup>79</sup> This represents less than two percent of all Canadian imports processed in PADD 3 in that year.

<sup>79</sup> U.S. Army Corps of Engineers, Navigation Data Center, Waterborne Commerce Statistics Center. "Foreign Cargo Inbound and Outbound." Accessed November 4, 2014 at: <http://www.navigationdatacenter.us/data/dataimex.htm>

Table 2: Imports of Crude Oil by Country of Origin (Thousand Barrels, 2013)

PADD	IMPORTS PROCESSED FROM CANADA	IMPORTS PROCESSED FROM ALL OTHER COUNTRIES
PADD 1 (East Coast)	78,254	208,822
PADD 2 (Midwest)	655,581	15,582
PADD 3 (Gulf Coast)	46,877	1,326,805
PADD 4 (Rocky Mountains)	90,009	-
PADD 5 (West Coast)	70,515	329,035
<b>Total</b>	<b>941,236</b>	<b>1,880,244</b>

Source:

1. U.S. EIA. Crude Oil Imports from Canada. Released November 26, 2014. Accessed December 9, 2014 at: [http://www.eia.gov/dnav/pet/pet\\_move\\_impcp\\_a1\\_nca\\_epc0\\_ip0\\_mbb1\\_a.htm](http://www.eia.gov/dnav/pet/pet_move_impcp_a1_nca_epc0_ip0_mbb1_a.htm)
2. U.S. EIA. Crude Oil Imports by Processing Area. Released October 30, 2014. Accessed November 3, 2014 at: [http://www.eia.gov/dnav/pet/pet\\_move\\_imp2\\_a\\_epc0\\_ip0\\_mbb1\\_a.htm](http://www.eia.gov/dnav/pet/pet_move_imp2_a_epc0_ip0_mbb1_a.htm)

Data on crude oil imports by country of origin therefore provide two primary insights:

1. PADD 2 processed 15,582 thousand barrels of crude oil from foreign countries other than Canada. Since PADD 2 is landlocked, this crude must have been transported from PADD 1 or PADD 3. Since PADD 1 only transported 2,729 thousand barrels of oil to PADD 2 overall (domestic or foreign; see Table 3), it is assumed that these deliveries are from PADD 3.
2. PADD 3 processed 46,877 thousand barrels of crude from Canada. Aside from a small amount imported via tanker, this crude must have first passed through PADD 2 or PADD 4. Since PADD 4 only transported 5,385 thousand barrels of oil to PADD 3 overall, it is assumed that all deliveries of Canadian crude to PADD 3 not sent by tanker pass through PADD 2.

The various sources of data on crude oil imports described above, combined with data on the movement of all crude oil, allow for the estimation of the movement of foreign crude between PADDs. The transport of domestic crude can then be estimated by subtracting foreign movements of crude oil from total movements. Table 3 displays the transport of all crude oil (both foreign and domestic) between PADDs.

Table 3: Inter-PADD Transport of All Crude Oil (Thousand Barrels, 2013)

	TRANSPORT TO PADD 1	TRANSPORT TO PADD 2	TRANSPORT TO PADD 3	TRANSPORT TO PADD 4	TRANSPORT TO PADD 5
PADD 1 (East Coast)	-	2,729	9,369	-	-
PADD 2 (Midwest)	43,052	-	194,911	25,727	-
PADD 3 (Gulf Coast)	8,426	332,053	-	-	-
PADD 4 (Rocky Mountains)	-	86,565	5,835	-	25,683
PADD 5 (West Coast)	-	-	-	-	-

Note: Table derived from the baseline EIA data on inter-PADD transport of crude by pipeline, tanker, and barge, adjusted to include all domestic receipts of crude by rail as deliveries from PADD 2.

Table 4 displays an estimate of the foreign portion of inter-PADD transports. These estimates incorporate the information derived from the examination of imports by country, while ensuring that net receipts of foreign crude for each PADD match the values indicated in Table 1. Specifically, the following assumptions and calculations were made:

- On net, PADD 5 receives 278,000 barrels of foreign crude from other PADDs. PADD 5 receives no crude from PADD 3 (see Table 3), so all of these barrels must be delivered from PADD 4.
- On net, PADD 4 delivers 17,870 thousand barrels of foreign crude to other PADDs. As discussed above, 278 thousand barrels are delivered to PADD 5. The remaining 17,592 thousand barrels are assumed to be delivered to PADD 2. While it is possible that PADD 4 could also deliver foreign crude to PADD 3, this seems much less likely. PADD 4 delivers 86,565 thousand barrels of crude (domestic or foreign) to PADD 2, versus only 5,835 to PADD 3. Additionally, a map of crude oil pipelines produced by the American Petroleum Institute (API) indicates that there are no major pipelines transporting imported crude oil directly between PADD 4 and PADD 3 (see Figure 2).

Table 4: Inter-PADD Transport of Foreign Crude Oil (Thousand Barrels, 2013)

	TRANSPORT TO PADD 1	TRANSPORT TO PADD 2	TRANSPORT TO PADD 3	TRANSPORT TO PADD 4	TRANSPORT TO PADD 5
<b>PADD 1 (East Coast)</b>	-	-		-	-
<b>PADD 2 (Midwest)</b>	-	-	45,927	-	-
<b>PADD 3 (Gulf Coast)</b>	4,036	15,582	-	-	-
<b>PADD 4 (Rocky Mountains)</b>	-	17,592	-	-	278
<b>PADD 5 (West Coast)</b>	-	-	-	-	-

- PADD 2 processes 15,582 thousand barrels of crude from foreign countries other than Canada. This crude is assumed to be delivered from PADD 3. While it is possible that PADD 1 could also deliver foreign crude to PADD 2, this seems much less likely. PADD 2 receives 332,053 thousand barrels of crude (domestic or foreign) from PADD 3, and only 2,729 from PADD 1. Additionally, there are no major pipelines transporting non-Canadian foreign crude directly between PADD 1 and PADD 2 (see Figure 2).
- PADD 3 processes 46,877 thousand barrels of Canadian crude. Only a small portion of this amount is imported by tanker directly from Canada, so the majority must travel by pipeline through PADD 2. For the net receipts of foreign crude from PADD 2 and PADD 3 to match the constraints in Table 1, 45,927 thousand barrels of Canadian crude must be transported from PADD 2 to PADD 3. This leaves 950 thousand barrels of Canadian imports unaccounted for which must have been shipped directly from Canada (which is comparable to the estimate of 890 thousand barrels discussed earlier).<sup>80</sup>

<sup>80</sup> The estimate of 890,000 barrels of crude shipped directly from Canada was derived from USACE data on imports of foreign cargo. The USACE data are presented in tons of crude oil instead of barrels. The USACE estimate of tons of crude imports was converted to barrels using EIA data on barrels of crude oil per metric ton for Canada. Because this conversion may lead to some imprecision in estimating the number of barrels of Canadian crude oil supplies to the U.S. via tanker, this analysis assumes that the 950,000 barrels of Canadian imports left unaccounted for in the EIA data represents the amount of Canadian imports delivered to PADD 3 via tanker. For information on the barrels of metric ton of Canadian crude oil, see U.S. EIA, International Energy Statistics. “Barrels of Crude Oil per Metric Ton,” accessed December 2014 at: <http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=94&pid=57&aid=32>

- On net, PADD 1 receives 4,036 thousand barrels of foreign crude from other PADDs. This crude is assumed to be delivered from PADD 3 (instead of PADD 2) to ensure consistency with the net receipts for each PADD presented in Table 1 and the other assumptions stated above.<sup>81</sup>

Inter-PADD transport of domestic crude can now be estimated by subtracting the estimate of inter-PADD transport of foreign crude from the data on inter-PADD transport of all crude. Table 5 provides a summary of domestic inter-PADD transfers.

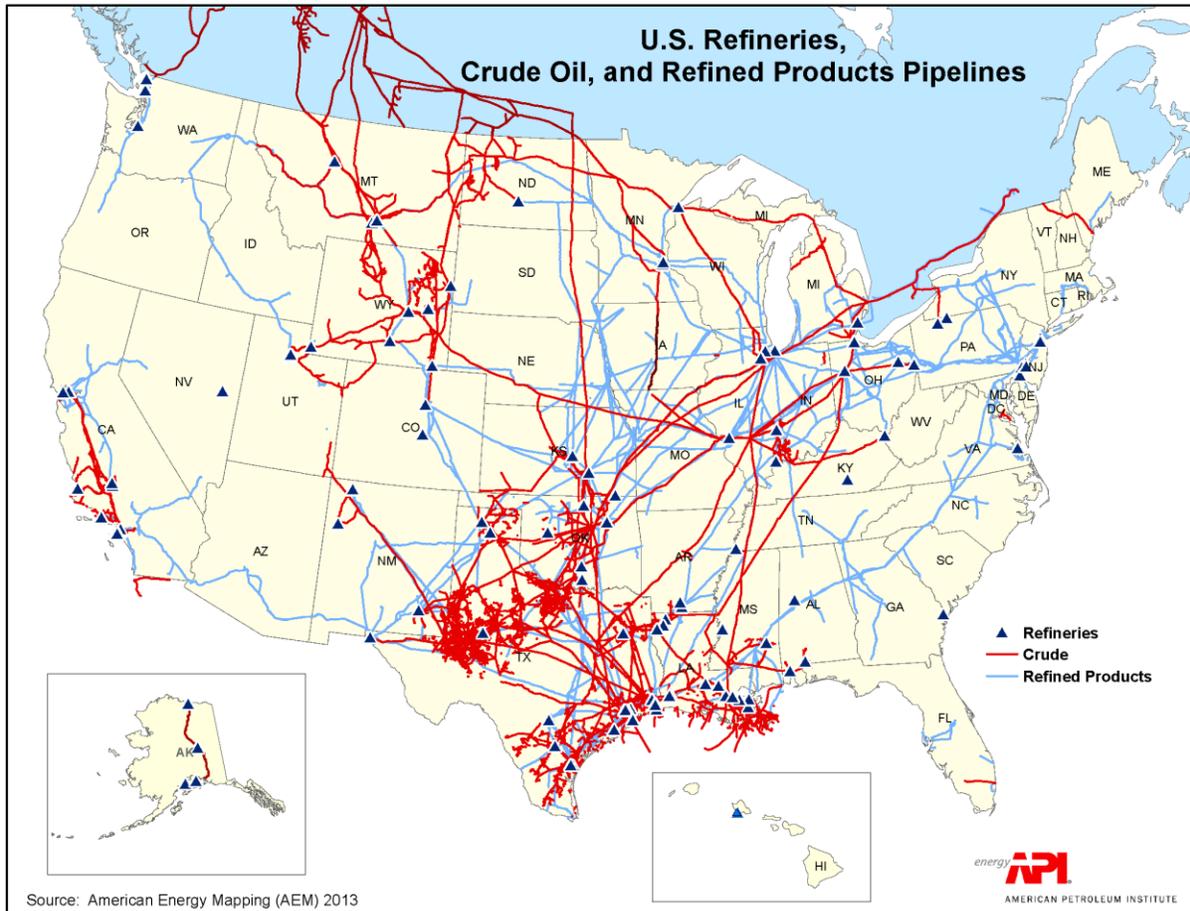
Table 5: Inter-PADD Transport of Domestic Crude Oil (Thousand Barrels, 2013)

PADD	TRANSPORT TO PADD 1	TRANSPORT TO PADD 2	TRANSPORT TO PADD 3	TRANSPORT TO PADD 4	TRANSPORT TO PADD 5
PADD 1 (East Coast)	-	2,729	9,369	-	-
PADD 2 (Midwest)	43,052	-	148,984	25,727	-
PADD 3 (Gulf Coast)	4,390	316,471	-	-	-
PADD 4 (Rocky Mountains)	-	68,973	5,835	-	25,405
PADD 5 (West Coast)	-	-	-	-	-

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<sup>81</sup> As established above, PADD 3 likely receives 45,927 thousand barrels from PADD 2, and likely sends 15,582 thousand barrels to PADD 2. Together these transfers leave PADD 3 receiving 30,345 thousand barrels on net. Table 1 shows that on net, PADD 3 receives 26,309 thousand barrels of imported crude from other PADDs. Thus PADD 3 is assumed to deliver 4,036 thousand barrels of crude to PADD 1 to bring its net receipts down to 26,309 thousand barrels.

Figure 2: Map of U.S. Crude Oil Pipelines



Source: American Petroleum Institute. “Where are the oil pipelines?” Accessed at: <http://www.api.org/oil-and-natural-gas-overview/transporting-oil-and-natural-gas/pipeline/where-are-the-oil-pipelines>

### *Distribution of imports between PADDs*

To determine the proportion of OCS production that would serve each PADD, the data on inter-PADD transfers must be combined with data on the quantity of crude that remains in its PADD of production. This analysis defines the amount of domestic crude produced and refined within the same PADD as production in a given PADD minus transfers of domestic crude to other PADDs. In addition, because the OECM estimates impacts related to an increase in crude imports via tanker, any incremental imports are distributed between the three coastal PADDs (PADD 1, PADD 3, and PADD 5).

Taking these factors into consideration, the distribution of tanker imports under the NAA that would displace a planning area’s production is a function of (1) the percentage of crude produced in a given PADD that is also refined there and (2) the percentage of crude oil produced in that PADD that is sent to other PADDs. For example, PADD 1 produced 14,353 thousand barrels of crude in 2013, and delivered 9,369 thousand barrels of domestic crude to PADD 3 (and no barrels to PADD 5; see Table 5). Consequently, 65.3% of incremental imports resulting from forgone production in the OCS planning areas within PADD 1 ( $9,369 \text{ thousand barrels} / 14,353 \text{ thousand barrels} = 0.653$ ), will be delivered to

PADD 3, and the remaining 34.7% will be delivered to PADD 1. Table 6 presents the allocation of incremental imports resulting from forgone production in each coastal PADD.

Table 6: Allocation of Incremental Crude Oil Imports by PADD

<b>PADD/OCS REGION WITH FORGONE PRODUCTION</b>	<b>REPLACED BY IMPORTS INTO PADD 1 (ATLANTIC OCS REGION)</b>	<b>REPLACED BY IMPORTS INTO PADD 3 (GULF OF MEXICO OCS REGION)</b>	<b>REPLACED BY IMPORTS INTO PADD 5 (PACIFIC AND ALASKA OCS REGIONS)</b>	<b>TOTAL</b>
PADD 1 (Atlantic OCS Region)	34.7%	65.3%	0%	100%
PADD 3 (GOM OCS Region)	0.3%	99.7%	0%	100%
PADD 5 (Pacific and AK OCS Regions)	0%	0%	100%	100%

***Distribution of imports within PADDs***

Table 6 above presents an estimate of which coastal PADDs are most likely to receive incremental imports in the absence of program activity. This section specifies how those imports are assumed to be distributed across the OCS planning areas within each PADD.

The U.S. Army Corps of Engineers (USACE) Navigation Data Center maintains information on foreign deliveries of cargo to U.S. ports. For each port receiving foreign cargo, this dataset contains information on the tonnage of cargo received for each type of commodity. Each port that imports crude oil was located on a map to determine the associated PADD and OCS planning area. This enabled the calculation of the distribution of crude oil imports across the planning areas located in each PADD. For oil imported into a given PADD, the OECM allocates across planning areas according to the distribution within the USACE data. This distribution of impacts is representative as long as the average size of a crude oil delivery does not differ greatly between planning areas.

Table 7: Crude Oil Imports to U.S. Ports, Organized by Planning Area and PADD

<b>PLANNING AREA</b>	<b>CRUDE OIL TONNAGE</b>	<b>PERCENT OF PADD IMPORTS</b>
<b>PADD 1 (East Coast, corresponds to the Atlantic OCS Region)</b>		
North Atlantic	40,042,470	83.9%
Mid Atlantic	7,274,415	15.3%
South Atlantic	383,815	0.8%
<b>PADD 3 (Gulf Coast, corresponds to the Gulf of Mexico OCS Region)</b>		
Central Gulf of Mexico	103,701,134	40.7%
Western Gulf of Mexico	151,294,769	59.3%
<b>PADD 5 (West Coast, corresponds to the Pacific OCS Region)</b>		
Central California	16,874,529	32.4%
Cook Inlet	273,230	0.5%
Southern California	29,081,637	55.8%
Washington Oregon	5,889,823	11.3%

Table 8 combines the information in Tables 6 and 7 to estimate the allocation of incremental imports by planning area. The values in Table 8 were derived by multiplying the proportion of incremental imports allocated to each PADD by the proportion of imports delivered to each planning area within a PADD. For example, Table 6 shows that 65.3% of incremental imports resulting from forgone production in PADD 1 will be delivered to PADD 3, and Table 7 shows that 40.7% of imports into PADD 3 arrive in the Central Gulf of Mexico planning area. As a result, 26.5% ( $65.3\% \times 40.7\%$ ) of incremental imports resulting from forgone production in PADD 1 are assumed to be delivered to the Central Gulf of Mexico.

The values in Table 8 are incorporated directly into the OECM (under Manage Scenario Inputs → No Action Alternative) and are combined with data on the E&D scenario and MarketSim results to estimate the allocation of crude oil tanker imports across planning areas. For example, assume that MarketSim projects a one million barrel increase in tanker imports under the No Action alternative and that 30 percent of new OCS oil production under the E&D scenario occurs in the Atlantic, 60 percent is in the Gulf of Mexico, and 10 percent is in the Pacific and Alaska OCS regions. Under this scenario, the increase in crude oil tanker imports under the NAA is assumed to be distributed as follows: 300,000 barrels for the Atlantic, 600,000 barrels for the Gulf of Mexico, and 100,000 barrels for the Pacific/Alaska. Using these data in conjunction with the values in Table 8, the estimated increase in imports to the Western Gulf of Mexico planning area is 471,000 barrels ( $300,000 \times 0.387 + 600,000 \times 0.592 + 100,000 \times 0$ ).

Table 8: Allocation of Incremental Crude Oil Imports by Planning Area

PADD/OCS REGION WITH FORGONE PRODUCTION	PADD 1 (ATLANTIC OCS REGION)			PADD 3 (GULF OF MEXICO OCS REGION)		PADD 5 (PACIFIC AND ALASKA OCS REGIONS)				TOTAL
	NORTH ATLANTIC	MID ATLANTIC	SOUTH ATLANTIC	CENTRAL GULF OF MEXICO	WESTERN GULF OF MEXICO	CENTRAL CALIFORNIA	COOK INLET	SOUTHERN CALIFORNIA	WASHINGTON OREGON	
PADD 1 (Atlantic OCS Region)	29.1%	5.3%	0.3%	26.5%	38.7%	0.0%	0.0%	0.0%	0.0%	100%
PADD 3 (Gulf of Mexico OCS Region)	0.2%	0.0%	0.0%	40.6%	59.2%	0.0%	0.0%	0.0%	0.0%	100%
PADD 5 (Pacific and Alaska OCS Regions)	0.0%	0.0%	0.0%	0.0%	0.0%	32.4%	0.5%	55.8%	11.3%	100%

## **Geographic distribution of onshore oil production**

In the absence of OCS program activity, onshore oil production in the U.S. may increase. The OECM allocates such increases to the regions of the country that would be most likely to substitute for OCS production in the absence of program activity. The OECM makes this determination based where OCS oil is sent in the U.S. (i.e., OCS oil destinations) and the domestic sources of oil for each OCS oil destination. More specifically, the steps in making this determination are as follows:

1. Identify which regions of the country are most likely to be served by OCS production. This is defined as the percentage of the production in each coastal region (PADD) that is refined in that region (PADD) and the percentage that is transported to other regions (PADDs).
2. For each region identified in Step 1 (i.e., the OCS oil destinations), identify the sources of domestic crude oil refined in each PADD. This is defined as the percentage of domestic crude refined in each PADD that is produced in that same PADD and the percentage that is received from other PADDs.

Incremental onshore oil production under the No Action Alternative is distributed to each region (PADD) based on the percentage of domestic crude they supply to the regions served by OCS production.

### ***PADDs served by OCS oil production***

The first step in this analysis is to identify which regions of the country are served by OCS production in a given planning area. This step requires the same analysis used to allocate the distribution of incremental imports, the only difference being that this part of the analysis is concerned with movements to all regions of the country, not just coastal regions. This is because incremental domestic production could occur in any PADD, whereas incremental imports can only be delivered to coastal PADDs. Table 9 presents the regions of the country served by OCS production. For example, the data in Table 9 show that nearly 20 percent of the production in the Gulf Coast region (PADD 3) is sent to the Midwest (PADD 2). While the data in Table 9 are for the entirety of a given PADD and are not specific to a given OCS planning area, this analysis assumes that the values for each PADD apply to the corresponding OCS planning areas within each PADD.

Table 9: PADDs Served by Domestic Crude Oil Production in Coastal PADDs

	SERVING PADD 1 (EAST COAST)	SERVING PADD 2 (MIDWEST)	SERVING PADD 3 (GULF COAST)	SERVING PADD 4 (ROCKY MOUNTAINS)	SERVING PADD 5 (WEST COAST)	TOTAL
<b>PADD 1 (Atlantic OCS Region) production</b>	15.7%	19.0%	65.3%	0.0%	0.0%	100%
<b>PADD 3 (Gulf of Mexico OCS Region) production</b>	0.28%	19.8%	79.9%	0.0%	0.0%	100%
<b>PADD 5 (Pacific and AK OCS Regions) production</b>	0.0%	0.0%	0.0%	0.0%	100.0%	100%
Source: U.S. EIA. Movements by Pipeline, Tanker, and Barge between PAD Districts. Released September 29, 2014. Accessed October 20, 2014 at: <a href="http://www.eia.gov/dnav/pet/pet_move_pipe_dc_R20-R10_mbbl_m.htm">http://www.eia.gov/dnav/pet/pet_move_pipe_dc_R20-R10_mbbl_m.htm</a> and <a href="http://www.eia.gov/dnav/pet/pet_move_tb_dc_R20-R10_mbbl_m.htm">http://www.eia.gov/dnav/pet/pet_move_tb_dc_R20-R10_mbbl_m.htm</a>						

***Geographic distribution of domestic production for areas served by OCS oil***

After identifying the areas served by OCS production, the next step in determining the distribution of onshore oil production is examining where the areas served by OCS oil get their oil. For instance, as shown in Table 9, 19.8 percent of domestic production in PADD 3 is transported to PADD 2. Absent program activity in PADD 3, PADD 2 would likely receive substitute sources of domestic crude. As shown in Table 10, PADD 2 receives 0.4 percent of its domestic crude from PADD 1, 46.7 percent from PADD 3, 10.2 percent from PADD 4, and 42.7 percent from production within PADD 2. These PADDs would therefore be assigned incremental onshore production in these proportions to make up for the portion of forgone OCS production in PADD 3 that would have been delivered to PADD 2. Table 10 shows the sources of domestic crude for each region (PADD) of the U.S.

Table 10: Sources of Domestic Crude for Each Region (PADD)

	PRODUCED IN PADD 1 (EAST COAST)	PRODUCED IN PADD 2 (MIDWEST)	PRODUCED IN PADD 3 (GULF COAST)	PRODUCED IN PADD 4 (ROCKY MTNS.)	PRODUCED IN PADD 5 (WEST COAST)
<b>Sources of crude for PADD 1 (East Coast)</b>	4.5%	86.6%	8.8%	0.0%	0.0%
<b>Sources of crude for PADD 2 (Midwest)</b>	0.4%	42.7%	46.7%	10.2%	0.00%
<b>Sources of crude for PADD 3 (Gulf Coast)</b>	0.7%	10.3%	88.6%	0.4%	0.0%
<b>Sources of crude for PADD 4 (Rocky Mountains)</b>	0.0%	21.8%	0.0%	78.2%	0.0%
<b>Sources of crude for PADD 5 (West Coast)</b>	0.0%	0.0%	0.0%	5.9%	94.1%

Source: U.S. EIA. Movements by Pipeline, Tanker, and Barge between PAD Districts. Released September 29, 2014. Accessed October 20, 2014 at: [http://www.eia.gov/dnav/pet/pet\\_move\\_pipe\\_dc\\_R20-R10\\_mbb1\\_m.htm](http://www.eia.gov/dnav/pet/pet_move_pipe_dc_R20-R10_mbb1_m.htm) and [http://www.eia.gov/dnav/pet/pet\\_move\\_tb\\_dc\\_R20-R10\\_mbb1\\_m.htm](http://www.eia.gov/dnav/pet/pet_move_tb_dc_R20-R10_mbb1_m.htm)

Combining the information presented in Tables 9 and 10 yields the percentage of incremental onshore production that would be expected in each region (PADD) absent program activity (see Table 11). For instance, Table 11 indicates that absent program activity in the Gulf of Mexico OCS Region (part of PADD 3), 17% of incremental production is expected to occur in PADD 2. This was calculated as the proportion of PADD 3 production that serves each PADD, multiplied by the proportion of crude supplied to each of these PADDs by PADD 2. Specifically:

- 0.28% of PADD 3 production serves PADD 1 (Table 9), and PADD 2 produces 86.6% of the crude supplied to PADD 1 (Table 10) (0.28% x 86.6% = 0.2%)
- 19.8% of PADD 3 production serves PADD 2, and PADD 2 produces 42.7% of the crude supplied to PADD 2 (19.8% x 42.7% = 8.5%).
- 79.9% of PADD 3 production serves PADD 3, and PADD 2 produces 10.3% of the crude supplied to PADD 3 (79.9% x 10.3% = 8.3%).

- So overall, PADD 2 will supply 0.2% + 8.5% + 8.3% = 17% of incremental production resulting from forgone program activity in PADD 3.

Table 11: Incremental Onshore Crude Oil Production in Each PADD Resulting From Forgone OCS Production

PADD/OCS REGION WITH FORGONE PRODUCTION	INCREMENTAL PRODUCTION IN PADD 1	INCREMENTAL PRODUCTION IN PADD 2	INCREMENTAL PRODUCTION IN PADD 3	INCREMENTAL PRODUCTION IN PADD 4	INCREMENTAL PRODUCTION IN PADD 5	TOTAL
<b>PADD 1 (Atlantic OCS Region)</b>	1.2%	28.5%	68.1%	2.2%	0.0%	100%
<b>PADD 3 (Gulf of Mexico OCS Region)</b>	0.6%	17.0%	80.1%	2.3%	0.0%	100%
<b>PADD 5 (Pacific and Alaska OCS Regions)</b>	0.0%	0.0%	0.0%	5.9%	94.1%	100%

The values in Table 11 were used to inform the development of air pollutant-specific dollar-per-ton values for onshore oil production under the NAA. For example, the dollar-per-ton values used to monetize the damages associated with onshore oil production that substitutes for OCS production in the Atlantic Region is a weighted average of the dollar-per-ton values in PADDs 1 through 5, with weights of 0.012 for PADD 1, 0.285 for PADD 2, 0.681 for PADD 3, 0.022 for PADD 4, and 0 for PADD 5.

### Geographic distribution of incremental natural gas imports

In the absence of program activity, the United States may import a greater quantity of natural gas. There are only 11 natural gas import terminals in the United States, so any increase in imports must be divided between these terminals.<sup>82</sup> Six of the import terminals are located along the Gulf Coast (PADD 3) and five are located along the East Coast (PADD 1).<sup>83</sup> Of these, only five import terminals received any natural gas deliveries in 2014. This likely reflects the significant reduction in U.S. natural gas imports in recent years due to the rapidly increasing shale gas production in the U.S. (see Figure 3). The quantity of LNG imports, by terminal, is presented in Table 12.

<sup>82</sup> While incremental imports may also arrive via pipeline, the OECM does not estimate costs associated with pipeline imports due to the small risk of environmental impacts relative to tankers. Consequently, the *MarketSim* output is exclusive to tankers and this appendix considers only the distribution of tanker imports.

<sup>83</sup> As noted at the beginning of this appendix, we aggregate the available data on natural gas production and shipments to the PADD level for consistency with the data for crude oil presented earlier in this appendix.

Figure 3: U.S. LNG Imports 2009 – 2014

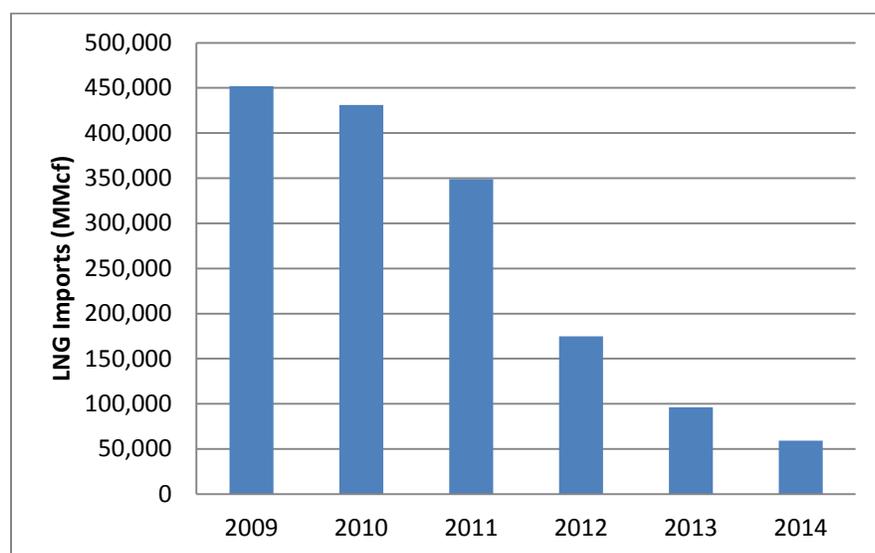


Table 12: Distribution of LNG Imports (Mmcf, 2009-2013)

PADD	PLANNING AREA	IMPORT TERMINAL	IMPORTS (2009)	IMPORTS (2010)	IMPORTS (2011)	IMPORTS (2012)	IMPORTS (2013)	IMPORTS (2014)
PADD 1	North Atlantic	Everett, MA	155,817	148,954	135,278	86,609	63,987	28,825
	North Atlantic	Neptune Deepwater Port, MA	-	1,332	-	-	-	-
	North Atlantic	Northeast Gateway, MA	5,669	14,698	-	-	-	-
	Mid-Atlantic	Cove Point, MD	72,339	43,431	13,981	2,790	5,366	11,585
	South Atlantic	Elba Island, GA	142,244	106,454	75,641	59,266	15,575	7,155
PADD 3	Central Gulf of Mexico	Cameron, LA	9,654	7,011	12,662	5,716	-	-
	Central Gulf of Mexico	Pascagoula, MS	-	-	5,774	-	-	-
	Central Gulf of Mexico	Lake Charles, LA	31,348	39,037	2,282	2,514	-	-
	Central Gulf of Mexico	Sabine, LA	29,097	44,819	45,610	11,902	5,750	5,880
	Western Gulf of Mexico	Freeport, TX	5,789	12,236	21,427	5,851	5,627	5,698
	Western Gulf of Mexico	Golden Pass, TX	-	13,037	36,284	-	-	-
Total			451,957	431,009	348,939	174,648	96,305	59,143

\*All values presented in million cubic feet (MMcf)

Since only PADD 1 (East Coast – Atlantic OCS Region) and PADD 3 (Gulf Coast – Gulf of Mexico OCS Region) receive imports of LNG, any incremental imports of LNG resulting from forgone OCS production are distributed between these two PADDs. Incremental imports are assigned to different PADDs (regions) based on the available information regarding the transportation patterns of gas produced in individual regions. Specifically:

- All natural gas produced in PADD 1 (East Coast – Atlantic OCS Region) is either consumed within the PADD, or transported to PADD 2 (Midwest). As a result, any incremental imports of LNG resulting from forgone OCS production in PADD 1 are assumed to be delivered to PADD 1.
- Natural Gas produced in PADD 3 (Gulf Coast – Gulf of Mexico OCS Region) is consumed in PADDs 1, 2, 3, and 5. As a result, this analysis assumes that incremental imports resulting from forgone OCS production in the Gulf of Mexico are delivered to PADD 3 and PADD 1, based on the proportion of PADD 3 production that remains in the PADD versus transported to PADD 1.<sup>84</sup>
- All natural gas produced in the Pacific and Alaska OCS Regions (PADD 5) is either consumed within the PADD, or transported to PADD 4 (Rocky Mountains). However, PADD 5 can not directly accept imports because it does not have any LNG ports. As a result, we assign all incremental imports associated with forgone OCS production in the Pacific and Alaska OCS Regions to PADD 3 (Gulf Coast), since PADD 3 borders PADD 5 (unlike PADD 1).

Table 13 summarizes the assumed distribution of incremental LNG imports resulting from forgone OCS activity in each PADD, based on natural gas production and interstate transfer data from the EIA (datasets and calculations are described at greater length in the following section).<sup>85</sup>

Table 13: Distribution of Incremental LNG Imports Between PADDs (Mmcf, 2012)

PADD/OCS REGION WITH FORGONE PRODUCTION	REPLACED BY IMPORTS TO PADD 1 (ATLANTIC OCS REGION)	REPLACED BY IMPORTS TO PADD 3 (GULF OF MEXICO OCS REGION)	TOTAL
PADD 1 (Atlantic OCS Region)	100.0%	0.0%	100%
PADD 3 (Gulf of Mexico OCS Region)	25.70%	74.30%	100%
PADD 5 (Pacific and Alaska OCS Regions)	0%	100%	100%

The allocation of incremental LNG imports can be further disaggregated by combining the information in Table 13 with the information on the distribution of imports by planning area from Table 12. More specifically, each value in Table 13 can be disaggregated to the individual planning areas within each

<sup>84</sup> No incremental imports are assumed to be distributed to PADD 5 because there are no LNG import terminals in PADD 5. No tanker imports are assumed to be transported to PADD 2 because it is landlocked.

<sup>85</sup> U.S. EIA. International & Interstate Movements of Natural Gas by State. Released September 30, 2014. Accessed October 24, 2014 at: [http://www.eia.gov/dnav/ng/ng\\_move\\_ist\\_a2dcu\\_nus\\_a.htm](http://www.eia.gov/dnav/ng/ng_move_ist_a2dcu_nus_a.htm)  
 U.S EIA. Natural Gas Dry Production (Annual Supply & Disposition). Released September 30, 2014. Accessed October 24, 2014 at: [http://www.eia.gov/dnav/ng/ng\\_sum\\_snd\\_a\\_epg0\\_fpd\\_mmcfc\\_a.htm](http://www.eia.gov/dnav/ng/ng_sum_snd_a_epg0_fpd_mmcfc_a.htm)

PADD in proportion to current import patterns. Table 14 summarizes the distribution of incremental LNG imports resulting from these calculations. For example, based on the data in Table 12, 61 percent of the imports to PADD 1 are shipped to the North Atlantic planning area. Applying this to the 25.7 percent of Gulf of Mexico OCS production replaced by imports to the Atlantic OCS Region, we estimate that approximately 16 percent ( $.257 \times .61 = .157$ ) of the imports that displace forgone OCS production in the Gulf of Mexico would be shipped to ports in the North Atlantic planning area.

Table 14: Distribution of Incremental LNG Imports Between Planning Areas (Mmcf, 2012)

PADD/OCS REGION WITH FORGONE PRODUCTION	PADD 1 (ATLANTIC OCS REGION)			PADD 3 (GULF OF MEXICO OCS REGION)		TOTAL
	NORTH ATLANTIC	MID ATLANTIC	SOUTH ATLANTIC	CENTRAL GULF OF MEXICO	WESTERN GULF OF MEXICO	
PADD 1 (Atlantic OCS Region)	61%	24%	15%	0%	0%	100%
PADD 3 (Gulf of Mexico OCS Region)	16%	6%	4%	38%	37%	100%
PADD 5 (Pacific and Alaska OCS Regions)	0%	0%	0%	51%	49%	100%

The values in Table 14 are incorporated directly into the OEMM and are combined with data on the E&D scenario and MarketSim results to estimate the allocation of natural gastanker imports across planning areas. For example, assume that MarketSim projects a 10 trillion cubic feet increase in tanker imports under the No Action alternative and that 20 percent of new OCS gas production under the E&D scenario occurs in the Atlantic, 70 percent is in the Gulf of Mexico, and 10 percent is in the Pacific and Alaska OCS regions. Under this scenario, the increase in natural gas tanker imports under the NAA is assumed to be distributed as follows: 2 trillion cubic feet for the Atlantic, 7 trillion cubic feet for the Gulf of Mexico, and 1 trillion cubic feet for the Pacific/Alaska. Using these data in conjunction with the values in Table 14, the estimated increase in natural gas tanker imports to the North Atlantic planning area is 2.34 trillion cubic feet (tcf) ( $2 \text{ tcf} \times 0.61 + 7 \text{ tcf} \times 0.16 + 1 \text{ tcf} \times 0$ ).

### Geographic distribution of onshore natural gas production

In the absence of OCS program activity, onshore natural gas production may increase. The OEMM spatially allocates such increases in production to those regions of the U.S. most likely to substitute for OCS production. The approach for determining this allocation follows the same basic methods used to determine the geographic distribution of incremental onshore oil production: (1) determine which regions of the country are most likely to be served by OCS production, and (2) determine which regions (PADDs) provide domestic natural gas to the regions served by OCS production.

### ***Regions served by OCS natural gas production***

Data on the transport of natural gas within the United States is available only at the level of interstate transfers. To determine regional flows of natural gas, interstate data was summed to the PADD level. This was accomplished by summing all transfers between states on the borders between PADDs. Production of natural gas was also summed to the PADD-level. Table 15 presents PADD-level production and transfers of natural gas.

Table 15: PADD Level Natural Gas Production and Transfers of Natural Gas (Mmcf, 2012)

	PRODUCTION	TRANSFERS TO PADD 1	TRANSFERS TO PADD 2	TRANSFERS TO PADD 3	TRANSFERS TO PADD 4	TRANSFERS TO PADD 5
<b>PADD 1 (East Coast)</b>	2,965,220	-	284,260	-	-	-
<b>PADD 2 (Midwest)</b>	2,654,532	903,383	-	1,130,868	841,622	-
<b>PADD 3 (Gulf Coast)</b>	13,785,715	2,960,757	3,611,945	-	-	1,256,916
<b>PADD 4 (Rocky Mnts.)</b>	4,087,396	-	2,790,462	462,284	-	1,838,894
<b>PADD 5 (West Coast)</b>	564,747	-	-	-	9,031	-

*Sources:*

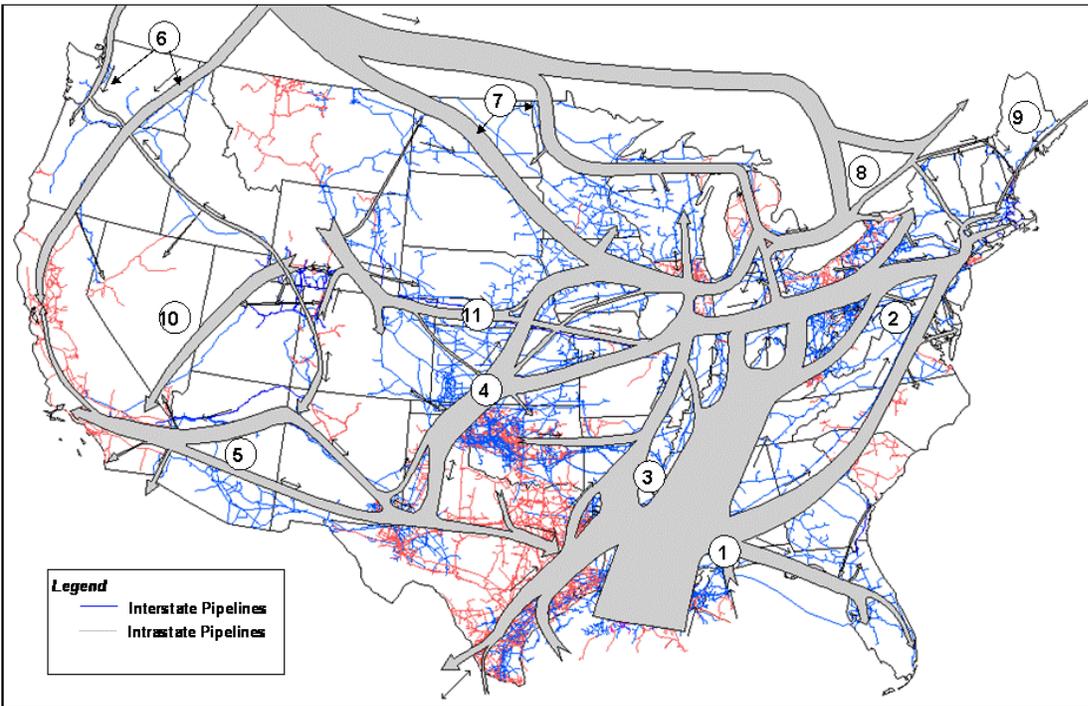
1. U.S. EIA. International & Interstate Movements of Natural Gas by State. Released September 30, 2014. Accessed October 24, 2014 at: [http://www.eia.gov/dnav/ng/ng\\_move\\_ist\\_a2dcu\\_nus\\_a.htm](http://www.eia.gov/dnav/ng/ng_move_ist_a2dcu_nus_a.htm)
2. U.S. EIA. Natural Gas Dry Production (Annual Supply & Disposition). Released September 30, 2014. Accessed October 24, 2014 at: [http://www.eia.gov/dnav/ng/ng\\_sum\\_snd\\_a\\_epg0\\_fpd\\_mmcfc\\_a.htm](http://www.eia.gov/dnav/ng/ng_sum_snd_a_epg0_fpd_mmcfc_a.htm)

Interstate transfer data as presented by the EIA includes transfers of all natural gas, domestically sourced or imported. For this analysis we are only interested in transfers of domestically produced natural gas. The transfer numbers were therefore adjusted to subtract any movement of imported natural gas.

Based on the directional flows of major natural gas transportation corridors (see Figure 4), it is likely that natural gas imports into PADDs 1, 2, and 5 (the East Coast, Midwest, and West Coast, respectively) are primarily consumed in their PADD of entry. While it is less clear if PADD 3 is transporting any imported natural gas to other PADDs, this should have little impact on the broader analysis as PADD 3 accounts for less than one percent of all natural gas imports. In PADD 4 however, it is clear that natural gas imports are delivered to other PADDs. As illustrated in Figure 4, natural gas imports into Idaho only pass through the northern portion of the state on the way to Washington and the rest of the West Coast. Similarly, natural gas imports into Montana only pass through the northeast corner of the state on the way to North Dakota and the rest of the Midwest. As a result:

- All interstate transfers from Idaho (PADD 4) to Washington (PADD 5) are assumed to contain imported Canadian natural gas and are subtracted from total transfers from PADD 4 to PADD 5.
- All interstate transfers from Montana (PADD 4) to North Dakota (PADD 2) are assumed to contain imported Canadian natural gas and are subtracted from total transfers from PADD 4 to PADD 2.

Figure 4: Major U.S. Natural Gas Transportation Corridors (2008)<sup>86</sup>



Source: Energy Information Administration, Office of Oil and Gas, Natural Gas Division, GasTran Gas Transportation Information System.

The EIA has determined that the informational map displays here do not raise security concerns, based on the application of the Federal Geographic Data Committee's *Guidelines for Providing Appropriate Access to Geospatial Data in Response to Security Concerns*.

One final adjustment is made to the inter-PADD transfer data to account for the fact that some natural gas transfers from PADD 3 to PADD 2 are ultimately destined for PADD 1. This intermediary transfer step is parsed out so that all natural gas that passes through PADD 2 on the way to PADD 1 is recorded as a delivery from PADD 3. While transfers from PADD 3 to PADD 2 that are destined for PADD 1 are not explicitly noted in EIA data, it is possible to parse out a reasonable estimate from the interstate transfer data. Greater than 99 percent of all natural gas deliveries to Tennessee (PADD 2) come from Alabama or Mississippi (PADD 3). The majority of this natural gas is then delivered to Kentucky (PADD 2), where it is dispersed to various states in PADD 1 and PADD 2. The portion of natural gas delivered from Kentucky to PADD 1 is therefore assumed to represent a transfer from PADD 3, not PADD 2. Additionally, Kentucky delivers natural gas to Ohio (PADD 2). Thirty-four percent of natural gas deliveries from Ohio are sent to West Virginia (PADD 1). This analysis will therefore assume that 34 percent of the natural gas delivered from Kentucky to Ohio is passed on to West Virginia. This portion is considered a delivery from PADD 3 to PADD 1.

Based on the assumptions outlined above, Table 16 presents Inter-PADD transfers of domestic natural gas, after subtracting transfers of imported natural gas and adjusting for intermediary transfers.

<sup>86</sup> The numbers on the map indicate 11 distinct corridors of natural gas transport identified by the EIA. Descriptions of these corridors can be accessed at: [http://www.eia.gov/pub/oil\\_gas/natural\\_gas/analysis\\_publications/ngpipeline/transcorr.html](http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/ngpipeline/transcorr.html)

Table 16: Inter-PADD Transfers of Domestic Natural Gas (Mmcf, 2012)

PADD OF ORIGIN	TRANSFERS TO PADD 1	TRANSFERS TO PADD 2	TRANSFERS TO PADD 3	TRANSFERS TO PADD 4	TRANSFERS TO PADD 5
<b>PADD 1 (East Coast)</b>	-	284,260	-	-	-
<b>PADD 2 (Midwest)</b>	321,550	-	1,130,868	841,622	-
<b>PADD 3 (Gulf Coast)</b>	3,542,590	3,611,945	-	-	1,256,916
<b>PADD 4 (Rocky Mountains)</b>	-	2,036,404	462,284	-	1,220,070
<b>PADD 5 (West Coast)</b>	-	-	-	9,031	-

*Source:* U.S. EIA. International & Interstate Movements of Natural Gas by State. Released September 30, 2014.  
 Accessed October 24, 2014 at: [http://www.eia.gov/dnav/ng/ng\\_move\\_ist\\_a2dcu\\_nus\\_a.htm](http://www.eia.gov/dnav/ng/ng_move_ist_a2dcu_nus_a.htm)

Combining the data on inter-PADD transfers of domestic natural gas (Table 16) with PADD level production data (from Table 15) indicates the percentage of production produced in each PADD that serves that same PADD as well as the percentage that serves other PADDs (see Table 17). For instance, PADD 1 produces 2,965,220 MMcf of natural gas and transfers 284,260 MMcf of natural gas to PADD 2. Natural gas that is not transported out of PADD 1 is assumed to be consumed in PADD 1. Thus, 9.6 percent of PADD 1 production is assumed to serve PADD 2, while the other 90.4 percent is assumed to serve PADD 1. Table 17 presents these data for the three coastal PADDs. The data in the table are assumed to apply to the OCS regions that correspond with each PADD.

Table 17: PADDs Served by OCS Production (Mmcf, 2012)

PADD/OCS REGION WITH FORGONE PRODUCTION	SERVING PADD 1	SERVING PADD 2	SERVING PADD 3	SERVING PADD 4	SERVING PADD 5	TOTAL
PADD 1 (Atlantic OCS Region)	90.4%	9.6%	0.0%	0.0%	0.0%	100%
PADD 3 (Gulf of Mexico OCS Region)	25.7%	26.2%	39.0%	0.0%	9.1%	100%
PADD 5 (Pacific and Alaska OCS Regions)	0.0%	0.0%	0.0%	1.6%	98.4%	100%

***Geographic distribution of domestic production for areas served by OCS gas***

As with incremental onshore oil production, increased onshore natural gas production is distributed geographically in proportion to the percent of domestic natural gas each PADD supplies to the regions served by OCS production. Table 18 presents the sources of domestic natural gas for each PADD. This information is then combined with the data on PADDs served by OCS production to produce estimates of the geographic location of incremental onshore natural gas production (see Table 19).

For instance, Table 19 suggests that absent program activity in PADD 1, 54 percent of incremental onshore production will occur in PADD 3. This was calculated by multiplying the proportion of PADD 1 production that serves each PADD by the proportion of natural gas supplied to each of those PADDs by PADD 3. Specifically:

- 90.4 percent of PADD 1 production serves PADD 1, and PADD 3 produces 54.1 percent of the natural gas supplied to PADD 1 (90.4% x 54.1% = 48.9%).
- 9.6 percent of PADD 1 production serves PADD 2, and PADD 3 produces 57.4 percent of the natural gas supplied to PADD 2 (9.6% x 57.4% = 5.5%).
- Thus, PADD 3 is likely to supply 48.9 percent + 5.5 percent = 54.4 percent of incremental natural gas production resulting from the absence of program activity in PADD 1.

Table 18: Sources of Domestic Natural Gas for Each PADD

	SUPPLY TO PADD 1	SUPPLY TO PADD 2	SUPPLY TO PADD 3	SUPPLY TO PADD 4	SUPPLY TO PADD 5
PADD 1 (East Coast)	41.0%	4.5%	0.0%	0.0%	0.0%
PADD 2 (Midwest)	4.9%	5.7%	16.2%	69.0%	0.0%
PADD 3 (Gulf Coast)	54.1%	57.4%	77.1%	0.0%	41.4%
PADD 4 (Rocky Mountains)	0.0%	32.4%	6.6%	30.2%	40.2%
PADD 5 (West Coast)	0.0%	0.0%	0.0%	0.7%	18.3%
TOTAL	100%	100%	100%	100%	100%

Table 19: Incremental Onshore Natural Gas Production From Forgone OCS Production (Mmcf, 2012)

PADD/OCS REGION WITH FORGONE PRODUCTION	REPLACED BY PRODUCTION IN PADD 1	REPLACED BY PRODUCTION IN PADD 2	REPLACED BY PRODUCTION IN PADD 3	REPLACED BY PRODUCTION IN PADD 4	REPLACED BY PRODUCTION IN PADD 5
PADD 1 (Atlantic OCS Region)	37.5%	5.0%	54.4%	3.1%	0.0%
PADD 3 (Gulf of Mexico OCS Region)	11.7%	9.1%	62.8%	14.7%	1.7%
PADD 5 (Pacific and Alaska OCS Regions)	0.0%	1.1%	40.8%	40.1%	18.0%

The values in Table 19 were used to inform the development of air pollutant-specific dollar-per-ton values for onshore natural gas production under the NAA. For example, the dollar-per-ton values used to monetize the damages associated with onshore gas production that substitutes for OCS production in the Gulf of Mexico Region is a weighted average of the dollar-per-ton values in PADDs 1 through 5, with weights of 0.117 for PADD 1, 0.091 for PADD 2, 0.628 for PADD 3, 0.147 for PADD 4, and 0.017 for PADD 5.

# APPENDIX G: A COMPARISON OF ECOSYSTEM SERVICE VALUATION AND HABITAT EQUIVALENCY ANALYSIS FRAMEWORKS

## Introduction

The purpose of the Bureau of Ocean Energy Management’s (BOEM’s) Offshore Environmental Cost Model (OECM) is to provide information on the anticipated environmental and social costs attributable to given oil and gas exploration and development scenarios on the Outer Continental Shelf (OCS), net of impacts that would be realized absent a given scenario. The current OECM evaluates six cost categories, as follows:

- 1) **Recreation:** spill-related consumer surplus losses associated with offshore fishing and beach visitation;
- 2) **Air quality:** emissions-related human health and environmental damage;
- 3) **Property values:** infrastructure-related impacts of visual disamenities and spill-related losses in economic rent;
- 4) **Subsistence harvest:** replacement costs for spill-related loss of select species harvested for subsistence;
- 5) **Commercial fishing:** increased operational costs due to infrastructure-related accessibility limitations; and
- 6) **Ecological:** restoration costs for spill-related habitat and biota injuries.

The focus of this appendix is assessing the methods applied in the OECM to evaluate ecological damages from oil spill events (category 6 above). Specifically, we consider the strengths and limitations of the habitat equivalency framework applied, and contemplate whether an ecosystem services approach – an alternative valuation framework – may affect the utility of BOEM’s model.

## HEA and ecosystem service valuation framework comparison

Ecosystems provide an array of goods and services of value to people. We refer to these goods and services collectively as “ecosystem services.” More specifically, the Science Advisory Board of the U.S. Environmental Protection Agency (USEPA) defines ecosystem services as, “...the direct or indirect contributions that ecosystems make to the well-being of human populations” (USEPA SAB, 2009). Accordingly, the distinction between ecosystem characteristics and ecological functions (e.g., nutrient cycling, carbon sequestration, and providing wildlife habitat), and ecosystem services (e.g., water purification, climate stabilization, and recreational opportunities) is grounded in the explicit connection between services and their value to people (USEPA SAB, 2009; NRC, 2005).<sup>87</sup> Measuring values of ecosystem services is a focus of environmental and resource economics, and is a central element of benefit-cost analyses and regulatory analyses of natural resource management alternatives.

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<sup>87</sup> The National Research Council (NRC, 2005) distinguishes between ecosystem functions and services, as follows (pg. 1): “Ecosystem function describes a process that takes place in an ecosystem as a result of the interactions of the plants, animals, and other organisms in the ecosystem with each other or their environment... Ecosystem structure and function provide various ecosystem goods and services of value to humans such as fish for recreational or commercial use, clean water to swim in or drink, and various esthetic qualities...”

### ***How do Habitat and Resource Equivalency Analyses measure ecological damages?***

A focus of Natural Resource Damage Assessment (NRDA) is determining appropriate compensation owed to the public for injuries to natural resources. For example, the Oil Pollution Act of 1990 (OPA) requires that the environment and the public be made whole for injuries to natural resources resulting from an oil discharge (15 CFR 990). Over the past two decades, Habitat Equivalency Analysis (HEA) and, more generically, Resource Equivalency Analyses (REA), have become the predominant frameworks for determining compensation for natural resource injuries, including those associated with oil spills.<sup>88</sup> The basic concept of HEA/REA analyses is that the public can be compensated for injuries to natural resources through replacement projects that are designed to provide habitats or resources of the same type, quality, and value (NOAA, 2006). In the context of NRDA, the costs of the restoration projects constitute the damage claim, and therefore reflect the costs of making the public whole from the pollution event. The OECM currently employs a HEA/REA framework to monetize the ecological damages from oil spills in terms of the costs of restoration.

### ***How is this different from Ecosystem Service Valuation approaches measuring service losses?***

While the notion of ecosystem services and their value to people is inherent in HEA/REA frameworks (i.e., through the concept of making the public whole from the ecological injury), the focus is on restoration *costs* and not on the *values* of the ecosystem service losses. From an economic perspective, the restoration cost is an accounting measure whereas the value of a good or service is a measure of its contribution to human well-being (and may therefore be greater or less than the cost). An ecosystem services approach to evaluating the costs and benefits of an oil spill focuses on quantifying the *values* associated with the ecosystem service losses due to ecological damages. The objective of an ecosystem services approach is to provide a holistic accounting of the gains and losses to society associated with changes in the quality or quantity of ecosystem services due to a pollution event or resource management decision. Simply stated, a HEA framework answers the question of the amount of restoration that would be sufficient to leave the public indifferent to the injury whereas an ecosystem services framework answers the question of how much the public valued what was lost (Zafonte and Hampton, 2007).

### ***Will HEA and Ecosystem Service Valuation approaches to measuring losses result in similar estimates?***

In effect, HEA represents a replacement cost approach to approximating the values lost due to the injury. Under certain circumstances, replacement costs are considered valid measures of economic value. Specifically, replacement costs, such as those measured through HEA, may be representative of the ecosystem service value losses if three conditions are met:

- 1) The replacement actions/projects provide services of equivalent quality and magnitude to those that were lost;
- 2) The replacement projects selected must be the least costly alternatives; and
- 3) The public is willing to incur these replacement costs (Freeman et al., 2014).

Accordingly, HEA approaches and ecosystem service valuation approaches to valuing ecological damages would theoretically provide a similar monetized estimate where these three conditions are met. When the conditions are met, the HEA measure of restoration costs may be considered a reasonable

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<sup>88</sup> Whereas HEA specifically references habitat-based restoration, REA more broadly applies to restoration of any given natural resource(s), such as fish or birds (Zafonte and Hampton, 2007).

approximation of the value of ecosystem service losses. Regulatory requirements and best practices regarding the conduct of HEA for a given damage case mirror these three replacement cost conditions.

First, HEA best practices specify processes for scaling the restoration actions so that they reflect a reasonable estimate of the value of the losses. For example, the National Oceanic and Atmospheric Administration's (NOAA's) Damage Assessment and Restoration Program specifies conditions for HEA focused on scaling the restoration actions to ensure that the project gains are equal to the value of the losses (incorporating appropriate discounting to account for the interim loss in services). These conditions are:

- 1) A common metric can be defined for natural resource services that captures the level of services provided by the habitats and captures any significant differences in the quantities and qualities of services provided by injury and replacement habitats; and
- 2) The changes in resources and services (due to the injury and the replacement project) are sufficiently small that the value per unit of service is independent of the change in service levels (NOAA, 2006).

These two HEA conditions are focused on ensuring that the quantity, quality, and value of services injured are equivalent to those replaced. This concept mirrors the first condition for replacement costs to serve as an adequate proxy for values, as described above.

Regarding the second replacement cost approach condition (i.e., that restoration is the least cost alternative), OPA requires that natural resource trustees select the most cost-effective restoration alternative (15 CFR 990.54). This ensures that, of the restoration projects identified that restore equivalent services, the least cost option is selected.

Finally, HEA involves two key assumptions regarding the value of the lost ecosystem services such that the third replacement cost approach condition described above would also be met (i.e., the public is willing to pay for the restoration). These assumptions are: a) a fixed proportion of habitat services to habitat value (e.g., a 40 percent loss in provision of a given service equates to a 40 percent loss in the value of the service); and b) equal unit value of the services lost due to injury and the services gained through the restoration activities (Dunford et al., 2004).<sup>89</sup> Where these assumptions hold true for a given site, the value the public holds for the restoration services would be reflective of the value lost due to damage. By definition, value is a measure of an individual's or population's willingness-to-pay for a service (as described further in Section III). Extending this concept, the values of services lost due to injury measure a loss in services in terms of what the public was willing to pay for them. If the HEA assumption holds that the value of what is being restored is equivalent to the value of what was lost (on a per unit basis), the public would likewise be willing to pay for the restored services. In other words, if the public was willing to pay for the service before the injury, they would be willing to pay for the equivalent quantity and quality of the same service as restored following the injury. These HEA assumptions replace the need to explicitly calculate the value the public holds for the given service because the service is being replaced in-kind through the restoration activities.

The HEA/REA framework applied in the OECM is a generalized version of this approach. The spatial scale of the model and the associated uncertainty regarding specific locations of potential spills under any

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<sup>89</sup> A number of studies define and explore HEA methods and assumptions in more detail in the context of their use in estimating damage claims. These studies highlight specific circumstances under which HEA/REA assumptions are most likely to hold. For example, additional information is included in: Unsworth and Bishop, 1995; Dunford et al., 2006; Zafonte and Hampton, 2007 and ; Shaw and Wlodarz, 2013.

given OCS development scenario make it infeasible to verify the analysis meets the conditions and assumptions regarding equivalency between what was lost and what is being replaced. Of note, these uncertainties are not specific to the HEA approach; the need to generalize the nature of injuries in the OECM would likewise require a simplified ecosystem service valuation approach. As emphasized in Freeman et al. (2014), when the three conditions for a valid replacement cost approach are not met, “there is no presumption that replacement cost is either an overestimate or an underestimate of true economic value—all that can be said is that the two numbers are measures of different things.”

## **Analytic methods comparison**

HEA/REA analyses all generally follow a similar analytic method. On the other hand ecosystem service valuation methods are various. In the context of welfare economics, value is most frequently measured in terms of people’s “willingness-to-pay” (WTP) for a good or service, where WTP is the maximum amount (typically in monetary terms) that an individual would be willing to pay rather than do without a particular benefit (Freeman et al., 2014). The White House Office of Management and Budget (OMB) recognizes WTP as the appropriate measure for valuing costs and benefits in the context of regulatory analysis (OMB, 2003). The analytic methods characterized below accordingly describe the various means by which economists may estimate WTP.

### ***What ecosystem services are measured in Ecosystem Service Approaches?***

The foundation of ecosystem service frameworks is to attempt to capture the full range of contributions ecosystems make to people’s well-being. This includes ecosystem services that are consumed (production of food or fiber), used but not consumed (e.g., wildlife viewing), as well as non-use values (e.g., existence values for threatened and endangered species). For example, the U.S. Environmental Protection Agency (USEPA) convened a subcommittee of its Science Advisory Board (SAB), the Committee on Valuing the Protection of Ecological Systems and Services (CVPESS), charged with assessing the Agency’s needs, identifying the state-of-the-art and science, and identifying key areas for research with respect to ecosystem service valuation. The CVPESS report provided the following three key recommendations, as well as specific advice on how to implement them:

1. Identify early in the valuation process the ecological responses that are likely to be of greatest importance to people and focus the valuation effort on these responses.
2. Predict ecological responses in terms that are relevant to valuation by focusing on the effects of decisions on ecosystem services that are of direct concern to people.
3. Consider the use of a wide range of possible valuation methods to better capture the full range of contributions stemming from ecosystem protection (USEPA SAB, 2009).

The suite of ecosystem services relevant to a resource management question or ecological injury event depends on the nature of the landscape in providing the services, as well as the population benefitting from them. The services that may be affected by oil spills in marine and coastal areas (including for example, beaches, wetlands, and forests) may include:

- Recreational opportunities (e.g., fishing, hunting, wildlife viewing, beach visitation, swimming, boating, hiking, etc.)
- Commercial fishing and aquaculture
- Flood protection (e.g., due to wetland water storage capacity)

- Coastal storm surge protection (e.g., due to wave attenuation)
- Climate stabilization (e.g., through carbon storage and sequestration)
- Aesthetic benefits (e.g., viewscales)
- Biodiversity and habitat provision (people may hold “existence values” for wildlife species even absent any direct or indirect use of them)
- Cultural or historical values (these may be use or non-use values)

***How does the HEA/REA analysis in the OECM currently account for these types of services?***

As discussed previously, the HEA/REA methods employed in the OECM to evaluate ecological losses avoid the need to measure lost social welfare benefits. The model estimates habitat impacts (in terms of the extent of intertidal oiling) and wildlife impacts (in terms of the biomass loss) and estimates what it would cost to replace those resource losses, assuming the services associated with those losses would also be replaced. As a result, the ecological injury module (the HEA/REA analysis) of the OECM does not provide insight on the particular ecosystem services affected.

Of note, however, three other modules of the OECM do attempt to estimate ecosystem service value losses associated with spill events, as mentioned in the introduction to this appendix. Specifically,

- **Recreation:** spill-related consumer surplus losses associated with offshore fishing and beach visitation;
- **Property values:** spill-related losses in economic rent; and
- **Subsistence harvest:** replacement costs for spill-related loss of marine life of cultural and subsistence value.

These functions of the OECM, while not a comprehensive accounting of the ecosystem services affected, provide information on the types and magnitude of ecosystem service losses using valid measures of value. The benefit of including these separate ecosystem service value analyses in the model is the additional information provided on why and to what extent the public may be worse off under a given development scenario. On the other hand, including these value losses in addition to estimates of ecological injury expressed in terms of restoration costs generates the potential for some double-counting across cost categories. That is, to the extent that the OECM’s HEA/REA measures of restoration costs are a reflection of the *value* losses associated with spill-related ecological injury (which is uncertain), the restoration cost estimates would reflect, at least in part, recreational, property value, and subsistence harvest losses.

***What are the different analytic methods for HEA versus Ecosystem Service Approaches?***

HEA/REA methods and ecosystem service valuation methods both begin with quantifying a change in ecological function, though this may be measured differently. Exhibit 1 provides a comparison of the general methodological approaches, highlighting how they diverge after this first step.

While the HEA method is more linear from the outset, requiring only a single metric of ecological change, this simplification can introduce uncertainty into the model results. The ecological metric used to determine the amount of interim losses in HEA can impact the subsequent damages amount. According to Shaw and Wlodarz (2013), "Some metrics lead to suggestions of full recovery within a relatively short amount of time, while others do not. The fact that different metrics give rise to different restoration

conclusions underscores the difficulty in measuring the impact of environmental change on human well-being in general."

The significant data requirements for an ecosystem services valuation approach is evident at each stage. In particular, estimating non-use values via stated preference surveys, such as the contingent valuation method (as described below), requires significant time and resources, and has been subject to scrutiny regarding the validity of results due to their hypothetical nature (i.e., survey respondents express values but are not required to actually pay) (Roach and Wade, 2006). While best practices have improved the implementation of these methods over time through integration of validity and scope tests (Shaw and Wlodarz, 2013), these methods remains resource-intensive processes.

As noted previously, a variety of methods with significant precedent in the economics literature are available to value ecosystem service losses. While some ecosystem services are amenable to valuation via market prices (e.g., contributions to commercial fisheries), others require use of non-market methods. Non-market valuation methods are divided into two types: revealed preference and stated-preference:

- Revealed preference methods** infer values for natural resources and associated services from people’s behavior. For example, the value of a day of beach recreation can be estimated using information on the costs one incurs to travel to that beach (**travel cost methods**) and the value of particular beach attributes can be estimated by examining how people make beach visit choices across a number of available sites (random utility maximization models). Similarly, the value of an environmental amenity (e.g., a viewscape) may be revealed through land and housing price premiums (**hedonic property value methods**). The advantage of revealed preference methods is that they are grounded in actual consumer choices. However, their applicability is limited to those ecosystem services for which a link to observable behavioral changes exists.

Table 1. Comparison of General HEA and Ecosystem Service Valuation Methods.

HEA/REA <sup>a</sup>	ECOSYSTEM SERVICE VALUATION
1) <b>Quantify the changes in ecological functions or processes associated with the injury.</b> HEA/REA methods typically rely on a single metric of change (e.g., in the OECM this is the extent of intertidal zone oiling (HEA) and numbers of wildlife organisms killed translated into biomass loss (REA)).	1) <b>Quantify the changes in ecological functions or processes associated with the injury.</b> For ecosystem service valuation, as much information on the ecological changes as possible is required to ensure as full an accounting as achievable of the related ecosystem services. For example, an oiling event could reduce fish and bird populations, decrease carbon sequestration potential, and reduce flood protection. Measures of all of these changes would be needed.
2) <b>Identify appropriate restoration project and evaluate it in terms of the degree and duration of ecological benefits that it is likely to provide.</b> Given the need to generalize for the purposes of the OECM, this HEA/REA step is not included.	2) <b>Identify the full suite of ecosystem services associated with the injured resources (inclusive of use and non-use values).</b> A comprehensive list requires understanding of the accessibility of the site (for on-site use values), whether the public likely holds non-use, or existence, values for damaged resources, etc.
3) <b>Scale the project in size so that the total value of ecological service benefits offsets the value of ecological service losses resulting from the injury, including discounting over time.</b> The OECM estimates the amount of salt marsh restoration required based on habitat and resource scaling factors taking into account the timeframe of injury and recovery, and discounting over time.	3) <b>Quantify the ecosystem service losses for each type of service.</b> Beyond quantifying the injury, the analyst needs to relate the injury change to a change in the production of an ecosystem service at the site. For example, reductions in fish populations may reduce the quality or quantity of recreational fishing (reduced fishing trips). Similarly, reductions in water retention may increase flood risk; this increased risk would need to be quantified.

HEA/REA <sup>a</sup>	ECOSYSTEM SERVICE VALUATION
<p><b>4) Quantify costs of implementing the restoration project.</b> The OECM applies average, area-specific, per-acre coastal marsh restoration costs.</p>	<p><b>4) Monetize the quantified ecosystem service losses and discount over time.</b> There are many valuation methods that may be used to quantify ecosystem services. Generally an injury that affects multiple ecosystem services will require studies (or primary research) that rely on multiple different methods. In some cases, a single stated preference study may estimate the total value of all ecosystem service losses. The information in steps 1 through 3 are still required for such a survey, however, to ensure the public has sufficient information on service losses to express a value.</p>
<p><sup>a</sup> HEA/REA method adapted from Zafonte and Hampton, 2007 to be descriptive of the steps followed in the current OECM model.</p>	

- Stated-preference methods** involve the creation of hypothetical markets that allow individuals to explicitly state their value for a resource. This is accomplished through carefully designed surveys (known as **contingent valuation and attribute-based or choice modeling** methods). Numerous stated preference studies related to ecosystem services have been conducted. The advantage of stated preference methods is that they can be applied to any actual or potential change in all categories of ecosystem services. Absent a related market or change in behavior, stated preference methods are the only way to measure non-use values for ecosystem services, such as existence values for wildlife species. However, defensible stated preference studies can be costly and time-consuming to conduct.

Circumstances often do not justify the time and resources required to implement a primary study using one of the above methods. In this case, existing valuation information can be adapted to new applications or policy questions, a process referred to as “benefit transfer.” Owing to schedule and budget constraints, the majority of policy and resource management decisions are informed by benefit-transfer analyses, and best-practice guidelines exist for the conduct and evaluation of such studies (USEPA, 2000; OMB, 2003). Benefit transfer analyses are convenient in this manner, and there exists a broad literature to draw upon. The OECM currently relies on benefit transfer, for example, in valuing recreational fishing and beach visitation losses.

When conducted properly, benefit transfer is an appropriate and less-resource intensive method to value ecosystem services. OMB has written guidelines for conducting credible benefit transfers. The important steps in the OMB guidance are: (1) specify the value to be estimated; and (2) identify appropriate studies to conduct benefits transfer based on the following criteria (OMB, 2003):

- The selected studies should be based on adequate data as well as sound and defensible empirical methods and techniques.
- The selected studies should document parameter estimates of the valuation function.
- The study and policy contexts should have similar populations (e.g., demographic characteristics). The market size (e.g., target population) between the study site and the policy site should be similar.
- The good, and the magnitude of change in that good, should be similar in the study and policy contexts.
- The relevant characteristics of the study and policy contexts should be similar.

- The distribution of property rights should be similar so that the analysis uses the same welfare measure (i.e., if the property rights in the study context support the use of willingness-to-accept measures while the rights in the rulemaking context support the use of willingness-to-pay measures, benefits transfer is not appropriate).
- The availability of substitutes across study and policy contexts should be similar.

A number of comments submitted on BOEM’s Net Benefits Analysis of the Proposed Outer Continental Shelf Oil & Gas Leasing Program, highlighted existing studies valuing ecosystem services, and suggesting BOEM could use them in evaluating the effects of oil and gas exploration and development scenarios on ecosystem services. Specifically, two comments cited a study of Gulf Coast wetlands that estimated values of wetland ecosystem services of between \$2,760 and \$12,630 per acre per year (Batker et al., 2010). This study is a benefit transfer study that relies on literature regarding the value of particular wetland ecosystem services to develop a low and high end estimate of value per service per acre per year. These estimates are then summed across services and acres, and discounted over time. This is sometimes characterized as a “rapid ecosystem service valuation.” The comments on the Net Benefits analysis suggested that BOEM could apply similar methods to evaluate ecosystem service losses (to wetlands and other affected ecosystems) due to oil spill events.

A rapid assessment of ecosystem services, such as that described in the comments, is unlikely to meet the criteria specified by OMB. Multiple responses to similar studies have highlighted the theoretical and practical problems associated with estimating and extrapolating per acre estimates of values taken from other studies of ecosystem services (e.g., Bockstael et al., 2000). Of particular relevance to the OECM, rapid assessment ecosystem service values do not provide information on the effects of changes in the condition or quality of an ecosystem on the associated service values. These studies assign an equal per unit (acre) value to a given land or habitat type (e.g., coastal wetland) and therefore do not provide any information to support an analysis of the ecosystem service losses of changes in quality of a service, as opposed to quantity of a land cover type (e.g., wetlands).

The USEPA, in its September 2000 guidance document on cost-benefit analysis (USEPA, 2000), also broadly rejects this approach, stating:

“In estimating ecological benefits, one is generally forced to value individual ecological service flows separately and then sum these estimates rather than constructing prices for changes in the structure and function of entire ecosystems. Alternative approaches that estimate the total value of ecosystems based on the replacement cost of the entire ecosystem or its embodied energy (e.g., Costanza et al., 1997; Ehrlich and Ehrlich, 1997; Pearce, 1998; Pimentel et al., 1997) have received considerable attention as of late. However, the results of these studies should not be incorporated into benefit assessments. The methods adopted in these studies are not well grounded in economic theory nor are they typically applicable to policy analysis. Pearce (1998) contains a critical review of the total value approach, as does Bockstael et al. (2000).”<sup>90</sup>

## Implications for the OECM

Overall, while ecosystem service approaches would provide more information on what the public values with respect to an ecosystem, information limitations in the context of the OECM would preclude a comprehensive accounting of ecosystem services.

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<sup>90</sup> USEPA. 2000. Guidelines for Preparing Economic Analyses.

### ***Would ecosystem service approaches provide better information?***

The OECM's current approach is to value the oil spill-related ecosystem services for which data are available and reasonably generalizable to do so, including for recreational fishing and beach visitation, property value losses, and subsistence values. These services, however, reflect only a subset of the ecosystem services potentially affected, and exclude non-use values entirely. Non-use, such as existence values, can represent a significant portion of the lost ecosystem service values.

In their book, *Economic Analysis for Ecosystem-Based Management*, Holland et al. (2010) explain that values associated with preserving the north Atlantic whale mostly comprise non-use values, and if the species' value to society were only measured using recreation-demand models (i.e. the value of whale watching), a significant portion of the total economic value would be ignored. Along the same lines, in a literature survey on passive-use values of public forestlands, Vincent et al. (1995) find that most studies on the economic value of forest preservation focus on the recreational value of the forest. They argue that this methodology understates the benefits associated with the preservation of wilderness areas because it does not account for the relatively more dominant, passive-use value. For example, from one study on the total valuation of wildlife and fishery resources in the Northern Rockies, Vincent et al. find that in four out of the five cases, existence value was at least 62 percent and as high as 83 percent of the total value. As a result, it is appropriate to include a separate measure of the ecological injuries that attempts to capture these types of values.

Ecosystem service approaches would more explicitly account for service-by-service values than HEA-based approaches, thereby providing additional information on what is being lost due to a spill event in the OECM and avoiding double counting.<sup>91</sup> The OECM mirrors an ecosystem services approach in valuing a subset of services for which information is available and reasonably generalizable. For services not currently in the OECM, including non-use values, the existing stated preference literature is limited and specific, and unlikely to meet the conditions of a benefit transfer for use in the OECM. At the very least, traditional methods to value non-use ecosystem services would be subject to similar levels of uncertainty as the HEA/REA approach applied to measure ecological injury costs.

### ***What are the key limitations of integrating ecosystem service valuation methods into the OECM?***

The data requirements to integrate a holistic accounting of ecosystem services would likely be prohibitive. Whereas the ecological injury and cost estimates in HEA are boiled down to a single metric for each (one injury metric and one restoration cost), ecosystem service approaches would require additional specificity, linking the injury to the production of ecosystem services and then again to their associated economic value. A key benefit of HEA is the relative ease of estimating restoration costs as compared to conducting a series of linked ecological and economic assessments of lost goods and services.

Furthermore, the HEA/REA restoration costs are more readily transferable across geographies and scalable at various geographic scopes. There is not a great deal of variation in restoration costs for a given habitat type across geographies. On the other hand, ecosystem service values may vary greatly by site regardless of the scope of the injury. Use values depend on accessibility to a site and the size of the

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<sup>91</sup> In some instances, stated preference studies may be focused on eliciting information on the public's WTP to avoid a particular type of ecological injury, thus providing information on the "total value" of the ecosystem. Depending on how the survey is designed, these studies may provide information on values of particular ecosystem services (e.g., recreation versus non-use values for a particular resource). Under an ecosystem services framework, more information on values for particular services, and therefore on tradeoffs across services under alternative resource management scenarios, is preferable.

population benefitting from a given service. Non-use values may not be as readily scalable, as it is often unclear the extent to which marginal changes in population size for a given species affect the existence values held by the public.

### ***Summary conclusion***

HEA and ecosystem service valuation methods are both subject to uncertainty. As noted above, at any given site, it is unclear whether the HEA approach overestimates or underestimates the true value of the ecosystem service losses. The HEA approach requires simplifying assumptions – in particular that people derive utility from natural resources in proportion to the ecological services they provide (Roach and Wade, 2006). In addition, the restoration costs measured do not provide information on what aspects of the natural resource are valued by people.

Despite these limitations, the data requirements for developing ecosystem service-specific valuation models in the OECM may make it impractical. In addition, simplified approaches to valuing ecosystem services that would be required to accommodate a national scale model like the OECM would introduce their own uncertainties, requiring additional assumptions not only about the ecological changes, but also the number of people affected and their WTP for the foregone benefit.

Overall, ecosystem service valuation methods would be more difficult to implement and would not necessarily provide better information to BOEM. These methods would likely result in different monetary estimates, and the relative differences across regions and development scenarios are uncertain.

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