OCS Study
BOEM 2023-056

Forecasting Environmental and Social Externalities Associated with Outer Continental Shelf (OCS) Oil and Gas Development, Volume 1: 2023 Revised Offshore Environmental Cost Model (OECM)

US Department of the Interior
Bureau of Ocean Energy Management
Headquarters

Bureau of Ocean Energy Management

OCS Study
BOEM 2023-056

Forecasting Environmental and Social Externalities Associated with Outer Continental Shelf (OCS) Oil and Gas Development, Volume 1: 2023 Revised Offshore Environmental Cost Model (OECM)

October 2023

Prepared by

Industrial Economics, Inc.
2067 Massachusetts Avenue
Cambridge, MA 02140

with

RPS ASA
55 Village Square Drive
South Kingstown, RI 02879

Northern Economics
880 H Street, Suite 210
Anchorage, AK 99501

SC&A, Inc.
2200 Wilson Blvd., Suite 300
Arlington, VA 22201

Dr. Nicholas Z. Muller
215 Hillcrest Environmental Center
Middlebury College
Middlebury, VT 05770

US Department of the Interior
Bureau of Ocean Energy Management
Headquarters

DISCLAIMER

Study concept, oversight, and funding were provided by the US Department of the Interior, Bureau of Ocean Energy Management (BOEM), Environmental Studies Program, Washington, DC, under Contract Number 47QRAA20D0044, Order Number 140M0122F0019. This report has been technically reviewed by BOEM, and it has been approved for publication. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the US Government, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

REPORT AVAILABILITY

Download a PDF file of this report at https://espis.boem.gov/Final%20Reports/BOEM_2023-056.pdf. To search other studies completed by BOEM's Environmental Studies Program, visit https://www.boem.gov/environment/environmental-studies/environmental-studies-information/.

CITATION

Industrial Economics, Inc. 2023. Forecasting environmental and social externalities associated with Outer Continental Shelf (OCS) oil and gas development, volume 1: 2023 revised Offshore Environmental Cost Model (OECM). Sterling (VA): U.S. Department of the Interior, Bureau of Ocean Energy Management. 120 p + appendices. Report No.: OCS Study BOEM 2023-056.

Contents

List of Figures

List of Tables

Abbreviations and Acronyms

ADFG	Alaska Department of Fish and Game
AEO	Annual Energy Outlook
AFS	American Fisheries Society
ANL	Argonne National Laboratory
APEEP	Air Pollution Emission Experiments and Policy
bbl	barrel of oil
BBO	billion barrels of oil
BEACH	Beaches Environmental Assessment and Coastal Health
BenMAP	Benefits Mapping and Analysis Program
BOEM	Bureau of Ocean Energy Management
CDC	Centers for Disease Control
CDFG	California Department of Fish and Game
CFEC	Commercial Fishing Entry Commission
CFI	Commercial Fisheries Impact
CH_4	methane
CO	carbon monoxide
CO_2e	CO_2 equivalents
COI	cost-of-illness
C-R	concentration-response
CSA	combined statistical areas
CV	contingent valuation
CVPESS	Committee on Valuing the Protection of Ecological Systems and Services
DOI	Department of the Interior
E&D	exploration and development
EEZ	exclusive economic zone
EIA	Energy Information Administration
EIS	environmental impact statement
ELI	Environmental Law Institute
ERS	Economic Research Service
FPSO	floating production storage and offloading
ft	foot/feet
g	gram
GDP	gross domestic product
GHG	greenhouse gas
GIS	geographic information system
GOM	Gulf of Mexico
GREET	Greenhouse Gas Regulated Emissions and Energy Use
HA M	millions of hectares
HEA	habitat equivalency analysis
HPI	Housing Price Index
ICP	International Cooperative Programme
INPFC	International North Pacific Fishery Commission
IPHC	International Pacific Halibut Commission
km	kilometer(s)
LNG	liquefied natural gas
m	meter(s)
mi	miles(s)

MMcf	1 million cubic feet
MMS	Minerals Management Service
MRIP	Marine Recreational Information Program
MSA	Metropolitan Statistical Area
N_2O	nitrous oxide
NAA	No Action Alternative
NAAQS	National Ambient Air Quality Standard
NAPAP	National Acid Precipitation Assessment Program
NETL	National Energy Technology Laboratory
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NO_x	nitrogen oxides
NRDA	natural resources damage assessment
OC	oil consumption
OCS	Outer Continental Shelf
OECM	Offshore Environmental Cost Model
OMB	Office of Management and Budget
PacFIN	Pacific Fisheries Information Network
PADD	Petroleum Administration for Defense Districts
PDARP	Programmatic Damage Assessment and Restoration Plan
PFMC	Pacific Fishery Management Council
PM	particulate matter
$PM_{2.5}$	particulate matter up to 2.5 micrometers in size
PM_{10}	particulate matter up to 10 micrometers in size
PPI	producer price index
REA	resource equivalency analysis
RecFIN	Recreational Fisheries Information Network
RIA	regulatory impact analysis
SAB	Science Advisory Board
SCC	Standard Classification Code
SCORP	State Comprehensive Outdoor Recreation Plans
SIMAP	Integrated Oil Spill Impact Model System
SO_2	sulfur dioxide
TAPS	Trans-Alaska Pipeline System
USACE	U.S. Army Corp of Engineers
U.S. DOE	U.S. Department of Energy
U.S. EPA	U.S. Environmental Protection Agency
VOC	volatile organic compound
VSL	Value of Statistical Life
WRAP	Western Regional Air Partnership
WTP	willingness-to-pay

1 Introduction

The Bureau of Ocean Energy Management (BOEM) assists the Secretary of the U.S. Department of the Interior (DOI) in carrying out the mandates of the Outer Continental Shelf (OCS) Lands Act. The OCS Lands Act 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 OCS Lands 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 National OCS Oil and Gas Leasing Programs (National OCS Programs), BOEM completes an analysis of the anticipated environmental and social costs attributable to the exploration, development, production, and transport of oil and natural gas, 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,[1] BOEM utilizes the Offshore Environmental Cost Model (OECM), a revised Microsoft (MS) Access-based model that has been updated in conjunction with development of the 2024–2029 National OCS Program (referred to hereafter as the 2024–2029 Program).[2] This guide presents the model's cost calculation methodologies and descriptions of each calculation driver, including the sources of underlying data and any necessary assumptions.

The model currently addresses six cost categories:

1. **Recreation:** 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:** estimated replacement cost for marine subsistence organisms killed by oil spills
5. **Commercial Fishing:** costs of fishing area preemption 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 allows for assessment 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). Chapter 10 includes a discussion of key potential benefit categories.

---

[1] 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 a National OCS Program. An E&D scenario includes 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.

[2] For general references not specific to the 2024–2029 Program, this document refers broadly to the National OCS Program.

However, note that the current version of the model does not include any benefit calculations due to a lack of data that would support a credible and consistent assessment across all BOEM planning areas.

Although 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 the costs. Because the OECM captures the most significant costs associated with OCS E&D, BOEM considers additional non-monetized costs and benefits qualitatively in the supplemental document *Economic Analysis Methodology for the 2024–2029 National Outer Continental Shelf Oil and Gas Leasing Program*.[3] Categories of impacts not captured in the OECM include the following:

- **Select oil spill impacts.** Although the OECM 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 F, estimating these values would require more detailed data than are currently available. Furthermore, the OECM does not include ecological costs associated with the use of dispersants. Data on the likelihood of their use on a given spill and the likely impacts associated with their use are highly uncertain. Finally, the OECM does not estimate air quality costs associated with response vessel activity in the event of an oil spill. Most oil spills involve limited volumes of oil, and emissions from vessel activity are not likely to be substantial.
- **Ecological damage from E&D operations.** As discussed in detail in this document, the OECM monetizes ecological damages associated with oil spills but does not monetize impacts to marine resources from general E&D 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 OECM 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 OECM 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).
- **Impacts from development of onshore infrastructure.** With one exception, the OECM 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.
- **Greenhouse gas impacts.** The OECM estimates greenhouse gas emissions under program scenarios and the NAA. Although 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.

[3] https://www.boem.gov/2024-2029-Economic-Analysis-Methodology

- **Other impacts.** Furthermore, 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 E&D scenario.

Just as there are non-monetized environmental impacts under program scenarios, there are also non-monetized impacts associated with the NAA. These costs are not captured and 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 broader regional economic impacts of oil and natural gas E&D 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 August 2018 documentation of the OECM,[4] which presents the methods and data incorporated into the OECM for the purpose of developing the National OCS Program for 2020–2025 (2020–2025 Program), and it corresponds to the Decision Document for the 2020–2025 Program. This update to the OECM documentation reflects refinements to the methods and data in the model since publication of the August 2018 model documentation. These changes include the following:

- Updates to several emission factors in the model, including those for OCS oil and gas activity and those related to substitutes for OCS oil and gas (Chapter 4)
- Updates to oil spill rates and average spill sizes (Appendix A, sub-Appendix D)

A principal goal of this guide is to aid the user in navigating the details contained within the revised model. 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 Integrated Oil Spill Impact Oil System (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.[5] 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

[4] https://espis.boem.gov/final%20reports/BOEM_2018-066.pdf

[5] 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 and potentially high consequence events. As a result, OECM results do not reflect the costs that might be associated with such events.

- 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.

2 Model Description

The OECM was built using the MS Access 2003 platform and is compatible with MS Access 2021. As defined in the E&D scenario worksheet[6], 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 Figure 1.

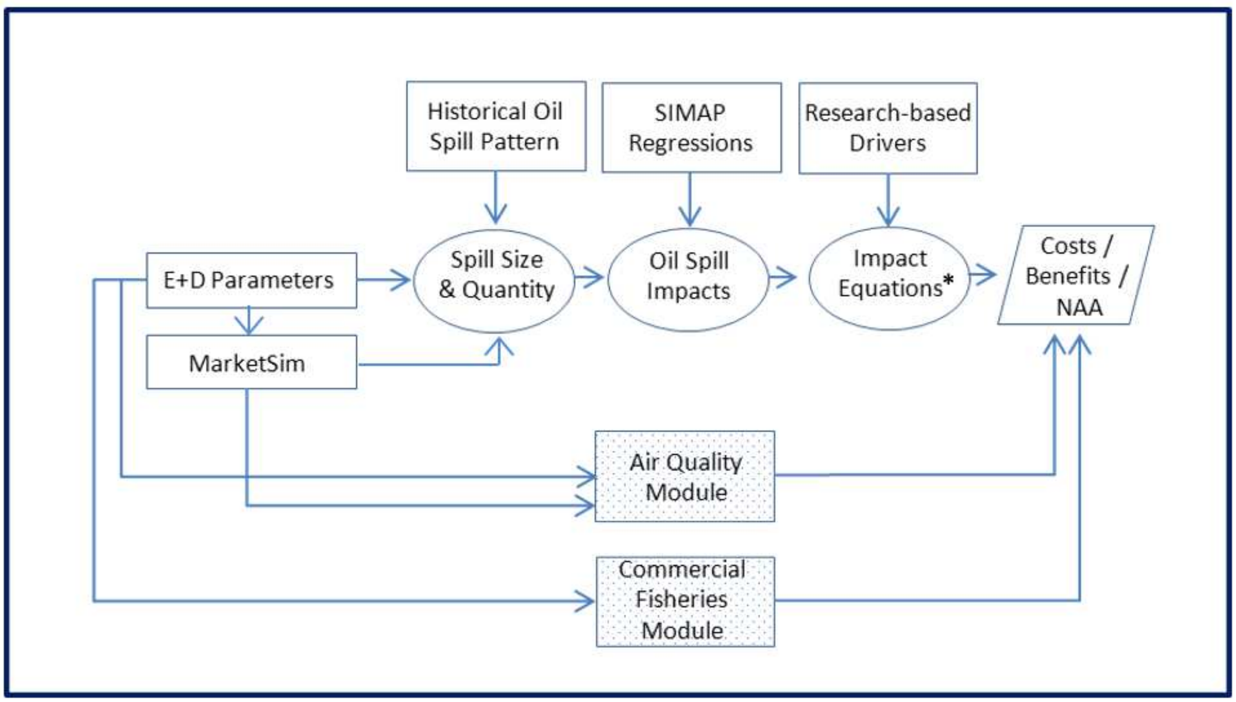


Figure 1. Structure of the Offshore Environmental Cost Model

Note: Impact equations apply to recreation, property values, subsistence, and ecological effects.

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

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

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 and includes a discussion of the calculations associated with the energy sources that would serve as substitutes for forgone OCS production under the NAA.

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.[7]

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

The OECM estimates annual oil production based on each platform group's anticipated total oil production adjusted by the activity and production schedule from the E&D scenario. Next, the annualized oil production is distributed across production and transportation modes (i.e., platform, pipeline, barge, and tanker) based on the percentages held in the OECM.[8] The OECM assumes all oil originates at the platform and therefore attributes 100 percent of oil production to platforms.

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

Based on historical oil spill information, the OECM applies the mean spill size per barrel (bbl) of oil production or transport for four spill sources (platforms, pipelines, OCS supply vessels, and tankers) and three oil types (crude and condensate, heavy fuel oil, and diesel). The OECM classifies mean spill sizes into five or six size classes ranging from very small (1 to 10 bbl) to extra large (10,001 to 100,000 bbl).[9] The default OECM size classes and mean spill rates can be found and edited on the Oil Spill Data page within the model.

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

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

---

[7] 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.

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

[9] 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.

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

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 OECM applies regressions developed using SIMAP to estimate the impacts of oil spills based on a volume of oil spilled and distance from shore.[10] 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^2)
- Surface area of shoreline oiled—rock and gravel (m^2)
- Surface area of shoreline oiled—sand (m^2)
- Surface area of shoreline oiled—mudflat and wetland (m^2)
- Surface area of shoreline oiled—artificial (m^2)
- Water surface area—impacts to shorebirds and waders (kilometers squared [km^2])
- Water surface area—impacts to birds, mammals, and sea turtles (km^2)
- Volume of oil water exposed—impacts to water column organisms (m^3)

For each spill size class, oil type, and oil source, the model applies the mean spill size 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 significantly over- or underestimating 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.

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

Step 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.

2.1.1 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 be able to attribute them to specific program options, 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 (GOM) Planning Area, 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.[11] 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).

2.1.2 Impacts Associated with Exports of Crude Oil and Refined Petroleum Products

Following the 2015 repeal of the U.S. ban on crude oil exports that had been in place since 1973, oil producers are now free to export U.S. crude oil, including crude oil produced on the OCS, to markets outside the U.S. To ensure that BOEM's estimates of the environmental and social costs associated with National OCS Program activity are as comprehensive as possible, the OECM estimates the environmental and social costs related to the changes in exports expected under a user-defined E&D scenario. The model estimates these impacts as they relate to both crude oil exports and exports of refined petroleum products. The process for calculating these costs begins with the application of the *Market Simulation Model* (*MarketSim*) to an E&D scenario. For a given scenario, *MarketSim* estimates a variety of energy market responses in the U.S. and internationally, including changes in U.S. crude oil exports and refined product exports. Based on these projected changes, the OECM estimates the corresponding environmental costs (i.e., costs related to oil spills and air pollutant emissions) using the same methods that it applies for oil

[11] 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.

remaining in the U.S. The magnitude of these costs depends in large part on the OCS planning area(s) from which exports are sourced. Appendix G presents detailed information on the spatial distribution of crude oil exports and refined petroleum exports, according to the planning area of origin, for a given E&D scenario.

2.2 Cost Calculations for the NAA

An assessment of net environmental and social costs depends on monetization of anticipated costs and benefits in the absence of National OCS Program activity (i.e., the Secretary decides not to hold any lease sales during the five-year period of analysis). The absence of program activity is referred to as the NAA. The process for calculating these costs begins with the application of the *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 U.S. via tanker; and (3) an increase in the onshore production of oil, natural gas, and coal within the U.S.[12] 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). [13]

2.2.1 Oil Spill Costs Under the NAA

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 National OCS Program. Note that the relevant *MarketSim*

[12] 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, although pipeline oil and natural gas imports from Canada may change under the NAA, no impacts are estimated for these specific changes in imports.

[13] 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.

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 NAA page under Manage Scenarios. Specifically, users may adjust the distribution of imports displaced by production in a given region. Appendix E presents the approach for deriving default values.
- To estimate costs associated with the transportation of OCS oil to shore and, in the case of Alaska, to the continental U.S., 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 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 U.S. 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.[14]
- Because 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 underestimating 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 NAA

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 first 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.

  Following the estimation of emissions, the model estimates costs for each location by a series of dollar-per-ton[15] values—representing the monetized cost of offshore emissions—by pollutant, year, and offshore location.[16] These values were derived from outputs and data in the Air Pollution Emission Experiments and Policy (APEEP) analysis model (Appendix C).

---

[14] Appendix A outlines the oil spill rates used within the OECM.

[15] Throughout this document, the term ton refers to short tons (i.e., 2,000 pounds), unless indicated otherwise.

[16] Throughout this document, the term ton refers to short tons (i.e., 2,000 pounds), unless indicated otherwise.

- To estimate the air quality costs related to increased onshore production of oil, natural gas, and coal, the model follows a similar 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 calculation yields the estimated 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. Similar to the dollar-per-ton values for the offshore environment, these values were derived from outputs of the APEEP model (Appendix C). For a given pollutant, the dollar-per-ton values applied depend on the location of displaced OCS production (Appendix E).

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 in the Atlantic, Pacific, and GOM Regions, as well as two areas off Alaska. The Gulf of Alaska and Cook Inlet Planning Areas account for nearly all recreational saltwater angling activity in the planning areas off Alaska. The model estimates and values changes in beach use only for the planning areas in the Atlantic, Pacific, and GOM 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 (or, 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:

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

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 several sources that differ by OCS region. For the Atlantic and GOM, the model uses the National Oceanic and Atmospheric Administration's (NOAA's) Marine Recreational Information Program (MRIP) (NOAA 2018). MRIP provides state-level estimates of total annual angler trips based on surveys conducted throughout the year by mode and area fished. The model uses the average annual number of recreational fishing trips over the last 5 years with complete data in MRIP (2012–2016). To avoid double counting recreational fishing trips to beaches, the OECM uses the estimate for recreational angler trips taken away from the beach.[17]

The total for each planning area in the Atlantic and GOM is the sum of the state-level estimates for states associated with that planning area, with one exception; MRIP provides aggregated recreational fishing trip data for two sub-regions for Florida: East Florida and West Florida. The model uses the raw survey data to generate county-level recreational fishing estimates for every county in Florida. The totals reported by MRIP for East and West Florida are then distributed to the county level based on the distribution of the county-level estimates. Finally, the OECM generates planning-area-level estimates for the Eastern GOM, Straits of Florida, and South Atlantic Planning Areas by assigning the coastal counties to planning areas.[18]

For the Pacific planning areas, the model uses recreational fishing data from the Recreational Fisheries Information Network (RecFIN) database, which compiles data reported by the three Pacific states (RecFIN 2018). The OECM uses the average number of annual angler trips over the last 5 years of data reported (2013–2017). The data are reported at a regional level. The model combines all Oregon and Washington regions to produce the estimates for annual angler trips for the Washington/Oregon Planning Area. The OECM assumes that all Southern California angler trips in the RecFIN data are also in the Southern California Planning Area. To divide the Northern California RecFIN region into the Central and Northern California Planning Areas, the model uses RecFIN data on total fish caught at the county level. Specifically, the model assumes that baseline recreational fishing in the Northern California RecFIN region is divided between Central and Northern California Planning Areas in proportion to the total fish caught in the counties that comprise the Northern California region reported in RecFIN. In addition, because the angler trip data available for Oregon and Washington do not accurately differentiate between modes and locations of fishing, the model assumes that the percent of fishing trips in Northern California that are non-beach trips applies to the Washington/Oregon Planning Area.

To estimate the number of recreational fishing trips in Alaska, the model uses data available from MRIP on the annual number of saltwater angler trips in the state of Alaska, obtained through the same method as for the Atlantic OCS Region. The OECM also integrates these data with regional recreational fishing data

---

[17] Specifically, the OECM includes all angler trips in MRIP, excluding trips characterized by (1) a mode of "Shore" *and* (2) a fished area of "Ocean, within three miles."

[18] All Florida counties align exactly with the OCS Planning Area designations with the exception of Monroe County. The model assumes that half of the recreational fishing trips in Monroe County occur in the Straits of Florida and half occur in the Eastern GOM.

for the Gulf of Alaska and Cook Inlet from the Alaska Department of Fish and Game's (ADFG) Sport Fishing Survey (ADFG 2018) to estimate the regional distribution of the total annual angler trips.[19,20]

Table 1 below displays the estimates of recreational fishing trips by OCS planning area.

Table 1. Annual recreational fishing trips by planning area

Planning Area	Annual Angler Trips
North Atlantic	12,715,056
Mid-Atlantic	8,648,391
South Atlantic	5,683,687
Straits of Florida	5,292,396
Eastern GOM	11,832,589
Central GOM	4,814,803
Western GOM	922,164
Southern CA	2,162,342
Central CA	792,945
Northern CA	112,436
Washington/Oregon	378,340
Gulf of Alaska	391,680
Cook Inlet	159,256
TOTAL	53,906,086

3.3.2 Area of Recreational Fishing Activity

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

3.3.3 Area of Recreational Fishing Closure

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

[19] Because ADFG only provides data on the number of recreational fishing days instead of trips, MRIP data on the number of trips is spatially distributed across planning areas according to total angler days.

[20] According to ADFG (2018), 98 percent of all recreational saltwater fishing days were spent in either the Gulf of Alaska or Cook Inlet Planning Areas. The model does not quantify the impacts of recreational fishing outside of these two planning areas.

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

The OECM estimates the economic value of lost recreational fishing trips in the model based on the results of studies from the empirical environmental economics literature. The model applies values for specific planning areas based on regional studies when applicable. Table 2 details the economic values used and lists the source(s) and averaging method where applicable. Values were converted to year 2010 dollars using the GDP deflator (BEA 2018).

Table 2. Summary of the economic values of recreational fishing trips

Planning Area	Value Per Lost Recreational Fishing Trip (2010$)	Source(s)
North Atlantic	$64.82	Average of two studies: Johnston et al. (2002) and McConnell and Strand (1994). Value used from McConnell and Strand (1994) is the average value of trips in New York and New Jersey, weighted by the average number of trips in each state.
Mid-Atlantic	$71.38	Value derived from McConnell and Strand (1994). Value used is the average of trips in Delaware, Maryland, and North Carolina, weighted by the average number of annual trips.
South Atlantic	$68.83	Average of two studies: Whitehead et al. (2000) and McConnell and Strand (1994). Value used for McConnell and Strand (1994) is the average value of trips taken to the Atlantic coast of Florida, Georgia, and South Carolina, weighted by the average number of trips in each state.
Straits of Florida Eastern GOM Central GOM Western GOM	$34.35	Value per lost recreational fishing trip from the *Deepwater Horizon* Damage Assessment (NOAA 2016) for the North Gulf. Value used is the average value of a lost fishing trip over two study periods, weighted by baseline trips.
Southern California Central California Northern California Washington/Oregon	$45.85	Leggett and Curry (2010). Value used was originally derived from Kling and Thomson (1996) and was adjusted for use in the *Cosco Busan* Natural Resource Damage Assessment for recreational fishing losses in the San Francisco Bay Area.
Cook Inlet Gulf of Alaska	$181.61	Average of two studies: Hamel et al. (2000) and Hausman et al. (1995).

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.

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

where:

T = Number of beach-use days per year

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

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

C = Duration of beach closure (days)

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

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

3.5 Calculation Drivers—Beach Use

3.5.1 Beach-use Days Per Year

The number of beach-use days per year is estimated at the planning area level using several sources that vary by planning area. To identify credible beach-use estimates, the OECM relies first on primary data collection where available, and then relies on other recent, rigorous surveys or state-reported values. The model estimates beach use by state before aggregating to planning areas. The general sources are described below by OCS region and the detailed sources and methods are outlined in Table 3 below:

- ***For the GOM***, the OECM uses estimates that are either directly estimated or extrapolated from the shoreline assessment conducted for the natural resources damage assessment (NRDA) for the *Deepwater Horizon* oil spill.
- ***For the Atlantic,*** the OECM uses estimates that are either directly estimated or extrapolated from a recent paper by Parsons and Firestone that conducted an extensive survey of Atlantic beach use.[21]
- ***For the Pacific,*** lacking a single data source for beach use, the OECM uses several state and regional reports. The Oregon and Washington values are based on State Comprehensive Outdoor Recreation Plans (SCORPs), while the California Planning Area estimates are derived from two surveys on coastal recreation in California (Chen et al. 2015; California State Parks 2014).
- ***For Alaska,*** beach use is not modeled because there is little beach recreation expected to occur in the Alaska planning areas.

[21] Parsons and Firestone provided state-level estimates of total beach trips by trip length. Multiplying the number of trips by the average number of trips per day yields the total number of beach days per state.

Table 3. Overview of beach-use data and sources

Planning Area State	**Annual Beach Days (millions)**	**Source/Method**
NORTH ATLANTIC	**168**	**-**
Maine	18.3	Apply estimated beach use per beach mile for Rhode Island, as derived from Parsons and Firestone (2018) and U.S. EPA (2018a), to Maine beach miles reported in U.S. EPA (2018a).
New Hampshire	5.2	Apply estimated beach use per beach mile for Rhode Island, as derived from Parsons and Firestone (2018) and U.S. EPA (2018a), to New Hampshire beach miles reported in U.S. EPA (2018a).
Massachusetts	36.2	Parsons and Firestone (2018) report visitation only for the outer coast of Cape Cod. Extrapolate estimated day-trip beach use per beach mile on Cape Cod, as derived from Parsons and Firestone (2018) and U.S. EPA (2018b), to rest of Massachusetts beaches.
Rhode Island	14.8	Parsons and Firestone (2018) report visitation only for the ocean beaches in Rhode Island. Extrapolate estimated beach use per beach mile, as derived from Parsons and Firestone (2018) and U.S. EPA (2018b), to rest of Rhode Island beaches (Narragansett Bay).
Connecticut	9.15	Apply estimated beach use per beach mile for Rhode Island, as derived from Parsons and Firestone (2018) and U.S. EPA (2018a), to Connecticut beach miles reported in U.S. EPA (2018a).
New York	39.5	Parsons and Firestone (2018) report visitation only for the ocean beaches in New York. Extrapolate estimated beach use per beach mile, as derived from Parsons and Firestone (2018) and U.S. EPA (2018b), to rest of New York beaches (Long Island Sound).
New Jersey	45.1	Estimated beach use from Parsons and Firestone (2018)
MID-ATLANTIC	**70.5**	-
Delaware	11.3	Parsons and Firestone (2018) report visitation only for the ocean beaches in Delaware. Calculated total beach use for Delaware based on the sum of estimated beach use from Parsons and Firestone (2018) and beach use at Delaware Bay beaches from Parsons et al. (2013).
Maryland	12.1	Use estimated beach use for ocean beaches in Maryland from Parsons and Firestone (2018). Apply estimated beach use per bay beach mile for Delaware's bay beaches, as derived from Parsons et al. (2013), to Maryland bay beach miles reported in U.S. EPA (2018b). Total beach visitation is the sum of ocean and bay beach visits.
Virginia	13.7	Use estimated beach use for ocean beaches in Virginia from Parsons and Firestone (2018). Extrapolate estimated beach use per bay beach mile for Delaware, as derived from Parsons et al. (2013) and U.S. EPA (2018b), to bay beach miles in Virginia reported in U.S. EPA (2018b).
North Carolina	33.4	Estimated beach use from Parsons and Firestone (2018).
SOUTH ATLANTIC	**74.0**	-
South Carolina	47.2	Estimated beach use from Parsons and Firestone (2018).
Georgia	14.4	Apply estimated beach use per beach mile for North Carolina, as derived from Parsons and Firestone (2018) and U.S. EPA (2018a), to Georgia beach miles reported in U.S. EPA (2018a).
Florida (South Atlantic)	12.4	Extrapolate *Deepwater Horizon* Damage Assessment beach-use values for Florida to entire state using the regional distribution of beach use estimated in the Florida DEP (2013) and Florida DEP (2018).

Planning Area State	**Annual Beach Days (millions)**	**Source/Method**
STRAITS OF FLORIDA	**24.5**	Extrapolate *Deepwater Horizon* Damage Assessment beach-use values for Florida to entire state using the regional distribution of beach use estimated in the Florida DEP (2013) and Florida DEP (2018).
EASTERN GOM	**41.2**	Extrapolate *Deepwater Horizon* Damage Assessment beach-use values for Florida to entire state using the regional distribution of beach use estimated in the Florida DEP (2013) and Florida DEP (2018).
Louisiana	3.14	Extrapolate *Deepwater Horizon* Damage Assessment beach use per mile for Mississippi and Alabama to Louisiana.
Mississippi	1.52	Baseline visitation from *Deepwater Horizon* Damage Assessment.
Alabama	5.01	Baseline visitation from *Deepwater Horizon* Damage Assessment.
CENTRAL GOM	**9.67**	**-**
WESTERN GOM	**48.1**	Extrapolate *Deepwater Horizon* Damage Assessment beach use per mile for Mississippi and Alabama to Texas.
SOUTHERN CALIFORNIA	**69.8**	Use value reported in South Coast Recreation Survey (Chen et al. 2015) for beach visitation.
CENTRAL CALIFORNIA	**40.6**	Extrapolate total beach visitation from the South Coast Recreation Survey (Chen et a., 2015) to planning areas based on distribution of state resident beach use in the CA Survey of Public Opinions and Attitudes (California State Parks 2014).
NORTHERN CALIFORNIA	**5.1**	Extrapolate total beach visitation from the South Coast Recreation Survey (Chen et al. 2015) to planning areas based on distribution of state resident beach use in the CA Survey of Public Opinions and Attitudes (California State Parks 2014).
WASHINGTON/OREGON	**29.7**	-
Washington	12.4	Estimate number of beach days from Washington SCORP (2013) using reported average days of participation, percent of beach use occurring at saltwater beaches, and percent of residents participating in beach activities.
Oregon	17.3	Use value reported in Oregon Parks and Recreation Department (2018) for saltwater beach activities.
TOTAL	**582**	**-**

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 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

The OECM uses a variety of regional economic values per lost beach day based on recent literature and values used in natural resource damage assessments. Table 4 displays the value per lost beach day and the source(s) used to develop each estimate. Values were converted to 2010$ using the GDP deflator (BEA 2018).

Table 4. Summary of beach use economic valuation sources

Planning Area	Value Per Lost Beach Day (2010$)	Source(s)
North Atlantic	$34.07	Bouchard B-120 Oil Spill Lost Use Technical Working Group (2009), used in the Buzzards Bay NRDA.
Mid-Atlantic	$44.11	Average of two studies: Parsons et al. (2013) and Bin et al. (2005). The value used for Parsons et al. (2013) is the average consumer surplus value for day trips and overnights for beaches on Delaware Bay. The value used for Bin et al. (2005) is the average of seven beaches in North Carolina.
South Atlantic	$30.95	Average of two studies: Bell and Leeworthy (1990) and Landry and McConnell (2007). Bell and Leeworthy estimate the consumer surplus of trips on the Atlantic coast of Florida. Landry and McConnell (2007) estimate the consumer surplus of beach use in Georgia.
Straits of Florida	$32.94	Value per lost shoreline visit from the *Deepwater Horizon* Damage Assessment (NOAA 2016). Value for the Florida Peninsula region in the damage assessment is applied to the Straits of Florida and Eastern GOM; value for the North Gulf Region in the damage assessment is applied to the Central GOM and Western GOM.
Eastern GOM	$32.94	Same as Straits of Florida
Central GOM	$34.64	Same as Straits of Florida
Western GOM	$34.64	Same as Straits of Florida
Southern California	$28.88	Average of two studies: Lew and Larson (2008) and Leggett et al. (2014).
Central California	$23.55	English (2010). Value used was estimated as part of the *Cosco Busan* NRDA for beach use losses in the San Francisco Bay Area.
Northern California	$23.55	Same as Central California
Washington/Oregon	$23.55	Same as Central California

3.6 References—Recreation

[ADFG] Alaska Department of Fish and Game. 2018. Alaska sport fishing survey. Regional effort summary by area (2007–2016). https://www.adfg.alaska.gov/sf/sportfishingsurvey/

[BEA] Bureau of Economic Analysis. 2018. Table 1.1.9. Implicit price deflators for gross domestic product. [accessed 2018 Apr 27]. https://apps.bea.gov/iTable/?reqid=19&step=3&isuri=1&1921=survey&1903=13.

Bell F, Leeworthy V. 1990. Recreational demand by tourists for saltwater beach days. Journal of Environmental Economics and Management 18(3):189205.

Bin O, Landry CE, Ellis CL, Vogelsong H. 2005. Some consumer surplus estimates for North Carolina beaches. Marine Resource Economics. 20(2):145–161.

Bouchard B-120 Oil Spill Lost Use Technical Working Group. 2009. Bouchard B-120 oil spill Buzzards Bay, Massachusetts, lost use valuation report. 290 p.

California State Parks. 2014. Survey on public opinions and attitudes on outdoor recreation in California 2012: complete findings. http://www.parks.ca.gov/SPOA

Chen C, Hesselgrave T, Enelow N, et al. 2015. An economic and spatial baseline of coastal recreation in the south coast of California: report to the California Sea Grant College Program. http://oceanspaces.org/projects/south-coast-baseline-characterization-human-uses.

English E. 2010. Appendix J: damage estimate for shoreline recreation. Boulder (CO): Stratus Consulting, Inc. 58 p. Prepared for Cosco Busan Natural Resource Damage Assessment. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=36963

[Florida DEP] Florida Department of Environmental Protection. 2013. Outdoor recreation in Florida 2013. Tallahassee (FL): State of Florida, Department of Environmental Protection, Division of Recreation and Parks. 77 p. https://floridadep.gov/parks/florida-scorp-outdoor-recreation-florida.

Florida DEP. 2018. Florida statewide comprehensive outdoor recreation plan: participation study 2016–2017. Tallahassee (FL): State of Florida, Department of Environmental Protection, Division of Recreation and Parks. 297 p. https://floridadep.gov/parks/florida-scorp-outdoor-recreation-florida.

Hamel C, Herrmann M, Lee ST, Criddle KR. 2000. An economic discussion of marine sport fisheries in Central and Lower Cook Inlet. 10 p.

Hausman JA, Leonard GK, McFadden D. 1995. A utility consistent, combined discrete choice and count data model; assessing recreational use losses due to natural resource damage. Journal of Public Economics. 56:1–30.

Johnston RJ, Grigalunas TA, Opaluch JJ, Mazzotta M, Diamantedes J. 2002. Valuing estuarine resource services using economic and ecological models: the Peconic Estuary System Study. Coastal Management. 30:47–65.

Kling CL, Thomson CJ. 1996. The implications of model specification for welfare estimation in nested logit models. American Journal of Agricultural Economics. 78:103–114.

Landry CE, McConnell KE. 2007. Hedonic onsight cost model of recreation demand. Land Economics. 83(2):253–267.

Leggett C, Curry M. 2010. Appendix H: recreational fishing damages due to the *Cosco Busan* Oil Spill. Cambridge (MA): Industrial Economics, Incorporated. 11 p. Prepared for Cosco Busan Natural Resource Damage Assessment. https://www.wildlife.ca.gov/OSPR/NRDA/cosco-busan.

Leggett C, Scherer N, Curry M, Bailey R, Haab T. 2014. Final report: assessing the economic benefits of reductions in marine debris: a pilot study of beach recreation in Orange County, California. Cambridge (MA): Industrial Economics, Inc. and Ohio State University. 51 p.

Lew DK, Larson DM. 2008. Valuing a beach day with a repeated nested logit model of participation, site choice, and stochastic time value. Marine Resource Economics. 23:233–252.

McConnell KE, Strand IE. 1994. The economic value of Mid and South Atlantic sportfishing. Washington (DC): Environmental Protection Agency, National Marine Fisheries Service, and National Oceanic and Atmospheric Administration. 135 p. Contract No.: CR811043-01. https://www.researchgate.net/publication/255505347_THE_ECONOMIC_VALUE_OF_MID_AND_SOUTH_ATLANTIC_SPORTFISHING

[NOAA] National Oceanic and Atmospheric Administration. 2016. *Deepwater Horizon* Oil Spill: Final Programmatic Damage Assessment and Restoration Plan and Final programmatic environmental impact statement. Chapter 4: Injury to natural resources. http://www.gulfspillrestoration.noaa.gov/restoration-planning/gulf-plan.

NOAA. 2018. MRIP recreational fisheries statistics query. 2012–2016. https://www.st.nmfs.noaa.gov/recreational-fisheries/data-and-documentation/queries/index.\

Oregon Parks and Recreation Department. 2018. 2013–2017 Statewide Comprehensive Outdoor Recreation Plan. Salem (OR): Oregon Parks and Recreation Department. 127 p. https://digital.osl.state.or.us/islandora/object/osl%3A103998

Parsons and Firestone. 2018. Atlantic offshore wind energy development: values and implications for recreation and tourism. Sterling (VA): U.S. Department of the Interior, Bureau of Ocean Energy Management. 58 p. Report No.: OCS Study BOEM 2018-013. https://espis.boem.gov/final%20reports/5662.pdf

Parsons GR, Chen Z, Hidrue MK, Standing N, Lilley J. 2013. Valuing beach width for recreational use: Combining revealed and stated preference data. Marine Resource Economics. 28(3):221–241.

[RecFin] Pacific Recreational Fisheries Information Network. 2018. CEE001 effort estimates report and CTE001 recreational fishery catch estimate report. https://reports.psmfc.org/recfin/f?p=601:1000

Roach B, Wade W, Plater J. 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. Herndon (VA): U.S. Department of the Interior, Minerals Management Service. Report No.: OCS Study BOEM 2001-018.

[U.S. EPA] U.S. Environmental Protection Agency. 2009. BEACH Act: Beaches National Geospatial Dataset.

U.S. EPA. 2018a. National list of beaches: interactive version. https://www.epa.gov/beach-tech/national-list-beaches.

U.S. EPA. 2018b. Beaches NHDPlus indexed dataset. https://www.epa.gov/waterdata/waters-geospatial-data-downloads.

[Washington SCORP] Washington State Recreation and Conservation Office. 2013. The 2013 state comprehensive outdoor recreation plan. https://www.rco.wa.gov/StateRecPlans/.

Whitehead JC, Haab TC, McConnell KE. 2000. Southeast marine recreational fishery statistical survey: distance and catch based choice sets. Marine Resource Economics. 14(4):283–298.

4 Air Quality

4.1 Overview

E&D of the OCS will lead to emissions of sulfur dioxide (SO_2), oxides of nitrogen (NO_x), VOCs, particulate matter (PM),[22] and other air pollutants that may adversely affect human populations and the environment. To account for these effects, the revised OECM includes an air quality module that estimates 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 U.S., 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 Washington/Oregon Planning Area. The geographic unit of analysis within the air quality module is a series of offshore grid cells approximately 2,500 km^2 in size, as illustrated in Figure 2.

The specific air pollution impacts that the OECM examines include:

- adverse human health effects associated with increases in ambient $PM_{2.5}$ and ozone concentrations,[23]
- changes in agricultural productivity caused by changes in ambient ozone concentrations, and
- damage to physical structures associated with increases in SO_2.

Emissions from OCS development also may affect visibility, forest productivity, and recreational activity (e.g., visits to national parks). The OECM does not include these effects, however, as the limited data on these impacts in the peer-reviewed literature are not amenable to the streamlined air quality modeling framework included in the APEEP model. Because human health effects generally dominate the results of more detailed air pollution impact analyses,[24] excluding emissions-related changes in visibility, forest productivity, and recreational activity from the OECM is unlikely to have a significant impact on the model's results.

[22] The PM estimates emissions of both fine particulate matter ($PM_{2.5}$) and coarse particulate matter (PM_{10}).

[23] See Appendix C for information on how the OECM reflects the impacts of offshore emissions to onshore air quality.

[24] See U.S. EPA (2011).

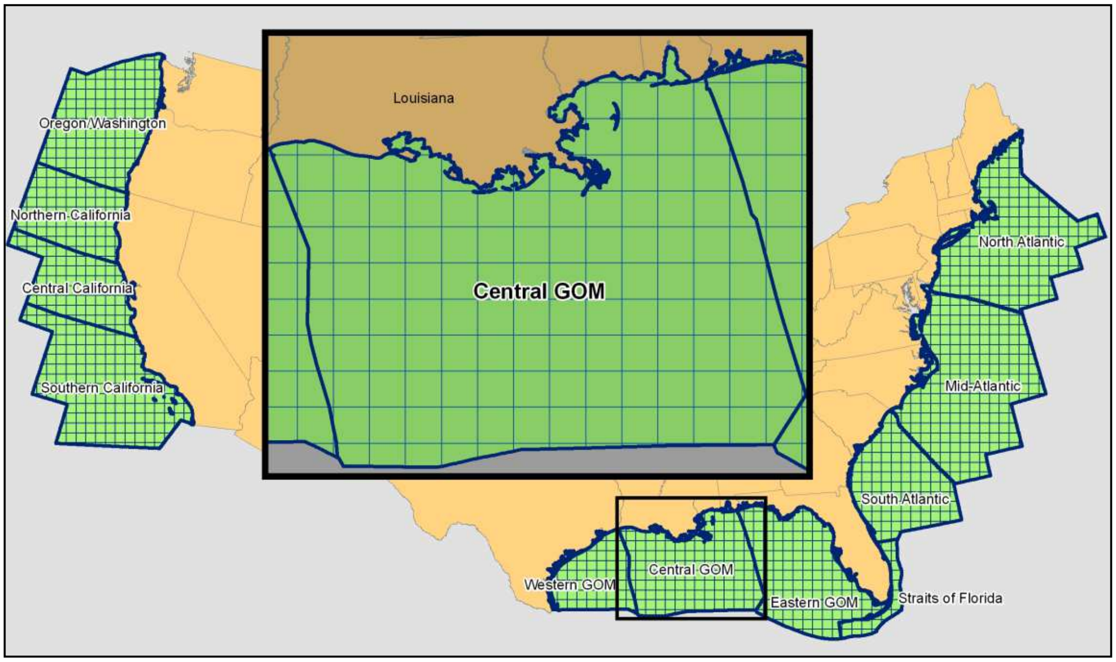


Figure 2. Offshore grid for the OCS adjacent to the contiguous U.S.

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., E&D, 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 E&D 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[25]
- Miles of pipeline laid, by year
- Production platforms decommissioned, by year
- For the NAA, changes in onshore energy production and tanker imports of oil and 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) FPSO vessel activity, (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) 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).[26] Table 5 summarizes the emission factors for each of these activities.

---

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

[26] 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

For planning areas along the contiguous U.S., the emissions factors in Table 5 for OCS E&D activities are based upon data from BOEM's Gulfwide Offshore Activities Data System (GOADS) that supported the Bureau's 2017 emissions inventory (Wilson et al. 2019). This dataset is the most recent BOEM inventory that includes both facility and vessel information. The emissions factors were calculated by dividing the total emissions generated from each activity Gulf-wide (e.g., emissions from laying pipelines, operating caissons) by the amount of that activity. These emission factors are applied to all OCS regions adjacent to the contiguous U.S. under the assumption that oil and natural gas operations in these areas would not differ significantly from operations in the GOM.[27]

Emission factor data are unavailable for Alaska planning areas because OCS oil and gas activity has been limited in this region. In the absence of such data, BOEM used two hypothetical Alaska facilities as the basis for the emission factors used in the OECM for the Alaska region. To derive emissions factors for Cook Inlet, BOEM modeled a man-made gravel island, including both drilling and production emissions. In addition to Cook Inlet, the OECM uses these emission factors for Alaska planning areas not located in the Arctic. For the Arctic planning areas, BOEM modeled an exploration campaign scenario in the Chukchi Sea simulating a harsh environment drilling system with equipment functioning at maximum emissions (Huisman Equipment 2015). BOEM verified these hypothetical facilities using the AERMOD and CALPUFF modeling systems to ensure that they produce similar dispersion to proprietary plans that have been historically submitted to BOEM. These air dispersion models were used to ensure that the hypothetical facilities have similar dispersion patterns to actual proposed facilities.

Table 5 also presents the emission factors for activities associated with the NAA, including: (1) onshore oil production in the contiguous U.S., (2) onshore natural gas production in the contiguous U.S., (3) coal production in the contiguous U.S., (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***: Emission factors for onshore oil production for the contiguous U.S. were based on the Western Regional Air Partnership's (WRAP's) 2014 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 2018).[28] 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 29 percent of onshore crude oil production in 2014. More detailed information on the derivation of the onshore oil emission factors for criteria pollutants is available in Appendix B.

assumed to be zero. The only pipeline-related emissions estimated by the OECM are emissions associated with the laying of pipelines.

[27] 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.

[28] WRAP also includes the States of Washington and Idaho, but they did not produce crude oil or natural gas in 2014, so these two States were not considered in this analysis.

Table 5. Emission factors for the GOM, Atlantic, and Pacific Regions[1]

Activity	Planning Area	Water Depth	NO_X	SO_2	PM_{10}	$PM_{2.5}$	CO	VOC	CO_2	CH_4	N_2O
Oil and Natural Gas Platform Operations (tons/platform/yr)	All planning areas except for Alaska planning areas[2]	All depths	49	0.5	0.6	0.6	38	50	6,700	181	0.1
	Alaska planning areas[3]	All depths	106	0.4	25	0.8	39	1.8	22,352	7.6	0.6
Caisson Operations (tons/caisson/yr)[4]	All planning areas	All depths	1.1	0.005	0.01	0.01	1.6	3.6	60	18	*
Exploration and Delineation Wells (tons/well, by water depth)	All, except for Alaska planning areas[5]	All depths	42	0.9	1.0	0.9	8.7	1.4	3,347	0.02	0.2
	Alaska planning areas[3]	All depths	41	0.02	0.7	0.7	11	1.0	2,211	0.1	0.002
Development and Production Wells (tons/well, by water depth)	All, except for Alaska planning areas[5]	All depths	42	0.9	1.0	0.9	8.7	1.4	3,347	0.02	0.2
	Cook Inlet	≤1,600 m [3]	41	0.02	0.7	0.7	11	1.0	2,211	0.1	0.002
	Cook Inlet	>1,600 m [5]	42	0.9	1.0	0.9	8.7	1.4	3,347	0.02	0.2
	Other Alaska[3]	All depths	41	0.02	0.7	0.7	11	1.0	2,211	0.1	0.002
Helicopters (tons/platform/yr)[5]	All planning areas	All depths	0.1	0.02	0.004	0.004	0.08	0.08	51	0.001	0.002
Pipe-laying Vessels (tons/mile of pipe)[5]	All planning areas	All depths	25	1.0	0.5	0.4	2.7	1.4	1,620	0.01	0.08
Platform Construction/ Removal (tons/platform or caisson, by water depth)	All, except for Alaska planning areas[6]	<300 ft	8.7	0.2	0.3	0.3	2.1	0.1	602	0.004	0.03
	All, except for Alaska planning areas[6]	300–600 ft	26	0.5	1.0	0.9	6.1	0.4	1,780	0.01	0.08
	All, except for Alaska planning areas[6]	>600 ft	227	4. 8	8.5	8.3	53.5	3.2	15,595	0.09	0.7
	Non-Arctic Alaska	All depths[7]	307	31	6.7	6.3	50	12.5	13,910	0.1	0.6
	Beaufort and Chukchi	All depths[7]	801	32	34	31	263	48	13,910	0.1	0.6
Subsea Construction (tons/subsea/year)	All, except for Alaska planning areas[6]	0–197 ft (0–60 m)	58	1.6	1.8	1.8	11.2	1.7	5,222	0.06	0.005
	All, except for Alaska planning areas[6]	197–2,625 ft (60–800 m)	103	2.8	3.2	3.1	20	3.1	9,244	0.1	*
	All, except for Alaska planning areas[6]	2,625–5,248 ft (800–1,600 m)	265	6.0	9.7	9.4	59.4	4.8	19,556	0.1	0.9
	All, except for Alaska planning areas[6]	>5,248 ft (>1,600 m)	519	11	19	19	119	8.5	37,081	0.3	1.5

Activity	Planning Area	Water Depth	NO_X	SO_2	PM_{10}	$PM_{2.5}$	CO	VOC	CO_2	CH_4	N_2O
	Cook Inlet	All depths[8]	51	0.1	1.4	1.3	9.8	4.5	5,309	*	*
	Beaufort and Chukchi	All depths[8]	242	0.4	12	11	90	19	5,309	*	*
	Other Alaska	All depths[8]	51	0.1	1.4	1.3	9.8	4.5	5,309	*	*
FPSO Operation (tons/FPSO/year)	All planning areas	0–60 m [9]	40	0.4	0.4	0.4	51	30	2,759	148	0.05
	All planning areas	60–800 m [9]	85	3.0	1.0	1.0	76	74	9,964	286	0.2
	All planning areas	800–1,600 m [9]	627	61	5.2	5.1	177	57	144,970	261	2.6
	All planning areas	>1,600 m [10]	379	1.4	5.5	5.5	121.1	70.6	121,835	477	3.2
FPSO Construction, installation activity at site (tons/FPSO)[9]	All planning areas	All depths	146	0.05	1.6	1.5	43	1.2	5,591	0.03	0.3
FPSO Construction, en route to site (tons/mile (mi)/FPSO)[9]	All planning areas	All depths	0.2	0.03	0.004	0.004	0.05	0.005	6.8	0.0001	0.0003
FPSO Removal, removal activity at site (tons/FPSO)[9]	All planning areas	All depths	69	0.03	0.7	0.7	20	0.6	2,652	0.02	0.1
FPSO Removal, en route to site (tons/mi/FPSO)[9]	All planning areas	All depths	0.2	0.03	0.004	0.004	0.05	0.005	6.8	0.0001	0.0003
Support Vessels (tons/platform/yr)[2]	All planning areas	All depths	18	0.5	0.6	0.6	4.4	0.4	1,851	0.008	0.1
Survey Vessels (tons/platform or caisson/yr)[2]	All planning areas	All depths	2.6	0.07	0.08	0.08	0.5	0.07	226	0.001	0.01
Tugs Pulling Barges, Non-Alaska Regions—Cruising emissions (tons/BBO/mi)[11]	All planning areas	All depths	183	22	2.8	2.8	15	2.8	9,063	0.06	0.4
Tugs Pulling Barges, Non-Alaska Regions—Idling emissions during loading (tons/BBO) [11]	All planning areas	All depths	5,087	864	192	192	1,056	12,473	344,084	2,171	15
Tugs Pulling Barges, Non-Alaska Regions—Idling emissions during unloading (tons/BBO) [11]	All planning areas	All depths	5,087	864	192	192	1,056	6,332	344,084	1,087	15
Oil Tankers, Non-Alaska OCS Regions—Cruising emissions (tons/BBO/mi)[12]	All planning areas	All depths	41	0.9	0.5	0.4	3.4	14	1,468	2.1	0.07
Oil Tankers, Non-Alaska OCS Regions—Idling emissions during loading (tons/BBO)[12]	All planning areas	All depths	7,755	273	109	98	954	11,341	341,997	1,926	14

Activity	Planning Area	Water Depth	NO_X	SO_2	PM_{10}	$PM_{2.5}$	CO	VOC	CO_2	CH_4	N_2O
Oil Tankers, Non-Alaska OCS Regions—Idling emissions during loading (tons/BBO)[12]	All planning areas	All depths	7,755	2,730	109	98	954	6,879	341,997	1,139	14
Oil Tankers (Alaska Region or Exports/Imports)—Cruising emissions (tons/BBO/mi)[12]	All planning areas	All depths	164	0.3	0.2	0.2	1.3	11	567	1.8	0.03
Oil Tankers (Alaska Region or Exports/Imports) —Idling emissions during loading (tons/BBO)[12]	All planning areas	All depths	14,117	491	192	172	1,777	11,750	585,615	1,930	23
Oil Tankers (Alaska Region or Exports/Imports) —Idling emissions during unloading (tons/BBO)[12]	All planning areas	All depths	14,117	491	192	172	1,777	7,288	585,615	1,143	23
LNG Tankers—Cruising emissions (tons/trillion cubic feet (ft^3) of gas/mi)[13]	All planning areas	All depths	0.4	1.4	0.09	0.07	0.1	0.006	244	**	**
LNG Tankers—Loading emissions (tons/trillion ft^3 of gas)[13]	All planning areas	All depths	N/A	N/A	N/A	N/A	N/A	N/A	19,080	**	**
LNG Tankers—Unloading emissions (tons/trillion ft^3 of gas)[13]	All planning areas	All depths	55	136	9.6	6.5	16	1.0	772	**	**
Onshore Oil Production—Contiguous U.S. (tons/million barrels)[14]	All planning areas	Not applicable	29	3.8	1.3	1.3	35	914	11,841	1,059	0.2
Onshore Pipeline (tons/pipeline mile)[15]	Chukchi Sea	Not applicable	0.6	0.002	0.03	0.04	0.3	0.05	0.01	*	*
Onshore Gas Production (Conventional)—Contiguous U.S. (tons/trillion ft^3)[16]	All planning areas	Not applicable	22,135	111	33,572	333	3,839	115	1,174,163	190,601	1.3
Onshore Gas Production (Unconventional)—Contiguous U.S. (tons/trillion ft^3)[16]	All planning areas	Not applicable	34,606	158	54,742	727	6,591	186	2,360,312	74,653	2.8
Onshore Coal Production—Contiguous U.S. (tons/million short tons)[17]	All planning areas	Not applicable	121	149	187	26	41	162	35,596	3,248	0.7
Production of Oil Imported via Pipeline (tons/million barrels)[18]	All planning areas	Not applicable	N/A	N/A	N/A	N/A	N/A	N/A	75,103	1,331	0.5
Production of Oil Imported via Tanker (tons/million barrels) [18]	All planning areas	Not applicable	N/A	N/A	N/A	N/A	N/A	N/A	43,621	773	0.3
Production of Gas Imported via Pipeline (tons/trillion ft^3)[19]	All planning areas	Not applicable	N/A	N/A	N/A	N/A	N/A	N/A	5,709,250	*	*
Production of Gas Imported via Tanker (tons/trillion ft^3) [19]	All planning areas	Not applicable	N/A	N/A	N/A	N/A	N/A	N/A	954,958	*	*

Notes:
N/A signifies that a value is not applicable for a category, as it is outside the OECM's scope.
An asterisk (*) indicates that an emission factor value is not available for a specific emissions source and pollutant.
Two asterisks (**) indicates that that value for a pollutant (CH_4 or N_2O) is combined with CO_2 as CO_2 equivalents.

1. The emissions listed in this table are nitrogen oxides (NO_x), sulfur dioxide (SO_2), particulate matter up to 10 micrometers in size (PM_{10}), particulate matter up to 2.5 micrometers in size ($PM_{2.5}$), carbon monoxide (CO), volatile organic compounds (VOC), carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). For values less than 0.01, three or four decimal places are shown (the minimum necessary to show a non-zero value). For values between 0.01 and 0.1, two decimal places are shown. For values between 0.1 and 10, one decimal place is shown. For values greater than 10, no decimal places are shown.
2. Developed internally by BOEM (2023).
3. Derived from Wilson et al. (2019).
4. Emission factors from Wilson et al. (2019), Tables 6-2 and 6-12.
5. Emissions factors from Billings et al. 2012.
6. Emissions factors from U.S. EPA (2010b) Statement of Basis for Frontier Discoverer in Chukchi and EPA AP-42; Wolvovsky (2012); and Billings et al. (2012) memo to BOEM.
7. Emissions factors from U.S. EPA (2010b) Statement of Basis for Frontier Discoverer in Chukchi and EPA AP-42.
8. Emissions factors from Billings et al. (2015a and 2015b).
9. Emissions factors from ERG (2018). Calculated using data from the 2014 Gulfwide Emissions Inventory Study.
10. Emissions factors from Wolvovsky (2012) and Billings et al. (2012).
11. Emissions factors from SC&A, Inc. (2023).
12. Emissions factors from Jaramillo et al. (2007) and Afon and Ervic (2008).
13. Emissions factors derived from Western Regional Air Partnership Oil and Gas Workgroup (2018).
14. 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 in the National Petroleum Reserve in Alaska. See BLM (2013, 2014).
15. Emissions factors derived from NETL (2019).
16. Emissions factors derived from GREET model. See ANL (2022).
17. Emissions factors derived from National Energy Technology Laboratory (2019).
18. Emissions factors derived from GREET model. See Argonne National Laboratory (2022).
19. Emission factors derived from Mohammad et al. (2018). Emissions factors for NO_x, SO_2, PM_{10}, $PM_{2.5}$, CO, and VOC entered as N/A because the OECM does not assess impacts of criteria pollutant emissions outside the U.S.
20. Emissions factors derived from Advanced Resources International, Inc. and ICF International (2008). Emissions factors for NO_x, SO_2, PM_{10}, $PM_{2.5}$, CO, and VOC entered as N/A because the OECM does not assess impacts of criteria pollutant emissions outside the U.S.

- ***Onshore natural gas production*:** The OECM contains separate emission factors for conventional and unconventional natural gas production, drawing from data published by the NETL (2019). Focusing on the year 2016, NETL (2019) estimates the emissions, by pollutant, of onshore natural gas production across multiple production methods and sources. These include shale gas, tight 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 and shale gas. 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 2016, as reported in NETL (2019).
- ***Onshore coal production:*** Emissions per unit production of coal were derived using the Argonne National Laboratory's GREET Model (ANL 2022), 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 U.S. 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 U.S. Given the global effects of greenhouse gas (GHG) emissions, the model treats these emissions from imports separately from NO_x, SO_2, PM, CO, and VOCs. More specifically, the OECM estimates GHG emissions associated with both the production and transport of this oil. Production-related emission factors were derived from field-level GHG intensities from nearly 9,000 oil fields worldwide and country-level carbon intensities for oil production, both of which were from Mohammad et al. (2018). The OECM does not estimate NO_x, SO_2, PM, CO, and VOC emissions associated with the production of oil imported into the U.S. For transportation-related emissions, the OECM estimates GHG emissions for the full roundtrip journey from the country of production to the U.S. and back. For NO_x, SO_2, 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 U.S. 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.
- ***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 U.S. and GHG, NO_x, SO_2, PM, CO, and VOCs associated with the transportation of natural gas shipped to the U.S. 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_x, SO_2, 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 U.S. 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 U.S.

The OECM also includes emission factors for oil tankers that transport oil from the Alaska OCS region to the west coast of the contiguous U.S. or that transport U.S. oil exports or imports. The model similarly includes emission factors for smaller tankers that may transport OCS oil from offshore production locations to onshore facilities. The emission factors for both tanker types were derived from the emission factor equations in the U. S. EPA's Ports Emissions Inventory Guidance (U.S. EPA 2020).

As indicated in Table 5, the OECM estimates emissions for each emissions category (e.g., helicopter trips) are based on the emission factors for that category and an emissions driver that represents the amount of emissions-generating activity. For reference, Table 6 provides a crosswalk between the various emissions categories and the emissions drivers employed in the OECM.

Table 6. Crosswalk between emissions drivers and emissions category

Emissions Drivers	Emissions Categories
Number of operational platforms	Platform operations Helicopters Support vessels Survey vessels[1]
Number of operational caissons	Caisson operations Survey vessels[1]
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 Regions Cruising emissions—oil tankers non-Alaska Regions Cruising emissions—oil tankers Alaska Region Cruising emissions—oil tankers exporting crude oil Cruising emissions—tankers exporting refined petroleum products
Barrels of oil shipped	Idling emissions—oil tankers non-Alaska Regions Loading emissions—oil tankers Unloading emissions—oil tankers
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: 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 5, 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*: Although 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 7 summarizes these assumptions.
- *Onshore energy production*: The OECM allocates onshore oil and gas production under the NAA 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 E contains more detailed information on this approach. For onshore coal production, the model does not allocate production to specific locations within the U.S. 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 U.S. 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 7. 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 GOM	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 GOM, and Western GOM Planning Areas.
	Unloading and Ballasting	Unloading and ballasting assumed to occur only in existing LNG terminals.
Tankers—Crude Oil or Refined Product Exports	Cruising	For a given planning area exporting crude oil or refined petroleum, 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.
	Loading	Given the uncertainty regarding where loading would occur in each planning area, loading emissions are assumed to occur in the grid cells along the coast of the planning area exporting crude oil or refined petroleum products.

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 GOM Regions that will be discussed first below, and a second approach for planning areas in the Alaska 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 $PM_{2.5}$, VOC, NO_x, and SO_2 emissions.[29] To generate dollar-per-ton values for the OECM, the APEEP model 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 concentration-response functions[30] 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_x, SO_2, $PM_{2.5}$, and VOCs. Each of these steps is described in more detail below.

4.3.4 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 2 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 U.S. 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.

---

[29] The approach described in this section is based on the approach applied in Muller (2014).

[30] Concentration-response relationships have been referred to as "dose-response" relationships in earlier versions of this model documentation. We have updated the documentation to be more accurate to health epidemiology literature, where "concentration-response" relationships refer to exposures in observational studies.

4.3.5 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 8, 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 concentration-response (C-R) functions to estimate impacts for exposed receptors. Appendix D presents additional information on the assumptions employed in the modeling of physical effects.

Table 8. Summary of air pollution physical effects included in the APEEP model for the revised OECM

Impact Category	Pollutant(s)	Physical Effect	Studies Used For Concentration-Response
Human Health	$PM_{2.5}$	Premature mortality (adults aged 29 and older)	Krewski et al. (2009)
		Infant mortality (age < 1 year)	Woodruff et al. (1997)
		Chronic bronchitis (all ages)	All ages: Abbey et al. (1995)
	Ozone	Premature mortality (all ages)	Smith et al. (2009)
		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 5–17)	Chen et al. (2000)
Agriculture	Ozone	Change in yield for corn, cotton, peanuts, wheat, grain sorghum, soybeans, kidney beans, and tobacco	Lesser et al. (1990)
Material Damage	SO_2	Damage to galvanized steel, painted surfaces, and carbonate stone surfaces	Atteraas (1982), Haynie (1986), and ICP (1998)

4.3.6 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 9 and 10 summarize these values.

Table 9. Unit values for economic valuation of health endpoints—central estimate of value per statistical incidence, adjusted for income (2010$)

Health Endpoint	2015 Income	2065 Income	WTP or COI	Notes
Premature mortality	$9,1000,000	$12,000,000	WTP	Mean Value of Statistical Life (VSL), adjusted for income, based on 26 wage-risk and contingent valuation studies. A Weibull distribution provided the best fit to the 26 estimates. Note that VSL represents the value of a small change in mortality risk aggregated over the affected population. This is consistent with the VSL approach used in U.S. EPA (2010a).
Chronic bronchitis	$500,000	$730,000	WTP	WTP to avoid a case of pollution-related CB is calculated as $WTP_x = WTP_{13} \cdot e^{-\beta(13-x)}$, where x is the severity of an average CB case; WTP_{13} is WTP for a severe case of CB; and β is the parameter relating WTP to severity, based on the regression results reported in Krupnick and Cropper (1992). This valuation function and the rationale behind it are described in detail in U.S. EPA (1999).
Respiratory hospital admissions (age 65+)	$26,000	$26,000	COI	These COI point estimates (lost earnings plus direct medical costs) are based on ICD-9 code level information (e.g., average hospital care costs and average length of hospital stay) reported in Agency for Healthcare Research and Quality (2000). As noted in the text, no adjustments are made to COI values for income growth.
Respiratory hospital admissions (age <2 years)	$11,000	$11,000	COI	Same as above
Asthma-related emergency room visits	$390	$390	COI	Simple average, adjusted for income, of estimates from Smith et al. (1997) and Stanford et al. (1999).
Minor restricted activity days	$67	$75	WTP	Median WTP estimate to avoid one minor restricted activity day from Tolley et al. (1986).
School loss days	$95	$95	COI	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).

Table 10. Summary of crop and materials prices (2010$)

Category	Crop	Price
Agriculture	Corn	$4.36 per bushel
	Cotton	$0.63 per pound
	Peanut	$0.21 per pound
	Grain Sorghum	$7.56 per hundredweight
	Soybeans	$10.48 per bushel
	Spring Wheat	$7.80 per bushel
	Tobacco	$1.76 per pound
Materials	Galvanized Steel	$801 per ton
	Carbonate Stone	$123 per square meter
	Paint	$37 per gal

Sources:
Agriculture: USDA/NASS (2009)
Materials (galvanized steel and paint): Morici (2005)
Materials (stone): Masonry Advisory Council (2010)

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 COI as a primary estimate.

The data in Table 9 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.

4.3.7 Damages Per Ton in Alaska Planning Areas

As outlined above, the air quality analysis for the Atlantic, Pacific, and GOM 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 Region.[31] 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 GOM 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

[31] Although studies such as Dobson et al. (2010) examine the air quality impacts of oil development in Alaska, we identified no studies in the literature that show the relationship between emissions of a single pollutant (e.g., NO_x) and ambient pollutant concentrations, by location.

relationship into the scaling procedure, Alaska and Washington/Oregon grid cells were grouped into a series of 50-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 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 3 through 6 display the damages ($/ton) due to emissions of $PM_{2.5}$, SO_2, NO_x, 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, though it is interesting to note that the sources with $PM_{2.5}$-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 GOM. This top damage class for $PM_{2.5}$ 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 U.S. 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 U.S. 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 U.S. 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 3 through 6 show a similar pattern for emissions of SO_2, NO_x, and VOCs. In the GOM, the transition from high- to low-impact grid cells is much more gradual than in the northeast U.S.

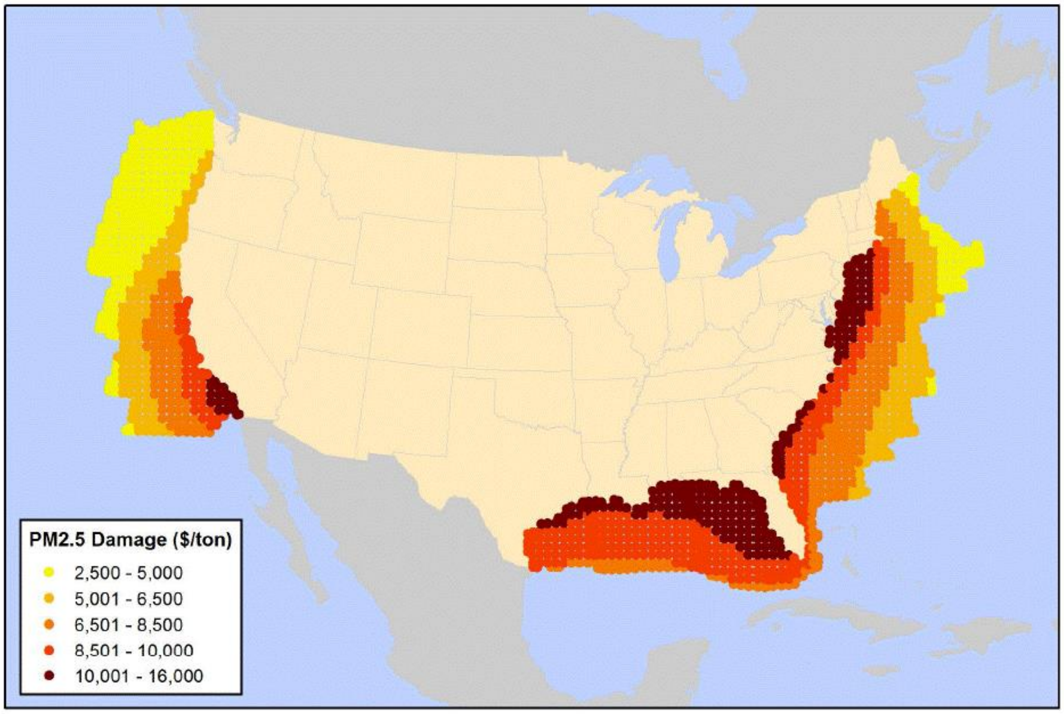


Figure 3. Damages due to $PM_{2.5}$ emissions

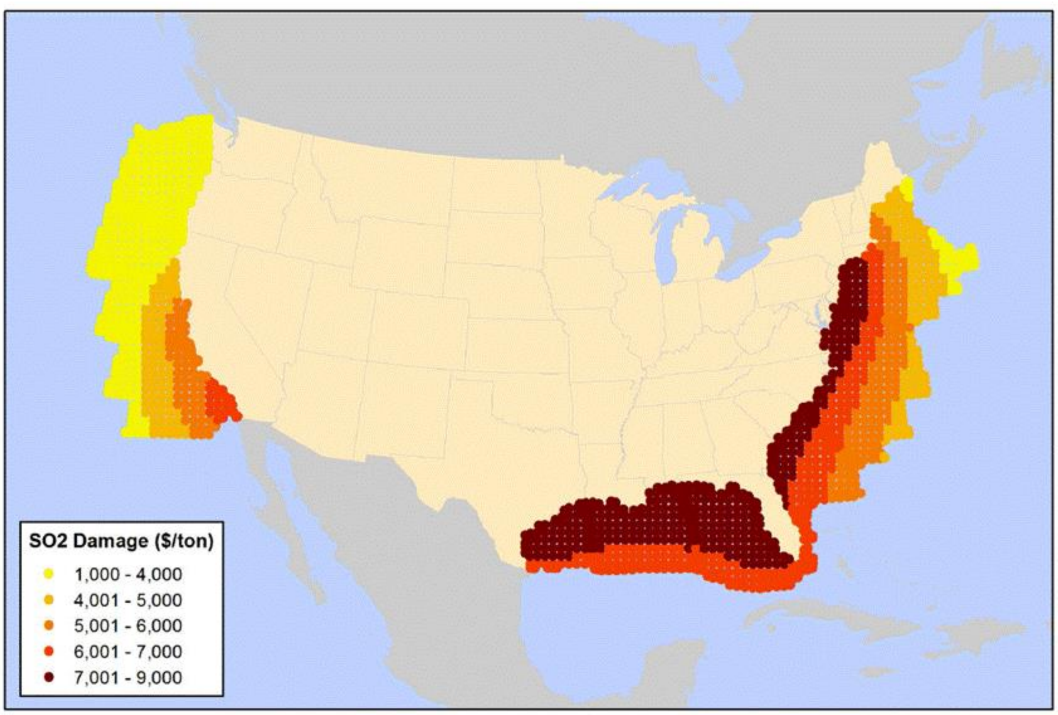


Figure 4. Damages due to SO_2 emissions

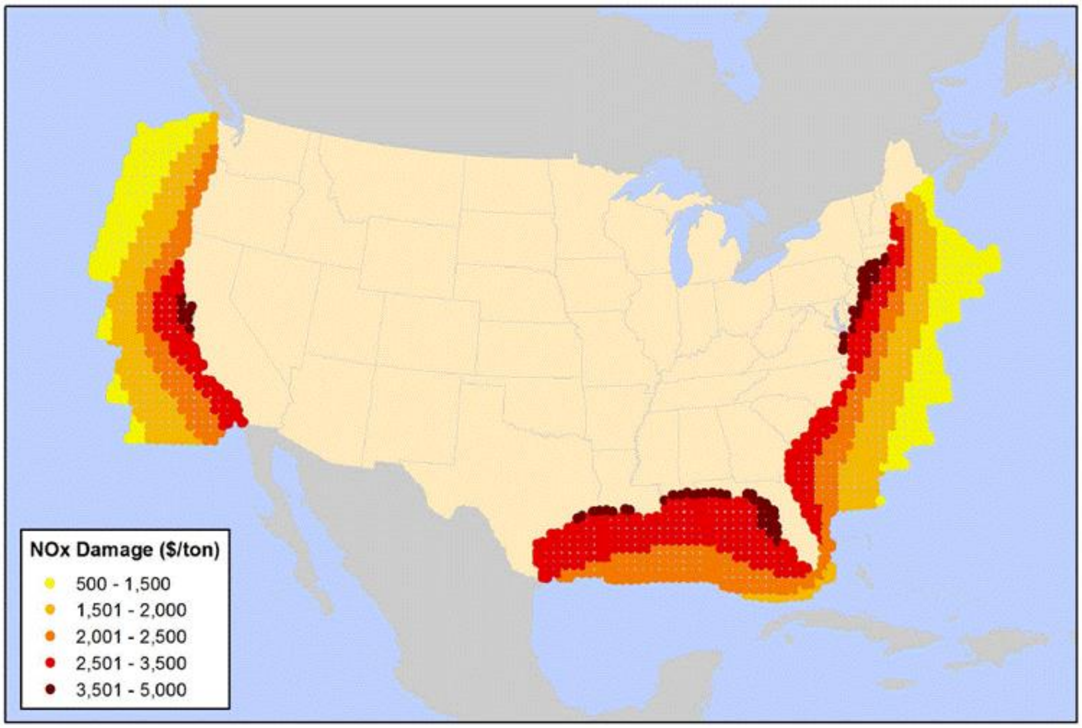


Figure 5. Damages due to NO_x emissions

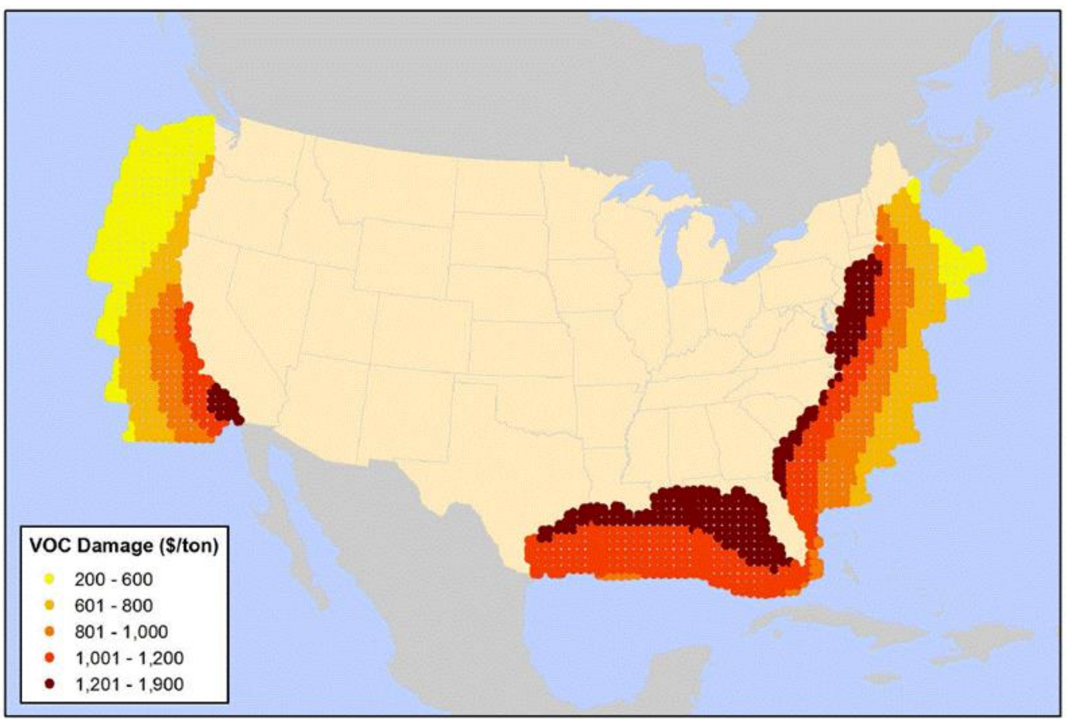


Figure 6. Damages due to VOC emissions

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 5. 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. To capture differences in the location of domestic onshore oil and gas substitutes for each OCS region, weighted average dollar-per-ton values (separately for oil and gas) were derived for the Atlantic OCS Region, the GOM OCS Region, and the combined Pacific OCS and Alaska OCS Regions. These region-specific values were derived through the following process:

1. ***Calculate weighted average dollar-per-ton values by Petroleum Area Defense District (PADD):*** Using county-level oil and gas production in 2011 (ERS 2014) as weights, the weighted average of the dollar-per-ton values from APEEP was calculated for each PADD. Separate weighted averages were developed by pollutant, year, and energy source (i.e., oil and gas).
2. ***Calculate spatial distribution of onshore oil and gas substitutes for each region:*** For the Atlantic, GOM, and combined Pacific/Alaska regions, EIA data on movements of oil and gas between PADDs were used to estimate the distribution across PADDs of the oil and gas substitutes associated with each region. The process for deriving these distributions is described in detail in Appendix E.
3. ***Calculate weighted average dollar-per-ton values for each region:*** Using the PADD-specific dollar-per-ton values calculated in Step 1 and each region's distribution of substitution domestic production across PADDs as specified in Step 2, the weighted average onshore dollar-per-ton value was calculated by region. Separate values were calculated for each region, pollutant, and year.

For coal, the OECM applies a single set of dollar-per-ton values for each year and pollutant (i.e., not differentiated by OCS production region). County-level coal production published in the EIA's (2017) *Annual Coal Report 2016*, was used to develop weighted average dollar-per-ton values specific to coal production.

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 TAPS. 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.[32]

Similar to the OECM's monetization of offshore emissions in the Alaska 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.

[32] 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 National OCS 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.

4.7 References—Air Quality

Abbey DE, Hwang BL, Burchette RJ, Vancuren T, Mills PK. 1995. Estimated long-term ambient concentrations of PM_{10} and development of respiratory symptoms in a nonsmoking population. Archives of Environmental Health. 50(2):139–152.

Abt Associates, Inc. 2008. Environmental Benefits Mapping and Analysis Program (BenMAP) user's manual appendices. Prepared for EPA/OAR/OAQPS.

Advanced Resources International, Inc. and ICF International. 2008. Greenhouse gas life-cycle emissions study: fuel life-cycle of U.S. natural gas supplies and international LNG.

Afon Y, Ervin D. 2008. An assessment of air emissions from liquefied natural gas ships using different power systems and different fuels. Journal of the Air & Waste Management Association. 58:404–411.

Agency for Healthcare Research and Quality. 2000. HCUPnet, Healthcare cost and utilization project. Rockville, MD.

[ANL] Argonne National Laboratory. 2022. Greenhouse Gas Regulated Emissions and Energy Use (GREET) model. https://greet.es.anl.gov/

Atteraas H. 1982. Atmospheric corrosion testing in norway. In: Atmospheric corrosion. Ailor WH, editor. New York (NY): Wiley-Interscience. p. 873–892.

Billings R, Wilson D, Enoch S. 2015a. FPSO emission factors. Provided to Jason Price of Industrial Economics via email on July 24, 2015.

Billings R, Wilson D, Enoch S. 2015b. FPSO emission factors. Provided to Jason Price of Industrial Economics via email on August 10, 2015.

Billings R, Bryan L, Wilson D. 2012. Emission estimates for Eastern Planning Area Sales 225-226. Memorandum to Holli Ensz of BOEM, September 7, 2012.

[BLM] Bureau of Land Management. 2013. Emissions submission for Alternative A, submitted in support of the Supplemental Environmental Impact Statement for the Alpine Satellite Development Plan for the Proposed Greater Mooses Tooth One Development Project. Washington (DC): U.S. Department of the Interior, Bureau of Land Management.

BLM. 2014. Emissions submission for Alternative D2, prepared in support of the Supplemental Environmental Impact Statement for the Alpine Satellite Development Plan for the Proposed Greater Mooses Tooth One Development Project. Washington (DC): U.S. Department of the Interior, Bureau of Land Management.

[BOEM] Bureau of Ocean Energy Mnaagement. 2023. Final economic analysis methodology for the 2024–2029 National Outer Continental Shelf Oil and Gas Leasing Program. Sterling (VA): U.S. Department of the Interior, Bureau of Ocean Energy Management. 145 p. Report No.: BOEM 2023-059.

Burnett RT, Smith-Doiron M, Stieb D, Raizenne ME, Brook JR, Dales RE, Leech JA, Cakmak S, Krewski D. 2001. Association between ozone and hospitalization for acute respiratory diseases in children less than 2 years of age. American Journal of Epidemiology. 153(5):444–452.

Chen L, Jennison BL, Yang W, Omaye ST. 2000. Elementary school absenteeism and air pollution. Inhalation Toxicology. 12(11):997–1016.

Dobson J, Ritter TL, Driscoll D. 2010. Impact of oil development on air quality in an Alaska Native village. Presented at the 138th APHA Annual Meeting and Exposition 2010.

[EIA] Energy Information Administration. 2017. Annual coal report 2016. Washington (DC): U.S. Department of Energy, Energy Information Administration. https://www.eia.gov/coal/annual/.

[ERG] Eastern Regional Group. 2018. Platform, caisson, and FPSO emissions factors. Provided to Hollis Ensz of BOEM on July 18, 2018.

[ERS] Economic Research Service. 2014. County-level oil and gas production in the U.S. 2000–2011. Washington (DC): U.S. Department of Agriculture, Economic Research Service. https://www.ers.usda.gov/data-products/county-level-oil-and-gas-production-in-the-us/.

Haynie FH. 1986. Atmospheric acid deposition damage to paints. Research Triangle Park (NC): Atmospheric Science Research Laboratory. Report No.: Environmental Research Brief EPA 600/M-85/019.

Huisman Equipment. 2015. Harsh environment semi-submersible drilling unit. Schiedam (The Netherlands): Huisman Equipment. 12 p. https://www.huismanequipment.com/documenten/brochures_2016/harsh_environment_semi-sub_2015_mail.pdf

[ICP] International Cooperative Programme on Effects on Materials, Including Historic and Cultural Monuments. 1998. Report no 30: statistical analysis of 8 year materials exposure and acceptable deterioration and pollution levels. Stockholm (Sweden): Swedish Corrosion Institute.

Jaramillo P, Griffin WM, Matthews HW. 2007. Comparative life-cycle air emissions of coal, domestic natural gas, LNG, and SNG for electricity generation. Environmental Science & Technology. 41:6290–6296.

Krewski D, Jerrett M, Burnett RT, Ma R, Hughes E, Shi Y, et al. 2009. Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality. Res Rep Health Eff Inst. 2009(140):5–136.

Krupnick AJ, Cropper ML. 1992. The effect of information on health risk valuations. Journal of Risk and Uncertainty. 5(1):29–48.

Lesser VM, Rawlings JO, Spruill SE, Somerville MC. 1990. Ozone effects on agricultural crops: statistical methodologies and estimated dose-response relationships. Crop Science. 30(1):148–155.

Masonry Advisory Council. 2010. 2009–2010 masonry cost guide. http://www.maconline.org/tech/estimating/cost/cost.html.

Mohammad S, et al. 2018. Global carbon intensity of crude oil production. Science. 361(6405):851–853.

Morici P. 2005. Manufacturing and steel prices. Working paper sponsored by the American Iron and Steel Institute and the Steel Manufacturers Association. https://www.sfsa.org/sfsa/news/2005/MoriciSteelPrices.pdf

Muller NZ. 2014. Air pollution damages from offshore energy production. The Energy Journal. 35(4):39–60.

Muller NZ, Mendelsohn R. 2006. The Air Pollution Emission Experiments and Policy Analysis Model (APEEP): technical appendix. New Haven (CT): Yale University. https://docs.google.com/viewer?a=v&pid=sites&srcid=ZGVmYXVsdGRvbWFpbnxuaWNrbXVsbGVyc2hvbWVwYWdlfGd4OjJkMzk0YjI1MjBjNjYzMzU

[NETL] National Energy Technology Laboratory. 2019. Life cycle analysis of natural gas extraction and power generation. Washington (DC): U.S. Department of Energy, National Energy Technology Laboratory. 200 p. Report No.: DOE/NETL-2014/1646.

Ostro BD, Rothschild S. 1989. Air pollution and acute respiratory morbidity: an observational study of multiple pollutants. Environmental Research. 50(2):238–247.

Peel JL, Tolbert PE, Klein M, Metzger KB, Flanders WD, Todd K, Mulholland JA, Ryan PB, Frumkin H. 2005. Ambient air pollution and respiratory emergency department visits. Epidemiology. 16(2):164–174.

SC&A, Inc. 2023. Oil tanker emission factors. Prepared for U.S. Department of the Interior, Bureau of Ocean Energy Management.

Schwartz J. 1995. Short term fluctuations in air pollution and hospital admissions of the elderly for respiratory disease. Thorax. 50(5):531–538.

Smith DH, Malone DC, Lawson KA, Okamoto LJ, Battista C, Saunders WB. 1997. A national estimate of the economic costs of asthma. American Journal of Respiratory and Critical Care Medicine. 156(3 Pt 1):787–793.

Smith RL, Xu B, Switzer P. 2009. Reassessing the relationship between ozone and short-term mortality in U.S. urban communities. Inhalation Toxicology. 21:37–61.

Stanford R, McLaughlin T, Okamoto LJ. 1999. The cost of asthma in the emergency department and hospital. American Journal of Respiratory and Critical Care Medicine 160(1): 211-215.

Tolley, G., A. Randall, G. Blomquist, M. Brien, R. Fabian, G. Fishelson, A. Frankel, M. Grenchik, J. Hoehn, A. Kelly, R. Krumm, E. Mensah, and T. Smith. 1986. Establishing and Valuing the Effects of Improved Visibility in Eastern United States. Prepared for U.S. EPA, Office of Policy, Planning and Evaluation. U.S. EPA Grant #807768-01-0.

[USDA/NASS] U.S. Department of Agriculture, National Agricultural Statistics Service. 2009. Agricultural prices 2008 summary (August 2009). http://usda.mannlib.cornell.edu/usda/current/AgriPricSu/AgriPricSu-08-05-2009.pdf .

[U.S. EPA] U.S. Environmental Protection Agency. 1999. The benefits and costs of the Clean Air Act: 1990 to 2010: EPA report to Congress. Washington (DC): U.S. EPA, Office of Air and Radiation, Office of Policy. Report No.: EPA 410-R-99-001. http://www.epa.gov/airprogm/oar/sect812/index.html.

U.S. EPA. 2010a. Final Regulatory Impact Analysis (RIA) for the NO_2 National Ambient Air Quality Standards (NAAQS). Research Triangle Park (NC): Office of Air Quality Planning and Standards. http://www.epa.gov/ttn/ecas/regdata/RIAs/FinalNO2RIAfulldocument.pdf.

U.S. EPA. 2010b. 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. Washington (DC): U.S. Environmental Protection Agency. http://www.epa.gov/region10/pdf/permits/shell/chukchi_revised_permit_statement_of_basis_010610.pdf.

U.S. EPA. 2011. The benefits and costs of the Clean Air Act from 1990 to 2020: Final Report – Rev. A. Washington (DC): U.S. Environmental Protection Agency. http://www.epa.gov/oar/sect812/feb11//fullreport_rev_a.pdf.

U.S. EPA. 2020. Ports emissions inventory guidance: methodologies for port-related and goods movement mobile source emissions. Wasghinton (DC): U.S. Environmental Protection Agency, Office of Transportation and Air Quality. 233 p. Report No.: EPA-420-B-20-046.

Western Regional Air Partnership Oil & Gas Workgroup. 2018. 2014 base case emission inventory spreadsheet. http://www.wrapair2.org/ogwg.aspx

Wilson AM, Wake CP, Kelly T, Salloway JC. 2005. Air pollution, weather, and respiratory emergency room visits in two northern New England cities: an ecological time-series study. Environmental Research. 97(3):312–321.

Wilson D, Billings R, Chang R, Do B, Enoch S, Perez H, Sellers J. 2019. Year 2017 emissions inventory study. New Orleans (LA): U.S. Department of the Interior, Bureau of Ocean Energy Management, Gulf of Mexico OCS Region. 231 p. Report No.: OCS Study BOEM 2019-072. [accessed 2020 Nov 22]. https://espis.boem.gov/final%20reports/BOEM_2019-072.pdf

Wolvovsky E. 2012. Emission factors provided by Eric Wolvovsky of BOEM, May 1, 2012.

Woodruff TJ, Grillo J, Schoendorf KC. 1997. The relationship between selected causes of postneonatal infant mortality and particulate air pollution in the United States. Environmental Health Perspectives. 105(6):608–612.

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; Hoen et al. 2011).
- No impacts occur beyond a fixed distance from shore, which varies regionally based on visibility information (Ladenburg 2009).

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 (22 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 2000) that are scaled to 2017 using the Federal Housing Finance Agency's Housing Price Index (HPI) (Federal Housing Finance Agency 2018a; 2018b). 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 2001). 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 2000). Table 11 provides an overview of the total residential property value per one-eighth mile by 1-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.

To scale the assessor and census data to 2017 values, the model uses the Federal Housing Finance Agency's HPI. The increase in housing value is assumed to be equal to the increase in HPI, after adjusting for inflation, using the implicit price deflator. The OECM uses the average of the four quarterly, seasonally adjusted HPI values reported for a given year as the representative annual HPI. The HPI is available at both the Metropolitan Statistical Area (MSA) level and the state level. Using the Census Bureau's crosswalk between counties and MSAs, the MSA HPI is used for all coastal block groups that are associated with counties within the MSA (U.S. Census Bureau 2017). If a coastal block group is not within an MSA with HPI data, the state-level HPI is used to scale the property value data to 2017.

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 1-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. Although this may result in an overestimate of the impact in areas of existing activity, such as the GOM, 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 11. 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	North Atlantic	$32,310,459
	Mid-Atlantic	$8,984,278
	South Atlantic	$18,353,004
GOM	Eastern GOM	$29,834,539
	Straits of Florida	$82,911,171
	Central GOM	$1,490,104
	Western GOM	$3,363,617
Pacific	Southern California	$51,085,466
	Central California	$40,149,241
	Northern California	$1,645,444
	Washington/Oregon	$4,414,728
Alaska	Beaufort Sea	$124
	Kodiak	$378,300
	Gulf of Alaska	$182,274
	Cook Inlet	$2,096
	North Aleutian Basin	$35,509
	Hope Basin	$63,033
	St. Matthew-Hall	$1,962
	North Aleutian Basin	$7,456
	Shumagin	$3,859
	Aleutian Arc	$8,133
	St. George Basin	$22,733
	Chukchi Sea	$24,119

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 2.78 and 3.06 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 2013 and 2017 of 3.93 percent (Freddie Mac 2018). The Federal tax rate at the median household income of $55,322 is 22 percent (U.S. Census Bureau 2018a; Tax Foundation 2018b), and state taxes at the median household income level weighted by coastline in each planning area vary between 0 and 9.30 percent (U.S. Census Bureau 2018b; Tax Foundation 2018a).

As noted above, the after-tax discount rate is determined using the following formula: (Pre-Tax Rate) − (Pre-Tax Rate)*[(Federal Tax Rate) + (State Tax Rate)*(1 − Federal Tax Rate)]. For example, for the North Atlantic Planning Area: 3.93 − 3.93*[0.22 + (0.0616)*(1 − 0.22)] = 2.87.

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 GOM (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 1 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 7 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.

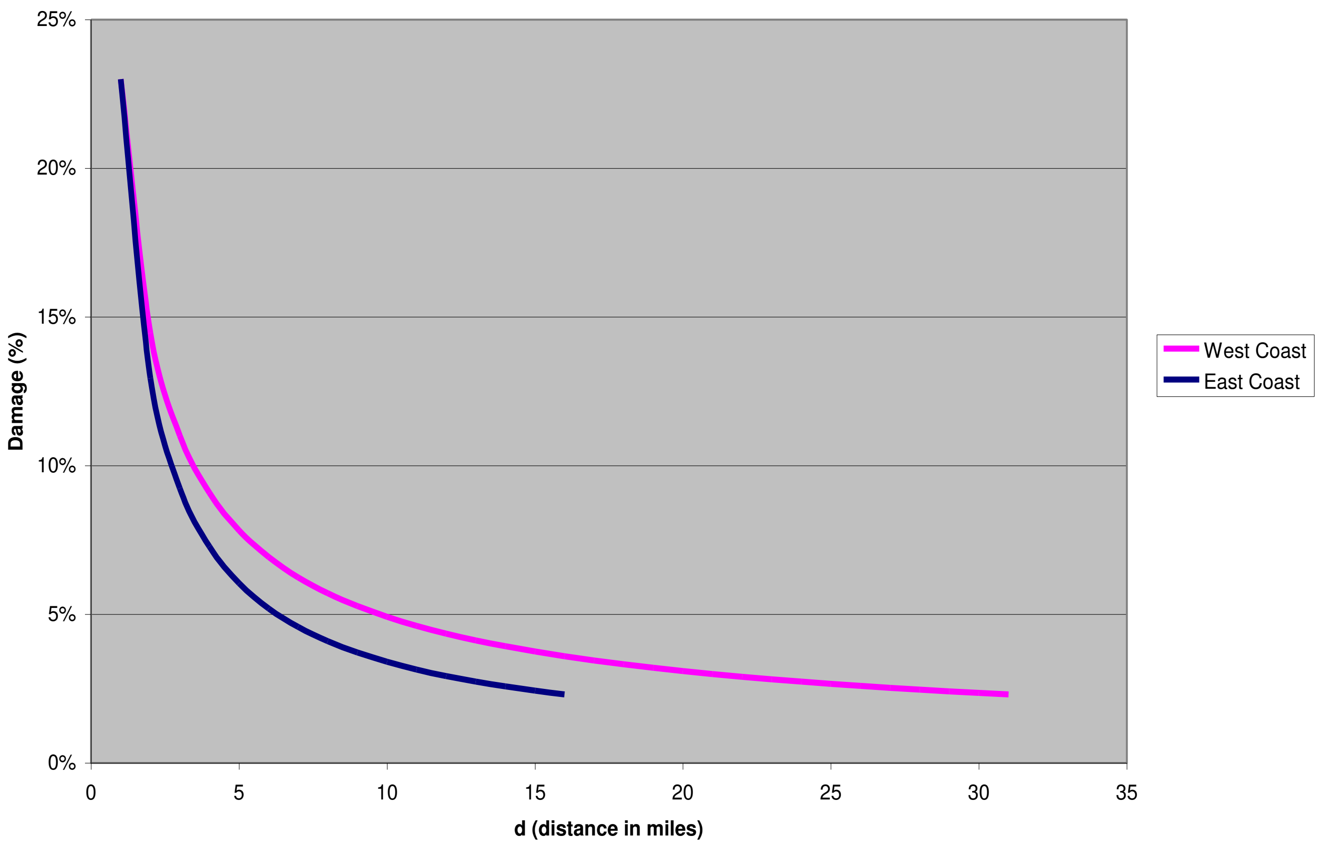


Figure 7. Relationship between percent reduction in economic rent from properties and distance from shore to platforms

5.4 References—Property Value: Visual Disamenity

A.T. Kearney, Inc., ICF, Inc., Impact Assessments, Inc., Batie S, Sorensen P. 1991. Estimating the environmental costs of OCS oil and gas development and marine oil spills: a general purpose model. Herndon (VA): U.S. Department of the Interior, Minerals Management Service. Report No.: OCS Study MMS 91-043.

Bishop ID, Miller DR. 2007. Visual assessment of off-shore wind turbines: the influence of distance, contrast, movement and social variables. Renewable Energy. 32(5):814–831.

Blomquist GC. 1974. The effect of electric utility power plan location on area property value. Land Economics. 50(1):97–100.

DataQuick. 2007–2009. Assessor data. Compiled by DataQuick.

Des Rosiers F. 2002. Power lines, visual encumbrance and house values: a microspatial approach to impact measurement. Journal of Real Estate Research. 23(3):275–301.

Federal Housing Finance Agency. 2018a. Quarterly purchase-only HPI by MSA and MSA division. https://www.fhfa.gov/DataTools/Downloads/Pages/House-Price-Index-Datasets.aspx

Federal Housing Finance Agency. 2018b. Quarterly purchase-only HPI by state. https://www.fhfa.gov/DataTools/Downloads/Pages/House-Price-Index-Datasets.aspx

Freddie Mac. 2018. 30-year fixed mortgage rates since 1971. [accessed 2010 Aug 25]. http://www.freddiemac.com/pmms/pmms30.htm.

Hoen B, Wiser R, Cappers P, Thayer M, Sethi G. 2011. Wind energy facilities and residential properties: the effect of proximity and view on sales prices. Journal of Real Estate Research. 33(3):279–316. http://emp.lbl.gov/sites/all/files/JOURNAL%20lbnl-2829e.pdf.

[IMPROVE] Interagency Monitoring of Protected Visual Environments. 2007. Data from the IMPROVE network based on the “New IMPROVE algorithm.” [updated August 2007]. http://vista.cira.colostate.edu/views/Web/IMPROVE/SummaryData.aspx.

Ladenburg J. 2009. Stated public preferences for on-land and offshore wind power generation – a review. Wind Energy 12(2):171–181.

Sims S, Dent P. 2005. High-voltage overhead power lines and property values: a residential study in the UK. Urban Studies. 42(4):665–694. http://www.offnews.info/downloads/MH67355810773164.pdf.

Tax Foundation. 2018a. State individual income tax rates and brackets for 2018. https://files.taxfoundation.org/20180315173118/Tax-Foundation-FF576-1.pdf

Tax Foundation. 2018b. Tax brackets and rates, 2018. [accessed 2018 May 08]. https://taxfoundation.org/2018-tax-brackets.

U.S. Census Bureau. 2017. Delineation files: core based statistical areas (CBSAs), metropolitan divisions, and combined statistical areas (CSAs). https://www.census.gov/geographies/reference-files/time-series/demo/metro-micro/delineation-files.html

U.S. Census Bureau. 2018a. QuickFacts: United States. Median household income 2012–2016. https://www.census.gov/quickfacts/fact/table/US/PST045216.

U.S. Census Bureau. 2018b. Median household income by state, 2016. 2012–2016 American Community Survey 5-year Estimates.

U.S. Census Bureau. 2001. Census tract cartographic boundary files. Washington (DC): U.S. Census Bureau, Geography Division, Cartographic Products Management Branch. Created July 2001. https://www.census.gov/geo/maps-data/data/cbf/cbf_tracts.html.

U.S. Census Bureau. 2000. SF1 and SF3 data. http://www.census.gov/prod/cen2000/doc/sf1.pdf; http://www.census.gov/prod/cen2000/doc/sf3.pdf.

6 Property Values—Oil Spills

6.1 Overview

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

6.2 Basic Calculation—Oil Spills

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

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

where:

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

d_p = Duration of event (in days)

l_p = Length of beach oiled (m)

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 (22 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 2000) that are scaled to 2017 using the Federal Housing Finance Agency's HPI (Federal Housing Finance Agency 2018a; 2018b). 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 2001). 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 2000). To scale the assessor and census data to 2017 values, the model uses the Federal Housing Finance Agency's HPI. The increase in housing value is assumed to be equal to the increase in HPI, after adjusting for inflation, using the implicit price deflator. The OECM uses the average of the four quarterly, seasonally adjusted HPI values reported for a given year as the representative annual HPI. The HPI is available at both the MSA level and the state level. Using the Census Bureau's crosswalk between counties and MSAs, the MSA HPI is used for all coastal block groups that are associated with counties within the MSA (U.S. Census Bureau 2017). If a coastal block group is not within an MSA with HPI data, the state-level HPI is used to scale the property value data to 2017.

Table 12 provides an overview of the total residential property value per 1-meter wide by 255-foot long (the length of an average property) area of coastline within each planning area based on assessor and census data.[33] 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 2018). Total housing value divided by the total area in each block group yielded the average residential values for a 1-meter by 255-foot area. The model assumes that this is the average residential property value of 1 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 12. Total residential property value per meter of coastline to an average property width inland

Region	Planning Area	Value (2010 USD)
Atlantic	North Atlantic	$7,760
	Mid-Atlantic	$2,160
	South Atlantic	$4,410
GOM	Eastern GOM	$7,170
	Straits of Florida	$19,900
	Central GOM	$358
	Western GOM	$808
Pacific	Southern California	$12,300
	Central California	$9,650
	Northern California	$395
	Washington/Oregon	$1,060
Alaska	Beaufort Sea	$0.0298
	Kodiak	$90.9
	Gulf of Alaska	$43.8
	Cook Inlet	$0.504
	North Aleutian Basin	$8.53
	Hope Basin	$15.1
	St. Matthew-Hall	$0.472
	North Aleutian Basin	$1.79
	Shumagin	$0.927
	Aleutian Arc	$1.95
	St. George Basin	$5.46
	Chukchi Sea	$5.80

[33] 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 (i.e., property value impacts), this analysis applies, in each year of the analysis, a discount rate of between 2.78 and 3.06 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 2013 and 2017 of 3.93 percent (Freddie Mac 2018). The Federal tax rate at the median household income of $55,322 is 22 percent (U.S. Census Bureau 2018a; Tax Foundation 2018b), and state taxes at the median household income level weighted by coastline in each planning area vary between 0 and 9.30 percent (U.S. Census Bureau 2018b; Tax Foundation 2018a).

As noted above, the after-tax discount rate is determined using the following formula: (Pre-Tax Rate) − (Pre-Tax Rate)*[(Federal Tax Rate) + (State Tax Rate)*(1 − Federal Tax Rate)]. For example, for the North Atlantic Planning Area: 3.93 − 3.93*[0.22 + (0.0616)*(1 − 0.22)] = 2.87.

6.3.3 Duration of Event

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

6.3.4 Length of Oiled Shore

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

6.4 Assumptions

Several assumptions are made in determining the driver values for each 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 255 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 (Bigelow and Borchers 2017; U.S. Census Bureau 2018c)
- Overlapping areas within planning areas are assigned to a single planning area
- Property values are lost entirely for the duration of the spill event
- Property values along all types of shoreline are affected equally

6.5 References—Property Value: Oil Spills

Bigelow D, Borchers A. 2017. Major uses of land in the United States, 2012. Washington (DC): U.S. Department of Agriculture, Economic Research Service. https://www.ers.usda.gov/publications/pub-details/?pubid=84879

[BEA] Bureau of Economic Analysis. 2018. Table 1.1.9. Implicit price deflators for gross domestic product. [accessed 2018 Apr 27]. https://apps.bea.gov/iTable/?reqid=19&step=3&isuri=1&1921=survey&1903=13.

DataQuick. 2007–2009. Assessor data. Compiled by DataQuick.

Federal Housing Finance Agency. 2018a. Quarterly purchase-only HPI by MSA and MSA division. https://www.fhfa.gov/DataTools/Downloads/Pages/House-Price-Index-Datasets.aspx

Federal Housing Finance Agency. 2018b. Quarterly purchase-only HPI by state. https://www.fhfa.gov/DataTools/Downloads/Pages/House-Price-Index-Datasets.aspx

Freddie Mac. 2018. 30-year fixed mortgage rates since 1971. [accessed 2010 Aug 25]. http://www.freddiemac.com/pmms/pmms30.htm.

Tax Foundation. 2018a. State individual income tax rates and brackets for 2018. https://files.taxfoundation.org/20180315173118/Tax-Foundation-FF576-1.pdf

Tax Foundation. 2018b. Tax brackets and rates, 2018. [accessed 2018 May 08]. https://taxfoundation.org/2018-tax-brackets.

U.S. Census Bureau. 2017. Delineation files: core based statistical areas (CBSAs), metropolitan divisions, and combined statistical areas (CSAs). Accessed at: https://www.census.gov/geographies/reference-files/time-series/demo/metro-micro/delineation-files.html

U.S. Census Bureau. 2018a. QuickFacts: United States. Median household income 2012–2016. https://www.census.gov/quickfacts/fact/table/US/PST045216.

U.S. Census Bureau. 2018b. Median household income by state, 2016. 2012–2016 American Community Survey 5-year Estimates.

U.S. Census Bureau. 2018c. QuickFacts: households, 2012–2016. https://www.census.gov/quickfacts/fact/table/US/PST045217

U.S. Census Bureau. 2001. Census tract cartographic boundary files. Washington (DC): U.S. Census Bureau, Geography Division, Cartographic Products Management Branch. Created July 2001. https://www.census.gov/geo/maps-data/data/cbf/cbf_tracts.html.

U.S. Census Bureau. 2000. SF1 and SF3 data. http://www.census.gov/prod/cen2000/doc/sf1.pdf; http://www.census.gov/prod/cen2000/doc/sf3.pdf.

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, though 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. Although 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 E&D 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 can 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. Although subsistence harvests do occur in other regions of the coastal U.S., 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.

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

7.2 Basic Calculation

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

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

where:

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

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

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

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

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

7.3 Calculation Drivers

7.3.1 Subsistence Harvest as Percentage of Total Harvest

The ADFG's Division of Subsistence reports that subsistence harvests, in the aggregate, account for 1 percent of the annual harvest of all fish and game in the state on average in 2012 and 2014 (Fall 2014; 2016). 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 1 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 toothed
- *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 8 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.[34]

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 the average of two replacement cost values per kilogram.

The first replacement cost is 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 GDP Implicit Price Deflator, the implied cost is approximately $103/kg.

Duffield et al. (2014b) calculate the replacement value of subsistence harvests using a compensating wage differential approach, which assumes that the time and resources spent on subsistence harvests can be valued as the opportunity cost of traditional full-time employment. As originally applied in Alaska for the damage assessment for the *Exxon Valdez* oil spill, Duffield et al. (2014b) updated the same model with recent income, subsistence harvest, education, and cost of living data, estimating a value of approximately $190/kg in 2009$, or $192/kg in 2010$. The same value is also applied in EPA's *Assessment of Potential Mining Impacts on Salmon Ecosystems of Bristol Bay, Alaska* (Duffield et al. 2014a).

The OECM uses the average of the two replacement cost values for a final value of approximately $147/kg.

[34] 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.

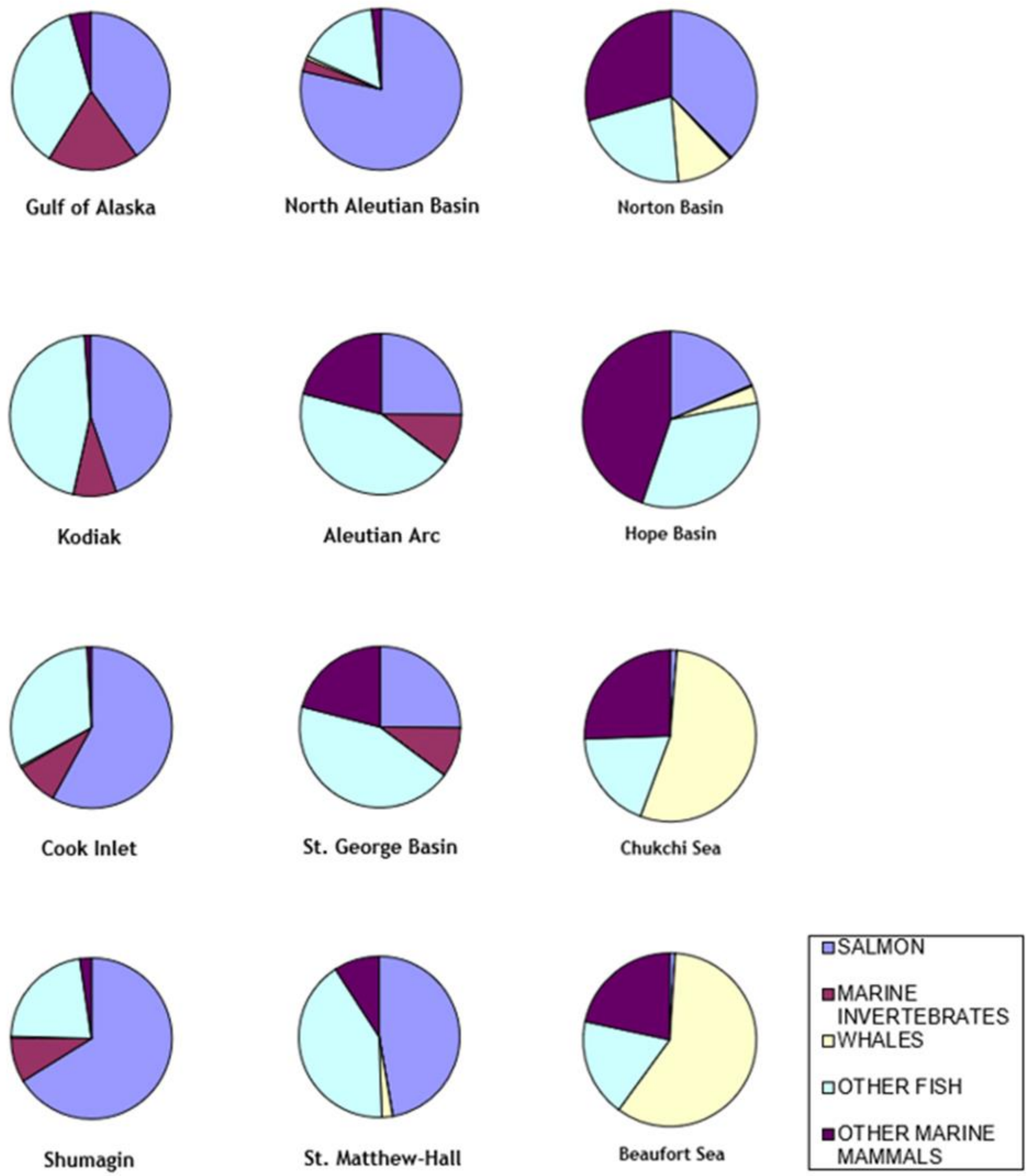


Figure 8. Marine harvest profiles for Alaska planning areas

7.4 References—Subsistence

[ADFG] Alaska Department of Fish and Game. 2001. Community profile database for Access 2000, Version 3.12. Anchorage (AK): Alaska Department of Fish and Game, Division of Subsistence.

Duffield J, et al. 2014a. Appendix J: Bristol Bay wild salmon ecosystem: baseline levels of economic activity and values U.S. In: An assessment of potential mining impacts on salmon ecosystems of Bristol Bay, Alaska, volume 3. Washington (DC): U.S. Environmental Protection Agency. Report No.: EPA 910-R-14-001C. https://www.epa.gov/bristolbay/bristol-bay-assessment-final-report-2014

Duffield J, Neher C, Patterson D. 2014b. Oil spill in northern waters: trial outcomes and the long-term in case of the Exxon Valdez. Arctic Review. 5(1).

Fall JA. 2014. Subsistence in Alaska: a year 2012 update. Anchorage (AK): Alaska Department of Fish and Game, Division of Subsistence. http://www.adfg.alaska.gov/static/regulations/regprocess/gameboard/pdfs/2013-2014/Statewide_03-14-14/rcs/rc011_ADFG_Subsistence_Update.pdf

Fall JA . 2016. Subsistence in Alaska: a year 2014 update. Anchorage (AK): Alaska Department of Fish and Game, Division of Subsistence. https://www.adfg.alaska.gov/static/home/subsistence/pdfs/subsistence_update_2014.pdf

Sharpe JP. 2001. Plans for the provision of interim transportation, provision of interim alternate food supplies, provision of interim counseling and cultural assistance, and provision of IWC quota restoration assistances. Attachment 1 to the BP Exploration (Alaska) Inc., Good Neighbor Policy, Northstar Project.

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.[35] 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.[36]

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 U.S., 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.[37] 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 distributed uniformly 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 platforms and pipelines preempted 100 square miles, then fish harvests were assumed to be reduced by

[35] 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.

[36] 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.

[37] 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 (Kruse 2010). Dr. Kruse indicated that it was very possible that unburied pipeline could affect migrations of king and tanner crab in the Bering Sea. Dr. Kruse indicated that to his knowledge there had not been any research directly on the topic, and that it would be difficult to estimate an impact without more research and without specific information regarding the locations of the pipelines. In the absences of specific information regarding potential impacts of pipelines on crab migrations, the decision was not to speculate, but note that there may be additional impacts beyond those reflected in the model.

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 OECM does not currently estimate the impact of oil spills on commercial fishing. Although 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 E&D 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. 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 National OCS 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.[38] 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 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: 0–60 m; Fixed Platforms and Buried Pipelines
- Depth Range 2: 60–150 m; Fixed Platforms
- Depth Range 3: 150–300 m; Floating Anchored Platforms; radius of buffer zones will be equal to 805 m + 2 × cell depth at centroid
- Depth Range 4: 300–1,500 m; Tension Leg Platforms
- Depth Range 5: 1,500+ m; Dynamically Positioned Floating Platforms

Data estimating the value of commercial fisheries harvested from each 10 × 10 cell has been generated using available data from NMFS or from other available sources of fishery data. Summary of these data by region are provided in the next section of this overview. The remainder of this section uses examples

[38] See MMS (1990).

from Alaska to describe the model and the way it generates estimates of impacts of oil and natural gas infrastructure on commercial fisheries.

Figure 9 shows groundfish harvests in Alaska planning areas. From Figure 9 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.

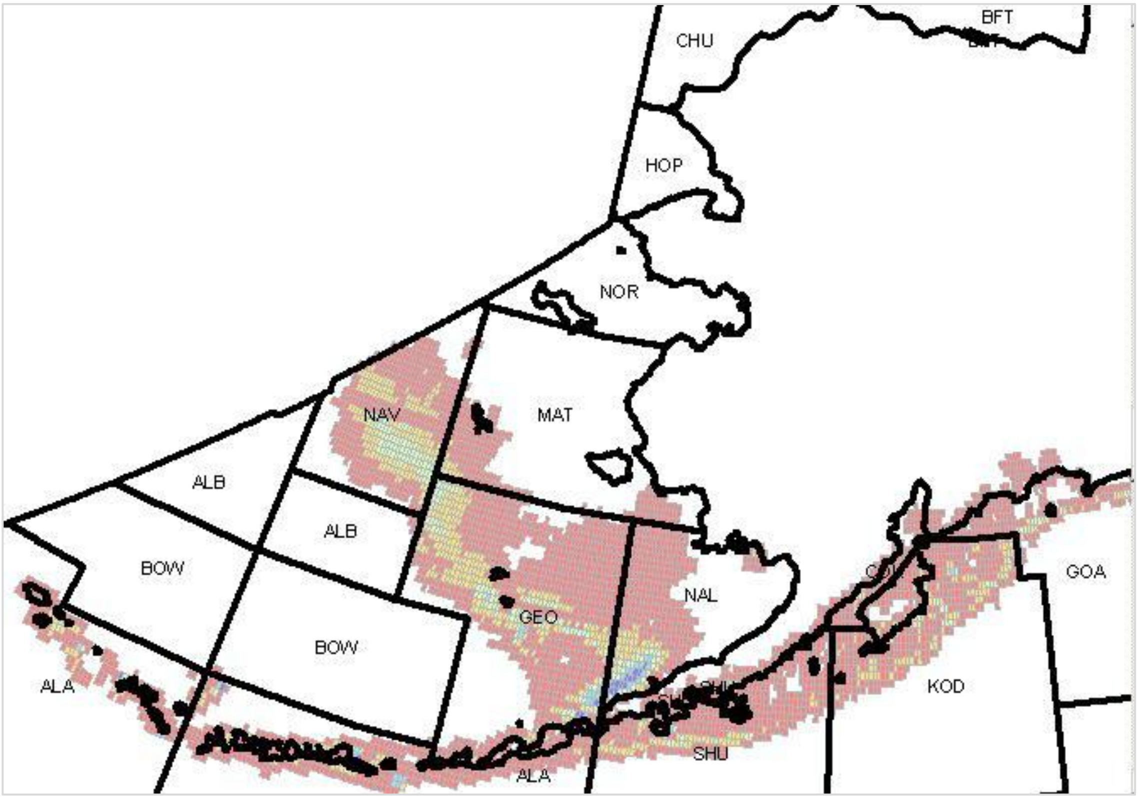


Figure 9. Locations of Alaska groundfish harvests by planning area (2006–2009)

Source: Developed for the OECM 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 × 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: five platforms with average depth of 40 meters, and
- Group 2: seven platforms with average depth of 55 meters

The model randomly assigns platforms to 12 different 10 × 10 cells in Depth Range 1, as both Group 1 and Group 2 fall into that range. The model assumes that no more than one new platform can be located in a single cell. It should be noted that if a legacy platform (pre-2010) already exists in that cell, then it is assumed new platforms may be added.

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

1. Reduce the fishery value in each cell with a platform in proportion to the reduction in available fishing area in the cell caused by the introduction of the platform: Preliminary Revenue for the cell (*PRc*) = Baseline Revenue for the cell (*BRc*) × (Cell area − buffer zone) ÷ Cell Area.
2. Increase the fishery value in all cells proportionally such that the total fishery value in all cells in the planning area is unchanged, and such that 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.[39]

In order to the 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 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 OECM result from regressions on thousands of simulation iterations[40] 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-

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

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

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

[40] 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.

configurations, and cost impacts are calculated for each location configuration.[41] 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 assigned intentionally to the cells that generate the highest amount of revenue and thus are likely to generate a "worst case" scenario in terms of impacts.[42]

8.3 Regression Coefficients

The OECM, as currently configured, will generate estimated impacts on commercial fisheries that result from BOEM-supplied E&D scenarios through the use of regression coefficients and equations. The estimated cost impacts for each simulated scenario were compiled into a regression dataset for each planning area 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 though 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.

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.

---

[41] Because of the large number of 10 × 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.

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

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 provide 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 13 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
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 13. Commercial fishing modeling: data summary for St. George Basin, Alaska

Variable	0–60 m	60–150 m	150–300 m	300–1,500 m	1,500+ m	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 14 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 D1are negative implies that additional platforms in this depth range will dampen the negative impacts of platforms in other depth ranges (D3 for example).

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 14, the regression coefficient for the number of platforms in D1 is positive, while the coefficients for the square are negative.

Table 14. Commercial fishing modeling: fishery impact coefficients for St. George Basin, Alaska

Platform Placement	Depth Band	Depth Range	Regression Coefficient a	Regression Coefficient b	*P*-values* a	*P*-values* b
In multiple depth ranges	D1	0–60 m	-0.6107	-0.0199	0.00%	0.00%
	D2	60–150 m	6.5774	-0.0083	0.00%	0.00%
	D3	150–300 m	22.0001	-0.2567	0.00%	0.00%
	D4	300–1,500 m	25.7349	-0.1509	0.00%	0.00%
	D5	1,500+ m	2.3083	-0.0098	0.00%	0.00%
In only one depth range	D1	0–60 m	0.0153	-0.0004	0.00%	0.00%
	D2	60–150 m	23.0807	-0.1633	0.00%	0.00%
	D3	150–300 m	39.9362	-0.5776	0.00%	0.00%
	D4	300–1,500 m	36.8306	-0.2414	0.00%	0.00%
	D5	1,500+ m	0	0	-	-

Notes: 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. * = significant if < 5%

The following examples show how to use the model coefficients under two different 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) Pacific Coast, (3) GOM and South Atlantic, and (4) Mid- and North Atlantic. The level of detail available for each region varied considerably, as did the process of assigning harvests to the 10 × 10 cells. An overview of the data sources and processes is provided below.

8.5.1 Alaska

The Alaska Region of NMFS provided data for groundfish by harvests by gear in 10 × 10 cells for all of Alaska for the years 2006–2009 (Lewis 2010). 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 × 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 additional 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 × 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 × 10 cells with one important twist. It was assumed that within a statistical area, halibut harvested were distributed to 10 × 10 cells in proportion to the amount of water area in each cell. In the case of halibut, however, 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 (BLS 2010). The final harvest value assigned to each cell was the average over four years of the annual adjusted value.

Salmon harvests were not included in the Alaska data. Although 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 × 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 × 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 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 10, 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 (PFMC 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 × 10 cells for trawls and assigned non-trawl landings to 10 × 10 cells in each INPFC Area in proportion to the landings those cells had in trawl fisheries for the same species. For example, non-trawl landings of rockfish in the Monterey INPFC Area were assigned to the same 10 × 10 cells that had rockfish trawl landings. In this case, 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 INPFC Area. Trawling for groundfish has not been allowed in the area for several years, and therefore there were no 10 × 10 data with which to associate non-trawl landings. In this case, 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 × 10 cells in these depth ranges in proportion to water area.

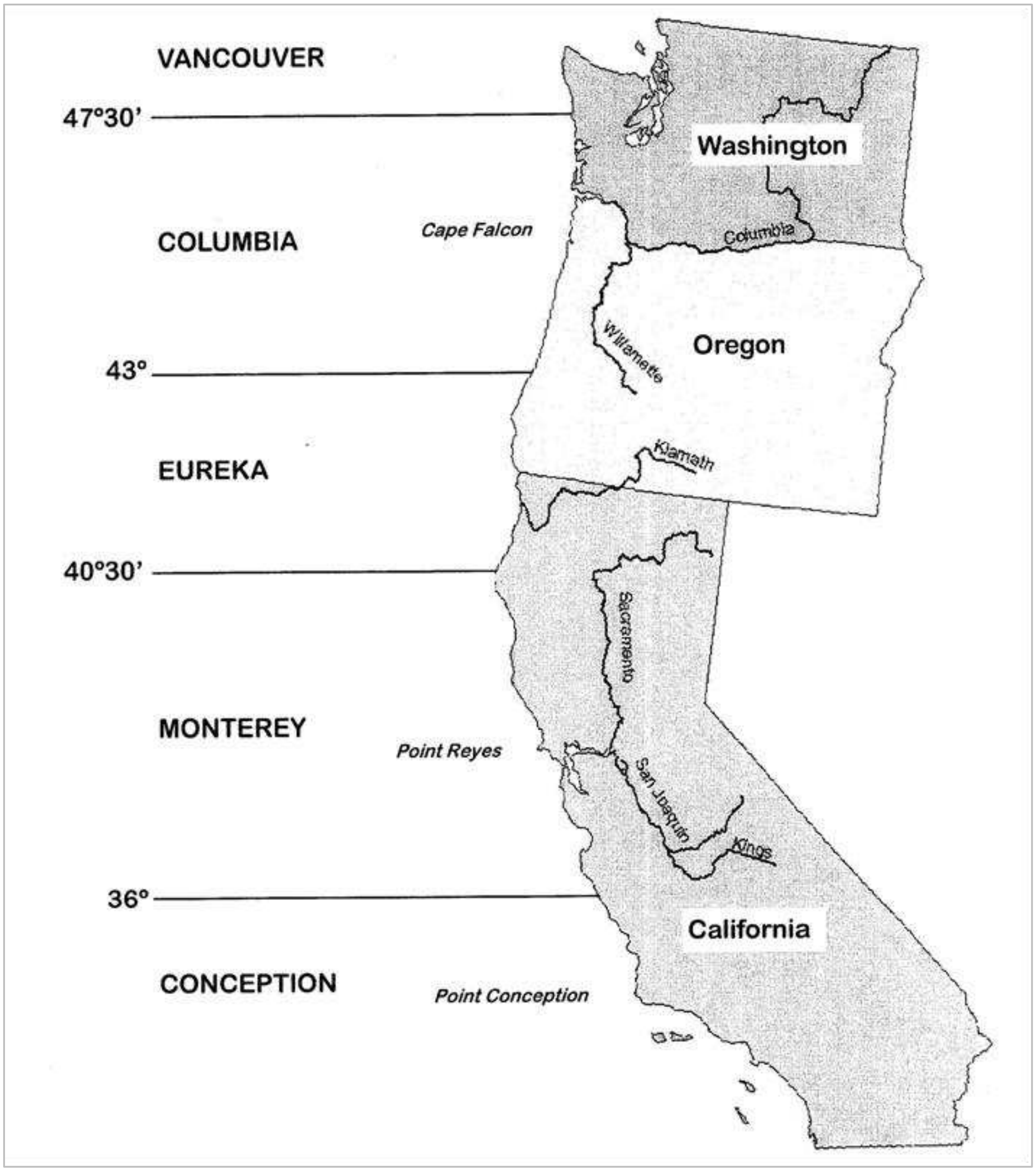


Figure 10. International North Pacific Fishery Commission (INPFC) statistical areas

8.5.3 GOM and South Atlantic

Information on commercial fish harvests for the GOM 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 11.

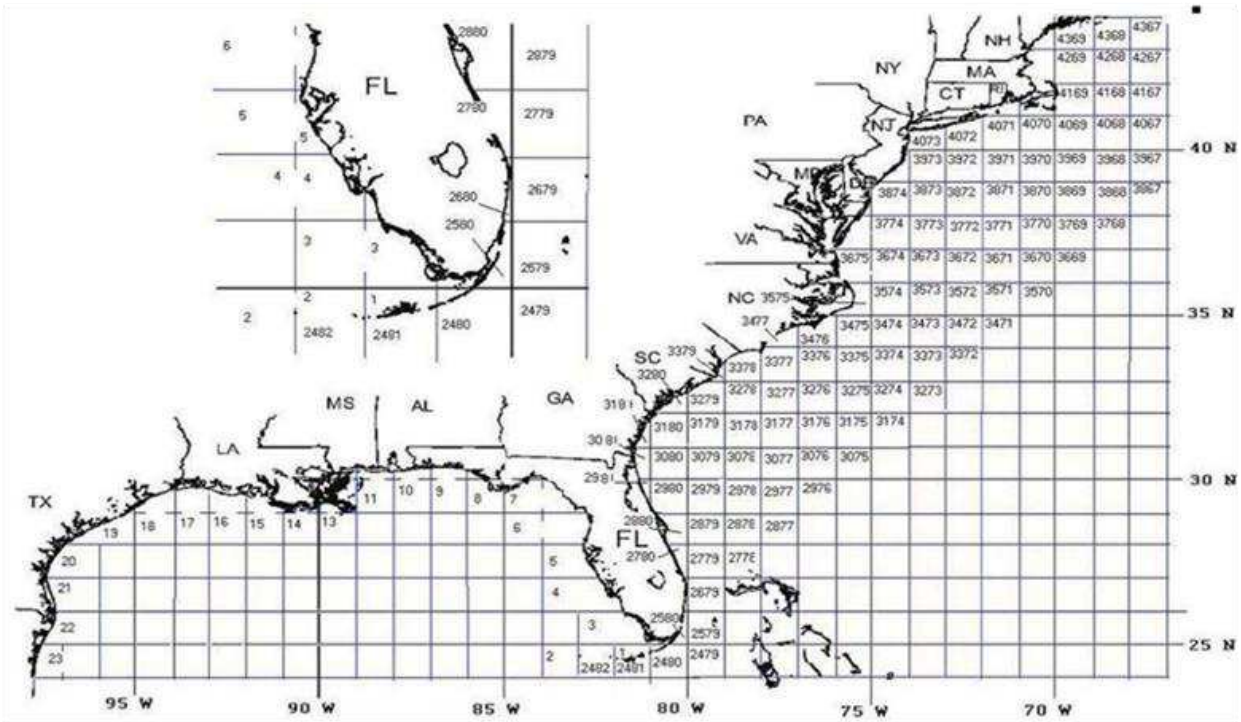


Figure 11. Statistical areas for GOM and South Atlantic fisheries

Source: Provided by NMFS SEFSC as part of the BOEM data request (Jamir 2010).

In the GOM 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.

NFMS provided harvest data and ex-vessel values from 2006–2009 for the fisheries shown in Table 15.

Table 15. Data provided for GOM and South Atlantic fisheries

Region	Fishery
GOM	Reeffish
GOM, South Atlantic	Shrimp
GOM, South Atlantic	Coastal Migratory
GOM, South Atlantic	Spiny Lobster
GOM, South Atlantic	Large Pelagics
GOM, South Atlantic	Stone Crab, Red Drum
GOM, 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 GOM, 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 (Aquamaps 2010). Table 16 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 reef fish landings reported for Statistical Area 12 in the GOM, then only those cells in the statistical area that had depths of 540 meters or less would be assigned reef fish landings. The cells with depths greater than 540 meters would not be assigned reef fish 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 16. Maximum cell depths to which fisheries were assigned landings by fishery and region

Region	Fishery	Maximum Cell Depth (m)
GOM	Reeffish	540
GOM, South Atlantic	Shrimp, Coastal Migratory, Spiny Lobster	200
GOM, South Atlantic	Large Pelagics	9,850
GOM, South Atlantic	Stone Crab, Red Drum	51
South Atlantic	Snapper Grouper	540
South Atlantic	Dolphin/Wahoo	85
South Atlantic	Golden Crab	1,400

As with other regions, there are significant harvests of species that are not federally managed. In the GOM, for example, there are very significant harvests of oysters and menhaden. Because 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 17 (Thunberg 2010). 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. Although 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 17. Federal fisheries for which data were requested and provided in the North and Mid-Atlantic regions

Region	North Atlantic	Mid-Atlantic
Species	black sea bass	black sea bass
	bluefish	bluefish
	butterfish	butterfish
	dogfish	dogfish
	fluke	fluke
	groundfish gillnet	monkfish gillnet
	groundfish hook	other
	groundfish trawl	scallop
	herring	shrimp
	mackerel	skates
	monkfish gillnet	squid
	monkfish trawl	tilefish
	other	
	scallop	
	scup	
	shrimp	
	skates	
	small mesh multispecies	
	squid	
	surf clam	
	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 (2010) 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 × 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 × 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 the Alaska Region

This section provides fishery data and regression coefficients for planning areas in the Alaska Region (Tables 18–41). 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 18. Commercial fishing modeling: data summary for Norton Basin

Variable	0–60 m	60–150 m	150–300 m	300–1,500 m	1,500+ m	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 19. Commercial fishing modeling: fishery impact coefficients for Norton Basin

Platform Placement	Depth Band	Depth Range	Regression Coefficient a	Regression Coefficient b	*P*-values* a	*P*-values* b
In multiple depth ranges	D1	0–60 m	0.1850	-0.0001	0.0%	0.0%
	D2	60–150 m	0.2952	-0.0105	0.0%	0.0%
	D3	150–300 m	0.0000	0.0000	-	-
	D4	300–1,500 m	0.0000	0.0000	-	-
	D5	1,500+ m	0.0000	0.0000	-	-
In only one depth range	D1	0–60 m	0.4889	-0.0047	0.0%	0.0%
	D2	60–150 m	0.0000	0.0000	-	-
	D3	150–300 m	0.0000	0.0000	-	-
	D4	300–1,500 m	0.0000	0.0000	-	-
	D5	1,500+ m	0.0000	0.0000	-	-

Notes: 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. * = significant if < 5%

Table 20. Commercial fishing modeling: data summary for Navarin Basin

Variable	0–60 m	60–150 m	150–300 m	300–1,500 m	1,500+ m	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 21. Commercial fishing modeling: fishery impact coefficients for Navarin Basin

Platform Placement	Depth Band	Depth Range	Regression Coefficient a	Regression Coefficient b	*P*-values* a	*P*-values* b
In multiple depth ranges	D1	0–60 m	57.1660	-3.4547	0.0%	0.0%
	D2	60–150 m	5.4190	-0.0086	0.0%	0.0%
	D3	150–300 m	42.5967	-0.3323	0.0%	0.0%
	D4	300–1,500 m	-6.3399	-0.1090	0.0%	0.0%
	D5	1,500+ m	2.0710	-0.0221	0.0%	0.0%
In only one depth range	D1	0–60 m	35.0192	-1.9134	0.0%	0.0%
	D2	60–150 m	21.1382	-0.2104	0.0%	0.0%
	D3	150–300 m	66.7881	-0.7613	0.0%	0.0%
	D4	300–1,500 m	0.0011	0.0000	35.4%	37.2%
	D5	1,500+ m	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. * = significant if < 5%

Table 22. Commercial fishing modeling: data summary for St. Matthew-Hall

Variable	0–60 m	60–150 m	150–300 m	300–1,500 m	1,500+ m	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 23. Commercial fishing modeling: fishery impact coefficients for St. Matthew-Hall

Platform Placement	Depth Band	Depth Range	Regression Coefficient a	Regression Coefficient b	*P*-values* a	*P*-values* b
In multiple depth ranges	D1	0–60 m	0.3618	-0.0005	0.0%	0.0%
	D2	60–150 m	-2.1276	0.0003	0.0%	18.9%
	D3	150–300 m	259.0227	-0.8606	0.0%	0.0%
	D4	300–1,500 m	0.0000	0.0000	-	-
	D5	1,500+ m	0.0000	0.0000	-	-
In only one depth range	D1	0–60 m	1.1314	0.0004	0.0%	86.7%
	D2	60–150 m	0.0041	-0.0001	0.0%	0.0%
	D3	150–300 m	264.0219	0.1602	0.0%	57.1%
	D4	300–1,500 m	0.0000	0.0000	-	-
	D5	1,500+ m	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. * = significant if < 5%

Table 24. Commercial fishing modeling: data summary for St. George Basin

Variable	0–60 m	60–150 m	150–300 m	300–1,500 m	1,500+ m	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 25. Commercial fishing modeling: fishery impact coefficients for St. George Basin

Platform Placement	Depth Band	Depth Range	Regression Coefficient a	Regression Coefficient b	*P*-values* a	*P*-values* b
In multiple depth ranges	D1	0–60 m	-0.6107	-0.0199	0.00%	0.00%
	D2	60–150 m	6.5774	-0.0083	0.00%	0.00%
	D3	150–300 m	22.0001	-0.2567	0.00%	0.00%
	D4	300–1,500 m	25.7349	-0.1509	0.00%	0.00%
	D5	1,500+ m	2.3083	-0.0098	0.00%	0.00%
In only one depth range	D1	0–60 m	0.0153	-0.0004	0.00%	0.00%
	D2	60–150 m	23.0807	-0.1633	0.00%	0.00%
	D3	150–300 m	39.9362	-0.5776	0.00%	0.00%
	D4	300–1,500 m	36.8306	-0.2414	0.00%	0.00%
	D5	1,500+ m	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. * = significant if < 5%

Table 26. Commercial fishing modeling: data summary for North Aleutian Basin

Variable	0–60 m	60–150 m	150–300 m	300–1,500 m	1,500+ m	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 27. Commercial fishing modeling: fishery impact coefficients for North Aleutian Basin

Platform Placement	Depth Band	Depth Range	Regression Coefficient a	Regression Coefficient b	*P*-values* a	*P*-values* b
In multiple depth ranges	D1	0–60 m	-5.6643	0.0006	0.0%	24.5%
	D2	60–150 m	58.1161	-0.0771	0.0%	0.0%
	D3	150–300 m	0.0000	0.0000	-	-
	D4	300–1,500 m	0.0000	0.0000	-	-
	D5	1,500+ m	0.0000	0.0000	-	-
In only one depth range	D1	0–60 m	0.0000	0.0000	-	-
	D2	60–150 m	107.0198	-0.8597	0.0%	0.0%
	D3	150–300 m	0.0000	0.0000	-	-
	D4	300–1,500 m	0.0000	0.0000	-	-
	D5	1,500+ m	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. * = significant if < 5%

Table 28. Commercial fishing modeling: data summary for Aleutian Basin

Variable	0–60 m	60–150 m	150–300 m	300–1,500 m	1,500+ m	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 29. Commercial fishing modeling: fishery impact coefficients for Aleutian Basin

Platform Placement	Depth Band	Depth Range	Regression Coefficient a	Regression Coefficient b	*P*-values* a	*P*-values* b
In multiple depth ranges	D1	0–60 m	0.0000	0.0000	-	-
	D2	60–150 m	0.0000	0.0000	-	-
	D3	150–300 m	0.0000	0.0000	-	-
	D4	300–1,500 m	0.0000	0.0000	-	-
	D5	1,500+ m	0.0000	0.0000	-	-
In only one depth range	D1	0–60 m	0.0000	0.0000	-	-
	D2	60–150 m	0.0000	0.0000	-	-
	D3	150–300 m	158.6262	0.0000	0.0%	-
	D4	300–1,500 m	0.0000	0.0000	-	-
	D5	1,500+ m	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. * = significant if < 5%

Table 30. Commercial fishing modeling: data summary for Bowers Basin

Variable	0–60 m	60–150 m	150–300 m	300–1,500 m	1,500+ m	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 31. Commercial fishing modeling: fishery impact coefficients for Bowers Basin

Platform Placement	Depth Band	Depth Range	Regression Coefficient a	Regression Coefficient b	*P*-values* a	*P*-values* b
In multiple depth ranges	D1	0–60 m	0.0000	0.0000	-	-
	D2	60–150 m	0.0000	0.0000	-	-
	D3	150–300 m	0.0116	-0.0041	0.0%	0.0%
	D4	300–1,500 m	0.0023	0.0000	0.0%	0.0%
	D5	1,500+ m	0.0019	0.0000	0.0%	0.0%
In only one depth range	D1	0–60 m	0.0000	0.0000	-	-
	D2	60–150 m	0.0000	0.0000	-	-
	D3	150–300 m	0.0000	0.0000	-	-
	D4	300–1,500 m	-0.0007	0.0000	0.0%	0.0%
	D5	1,500+ m	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. * = significant if < 5%

Table 32. Commercial fishing modeling: data summary for Aleutian Arc

Variable	0–60 m	60–150 m	150–300 m	300–1,500 m	1,500+ m	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 33. Commercial fishing modeling: fishery impact coefficients for Aleutian Arc

Platform Placement	Depth Band	Depth Range	Regression Coefficient a	Regression Coefficient b	*P*-values* a	*P*-values* b
In multiple depth ranges	D1	0–60 m	15.8745	-1.1003	0.0%	0.0%
	D2	60–150 m	36.1643	-0.1989	0.0%	0.0%
	D3	150–300 m	16.0232	-0.2565	0.0%	0.0%
	D4	300–1,500 m	14.1891	-0.0146	0.0%	0.0%
	D5	1,500+ m	-0.2148	0.0000	0.0%	1.4%
In only one depth range	D1	0–60 m	0.0000	0.0000	-	-
	D2	60–150 m	56.9089	-0.5447	0.0%	0.0%
	D3	150–300 m	26.4894	-0.4417	0.0%	0.0%
	D4	300–1,500 m	33.1780	-0.2485	0.0%	0.0%
	D5	1,500+ m	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. * = significant if < 5%

Table 34. Commercial fishing modeling: data summary for Shumagin

Variable	0–60 m	60–150 m	150–300 m	300–1,500 m	1,500+ m	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 35. Commercial fishing modeling: fishery impact coefficients for Shumagin

Platform Placement	Depth Band	Depth Range	Regression Coefficient a	Regression Coefficient b	*P*-values* a	*P*-values* b
In multiple depth ranges	D1	0–60 m	5.2925	-0.0303	0.0%	0.0%
	D2	60–150 m	-1.4832	0.0055	0.0%	0.0%
	D3	150–300 m	-6.1889	0.0656	0.0%	0.0%
	D4	300–1,500 m	7.2769	-0.0163	0.0%	0.0%
	D5	1,500+ m	0.1119	-0.0001	0.0%	0.0%
In only one depth range	D1	0–60 m	22.8590	-0.2496	0.0%	0.0%
	D2	60–150 m	8.2160	-0.1190	0.0%	0.0%
	D3	150–300 m	0.0910	-0.0022	1.6%	2.1%
	D4	300–1,500 m	18.2711	-0.0281	0.0%	0.0%
	D5	1,500+ m	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. * = significant if < 5%

Table 36. Commercial fishing modeling: data summary for Kodiak

Variable	0–60 m	60–150 m	150–300 m	300–1,500 m	1,500+ m	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 37. Commercial fishing modeling: fishery impact coefficients for Kodiak

Platform Placement	Depth Band	Depth Range	Regression Coefficient a	Regression Coefficient b	*P*-values* a	*P*-values* b
In multiple depth ranges	D1	0–60 m	-3.1155	-0.2197	0.0%	0.0%
	D2	60–150 m	9.9260	-0.0547	0.0%	0.0%
	D3	150–300 m	3.4458	-0.1301	0.0%	0.0%
	D4	300–1,500 m	33.9909	0.0812	0.0%	0.0%
	D5	1,500+ m	0.2553	-0.0003	0.0%	0.0%
In only one depth range	D1	0–60 m	0.0004	0.0000	74.8%	75.7%
	D2	60–150 m	23.4770	-0.2662	0.0%	0.0%
	D3	150–300 m	14.2944	-0.2833	0.0%	0.0%
	D4	300–1,500 m	57.3254	-0.0684	0.0%	0.0%
	D5	1,500+ m	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. * = significant if < 5%

Table 38. Commercial fishing modeling: data summary for Cook Inlet

Variable	0–60 m	60–150 m	150–300 m	300–1,500 m	1,500+ m	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 39. Commercial fishing modeling: fishery impact coefficients for Cook Inlet

Platform Placement	Depth Band	Depth Range	Regression Coefficient a	Regression Coefficient b	*P*-values* a	*P*-values* b
In multiple depth ranges	D1	0–60 m	0.0911	-0.1270	51.2%	0.0%
	D2	60–150 m	4.1009	-0.2174	0.0%	0.0%
	D3	150–300 m	53.6277	-0.1231	0.0%	0.0%
	D4	300–1,500 m	0.0000	0.0000	-	-
	D5	1,500+ m	0.0000	0.0000	-	-
In only one depth range	D1	0–60 m	0.0008	0.0000	68.8%	69.8%
	D2	60–150 m	3.3460	-0.1402	0.0%	0.0%
	D3	150–300 m	112.7147	-0.2888	0.0%	0.0%
	D4	300–1,500 m	0.0000	0.0000	-	-
	D5	1,500+ m	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. * = significant if < 5%

Table 40. Commercial fishing modeling: data summary for Gulf of Alaska

Variable	0–60 m	60–150 m	150–300 m	300–1,500 m	1,500+ m	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 41. Commercial fishing modeling: fishery impact coefficients for Gulf of Alaska

Platform Placement	Depth Band	Depth Range	Regression Coefficient a	Regression Coefficient b	*P*-values* a	*P*-values* b
In multiple depth ranges	D1	0–60 m	30.1512	-1.3129	0.0%	0.0%
	D2	60–150 m	-3.7119	-0.0151	0.0%	0.0%
	D3	150–300 m	-4.1361	-0.0166	0.0%	0.0%
	D4	300–1,500 m	71.5700	0.1964	0.0%	0.0%
	D5	1,500+ m	0.4133	-0.0003	0.0%	0.0%
In only one depth range	D1	0–60 m	0.0000	0.0000	-	-
	D2	60–150 m	0.3350	-0.0081	0.0%	0.0%
	D3	150–300 m	13.7071	-0.2405	0.0%	0.0%
	D4	300–1,500 m	111.8007	-0.0521	0.0%	3.4%
	D5	1,500+ m	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. * = significant if < 5%

8.7 Summary Tables of Fishery Data and Regression Coefficients for the Pacific Region

This section provides fishery data and regression coefficients for planning areas in the Pacific Region (Tables 42–49).

Table 42. Commercial fishing modeling: data summary for Washington/Oregon

Variable	0–60 m	60–150 m	150–300 m	300–1,500 m	1,500+ m	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 43. Commercial fishing modeling: fishery impact coefficients for Washington/Oregon

Platform Placement	Depth Band	Depth Range	Regression Coefficient a	Regression Coefficient b	*P*-values* a	*P*-values* b
In multiple depth ranges	D1	0–60 m	49.7169	-6.3516	0.0%	0.0%
	D2	60–150 m	13.3141	-0.3552	0.0%	0.0%
	D3	150–300 m	27.7859	-1.4289	0.0%	0.0%
	D4	300–1,500 m	27.8188	0.0261	0.0%	0.0%
	D5	1,500+ m	0.2841	-0.0004	0.0%	0.0%
In only one depth range	D1	0–60 m	0.0000	0.0000	-	-
	D2	60–150 m	30.2198	-0.6552	0.0%	0.0%
	D3	150–300 m	27.5531	-0.9806	0.0%	0.0%
	D4	300–1,500 m	48.0148	-0.2051	0.0%	0.0%
	D5	1,500+ m	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. * = significant if < 5%

Table 44. Commercial fishing modeling: data summary for Northern California

Variable	0–60 m	60–150 m	150–300 m	300–1,500 m	1,500+ m	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 45. Commercial fishing modeling: fishery impact coefficients for Northern California

Platform Placement	Depth Band	Depth Range	Regression Coefficient a	Regression Coefficient b	*P*-values* a	*P*-values* b
In multiple depth ranges	D1	0–60 m	0.0000	9.6002	-	0.0%
	D2	60–150 m	-2.3562	-0.7016	0.0%	0.0%
	D3	150–300 m	480.4073	-15.7714	0.0%	0.0%
	D4	300–1,500 m	15.2975	-0.3703	0.0%	0.0%
	D5	1,500+ m	0.1348	-0.0002	0.0%	0.0%
In only one depth range	D1	0–60 m	0.0000	0.0000	-	-
	D2	60–150 m	0.0000	0.0000	-	-
	D3	150–300 m	512.8884	-12.0618	0.0%	5.9%
	D4	300–1,500 m	22.3296	-0.4914	0.0%	0.0%
	D5	1,500+ m	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. * = significant if < 5%

Table 46. Commercial fishing modeling: data summary for Central California

Variable	0–60 m	60–150 m	150–300 m	300–1,500 m	1,500+ m	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 47. Commercial fishing modeling: fishery impact coefficients for Central California

Platform Placement	Depth Band	Depth Range	Regression Coefficient a	Regression Coefficient b	*P*-values* a	*P*-values* b
In multiple depth ranges	D1	0–60 m	73.4460	-5.3453	0.0%	0.0%
	D2	60–150 m	-2.0906	-0.1640	0.0%	0.0%
	D3	150–300 m	111.2114	-12.3236	0.0%	0.0%
	D4	300–1,500 m	1.2845	-0.1046	0.0%	0.0%
	D5	1,500+ m	0.0247	0.0000	0.0%	0.0%
In only one depth range	D1	0–60 m	0.0000	0.0000	-	-
	D2	60–150 m	129.8943	-14.5836	0.0%	0.0%
	D3	150–300 m	2.4434	-0.1020	0.0%	0.0%
	D4	300–1,500 m	0.0000	0.0000	-	-
	D5	1,500+ m	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. * = significant if < 5%

Table 48. Commercial fishing modeling: data summary for Southern California

Variable	0–60 m	60–150 m	150–300 m	300–1,500 m	1,500+ m	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 49. Commercial fishing modeling: fishery impact coefficients for Southern California

Platform Placement	Depth Band	Depth Range	Regression Coefficient a	Regression Coefficient b	*P*-values* a	*P*-values* b
In multiple depth ranges	D1	0–60 m	9.8322	1.7319	0.0%	0.0%
	D2	60–150 m	1.1087	-0.0887	0.0%	0.0%
	D3	150–300 m	-1.2919	0.0156	0.0%	0.0%
	D4	300–1,500 m	1.2125	-0.0066	0.0%	0.0%
	D5	1,500+ m	0.0073	0.0000	0.0%	0.0%
In only one depth range	D1	0–60 m	23.0426	0.1588	0.0%	4.0%
	D2	60–150 m	0.2636	-0.0198	0.0%	0.0%
	D3	150–300 m	0.0304	-0.0020	5.4%	6.5%
	D4	300–1,500 m	1.4216	-0.0073	0.0%	0.0%
	D5	1,500+ m	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. * = significant if < 5%

8.8 Summary Tables of Fishery Data and Regression Coefficients for the GOM Region

This section provides fishery data and regression coefficients for planning areas in the GOM Region (Tables 50–55).

Table 50. Commercial fishing modeling: data summary for Western GOM

Variable	0–60 m	60–150 m	150–300 m	300–1,500 m	1,500+ m	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 51. Commercial fishing modeling: fishery impact coefficients for Western GOM

Platform Placement	Depth Band	Depth Range	Regression Coefficient a	Regression Coefficient b	*P*-values* a	*P*-values* b
In multiple depth ranges	D1	0–60 m	41.1558	0.0856	0.0%	0.0%
	D2	60–150 m	17.1473	-0.4121	0.0%	0.0%
	D3	150–300 m	96.8024	-3.9112	0.0%	0.0%
	D4	300–1,500 m	-5.9425	-0.0090	0.0%	0.0%
	D5	1,500+ m	2.1800	-0.0706	0.0%	0.0%
In only one depth range	D1	0–60 m	58.8368	-0.0017	0.0%	17.5%
	D2	60–150 m	15.4988	-0.3156	0.0%	0.0%
	D3	150–300 m	99.2532	-3.4300	0.0%	0.0%
	D4	300–1,500 m	1.6356	-0.0111	0.0%	0.0%
	D5	1,500+ m	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. * = significant if < 5%

Table 52. Commercial fishing modeling: data summary for Central GOM

Variable	0–60 m	60–150 m	150–300 m	300–1,500 m	1,500+ m	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 53. Commercial fishing modeling: fishery impact coefficients for Central GOM

Platform Placement	Depth Band	Depth Range	Regression Coefficient a	Regression Coefficient b	*P*-values* a	*P*-values* b
In multiple depth ranges	D1	0–60 m	-166.4307	0.6090	0.0%	0.0%
	D2	60–150 m	23.0788	-2.0727	0.0%	0.0%
	D3	150–300 m	929.2590	-13.1703	0.0%	0.0%
	D4	300–1,500 m	224.2500	-0.0830	0.0%	0.5%
	D5	1,500+ m	84.9431	-0.0305	0.0%	0.0%
In only one depth range	D1	0–60 m	2.5466	-0.0198	0.0%	0.0%
	D2	60–150 m	153.1490	-0.6535	0.0%	0.0%
	D3	150–300 m	1362.5590	-2.9497	0.0%	0.0%
	D4	300–1,500 m	0.0000	0.0000	-	-
	D5	1,500+ m	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. * = significant if < 5%

Table 54. Commercial fishing modeling: data summary for Eastern GOM

Variable	0–60 m	60–150 m	150–300 m	300–1,500 m	1,500+ m	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	1,138
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 55. Commercial fishing modeling: fishery impact coefficients for Eastern GOM

Platform Placement	Depth Band	Depth Range	Regression Coefficient a	Regression Coefficient b	*P*-values* a	*P*-values* b
In multiple depth ranges	D1	0–60 m	-0.5223	0.0013	0.0%	0.0%
	D2	60–150 m	0.2414	-0.0059	0.0%	0.0%
	D3	150–300 m	-0.9243	0.0027	0.0%	1.8%
	D4	300–1,500 m	2.1622	-0.0080	0.0%	0.0%
	D5	1,500+ m	0.7573	-0.0020	0.0%	0.0%
In only one depth range	D1	0–60 m	0.0147	-0.0001	0.0%	0.0%
	D2	60–150 m	0.1527	-0.0014	0.0%	0.0%
	D3	150–300 m	0.0908	-0.0014	0.1%	0.2%
	D4	300–1,500 m	6.2401	-0.0071	0.0%	0.0%
	D5	1,500+ m	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. * = significant if < 5%

8.9 Summary Tables of Fishery Data and Regression Coefficients for the Atlantic Region

This section provides fishery data and regression coefficients for planning areas in the Atlantic Region (Tables 56–63). 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 56. Commercial fishing modeling: data summary for Straits of Florida

Variable	0–60 m	60–150 m	150–300 m	300–1,500 m	1,500+ m	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 57. Commercial fishing modeling: fishery impact coefficients for Straits of Florida

Platform Placement	Depth Band	Depth Range	Regression Coefficient a	Regression Coefficient b	*P*-values* a	*P*-values* b
In multiple depth ranges	D1	0–60 m	-17.8965	-7.6203	0.0%	0.0%
	D2	60–150 m	39.8724	-17.8959	0.0%	0.0%
	D3	150–300 m	519.6629	-2.6130	0.0%	0.0%
	D4	300–1,500 m	100.4700	-0.1348	0.0%	0.0%
	D5	1,500+ m	0.0000	0.0000	-	-
In only one depth range	D1	0–60 m	0.0000	0.0000	-	-
	D2	60–150 m	0.0000	0.0000	-	-
	D3	150–300 m	591.6000	-3.3874	0.0%	0.0%
	D4	300–1,500 m	136.0181	-0.5571	0.0%	0.0%
	D5	1,500+ m	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. * = significant if < 5%

Table 58. Commercial fishing modeling: data summary for South Atlantic

Variable	0–60 m	60–150 m	150–300 m	300–1,500 m	1,500+ m	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 59. Commercial fishing modeling: fishery impact coefficients for South Atlantic

Platform Placement	Depth Band	Depth Range	Regression Coefficient a	Regression Coefficient b	*P*-values* a	*P*-values* b
In multiple depth ranges	D1	0–60 m	13.0727	0.0160	0.0%	0.0%
	D2	60–150 m	10.6494	-0.4229	0.0%	0.0%
	D3	150–300 m	6.9703	-0.4178	0.0%	0.0%
	D4	300–1,500 m	-3.5769	0.0053	0.0%	0.0%
	D5	1,500+ m	4.5347	-0.0707	0.0%	0.0%
In only one depth range	D1	0–60 m	25.8040	-0.0574	0.0%	0.0%
	D2	60–150 m	0.5119	-0.0333	0.0%	0.0%
	D3	150–300 m	0.0000	0.0000	-	-
	D4	300–1,500 m	0.0000	0.0000	-	-
	D5	1,500+ m	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. * = significant if < 5%

Table 60. Commercial fishing modeling: data summary for Mid-Atlantic

Variable	0–60 m	60–150 m	150–300 m	300–1,500 m	1,500+ m	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	1,523	2,104
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 61. Commercial fishing modeling: fishery impact coefficients for Mid-Atlantic

Platform Placement	Depth Band	Depth Range	Regression Coefficient a	Regression Coefficient b	*P*-values* a	*P*-values* b
In multiple depth ranges	D1	0–60 m	338.5462	0.1483	0.0%	0.0%
	D2	60–150 m	969.9951	-23.2053	0.0%	0.0%
	D3	150–300 m	184.4773	-14.5967	0.0%	0.0%
	D4	300–1,500 m	13.8066	-0.4718	0.0%	0.0%
	D5	1,500+ m	-7.6396	-0.0009	0.0%	0.6%
In only one depth range	D1	0–60 m	485.5860	-0.7344	0.0%	0.0%
	D2	60–150 m	872.2275	-17.9010	0.0%	0.0%
	D3	150–300 m	0.0000	0.0000	-	-
	D4	300–1,500 m	0.2734	-0.0068	0.1%	0.1%
	D5	1,500+ m	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. * = significant if < 5%

Table 62. Commercial fishing modeling: data summary for North Atlantic

Variable	0–60 m	60–150 m	150–300 m	300–1,500 m	1,500+ m	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	1,022	2,121
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 63. Commercial fishing modeling: fishery impact coefficients for North Atlantic

Platform Placement	Depth Band	Depth Range	Regression Coefficient a	Regression Coefficient b	*P*-values* a	*P*-values* b
In multiple depth ranges	D1	0–60 m	42.8581	-0.1396	0.0%	0.0%
	D2	60–150 m	53.5270	-0.3556	0.0%	0.0%
	D3	150–300 m	27.8205	-0.2662	0.0%	0.0%
	D4	300–1,500 m	363.6121	-8.6874	0.0%	0.0%
	D5	1,500+ m	11.1531	-0.0176	0.0%	0.0%
In only one depth range	D1	0–60 m	125.1157	-0.7609	0.0%	0.0%
	D2	60–150 m	551.4754	-5.8763	0.0%	0.0%
	D3	150–300 m	63.8554	-0.6173	0.0%	0.0%
	D4	300–1,500 m	0.0000	0.0000	-	-
	D5	1,500+ m	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. * = significant if < 5%

8.10 References—Commercial Fishing

Aquamaps. 2010. Standardized distribution maps for 11,500 species of fishes, marine mammals and invertebrates. [accessed 2010 Dec 09]. http://www.aquamaps.org/.

[CDFG] California Department of Fish and Game. 2007. Information concerning the pink shrimp trawl fishery off northern California. Sacramento (CA): California Department of Fish and Game, Marine Region.

Hiatt T, Dalton M, Felthoven R, Garber-Yonts B, Haynie A, Kasperski S, Lew D, Package C, Pfeiffer L, Sepez J, Seung C, Northern Economics, Inc. 2009. Stock assessment and fishery evaluation report for the groundfish fisheries of the Gulf of Alaska and Bering Sea/Aleutian Island area: economic status of the groundfish fisheries off Alaska, 2008. Seattle (WA): Alaska Fisheries Science Center, Resource Ecology and Fisheries Management Division, Economic and Social Sciences Research Program; NMFS; and NOAA. [accessed 2009 Dec 18]. http://www.afsc.noaa.gov/REFM/docs/2009/economic.pdf.

Huntsman D. 2010. Data as requested on Alaska king and tanner crab landings and values by statistical area, 2006–2009, provided by the Alaska Commercial Fishing Entry Commission. August 4, 2010.

Jamir, T. 2010. Data on harvests and values by statistical areas in the Gulf of Mexico and the South Atlantic, 2006–2009, provided by the National Marine Fisheries Service, Southeast Science Center. November 29, 2010.

Kong, T. 2010. Data as requested on halibut landings by International Pacific Halibut Commission statistical area, 2006–2009. October 6, 2010.

Kruse, G. 2010. Personal Communication with M. Hartley, Interviewer. April 25, 2010.

Labelle, R. 2010. Data request provided by the Offshore Energy and Minerals Management to Dr. Bonnie Ponwith, Science Director NMFS, Southeast Fishery Science Center. September 28, 2010.

Lewis, S. 2010. Data as requested on Alaska groundfish harvests and values by 10 × 10 cells, 2006–2009, provided by National Marine Fisheries Service Alaska Region. July 8, 2010.

[MMS] Minerals Management Service. 1990. Economic impacts of the S.S. Glacier Bay oil spill. Anchorage (AK): U.S. Department of the Interior, Minerals Management Service. Report No.: MMS 90-0081.

[NMFS] National Marine Fisheries Service. 2010. Annual landings statistics, 2006–2009. Washington (DC): NMFS, Office of Science and Technology, Fisheries Statistics Division. [accessed 2010 Dec]. http://www.st.nmfs.noaa.gov/st1/commercial/landings/annual_landings.html.

[PFMC] Pacific Fishery Management Council. 2010a. PFMC gear group report: groundfish landed-catch (metric tons) for each INPFC area, for year 2009. Report No.: 009. [accessed 2010 Oct 05]. https://pacfin.psmfc.org/pacfin_pub/data_rpts_pub/pfmc_rpts_pub/r009_p09.txt

PFMC. 2010b. PFMC gear group report: commercial groundfish estimated revenue ($1000) for all areas, for year 2009. Report No.: 074. [accessed 2010 Oct 05]. https://pacfin.psmfc.org/pacfin_pub/data_rpts_pub/pfmc_rpts_pub/r074_p09.txt

Stenberg B. 2010. Data as requested from West Coast trawl logbooks, 2006–2009, provided by Pacific Fisheries Information Network (PacFIN). November 15, 2010.

Thunberg E. 2010. Data as requested from logbooks and dealer reports on harvests and values by fishery in the North and Mid-Atlantic, 2006–2009, provided by the National Marine Fisheries Service, Northeast Fishery Science Center. July 20, 2010.

Tuttle V. 2010. Data as requested on offshore Pacific whiting landings by 10 × 10 cells, 2006–2009, provided by the National Marine Fisheries Service, Northeast Fishery Science Center. July 15, 2010.

[BLS] U.S. Bureau of Labor Statistics. 2010. Producer Price Index (PPI) for unprocessed and packaged fish. [accessed 2010 Aug 21]. http://www.bls.gov/ppi/

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 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.[43] 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.

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

[43] 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.

public for any and all resource services lost due to injury.[44] 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, because they involve valuation of service losses, or at least economic tradeoffs. Although 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.

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. The sections below describe the original model (Section 9.2), and the 2018 updates (included in section 9.3).

[44] 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).

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[45] 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 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). 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 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 NRDAs.[46]

[45] 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.

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

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. This section is inclusive of updates made to the model between 2012 and 2018.

- 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. Furthermore, 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.
- The 2018 modifications include incorporating updated ecological efficiency (i.e., trophic transfer) and population density estimates for polar bears in Alaska.
- The restoration approach for higher trophic species (i.e., piscivores and species that consume piscivores) is based on supplemental feeding with fish, as opposed to salt marsh habitat restoration.
- Restoration cost estimates have been updated by:
  - applying estimated restoration costs for salt marsh restoration and supplemental feeding 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.[47] The model considers only the ecological costs of exploration, development, and transportation of OCS resources to shore, as these activities are within DOI 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 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.

[47] 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.

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. This approach is used for the species categories of small pelagic fish, demersal fish, crustaceans, mollusks, intertidal benthic invertebrates, waterfowl, shorebirds, herbivorous mammals, sea turtles, sea otters, and baleen cetaceans.
    d. Information about the trophic transfer efficiency from fish (species dependent on region) to trophic levels that consume fish is used to calculate the amount of fish required to restore for the lost biomass of the piscivorous resource. This approach is used for the species categories of large pelagic fish, seabirds, waders, raptors, pinnipeds, toothed cetaceans, and polar bears.
4) Using HEA or REA, the number of acres (or acre-equivalent) of salt marsh restoration or mass of fish required to replace injured habitat or resources from Step 2 and 3 are calculated (see discussion of model drivers below for more details). Additional information on the HEA and REA approaches can be found in Appendix A.
5) Impacts are monetized by determining the cost of restoring the required area of salt marsh or supplementally feeding a mass of fish determined by HEA and REA 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

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

where:

DH = *Habitat damages (dollars)*

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

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

where:

DW = *Wildlife damages for a given species (dollars)*

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_i = 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 or resource restoration factor (m^2 of marsh habitat required to be restored per kg lost of species, or kg of fish required to restore for kg lost of species)

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

The mortality factor is calculated as:

$$M_i = D_i * P_i * W_i$$

where:

D_i = Density of the number of organisms per unit area (#/km^2 or #/m^3)

P_i = Oiling probability which is derived from the probability of oiling for that species' behavior group and field observations of mortality after spills

W_i = Average weight of the species group

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, and raptors
- *Whales*: baleen and toothed
- *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)

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

This HEA calculation was performed for habitat types in which a benthic invertebrate injury would occur, 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^2 oiled for these individual habitats was calculated based on the percent of that habitat type present in the entire habitat grid for the particular OECM region.

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 or resource 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. REA was conducted using two restoration methods (1) marsh restoration for species categories that do not consume fish, and (2) supplemental feeding using fish for piscivorous species and species that consume piscivores; both approaches are described below.

Marsh Restoration Approach

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 m^{-2} yr^{-1}. In addition, benthic microalgal production provides another 105 g dry weight m^{-2} (Van Raalte et al. 1976). Thus, estimated total primary production rate in salt marshes in this region is 605 g dry weight m^{-2} yr^{-1}.
- GOM 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 m^{-2} yr^{-1}. In addition, benthic microalgal production provides another 105 g dry weight m^{-2} (Van Raalte et al. 1976). Thus, estimated total primary production rate in salt marshes in this region is 1,395 g dry weight m^{-2} 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) (CSA 1991) as 3,666 g dry weight m^{-2} yr^{-1}. In addition, benthic microalgal production

provides another 312 g dry weight m^{-2} (CSA 1991). Thus, estimated total primary production rate in salt marshes in this region is 3,978 g dry weight $m^{-2}\,yr^{-1}$.

- 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 $m^{-2}\,yr^{-1}$. In addition, benthic microalgal production provides another 375 g dry weight m^{-2} (CSA 1991). Thus, estimated total primary production rate in salt marshes in this region is 3,011 g dry weight $m^{-2}\,yr^{-1}$.
- 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 $m^{-2}\,yr^{-1}$. In addition, benthic microalgal production over a 6-month growing season provides another 1,488 g dry weight m^{-2} (CSA 1991). Thus, estimated total primary production rate in salt marshes in this region is 2,170 g dry weight $m^{-2}\,yr^{-1}$.
- 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 $m^{-2}\,yr^{-1}$. In addition, benthic microalgal production over a 6-month growing season provides another 744 g dry weight m^{-2} (CSA 1991). Thus, estimated total primary production rate in salt marshes in this region is 1,085 g dry weight $m^{-2}\,yr^{-1}$.

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.

Supplemental Feeding Restoration Approach

Scaling methods used here are similar in concept and calculation as those described above for marsh restoration. The concept is that supplemental feeding leads to a net gain in biomass of the lost resource. In a manner similar to the REA described above, the mass of the fish used for supplemental feeding on a weight basis is scaled to compensate for the injury (interim loss). In this case, the transfer of production up the food web is taken into consideration for one trophic step (or two in the case of polar bears). Specifically, total injuries in kilograms are translated into equivalent kilograms of fish as follows.

1. Values for production of predator per unit production of prey (ecological efficiency or trophic transfer efficiency) are taken from the ecological literature, as reviewed by French McCay and Rowe (2003) and Welch et al. (1992).
2. The equivalent compensatory amount of fish biomass of the restored resource is calculated as kilogram of injury divided by ecological efficiency. Estimated ecological efficiency between fish and the injured species is one step for all piscivorous species, except for the case of polar bears which is a two-step calculation (i.e., the product of the efficiency of transfer from fish to seals and efficiency from seals to polar bears).

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). 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.

Marsh Restoration Approach Cost Estimates

Planning Area-specific, per-acre coastal marsh restoration costs are applied in the OECM. As previously described, to quantify the ecological costs of oil spill scenarios, the OECM relies on scaled estimates of the area of salt marsh restoration needed to compensate for injuries to habitat and to particular species. The OECM estimates the monetary cost of the restoration by multiplying the total area of salt marsh restoration (in square meters) by an estimated region-specific median cost per square meter of salt marsh restoration.

The marsh restoration costs included in previous version of the OECM were based on costs of particular wetland restoration projects in the North Atlantic Region. The OECM then relied on estimated costs for wetland compensatory mitigation across coastal regions of the U.S., estimated by the Environmental Law Institute (ELI 2007), in order to extrapolate salt marsh restoration costs to other regions relative to the North Atlantic.

The 2018 model instead relies more specifically on the region-specific wetland compensatory mitigation cost data reported in the ELI report. ELI generated these estimates based on a survey of all 38 U.S. Army Corps of Engineer (USACE) districts across the U.S. and supplemented these data with additional information on wetland compensatory mitigation costs. The OECM relies on these wetland compensatory mitigation costs (inflated to 2010 dollars) as a proxy for wetland restoration costs, estimating average costs per acre for each BOEM planning area based on the USACE districts that overlap the shoreline adjacent to each planning area.

These compensatory mitigation costs reflect costs of wetland mitigation—including creation, restoration, enhancement, and preservation—to compensate for damages to wetlands associated with projects permitted under Section 404 of the Clean Water Act (i.e., ensuring "no net loss" in wetland functions). Most frequently, in the context of NRDAs, restoration projects and approaches are designed specific to the injury. Costs of wetland restoration may vary by several orders of magnitude, based on multiple factors such as project site and size, permitting and planning required, monitoring costs (ELI 2007). Given the similar goals of the no-net-loss goals of the Clean Water Act for wetlands and the HEA restoration framework of the OECM, the average regional compensatory mitigation costs is a consistent source of data that constitute a reasonable proxy for wetland restoration costs for the OECM.[48] Table 64 describes the estimated costs per unit of marsh restoration applied in the OECM.

Table 64. Salt marsh restoration costs (2010$)

Planning Area	Estimated Restoration Cost ($/m^2)
North Atlantic	$29.98
Mid-Atlantic	$13.84
South Atlantic	$12.59
Straits of Florida	$19.79
Eastern Gulf	$14.15
Central Gulf	$7.23
Western Gulf	$7.71
Southern California	$26.60
Central California	$38.54
Northern California	$38.54
Washington/Oregon	$12.33

[48] Although Clean Water Act compensatory mitigation considers alternative approaches to replacing lost wetland functions than restoration, on-site restoration and creation are generally the preferred approaches to mitigation (ELI, 2007).

Planning Area	Estimated Restoration Cost ($/m^2)
Gulf of Alaska	$2.44
Cook Inlet	$2.44
Kodiak	$2.44
Shumagin	$2.44
North Aleutian Basin	$2.44
Aleutian Arc	$2.44
St. George Basin	$2.44
St. Matthew-Hall	$2.44
Bowers Basin	$2.44
Aleutian Basin	$2.44
Navarin Basin	$2.44
Norton Basin	$2.44
Hope Basin	$2.44
Chukchi Sea	$2.44
Beaufort Sea	$2.44

Supplemental Feeding Approach Cost Estimates

As previously described, the OECM restoration approach for higher trophic species, including piscivorous fish, seabirds, wading birds, raptors, pinnipeds, cetaceans, and polar bears, is compensating for species biomass losses in terms of supplemental feeding (i.e., replacing prey fish). Replacement cost estimates for fish vary significantly by species. The OECM relies on data reported by the American Fisheries Society (AFS), which provides information on species- and region-specific replacement costs for fish (AFS 2003). The AFS data are developed specifically for use in quantifying the costs of natural resource damages and reflect fish replacement costs (i.e., the costs of raising and releasing the fish) based on surveys of public, private, and tribal hatcheries across the U.S. The replacement cost data are stratified by region-specific factors that affect fish production costs (e.g., water temperature, land availability, etc.). For species not cultured in hatcheries, replacement costs are estimated based on the most closely related species. Although the replacement costs often understate the full resource damage from species kill events, they reflect a reasonable estimate of the costs of restoration. For the purposes of the OECM, the fish replacement cost estimates are inflated to 2010 dollars.

For polar bears and other higher trophic species in the Arctic region of Alaska, the model assumes supplemental feeding based on Arctic cod ($18.66/kg of fish). For all other regions and species, the OECM quantifies restoration costs based on supplemental feeding using various species of herring/menhaden (specifically, for Pacific herring, Atlantic menhaden, and Gulf menhaden costs are $1.08/kg of fish). The estimated costs are as reported in Appendix A of AFS (2003).

9.5 References—Ecological

American Fisheries Society. 2003. Investigation and Monetary Values of Fish and Freshwater Mussel Kills: Special Publication 30.

Continental Shelf Associates, Inc. (CSA). 1991. A Comparison of Marine Productivity among Outer Continental Shelf Planning Areas. Supplement - An Evaluation of Benthic Habitat Primary Productivity.

Environmental Law Institute (ELI). 2007. Mitigation of Impacts to Fish and Wildlife Habitat: Estimating Costs and Identifying Opportunities (October). Accessed August 11, 2015. http://www.eli.org/sites/default/files/eli-pubs/d17_16.pdf.

French, D.P., C.A. Manen, M. Gibson, and J. Catena. 2001. Quantifying the Scale of Restoration Required to Compensate for the Impacts of the *North Cape* Oil Spill on Fish and Invertebrates. *In*: Proceedings of the 2001 International Oil Spill Conference & Exposition, March 26-29, 2001, Tampa, Florida. Washington, DC: American Petroleum Institute.

French, D., M. Reed, K. Jayko, S. Feng, H. Rines, S. Pavignano, T. Isaji, S. Puckett, A. Keller, F.W. French III, D. Gifford, J. McCue, G. Brown, E. MacDonald, J. Quirk, S. Natzke, R. Bishop, M. Welsh, M. Phillips, and B.S. Ingram. 1996. The CERCLA Type A Natural Resource Damage Assessment Model for Coastal and Marine Environments (NRDAM/CME), Technical Documentation, Vol. I-V. Final Report, PB96-501788. Submitted to the Office of Environmental Policy and Compliance, U.S. Department of the Interior, Washington, DC. [Available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.]

French McCay, D., N. Whittier, T. Isaji, and W. Saunders. 2003b . Assessment of the Potential Impacts of Oil Spills in the James River, Virginia. In: Proceedings of the Twenty Sixth Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, Victoria, BC, Canada, June 2003. Ottawa, ON, Canada: Environment Canada, Emergencies Science Division, pp. 857-878.

French McCay, D., J. J. Rowe, and N. Whittier. 2003a. Final Report, Estimation of Natural Resource Damages for 23 Florida Cases Using Modeling of Physical Fates and Biological Injuries. (23 volumes). Prepared for Florida Department of Environmental Protection (May 2003).

French McCay, D.P. and J.J. Rowe. 2003. Habitat Restoration as Mitigation for Lost Production at Multiple Trophic Levels. Marine Ecology Progress Series 264: 233-247.

French-McCay, D.P. 2009. State-of-the-Art and Research Needs for Oil Spill Impact Assessment Modeling. *In*: Proceedings of the 32nd AMOP Technical Seminar on Environmental Contamination and Response. Ottawa, ON, Canada: Environment Canada, Emergencies Science Division, pp. 601-653.

Louisiana Department of Environmental Quality (LA DEQ), Louisiana Department of Natural Resources, Louisiana Department of Wildlife and Fisheries, Louisiana Oil Spill Coordinator's Office (Office of the Governor), National Oceanic and Atmospheric Administration, and U.S. Department of the Interior. 2003. The Louisiana Regional Restoration Planning Program, Draft Regional Restoration Plan, Region 2 (September). http://www.darrp.noaa.gov/southeast/rrpp-la/pdf/larrp11_18_04.pdf.

National Oceanic and Atmospheric Administration (NOAA). 1997. Scaling Compensatory Restoration Actions: Guidance Document for Natural Resource Damage Assessment Under the Oil Pollution Act of 1990. NOAA Damage Assessment Center, Silver Spring, MD.

National Oceanic and Atmospheric Administration (NOAA). 1999. Habitat Equivalency Analysis: An Overview. NOAA Damage Assessment Center, Silver Spring, MD, 23 p.

Nixon, S.W. and C.A. Oviatt. 1973. Ecology of a New England Salt Marsh. Ecological Monographs 43(4): 463-498.

Sibley, D.A. 2003. The Sibley Field Guide to Birds of Eastern North America. New York: Alfred A. Knopf, Inc., 432 p.

Teal, J.M. 1962. Energy Flow in the Salt Marsh Ecosystem of Georgia. Ecology 43: 614-624.

U.S. Environmental Protection Agency (U.S. EPA). 2000. Guidelines for Preparing Economic Analyses. EPA 240-R-00-003 (September). Washington, DC: U.S. EPA, Office of the Administrator.

Van Raalte, C.D., I. Valiela, and J.M. Teal. 1976. Production of Epibenthic Salt Marsh Algae: Light and Nutrient Limitation. Limnology and Oceanography 21(6): 862-872.

Welch, H. E., Bergmann, M. A., Siferd, T. D., Martin, K. A., Curtis, M. F., Crawford, R. E., ... & Hop, H. (1992). Energy flow through the marine ecosystem of the Lancaster Sound region, arctic Canada. Arctic, 343-357.

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)[49] study, *Economic Impact of Recreational Fishing and Diving Associated with Offshore Oil and Gas Structures in the Gulf of Mexico* (Hiett and Milon 2002). This study used a combination of in-person and telephone surveys of marinas in the Central and Western GOM 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. Furthermore, 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 MMS (2002) 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.[50]

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 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,

[49] Predecessor agency to BOEM.

[50] 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.

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.

Although 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 Hiett and Milon (2002), 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 GOM planning areas to other regions (Hiett and Milon 2002, pg. 78). 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. Furthermore, Hiett and Milon (2002) 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 111th 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 110th 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 National OCS 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.[51] 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 in sources of supply, and the distance between sources of supply and the point of consumption (Blyth and Lefevre 2004; Le Coq and Paltsev 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.

[51] 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.

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 U.S. 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 U.S.

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

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

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.

Although 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.

10.4 References—Benefits

Blyth W, Lefevre N. 2004. Energy security and climate change policy interactions: an assessment framework. Paris (France): International Energy Agency. 88 p.

Brown SPA, Huntington HG. 2009. Estimating U.S. oil security premiums. Stanford University Energy Modeling Forum, EMF OP 68 (September). 32 p.

Bryce R. 2008. Gusher of lies: the dangerous delusions of "energy independence." New York (NY): Public Affairs. 371 p.

Gupta E. 2008. Oil vulnerability index of oil-importing countries. Energy Policy. 36(3):1195–1211.

Hiett RL, Milon JW, 2002. Economic impact of recreational fishing and diving associated with offshore oil and gas structures in the Gulf of Mexico: final report. New Orleans (LA): U.S. Department of the Interior, Minerals Management Service. 288 p. Report No.: OCS Study MMS 2002-010.

LaCasse C, Plourde A. 1995. On the renewal of concern for the security of oil supply. The Energy Journal. 16(2):1–24.

Le Coq C, Paltseva E. 2008. Common energy policy in the EU: the moral hazard of the security of external supply. SIEPS Report 2008:1.

Le Coq C, Paltseva E. 2009. Measuring the security of external energy supply in the European Union, Energy Policy. 37(2009):4474–4481.

Appendix A: Oil Spill Modeling for the Offshore Environmental Cost Model (OECM) Version 4

APPENDIX A: OIL SPILL MODELING FOR THE OFFSHORE ENVIRONMENTAL COST MODEL (OECM) VERSION 4

by

Deborah French McCay, Jill Rowe, Danielle Reich, Melanie Schroeder, and Eileen Graham

Version 4: October 2023

Applied Science Associates, Inc.
55 Village Square Drive
South Kingstown, RI 02879
Tel: +1 401 789 6224
Fax: +1 401 789 1932
Email: dfrench@asascience.com

Adapted by:

Industrial Economics, Inc. (IEc)
2067 Massachusetts Avenue
Cambridge, MA 02140
Revised August 2018

for submission to:

Bureau of Ocean Energy Management (BOEM)

VERSION 4 UPDATES

Industrial Economics, Incorporated (IEc) updated this Appendix in 2023 to reflect updated oil spill frequency and spill size data for platforms, pipelines, crude oil tankers, and tankers transporting refined petroleum products.

TABLE OF CONTENTS

Sub-appendices

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS & ACRONYMS

3D	=	3-dimensional
API	=	American Petroleum Institute
ASA	=	Applied Science Associates, Inc.
BODC	=	British Oceanographic Data Centre
BOEM	=	Bureau of Ocean Energy Management
CASE	=	Climatology and Simulation of Eddies
CBS	=	Chukchi Bering Sea
CERCLA	=	Comprehensive Environmental Response, Compensation and Liability Act of 1980
CUPOM	=	Colorado University Princeton Ocean Model
ERC	=	Environmental Research Consulting
ESI	=	Environmental Sensitivity Index
GEBCO	=	General Bathymetric Chart of the Oceans
GOM	=	Gulf of Mexico
HEA	=	Habitat Equivalency Analysis
MAH	=	monoaromatic hydrocarbon
NDBC	=	National Data Buoy Center
NOAA	=	National Oceanic and Atmospheric Administration
NRDA	=	Natural Resource Damage Assessment
NRDAM/CME	=	Natural Resource Damage Assessment Models for Coastal and Marine and Great Lakes Environments
OECM	=	Offshore Environmental Cost Model
OCS	=	Outer Continental Shelf
PAH	=	polyaromatic hydrocarbon
POP	=	Parallel Ocean Program
POM	=	Princeton Ocean Model
PDF	=	probability distribution function
RPI	=	Research Planning, Inc.
REA	=	Resource Equivalency Analysis
SCRUM	=	S-Coordinate Rutgers University Model
SBS	=	Southern Beaufort Sea

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,

Spill risk = probability of spill x impacts of spill

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

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

In summary, the SIMAP model was used to develop data (i.e., areas, shore lengths and water volumes affected as a function of oil type, spill volume, and environmental conditions) that were then described using regression analysis. The resulting functions are the basis for estimating oil spill-related costs within OECM. The oil impact model was developed for a matrix of potential environmental conditions representative of those in all 26 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 method 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 are then 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 Environments (NRDAM/CME) and Great Lakes Environments, which were developed for the U.S. Department of the Interior 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 99th percentile value for each impact category, location, and oil type. These 99th 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 (Tables 1 and 2). We then used the 99th percentile results from each scenario to develop regressions of exposures versus volume of oil spilled for each of the locations modeled (Table 3). The resulting sets of regressions were mapped to each of the 26 planning areas as described in Table 3.

Table 1. Spill volumes and durations for crude oils.

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

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

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

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

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

2.2 Model Input Data

Detailed descriptions of input data for each location modeled are provided in 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 because it is 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; none of the oils evaluated have densities near that of the water.

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

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

2.2.3 Currents

Currents have significant influence on the trajectory and oil fate, and are critical data inputs. Wind-driven, tidal and background currents are included in the modeling analysis and are dependent upon geographic location. 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, 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% 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 quickly dilute 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, tidal amplitude, and wave energy. In NRDAM/CME (French et al. 1996), shore holding capacity was based on observations from the *Amoco Cadiz* spill in France, 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 99th percentile value for each oil type, spill volume, and impact measure.

Table 4. Impact measures used to estimate consequences.

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

2.3.1 Biological Impacts

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

Biological impacts are calculated in 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^2 or higher. Regressions were developed of area exposed versus spill volume for each oil type. To determine biological density information for each species, we multiplied the annual average number per km^2 (from the Type A model) by the probability of oiling for that species' behavior group (Table 5) to estimate the number killed per km^2. Estimates for the probabilities shown in Table 5 are derived from information on behavior and field observations of mortality after spills (reviewed in French et al. 1996 and French McCay 2009). We also multiplied the number killed per km^2 by the mean weight per individual of each species to calculate the kilograms killed per km^2 (mortality factor; Equation 1). This information is summarized for each location in the enclosed digital sub-appendix (Sub-appendix E), except for polar bears, which has been updated and described here.

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

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

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

Equation 1. Mortality Factor

$$Mortality\ Factor = Density * Oiling\ probability * average\ mass$$

Where:

- Mortality factor is the mass of a species killed per unit area or volume of spill impact (kg lost per area, km^2 or km^3);
- Density is the number of organisms per unit area ($\#/km^2$ or $\#/m^3$);
- Oiling probability is the value in Table 5; and
- Average mass is the weight of the species group.

Mortality factor is calculated as described above and used as an input into the REA.

Polar Bear Density – 2018 Updates

The polar bear populations have been declining; as such, the density numbers are updated as of 2018 to reflect current population levels. Polar bear data are used in three BOEM planning areas in the OECM: Chukchi Sea, Beaufort Sea, and Hope Basin. Polar bear populations that intersect with those planning areas are the Chukchi Bering Sea (CBS) stock and the Southern Beaufort Sea (SBS) stock. The SBS stock range overlaps the Beaufort Sea Planning Area and a portion of the

Chukchi Sea Planning Area; the CBS stock range overlaps the Chukchi Sea Planning Area and a portion of the Hope Basin Planning Area.

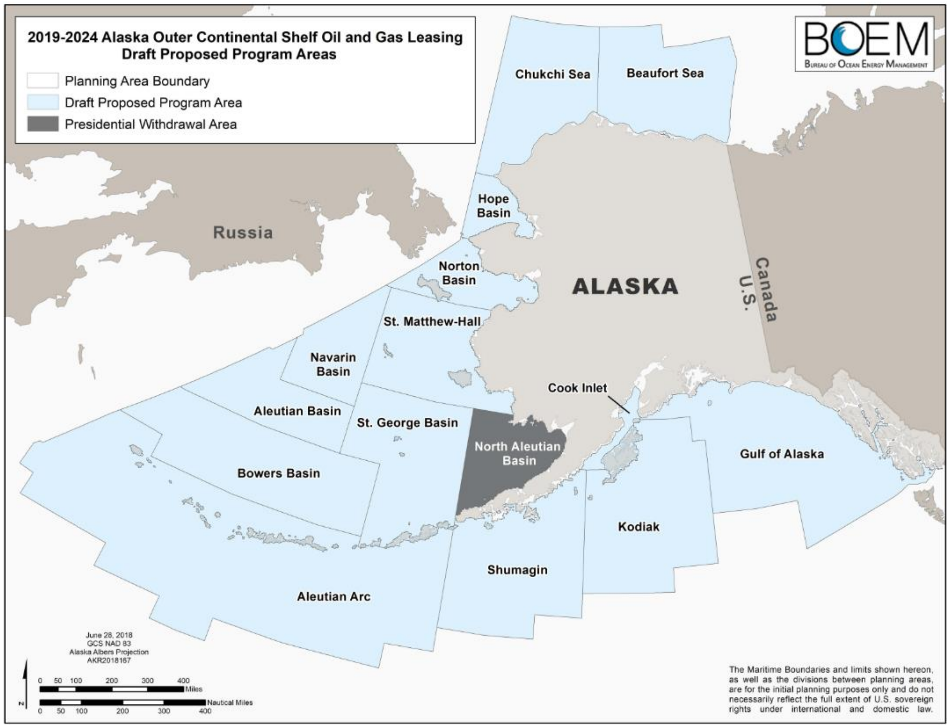


Figure 1: BOEM planning areas in Alaska.
Source: BOEM

Populations for polar bears are currently estimated from the U.S. Fish and Wildlife Service stock assessments. The CBS population is estimated at approximately 2,000 polar bears, while the SBS population is estimated to be approximately 900 polar bears (USFWS 2017a; 2017b; Table 6). We adjusted the population estimates for seasonality in both the CBS and SBS populations using the following assumptions:

- **CBS:**[1] 100% are present on the sea ice for 9 months of the year, and they all move inland for the remaining 3 months of the year (Rode et al. 2015; USFWS 2017a; COSEWIC 2008; Stirling and Parkinson 2006).
- **SBS:** 100% are present on the sea ice for 9 months of the year, and 20% move inland for the remaining 3 months of the year (Atwood et al. 2016).

These seasonality correction factors were applied to the population numbers by multiplying the population by the number of months where all the bears are present on the sea ice, then adding that to the population multiplied by the number of months where fewer (zero to 80%) of the bears are present on the ice. Then we divide that number by 12 months to get a seasonally adjusted average polar bear population for each stock (Table 6).

[1] The Hope Basin Planning Area is within the CBS stock's range. As such, the population assumptions are the same as the CBS stock.

Table 6: OECM polar bear population estimates and assumptions.

Parameter	Chukchi Bering Sea Stock	Southern Beaufort Sea Stock
Population	2,000	900
Seasonality Assumptions	100% present on sea ice for 9 months; 0% present on sea ice for the remaining 3 months.	100% present on sea ice for 9 months; 80% present on the sea ice for the remaining 3 months.
Population Adjusted for Seasonality	1,500	855

We estimate the area for each polar bear stock's range by digitizing an image of the two stock's ranges (Figure 2). The SBS and CBS bear stocks overlap in their ranges (dark grey area in Figure 2). Using GIS, the area for each population's range was calculated as the entire shaded region of their range in the ocean plus an inland buffer of 5 km. This distance was selected based on the distribution of bears studied in Rode et al. (2015).

The area that encompasses the range of the SBS population is 942,175 km^2, and the area that encompasses the range of the CBS population is 1,503,468 km^2 (Table 7), with 232,214 km^2 of those ranges overlapping.

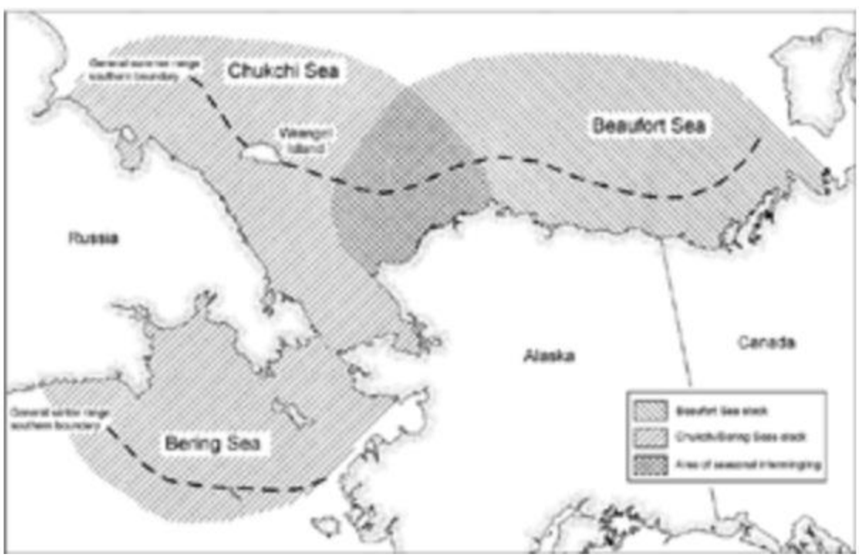


Figure 2: Chukchi/Bering and Beaufort Polar Bear Stock Ranges
Source: USFWS 2008

The Beaufort Sea Planning Area does not extend into the area where the bear population ranges overlap (Figure 2). As such, the SBS polar bear density is calculated by dividing the seasonally adjusted population of the SBS bears by the area of the range. The density used for the Beaufort Sea Planning Area is 0.0009 bears/km^2 (Table 7).

The Hope Basin Planning Area does not extend into the area where the bear population ranges overlap. As such, the Hope Basin polar bear density is calculated by dividing the seasonally adjusted population of CBS bears by the area of the range. The density used for the Hope Basin Planning Area is 0.000998 bears/km^2 (Table 7).

The Chukchi Sea Planning Area does extend into the shaded region where the populations for CBS and SBS stocks overlap (Figure 2). As such, the density for the CBS population needs to be further adjusted to include the SBS polar bears that could be in the Chukchi Sea Planning Area. To do this, we added the seasonally adjusted CBS population (1,500 bears) to the fraction of the SBS population that could be in the Chukchi Sea Planning Area. This fraction was calculated as the seasonally adjusted SBS population (855) multiplied by the fraction of the SBS stock's range that overlaps with the CBS range divided by the total SBS stock's range (232,214 km^2/942,175 km^2 = 0.25). This fraction assumes that the SBS bears are evenly distributed throughout their range (after accounting for seasonality). The addition of the CBS stock's seasonally adjusted population to the fraction of the SBS stock's seasonally adjusted population within the range of the CBS stock provides a new adjusted population of polar bears that could be in the Chukchi Sea Planning Area (Table 7).

The density for the Chukchi Sea Planning Area is then calculated by dividing the seasonally and planning area adjusted population by the area for the range. The density used for the Chukchi Sea Planning Area is 0.001 bears/km^2 (Table 7).

Table 7: Current OECM polar bear density numbers[1]

Parameter	Chukchi Sea Planning Area	Beaufort Sea Planning Area	Hope Basin Planning Area[2]
Population of Stock Overlapping Planning Area	2,000 (total Chukchi Bering Sea stock)	900 (total Southern Beaufort Sea stock)	2,000 (total Chukchi Bering Sea stock)
Seasonality Assumptions	100% present on sea ice for 9 months; 0% present on sea ice for the remaining 3 months.	100% present on sea ice for 9 months; 80% present on the sea ice for the remaining 3 months.	100% present on sea ice for 9 months; 0% present on sea ice for the remaining 3 months.
Population Adjusted for Seasonality	1,500	855	1,500
Population Adjustment Based on BOEM Planning Area	1,711	N/A	N/A
Area (km^2)	1,503,468 (estimated range of Chukchi Bering Sea stock)	942,175 (estimated range of Southern Beaufort Sea stock)	1,503,468 (estimated range of Chukchi Bering Sea stock)
Density (#/km^2)	0.001138	0.000907	0.000998

[1]Values may not calculate to the results reported due to rounding error.

[2]Hope Basin lies within the Chukchi Bering Sea stock range, but the Hope Basin Planning Area is outside the area where the CBS and SBS stocks overlap.

Impacts to Wildlife: Shorebirds and Waders

Impacts to shorebirds and waders were evaluated based on shore area exposed to oil with a thickness of 100 g/m^2 or higher. Shore area exposed was calculated by summing the impacts for rock, gravel, sand, mudflat, and wetland shore types. We excluded impacts to artificial shore types from this total because artificial shorelines are typically not suitable shorebird/wader habitat. Regressions were developed of area exposed versus spill volume for each oil type. To determine biological density information for each species, we multiplied the annual average number per km^2 (from the Type A model) by the probability of oiling for that species' behavior group (Table 5, French et al. 1996 and French McCay 2009) to estimate the number killed per km^2. We also multiplied the number killed per km^2 by the mean weight per individual of each species to calculate the kilograms killed per km^2. This information is summarized for each location in the enclosed digital 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 8; French McCay 2002). For temperatures not listed in the table, the lethal dose was interpolated.

Table 8. Lethal dose of aromatics as a function of temperature.

Temperature (°C)	Lethal Dose (ppb-hrs)
25	5,000
20	9,000
15	14,000
10	24,000
2	58,000

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

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

Then, we developed regressions 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 99th percentile run of the scenario with the largest spill volume of crude oil. This model outputs the total injury in kilograms for each species, which we then divided by the volume killed for that run to determine the injury in kilograms per unit volume. This information is summarized for each location in the enclosed digital 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 10 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 10.

Impacts to Benthic Organisms

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

2.3.2 Shoreline Recreation and Tourism Impacts

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

- Rock + Gravel
- Sand
- Mudflat + Wetland
- Artificial

2.3.3 Shoreline Cleanup Impacts

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

- Rock + Gravel
- Sand
- Mudflat + Wetland
- Artificial

2.3.4 Boating/Shipping and Water Surface Cleanup Impacts

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

3. HABITAT/RESOURCE EQUIVALENCY ANALYSIS

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. HEA and Resource Equivalency Analysis (REA) have 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/resource, 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 and REA analyses 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, we calculated the probability of spillage (i.e., how likely is a spill to occur from any particular offshore facility or tanker), 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.[2]

These data could be adjusted to reflect future changes (such as changes in tanker traffic, volumes of oil cargo being carried) 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 9.

[2] 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 ≥ 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: 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).

Table 9. Summary of OECM regressions and biological databases.

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

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

6. CONCLUSIONS

The modeling performed herein addresses oil spills associated with OCS development and oil imports that effectively occur at or near the water surface. In the SIMAP modeling, we assumed the release was at the water surface. For subsurface releases, oil behavior and fate would be considerably different than that modeled herein. Because the oil would not be immediately in contact with the atmosphere, the soluble and semi-soluble aromatics, the most toxic fractions of the oil, would dissolve rather than evaporate (to varying degrees, depending on the compound), resulting 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. Seabed blowouts are certainly a much more detrimental situation for water column biota, and application of dispersants to the release at the source would amplify 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, was 11 million gallons. The *Exxon Valdez* oil spill was not a catastrophic loss of the entire cargo; the largest “super” tankers used today (ultra-large cargo carriers) transport up to 3.52 million barrels (148 million gallons). While extrapolation of the regressions to 11 million gallons might be justifiable as reliable, the model results cannot be reliably extrapolated to spills of a size on the order of 148 million gallons.

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

7. REFERENCES

Atwood TC, Peacock E, McKinney MA, Lillie K, Wilson R, Douglas DC, Miller S, Terletzky P. 2016. Rapid environmental change drives increased land use by an Arctic marine predator. PLoS One. 11(6):e0155932.

[COSEWIC] Committee on the Status of Endangered Wildlife in Canada. 2008. COSEWIC assessment and update status report on the polar bear *Ursus maritimus* in Canada. Ottowa (Canada): Committee on the Status of Endangered Wildlife in Canada. 75 p.

Etkin DS (Environmental Research Consulting). 2009. Analysis of U.S. oil spillage. Washington (DC): American Petroleum Institute. 86 p. Report No.: API Publication 356.

French, D, Reed M, Jayko K, Feng S, Rines H, Pavignano S, Isaji , Puckett S, Keller A, French III FW, et al. 1996. The CERCLA type A natural resource damage assessment model for coastal and marine environments (NRDAM/CME), technical documentation, Vol. I-V. Final report. Washington (DC): U.S. Dept. of the Interior, Office of Environmental Policy and Compliance.

French McCay DP. 2002. Development and application of an oil toxicity and exposure model, OilToxEx. Environmental Toxicology and Chemistry. 21(10): 2080–2094.

French McCay DP. 2003. Development and application of damage assessment modeling: example assessment for the *North Cape* oil spill. Marine Pollution Bulletin. 47(9-12):341–359.

French McCay DP. 2004. Oil spill impact modeling: development and validation. Environmental Toxicology and Chemistry. 23(10):2441–2456.

French McCay DP. 2009. State-of-the-art and research needs for oil spill impact assessment modeling. In: Proceedings of the 32nd Arctic and Marine Oil Spill Program Technical Seminar on Environmental Contamination and Response, Emergencies Science Division, Environment Canada, Ottawa, ON, Canada. p. 601–653.

French McCay DP, Rowe JJ. 2003. Habitat restoration as mitigation for lost production at multiple trophic levels. Marine Ecology Progress Series. 264:235–249.

Gundlach ER. 1987. Oil holding capacities and removal coefficients for different shoreline types to computer simulate spills in coastal waters. In: Proceedings of the 1987 Oil Spill Conference. p. 451–457.

Kullenberg G, editor. 1982. Pollutant transfer and transport in the sea. Volume I. Boca Raton (FL): CRC Press. 227 p.

[LA DEQ] Louisiana Department of Environmental Quality, et al. 2003. The Louisiana Regional Restoration Planning Program, Draft Regional Restoration Plan, Region 2. Baton Rouge (LA): Department of Environmental Quality, Louisiana Department of Natural Resources, Louisiana Department of Wildlife and Fisheries, Louisiana Oil Spill Coordinator's Office, National Oceanic and Atmospheric Administration, U.S. Department of the Interior.

[NOAA] National Oceanic and Atmospheric Administration. 1997. Natural Resource Damage Assessment guidance document: scaling compensatory restoration actions (Oil Pollution Act of 1990). Silver Spring (MD): NOAA Damage Assessment Center.

NOAA. 1999. Habitat equivalency analysis: an overview. Silver Spring (MD): NOAA Damage Assessment Center. 23 p.

Okubo A. 1971. Oceanic diffusion diagrams. Deep-Sea Research. 8:789–802.

Okubo A, Ozmidov RV. 1970. Empirical dependence of the coefficient of horizontal turbulent diffusion in the ocean on the scale of the phenomenon in question. Atmospheric and Ocean Physics. 6(5):534–536.

Reed M, French DP, Feng S, French III FW, Howlett E, Jayko K, Knauss W, McCue J, Pavignano S, Puckett S, et al. (Applied Science Associates, Inc., Narragansett, RI). 1996. The CERCLA type a natural resource damage assessment model for the Great Lakes environments (NRDAM/GLE), Vol. I - III. Final report. Washington (DC): U.S. Department of the Interior, Office of Environmental Policy and Compliance.

Rode KD, Wilson RR, Regehr EV, Martin MS, Douglas DC, Olson J. 2015. Increased land use by Chukchi Sea polar bears in relation to changing sea ice conditions. PloS One. 10(11): e0142213.

Stirling I, Parkinson CL. 2006. Possible effects of climate warming on selected populations of polar bears (*Ursus maritimus*) in the Canadian Arctic. Arctic. 261–275.

[USFWS] U.S. Fish and Wildlife Service (USFWS). 2017a. Polar bear (*Ursus maritimus*): Chukchi/Bering Seas stock (draft). https://www.fws.gov/alaska/fisheries/mmm/polarbear/pdf/Chukchi_Bering%20Sea%20Draft%20SAR%20for%20public%20comment.pdf

USFWS. 2017b. Polar bear (*Ursus maritimus*): Southern Beaufort Sea stock (draft). https://www.fws.gov/alaska/fisheries/mmm/polarbear/pdf/Southern%20Beaufort%20Sea%20Draft%20SAR%20%20for%20public%20comment.pdf

USFWS. 2008. Alaska region marine mammals management. Polar bear. [updated 2008 Sep 10]. https://www.fws.gov/alaska/fisheries/mmm/polarbear/map.htm

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

SUB-APPENDIX A

Detailed Model Input Information for Each Location

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Mid-Atlantic

Habitat Grid

The digital shoreline, shore type, and habitat mapping for the Mid-Atlantic region were obtained from the 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. Table A-1 summarizes the dimensions of the habitat grid cells.

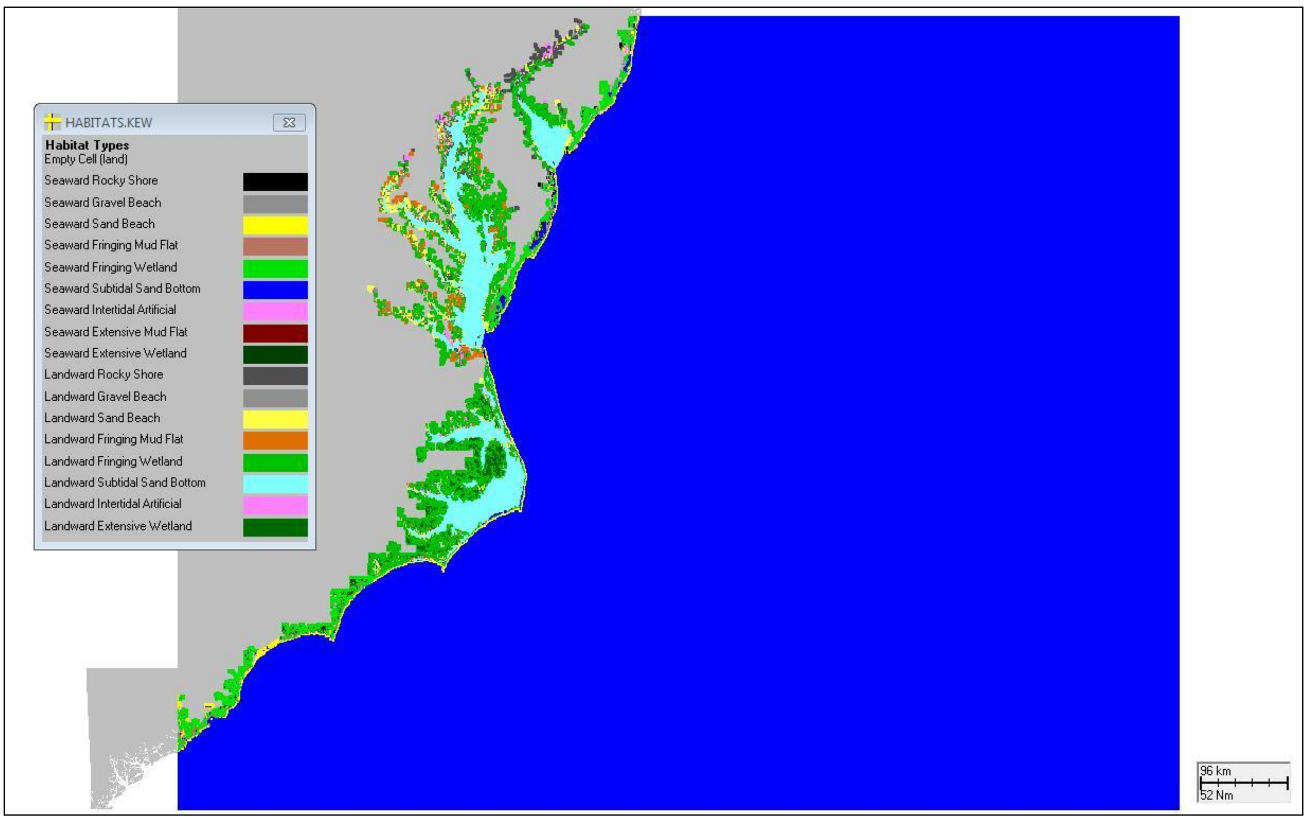


Figure A-1. Habitat grid developed for the Mid-Atlantic region.

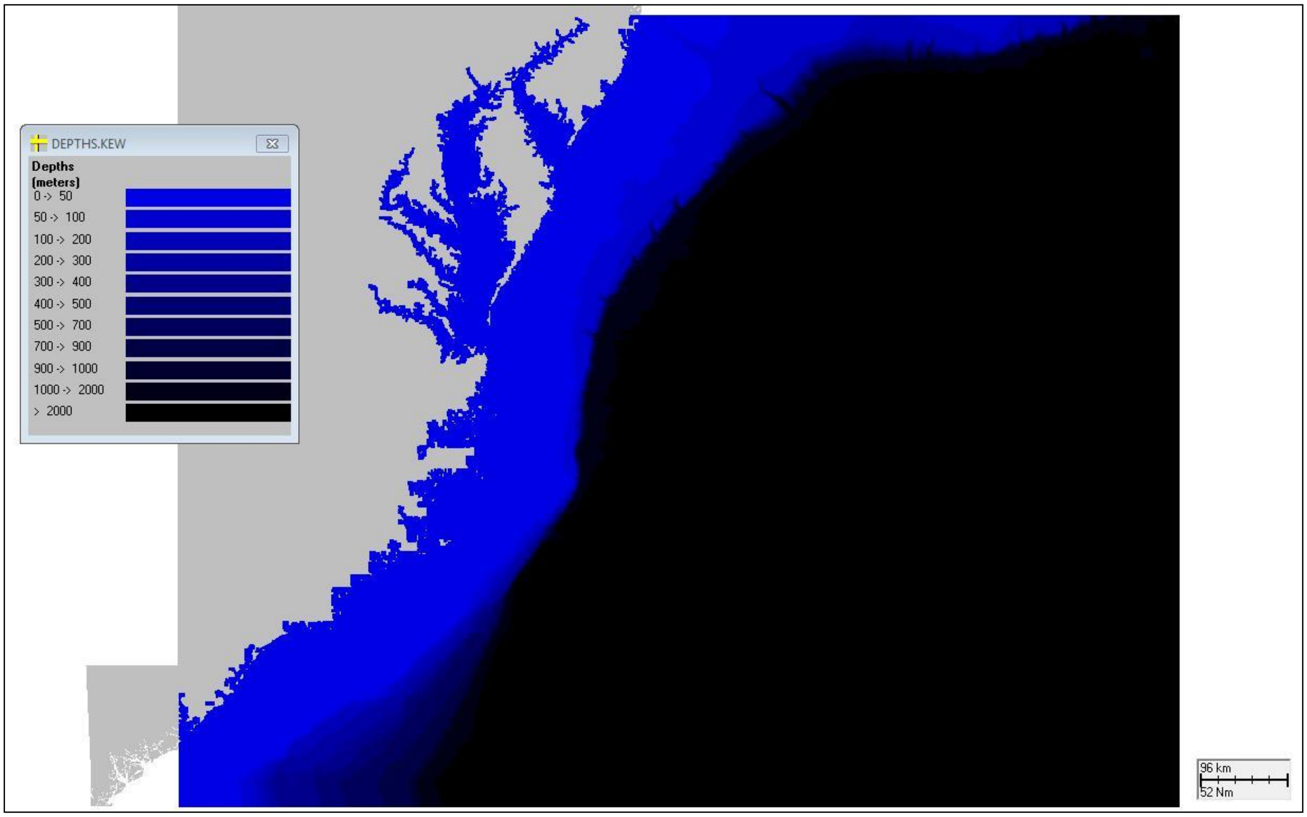


Figure A-2. Depth grid developed for the Mid-Atlantic region.

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

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

Currents

Currents were based on the study "Mid-Atlantic Ocean Model Calculations" performed for BOEM by Oey and Xu (2011). 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 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.

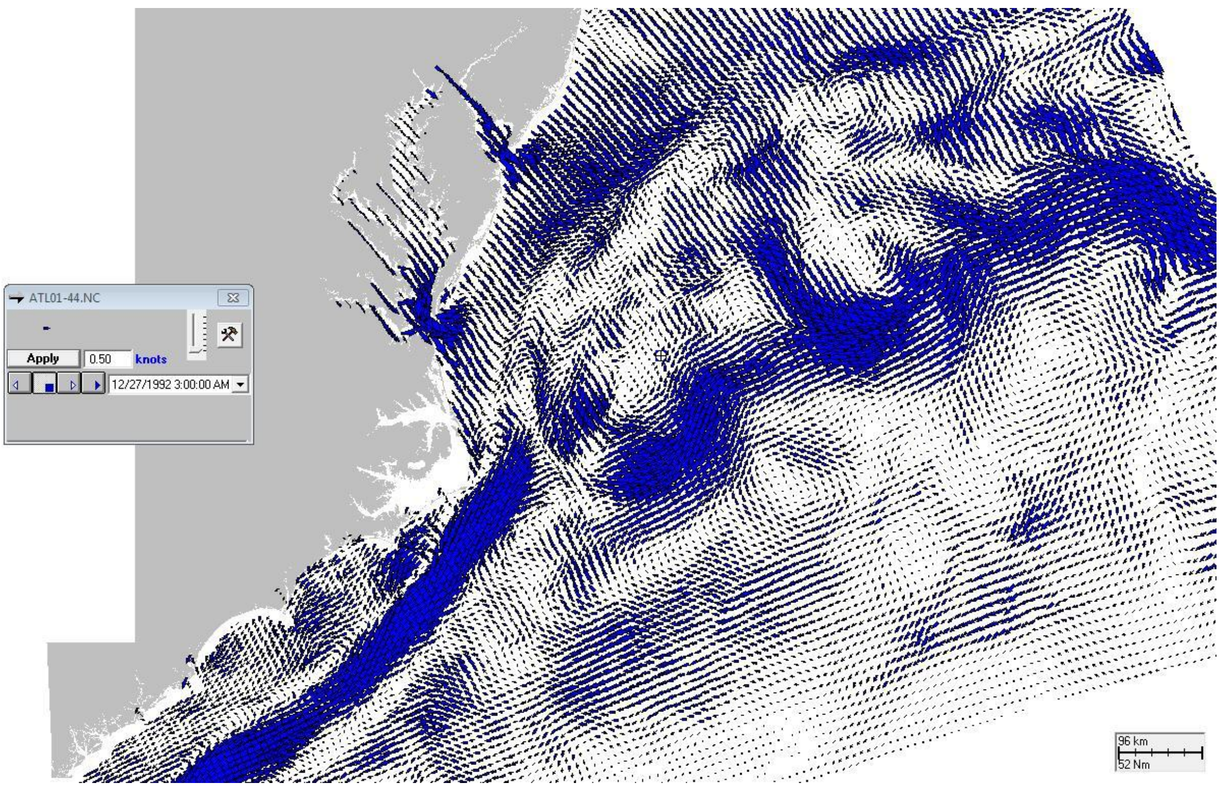


Figure A-3. Example of current component data used in modeling for the Mid-Atlantic region. Vector length indicates speed in the indicated direction.

Winds

Standard meteorological data were acquired from the National Data Buoy Center Internet site for the nearest National Data Buoy Center (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 20 spill sites were placed within the offshore spill area. The coordinates of these points are provided in Tables A-2 and A-3.

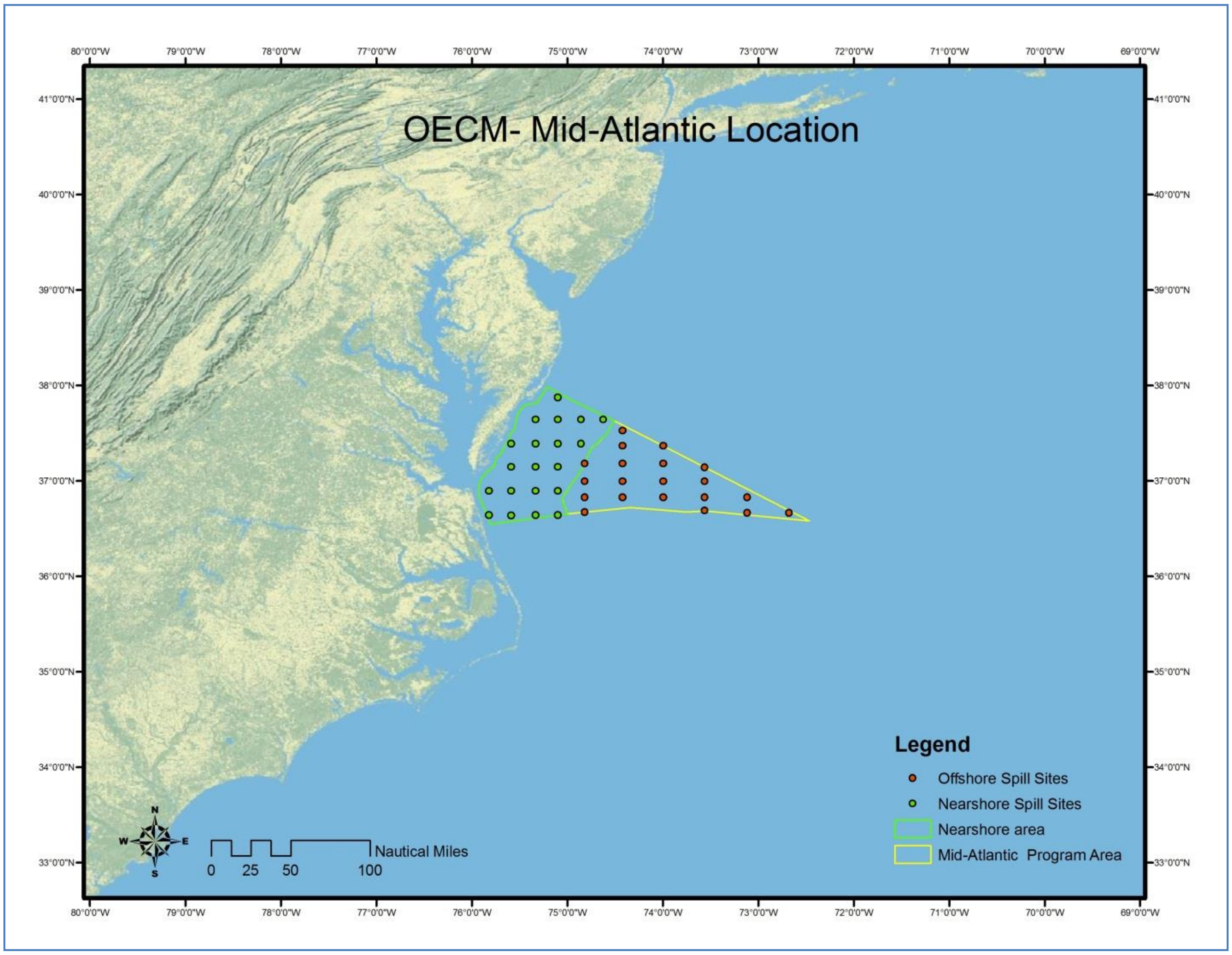


Figure A-4. Spill sites developed for the Mid-Atlantic region.

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

Spill Site #	Latitude	Longitude
1	36.64093	-75.81953
2	36.89273	-75.81953
3	36.64093	-75.58961
4	36.89273	-75.58961
5	37.14602	-75.58961
6	37.39152	-75.58961
7	36.64093	-75.33350
8	36.89273	-75.33350
9	37.14602	-75.33350
10	37.39152	-75.33350
11	37.64084	-75.33350
12	36.64093	-75.10066
13	36.89273	-75.10066
14	37.14602	-75.10066
15	37.39152	-75.10066
16	37.64084	-75.10066
17	37.87324	-75.10066
18	37.39152	-74.85619
19	37.64084	-74.85619
20	37.64084	-74.62335

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

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

Straits of Florida

<u>Habitat Grid</u>

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

Bathymetry data were available from bathymetric contours contained within the General Bathymetric Chart of the Oceans (GEBCO) Digital Atlas (BODC 2003).

The gridded habitat and depth data are shown in Figures A-5 and A-6. Table A-4 summarizes the dimensions of the habitat grid cells.

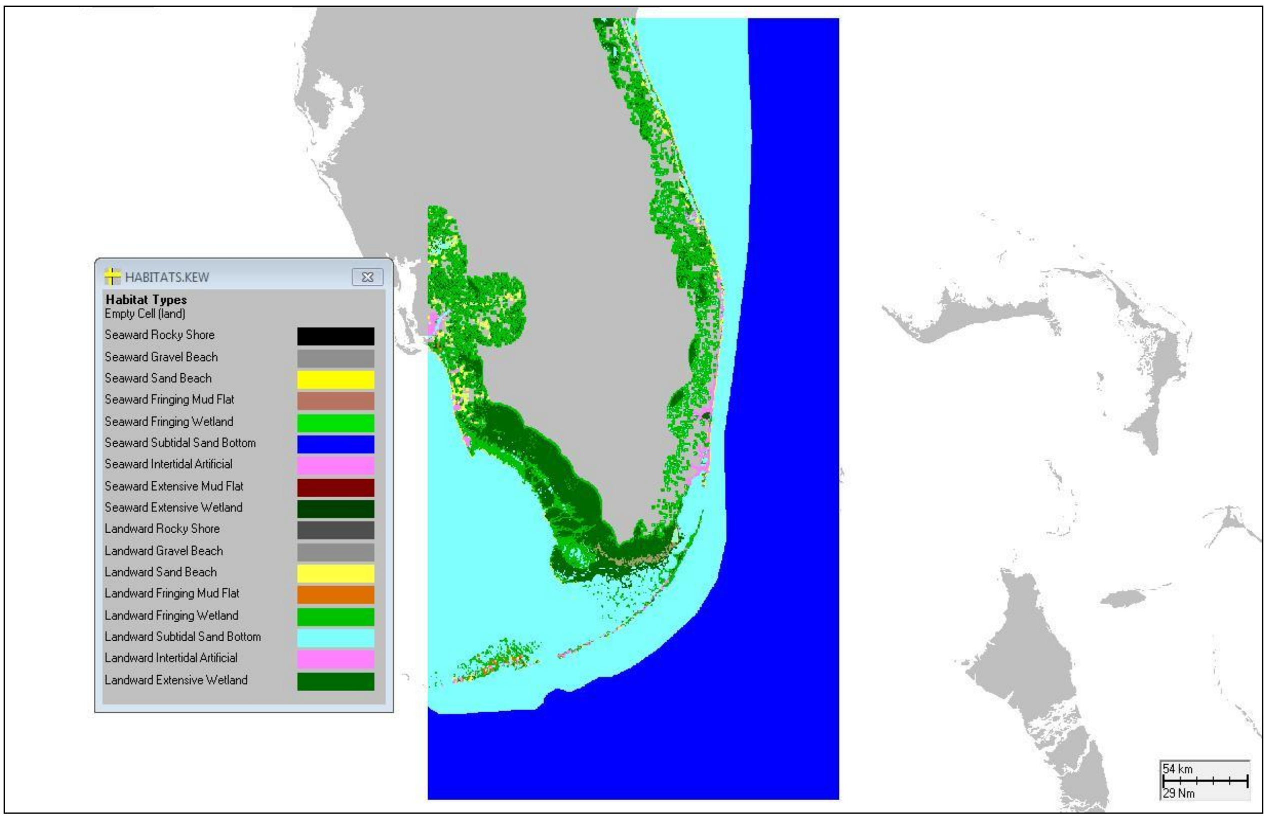


Figure A-5. Habitat grid developed for the Straits of Florida region.

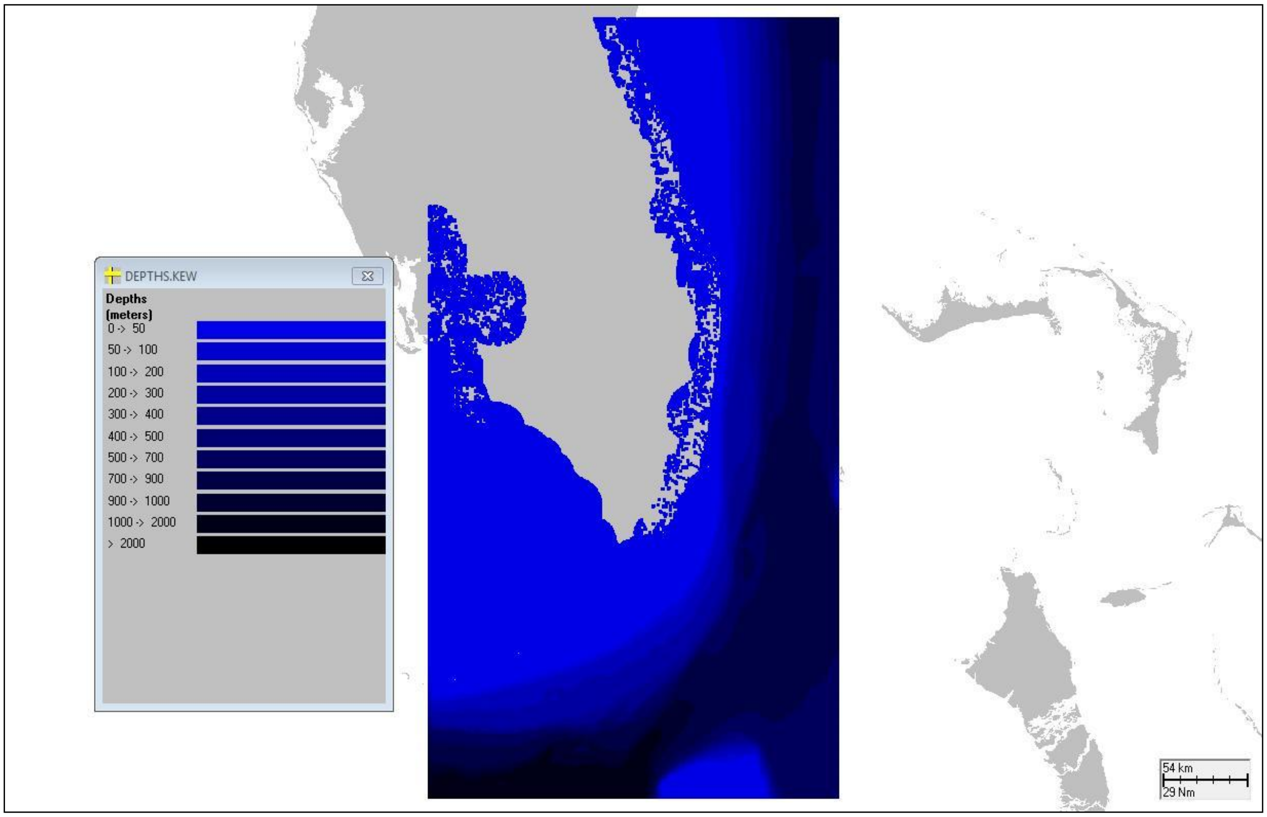


Figure A-6. Depth grid developed for the Straits of Florida region.

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

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

Currents

Currents for the Straits of Florida were mainly assembled from CUPOM (Colorado University POM; see GOM 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 the Parallel Ocean Program (POP). 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.

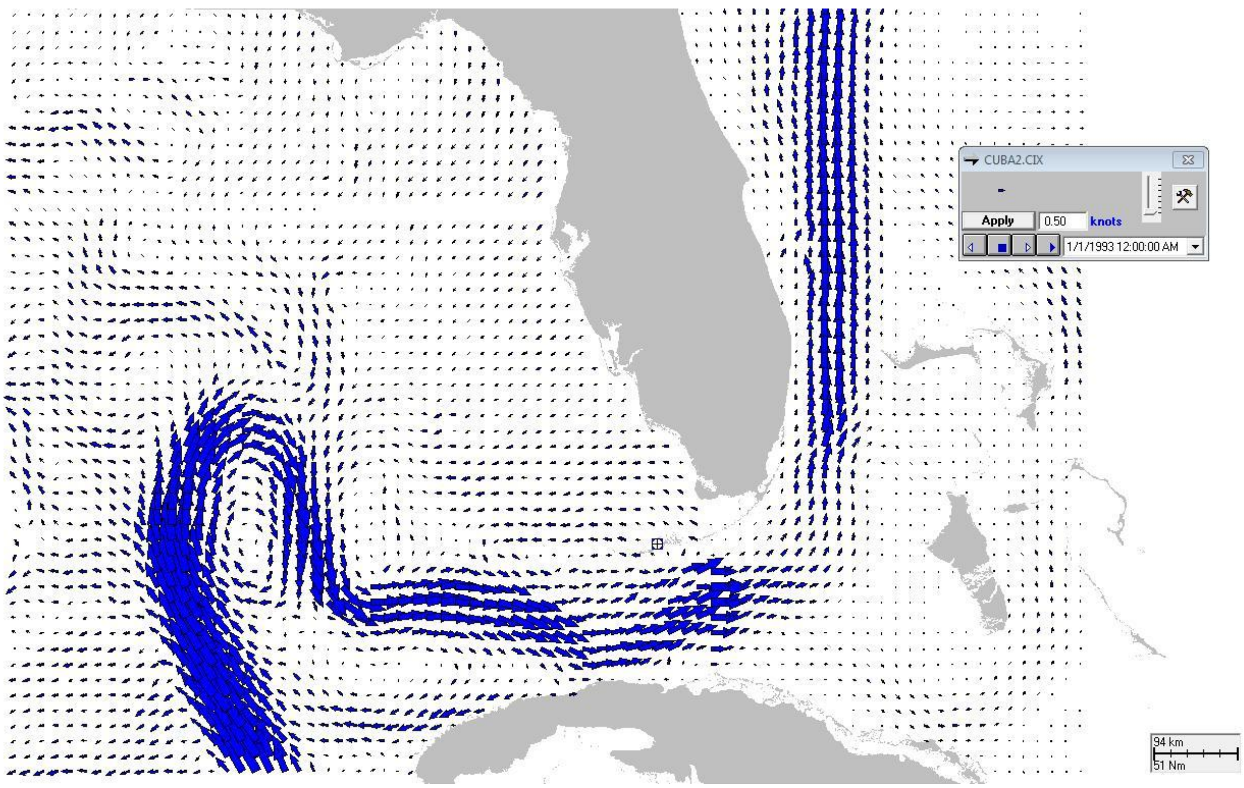


Figure A-7. Example of current component data used in modeling for the Straits of Florida region. Vector length indicates speed in the indicated direction.

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 20 spill sites were placed within the spill area. The coordinates of these points are provided in Table A-5.

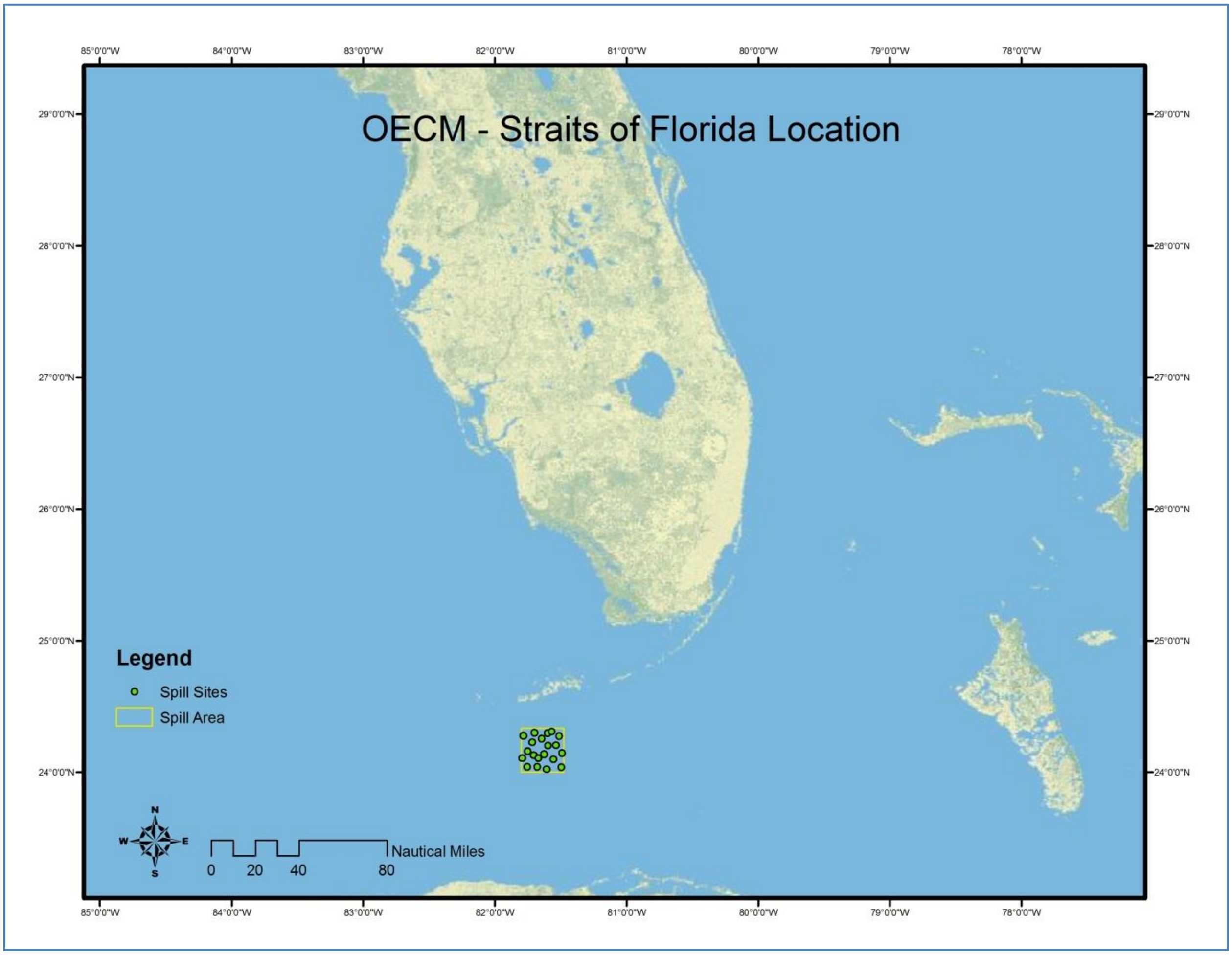


Figure A-8. Spill sites developed for the Straits of Florida region.

Table A-5. Straits of Florida spill sites.

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

Habitat Grid

The digital shoreline used to create the habitat grid was the "Land and Water Interface of the Louisiana Coastal Region" from the Louisiana Oil Spill Coordinator's Office, published in 2000 (LOSCO 2000). Although, there is a more recent shoreline 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 ESI dataset published by the U.S. Minerals Management Service and the U.S. Geological Survey Land Cover Institute.

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

The gridded habitat and depth data are shown in Figures A-9 and A-10. Table A-6 summarizes the dimensions of the habitat grid cells.

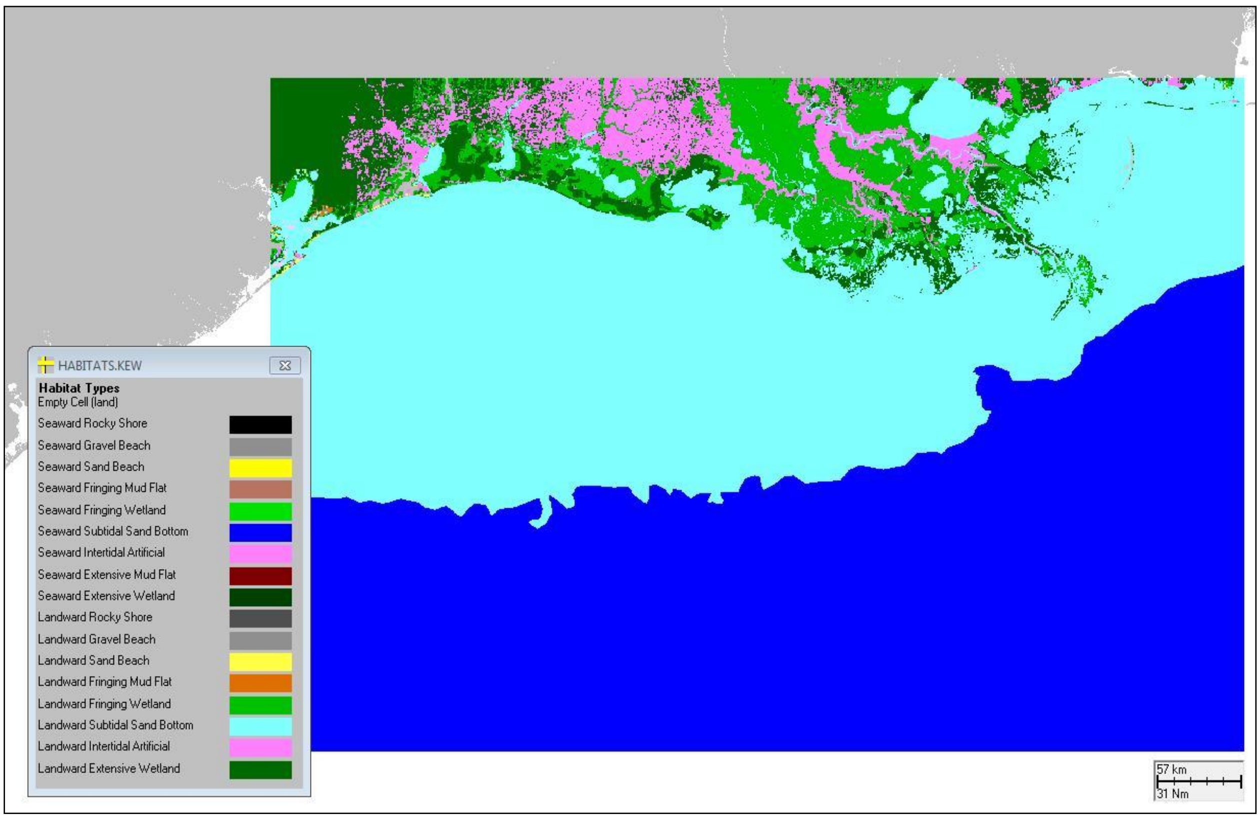


Figure A-9. Habitat grid developed for the GOM Region.

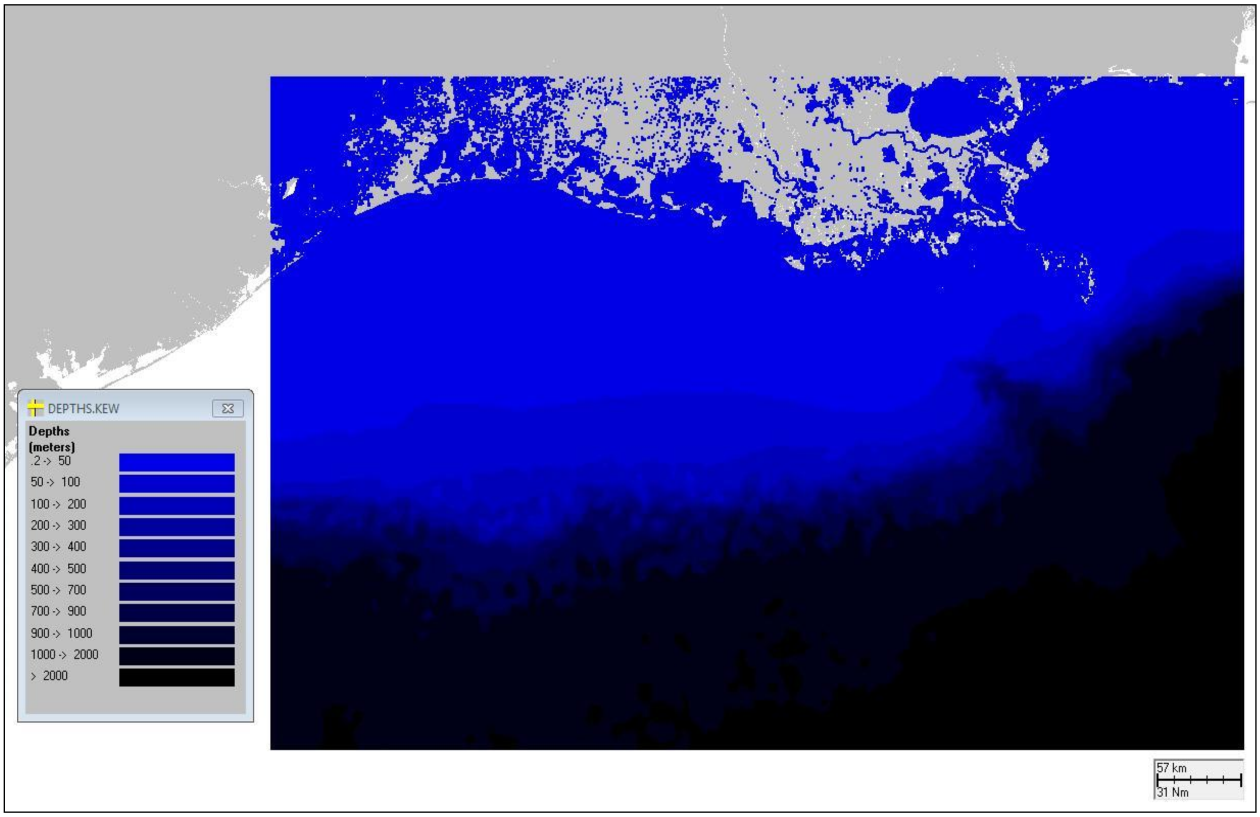


Figure A-10. Depth grid developed for the GOM Region.

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

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

Currents

Currents for the GOM were based on a study by Kantha et al. (1999) that produced current hindcasts of the GOM using the CUPOM model. The model was developed by Dr. Lakshmi Kantha and colleagues at the University of Colorado with partial support from an industry-sponsored study on Climatology and Simulation of Eddies (CASE). It is the University of Colorado version of the POM adapted for the GOM, 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 1,000 meters or more. It also assimilates satellite sea surface temperature data but uses climatological sea surface salinity. The 6-hourly, 1.125° resolution European Centre for Medium-Range Weather Forecasts 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 GOM can be found in Kantha et al. (1999).

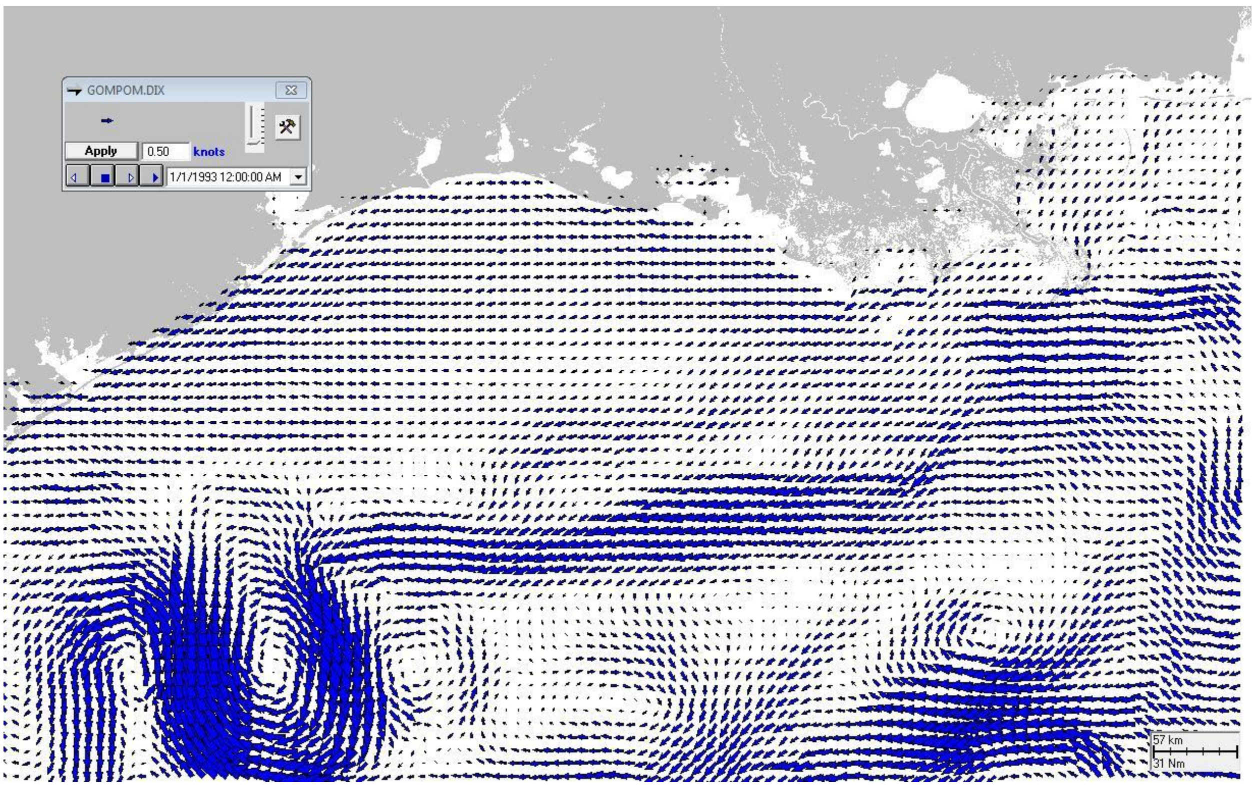


Figure A-11. Example current component data used in modeling for the GOM Region. Vector length indicates speed in the indicated direction.

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 GOM Region were randomly distributed within a portion of the Central GOM Planning Area (Figure A-12) to provide representative results for the entire planning area (and other GOM 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 25 spill sites were placed within the offshore spill area. The coordinates of these points are provided in Tables A-7 and A-8.

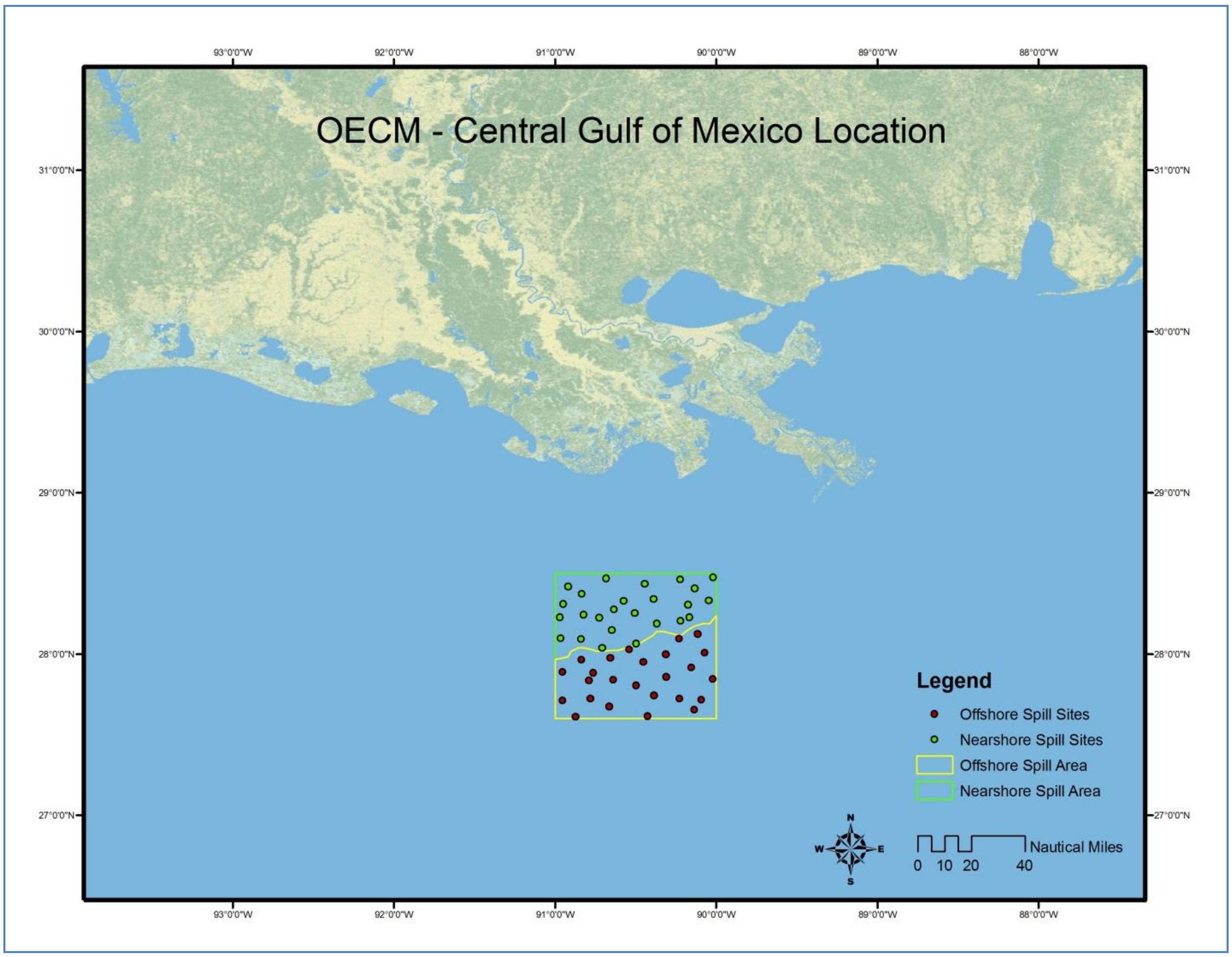


Figure A-12. Spill sites developed for the GOM Region.

Table A-7. GOM nearshore spill sites.

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

Table A-8. GOM offshore spill sites.

Spill Site #	Latitude	Longitude
1	28.02883	-90.54000
2	27.97720	-90.65663
3	27.95121	-90.45292
4	28.12660	-90.11544
5	27.84080	-90.63855
6	28.00041	-90.31300
7	27.83616	-90.78981
8	27.72352	-90.22744
9	27.72410	-90.77993
10	27.71269	-90.95298
11	27.65610	-90.13622
12	27.96562	-90.83508
13	28.09683	-90.23034
14	27.88465	-90.76178
15	27.61588	-90.42420
16	27.67656	-90.66392
17	27.71794	-90.09253
18	27.91786	-90.15377
19	27.85827	-90.31076
20	27.61158	-90.87315
21	27.80592	-90.49699
22	27.84537	-90.02027
23	27.89021	-90.95233
24	28.00849	-90.07113
25	27.74505	-90.38673

Southern California

Habitat Grid

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

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

The gridded habitat and depth data are shown in Figures A-13 and A-14. Table A-9 summarizes the dimensions of the habitat grid cells.

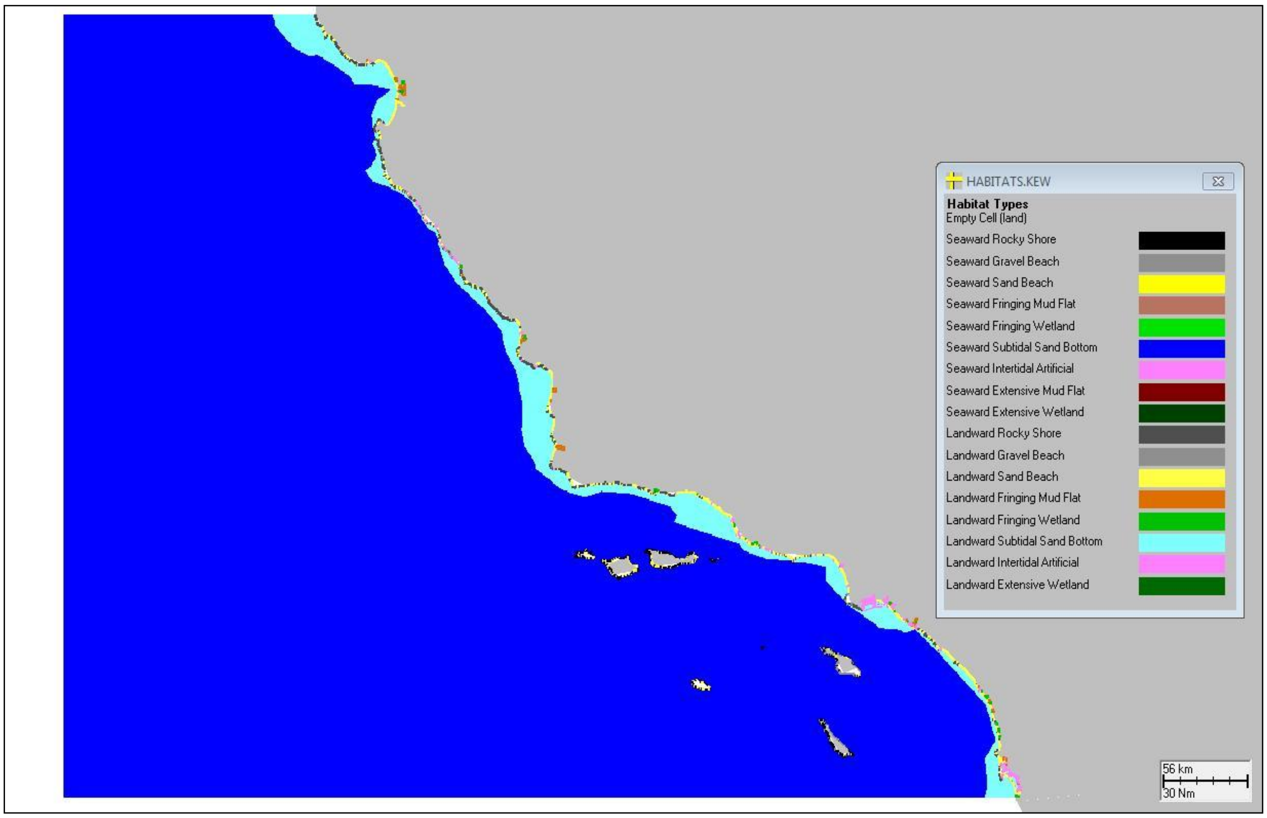


Figure A-13. Habitat grid developed for the Southern California region.

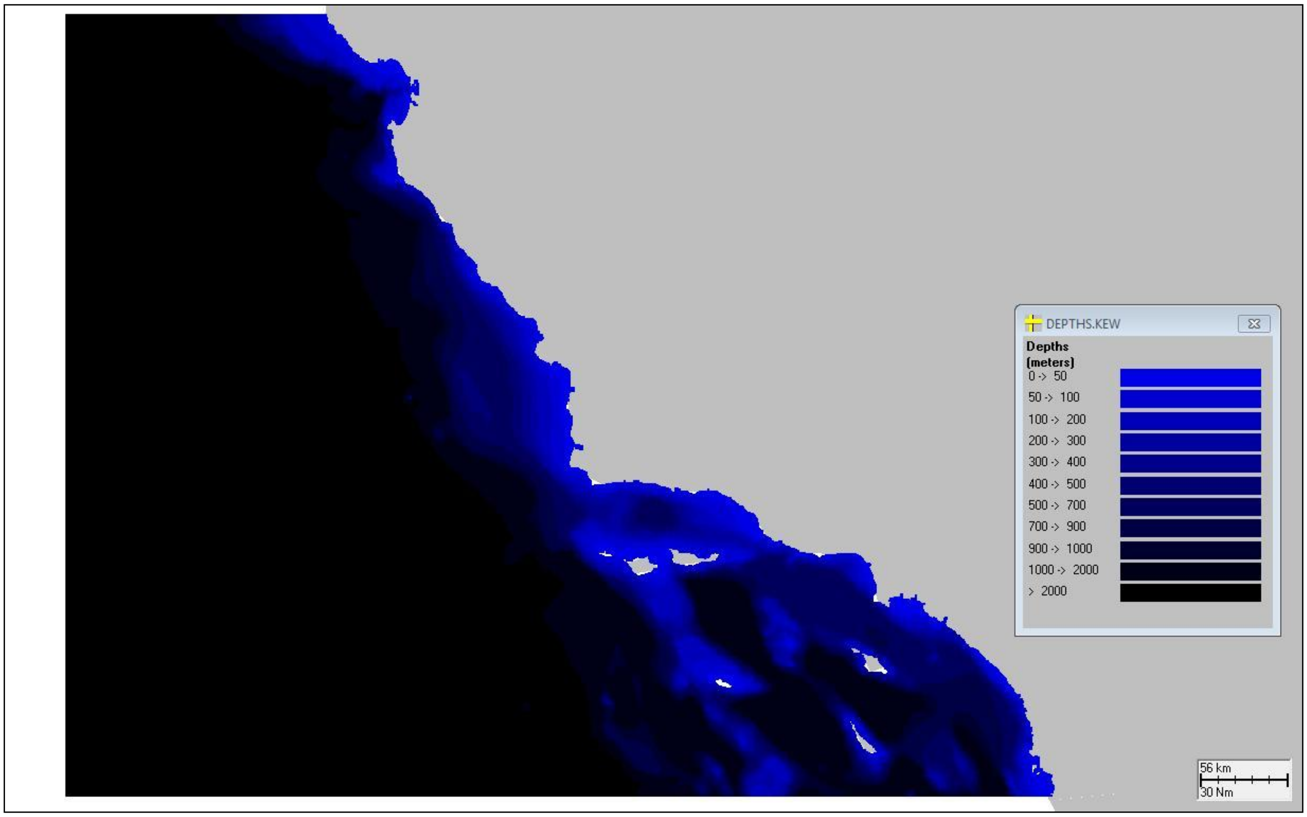


Figure A-14. Depth grid developed for the Southern California region.

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^2)	550,682.75
Shore cell length (m)	742.08
Shore cell width – Rocky shore (m)	2.0
Shore cell width – Artificial shore (m)	0.1
Shore cell width – Gravel beach (m)	2.0
Shore cell width – Sand beach (m)	10.0
Shore cell width – Mud flat (m)	120.0
Shore cell width – Wetlands (fringing, m)	120.0

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 ± 5 cm/s.

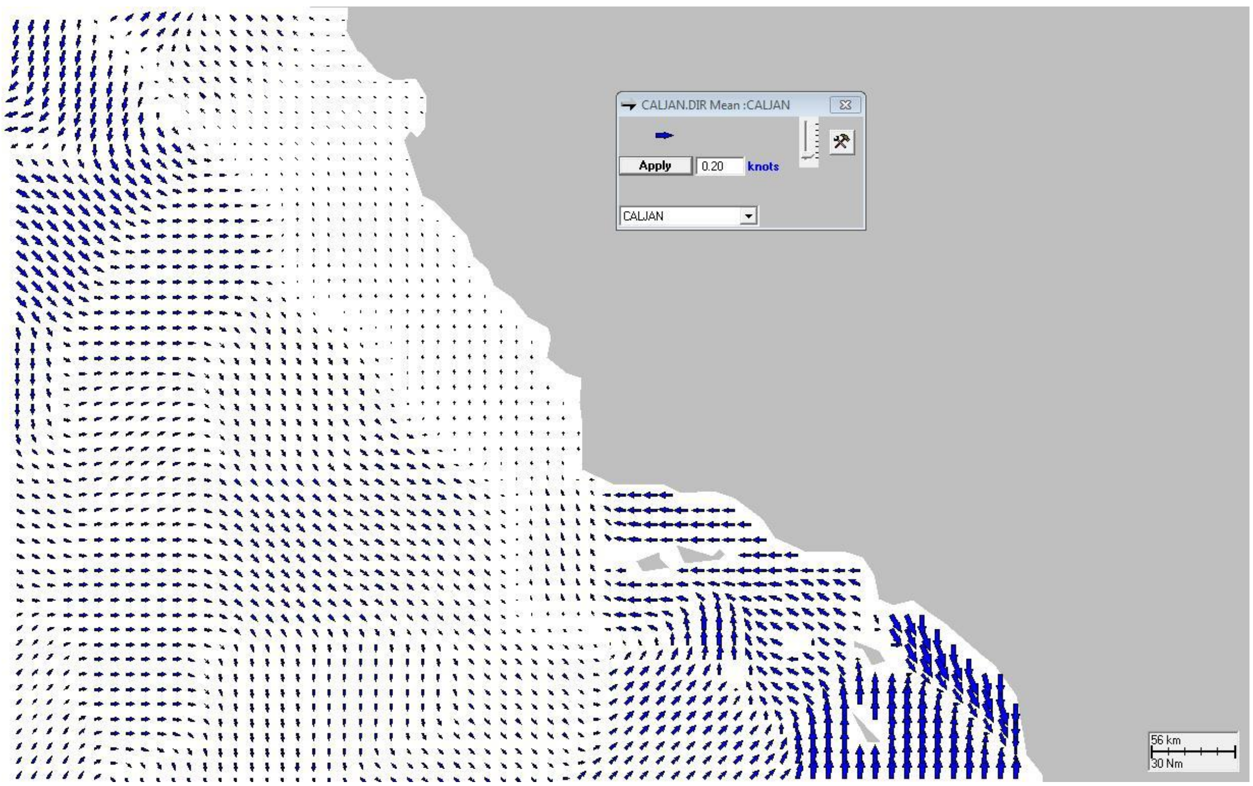


Figure A-15. Example current component data used in modeling for the Southern California region. Vector length indicates speed in the indicated direction.

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 20 spill sites were placed within the Santa Maria Basin spill area. The coordinates of these points are provided in Tables A-10 and A-11.

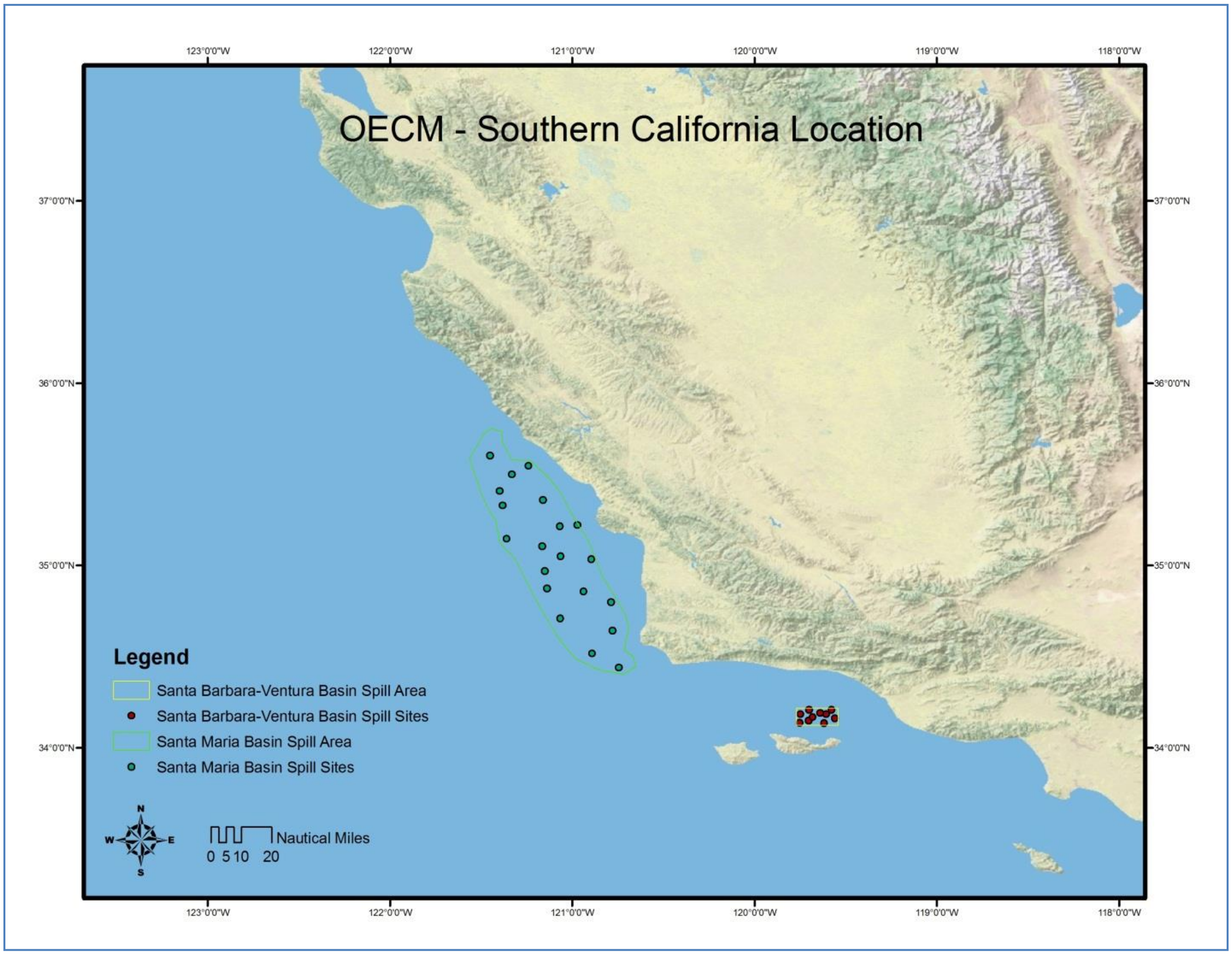


Figure A-16. Spill sites developed for the Southern California region.

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

Spill Site #	Latitude	Longitude
1	34.14906	-119.70352
2	34.18444	-119.60804
3	34.20766	-119.70123
4	34.20849	-119.57720
5	34.13387	-119.61862
6	34.13745	-119.75179
7	34.16097	-119.55994
8	34.18316	-119.74798
9	34.18931	-119.64070
10	34.16694	-119.68029

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

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

Washington/Oregon

Habitat Grid

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

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

The gridded habitat and depth data are shown in Figures A-17 and A-18. Table A-12 summarizes the dimensions of the habitat grid cells.

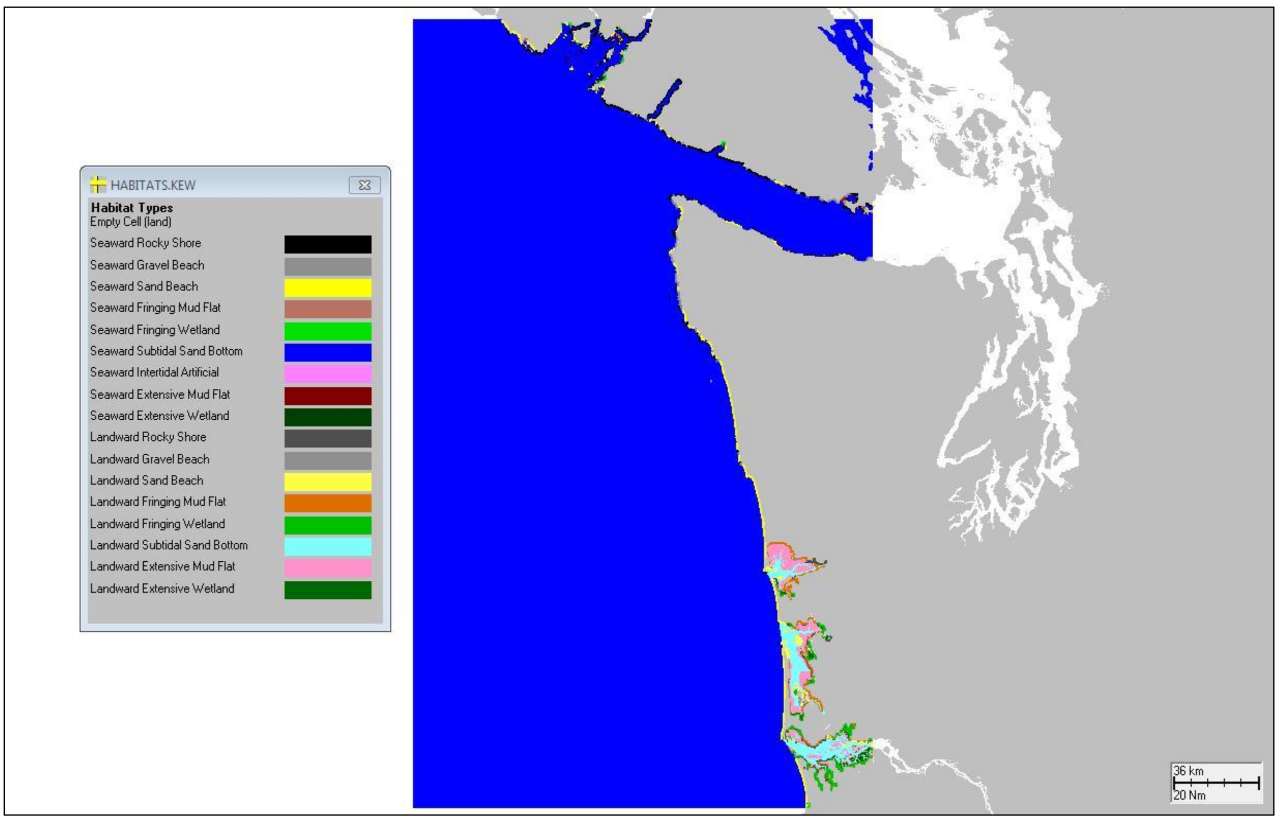


Figure A-17. Habitat grid developed for the Washington/Oregon region.

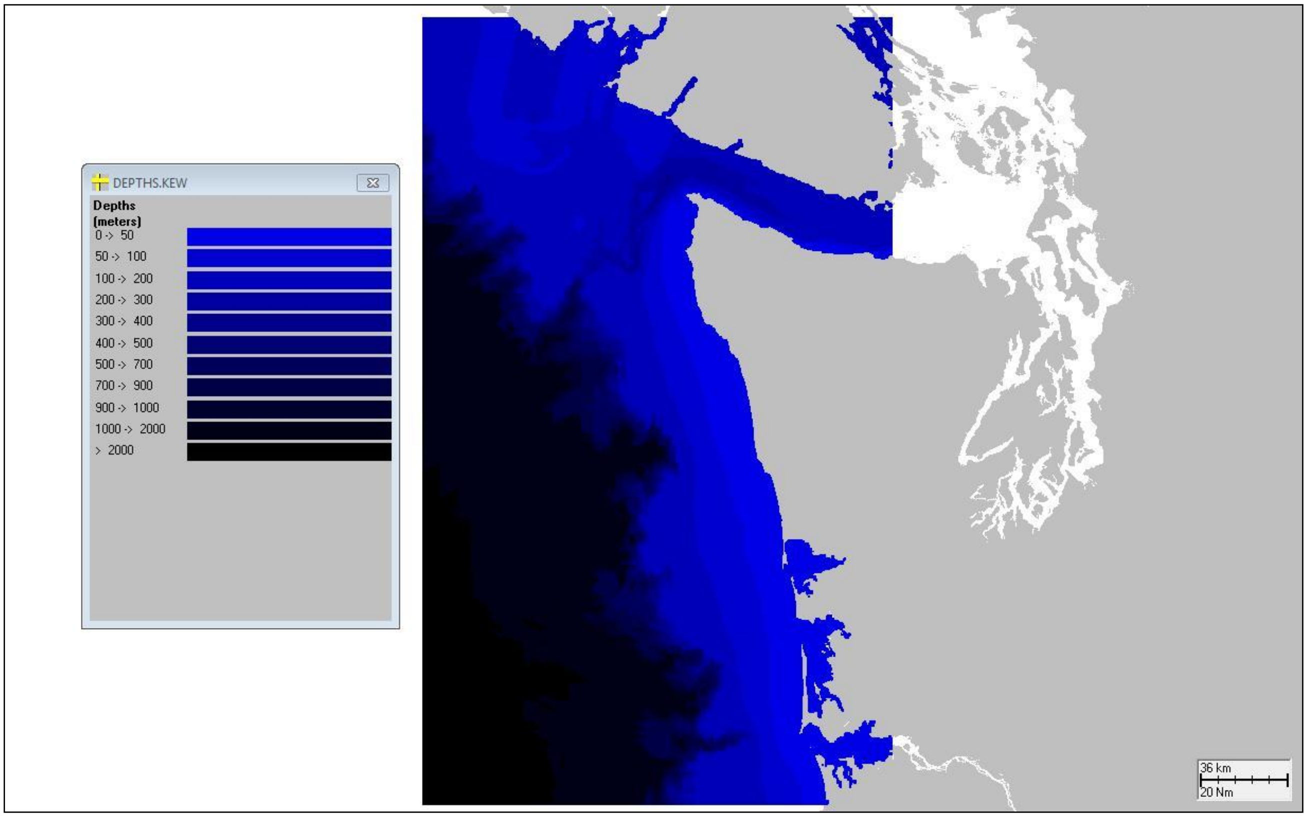


Figure A-18. Depth grid developed for the Washington/Oregon region.

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^2)	80,769.68
Shore cell length (m)	284.20
Shore cell width – Rocky shore (m)	3.0
Shore cell width – Artificial shore (m)	0.1
Shore cell width – Gravel beach (m)	4.0
Shore cell width – Sand beach (m)	15.0
Shore cell width – Mud flat (m)	210.0
Shore cell width – Wetlands (fringing, m)	210.0

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, 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) were 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).

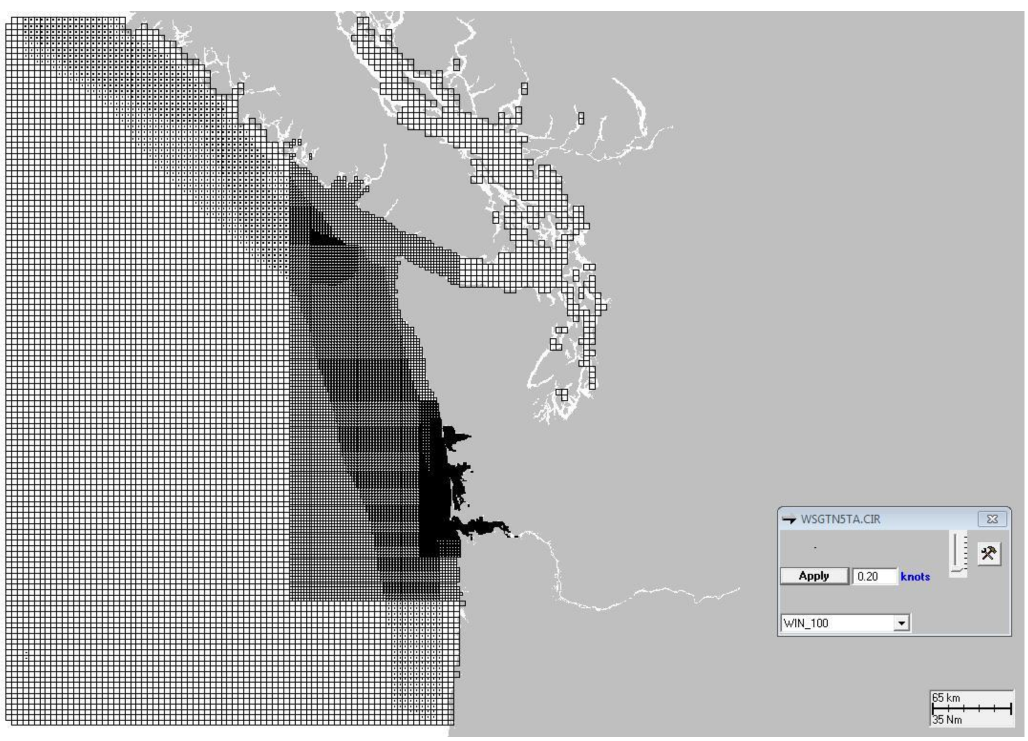


Figure A-19. Extent of current data used in modeling for the Washington/Oregon region.

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.

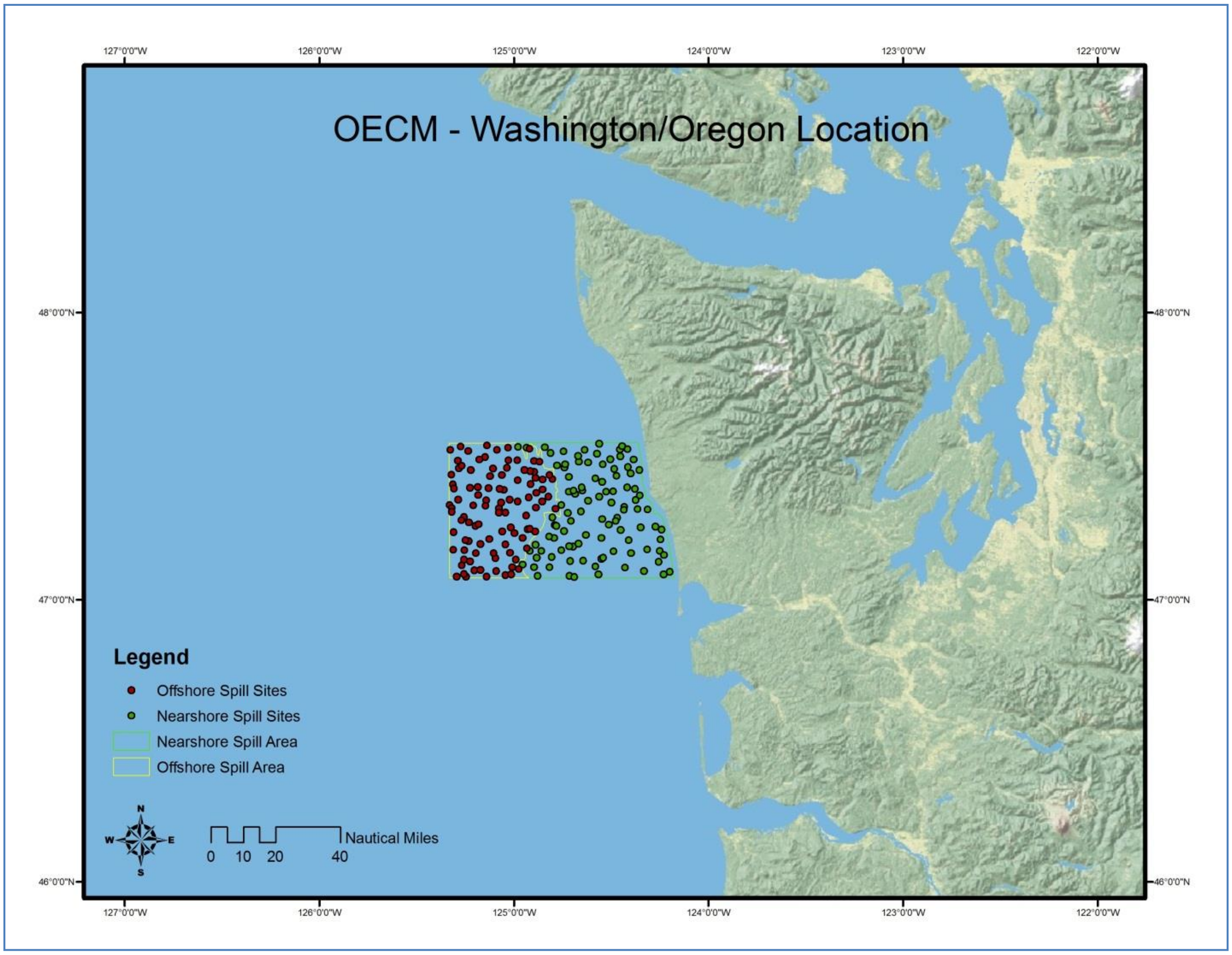


Figure A-20. Spill sites developed for the Washington/Oregon region.

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

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

Spill Site #	Latitude	Longitude
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

Spill Site #	Latitude	Longitude
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.

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

Spill Site #	Latitude	Longitude
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

Spill Site #	Latitude	Longitude
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 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 (BODC 2003).

The gridded habitat and depth data are shown in Figures A-21 and A-22. Table A-15 summarizes the dimensions of the habitat grid cells.

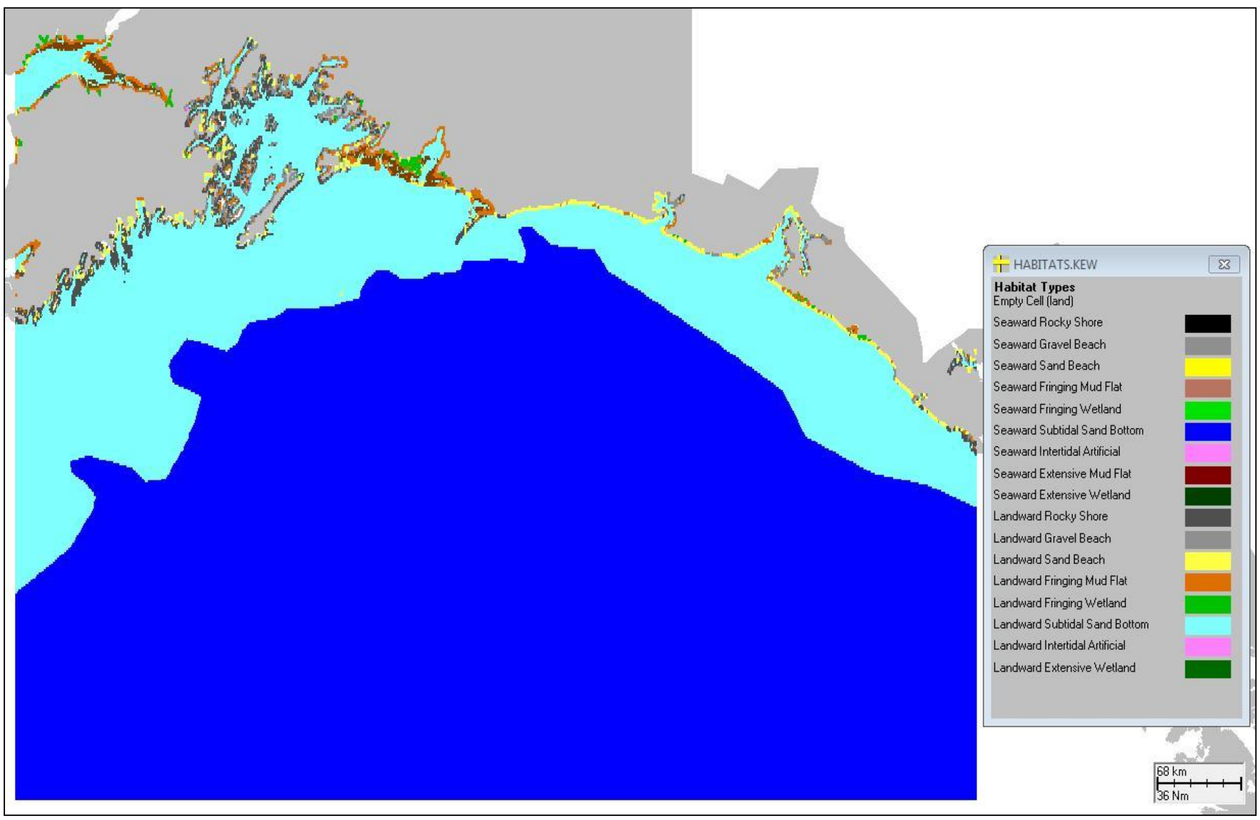


Figure A-21. Habitat grid developed for the Gulf of Alaska region.

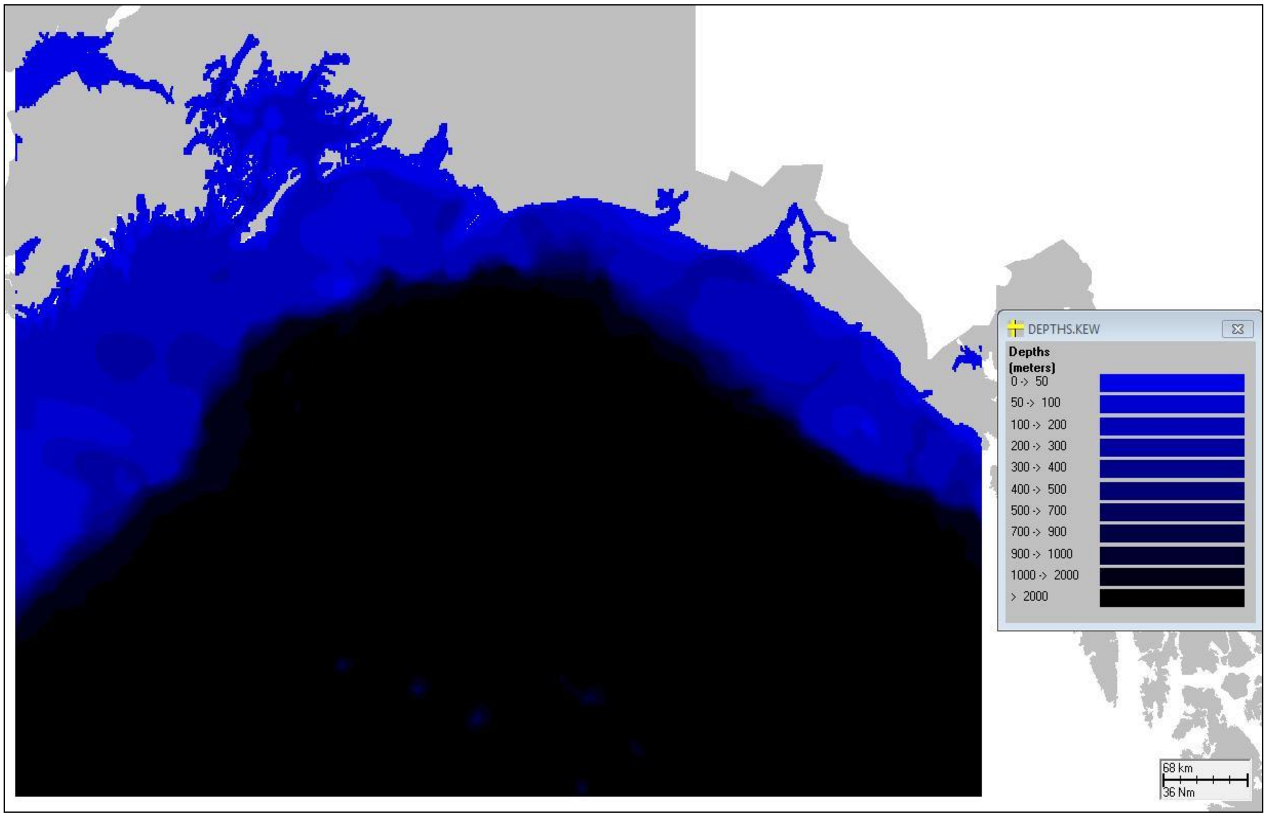


Figure A-22. Depth grid developed for the Gulf of Alaska region.

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

Currents

Currents were based on outputs from the NEP ROMS oceanographic model jointly developed by 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.

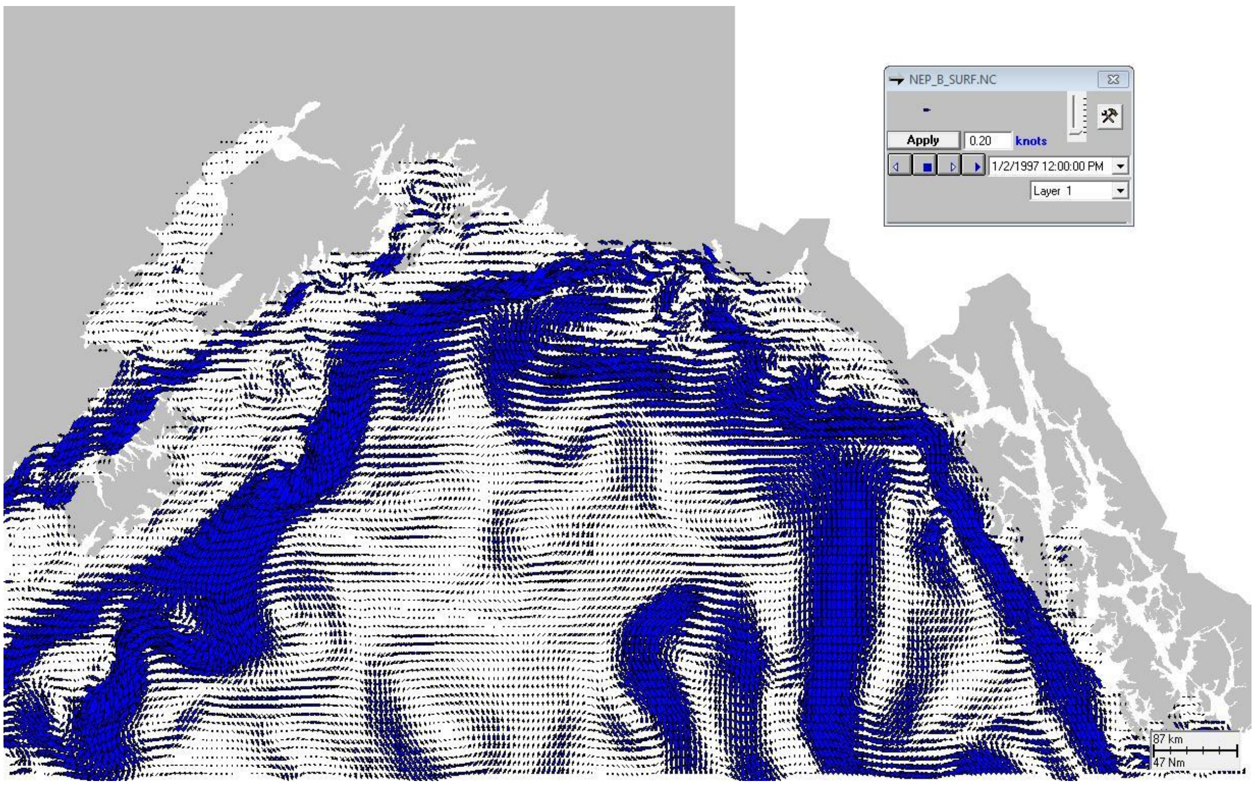


Figure A-23. Example current component data used in modeling for the Gulf of Alaska region. Vector length indicates speed in the indicated direction.

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.

<u>Spill Sites</u>

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 25 spill sites were placed within the offshore area. The coordinates of these points are provided in Tables A-16 and A-17.

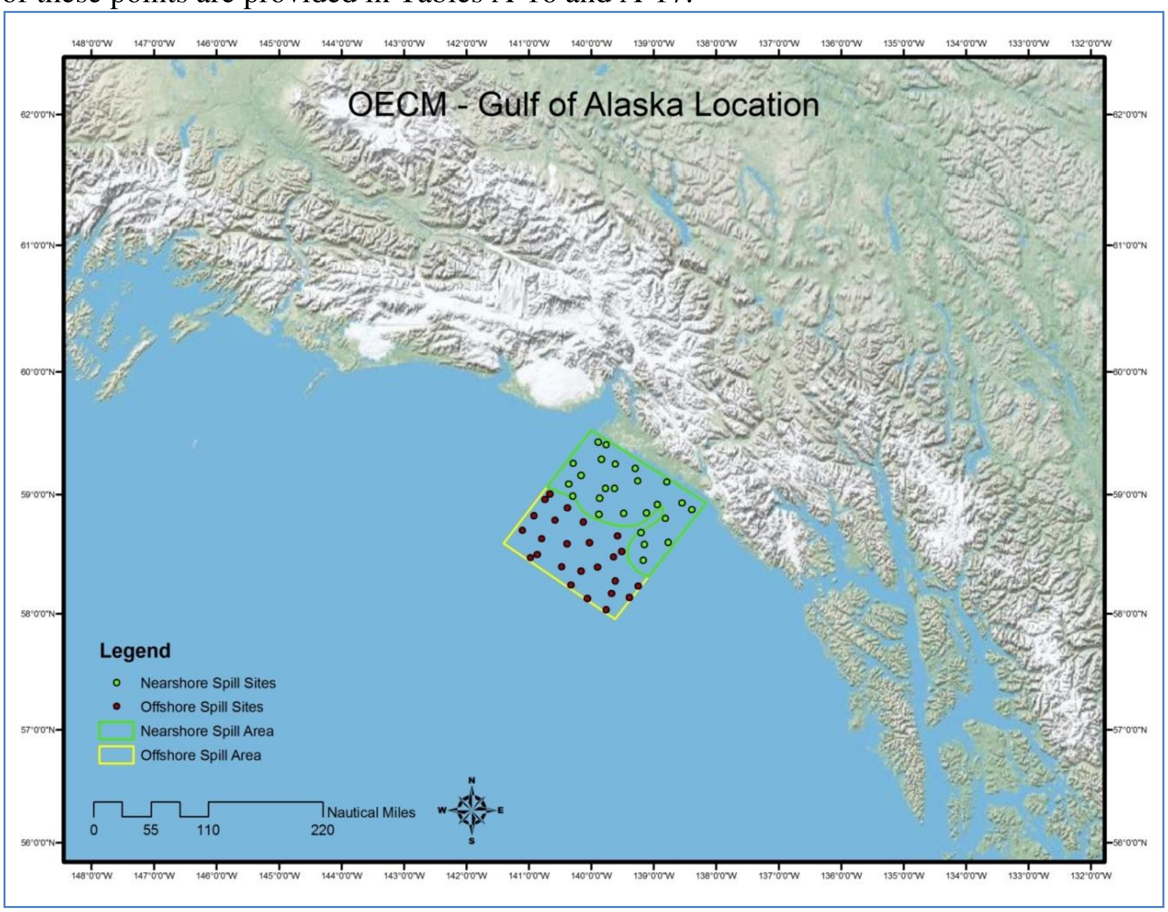


Figure A-24. Spill sites developed for the Gulf of Alaska region.

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

Spill Site #	Latitude	Longitude
1	59.25638	-140.28613
2	59.05296	-139.62432
3	58.84889	-139.11253
4	58.60369	-138.76499
5	58.58578	-139.14629
6	59.05238	-139.76825
7	59.40949	-139.75890
8	58.84560	-139.48058
9	59.43231	-139.88639
10	59.10423	-138.78885
11	58.80299	-138.81081
12	58.68438	-139.20439
13	59.21802	-139.29475
14	59.15781	-140.16484
15	58.92961	-138.54802
16	58.83876	-139.87945
17	58.91929	-138.93752
18	59.25115	-139.61176
19	58.87416	-138.38803
20	59.08766	-140.35988
21	58.45319	-139.16451
22	59.29274	-139.83694
23	59.11175	-139.25354
24	58.97117	-139.86721
25	58.98738	-140.29472

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

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

Cook Inlet/Shelikof Strait

Habitat Grid

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

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

The gridded habitat and depth data are shown in Figures A-25 and A-26. Table A-18 summarizes the dimensions of the habitat grid cells.

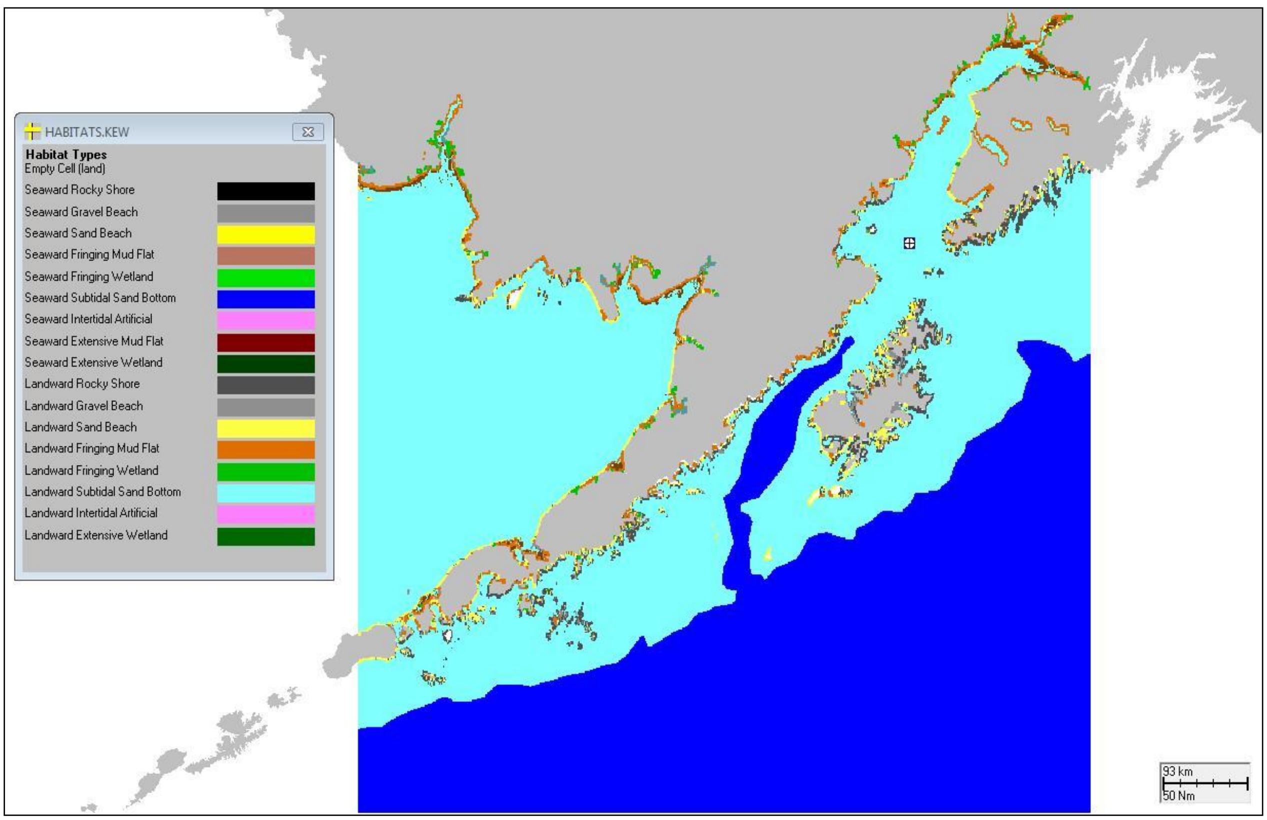


Figure A-25. Habitat grid developed for the Cook Inlet/Shelikof Strait region.

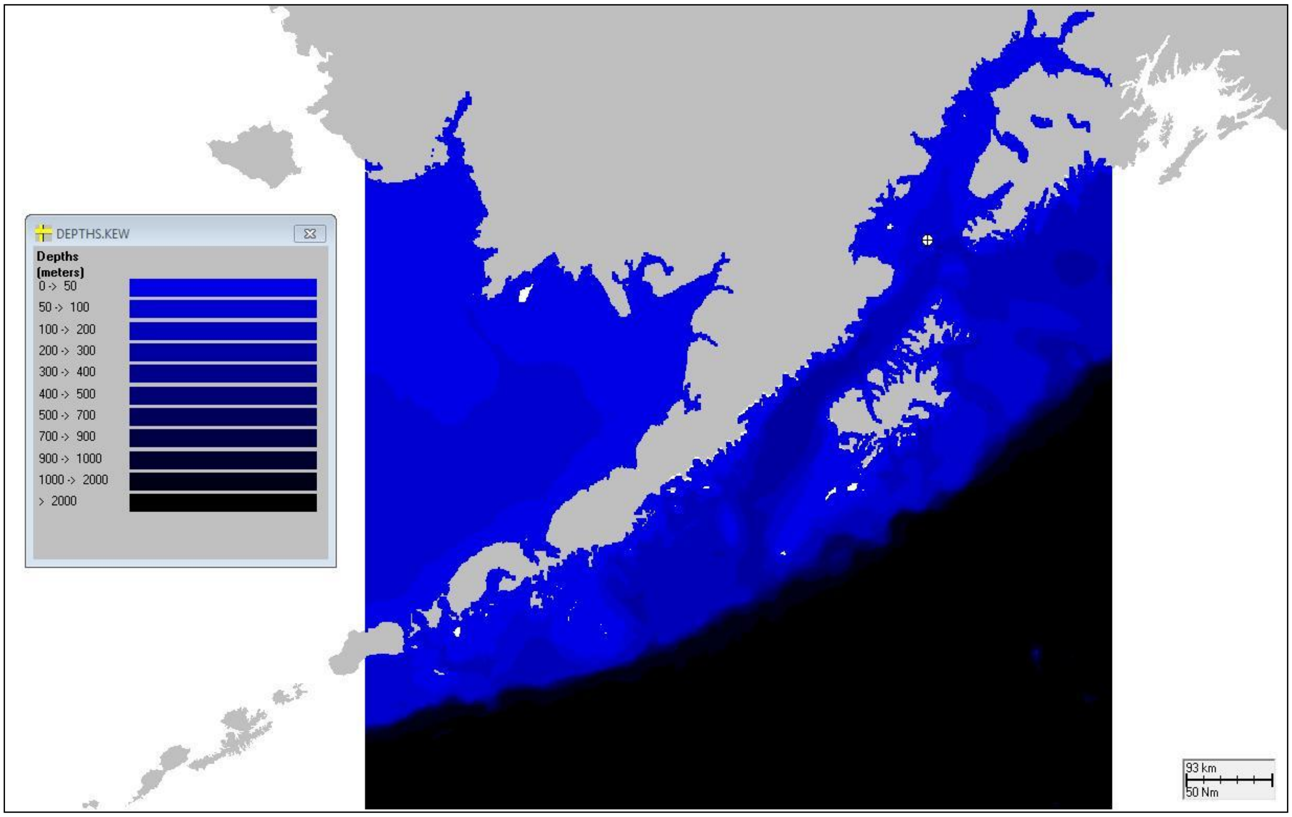


Figure A-26. Depth grid developed for the Cook Inlet/Shelikof Strait region.

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

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.

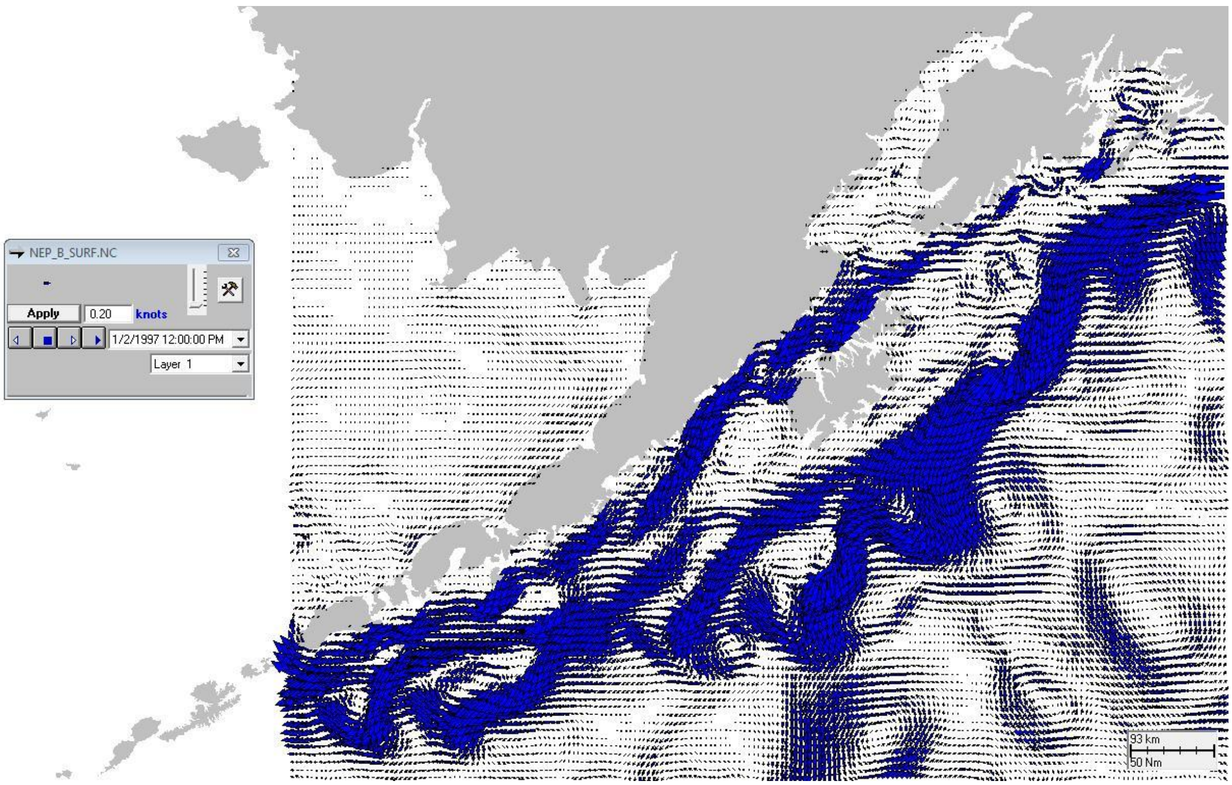


Figure A-27. Example current component data used in modeling for the Cook Inlet/Shelikof Strait region. Vector length indicates speed in the indicated direction.

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.

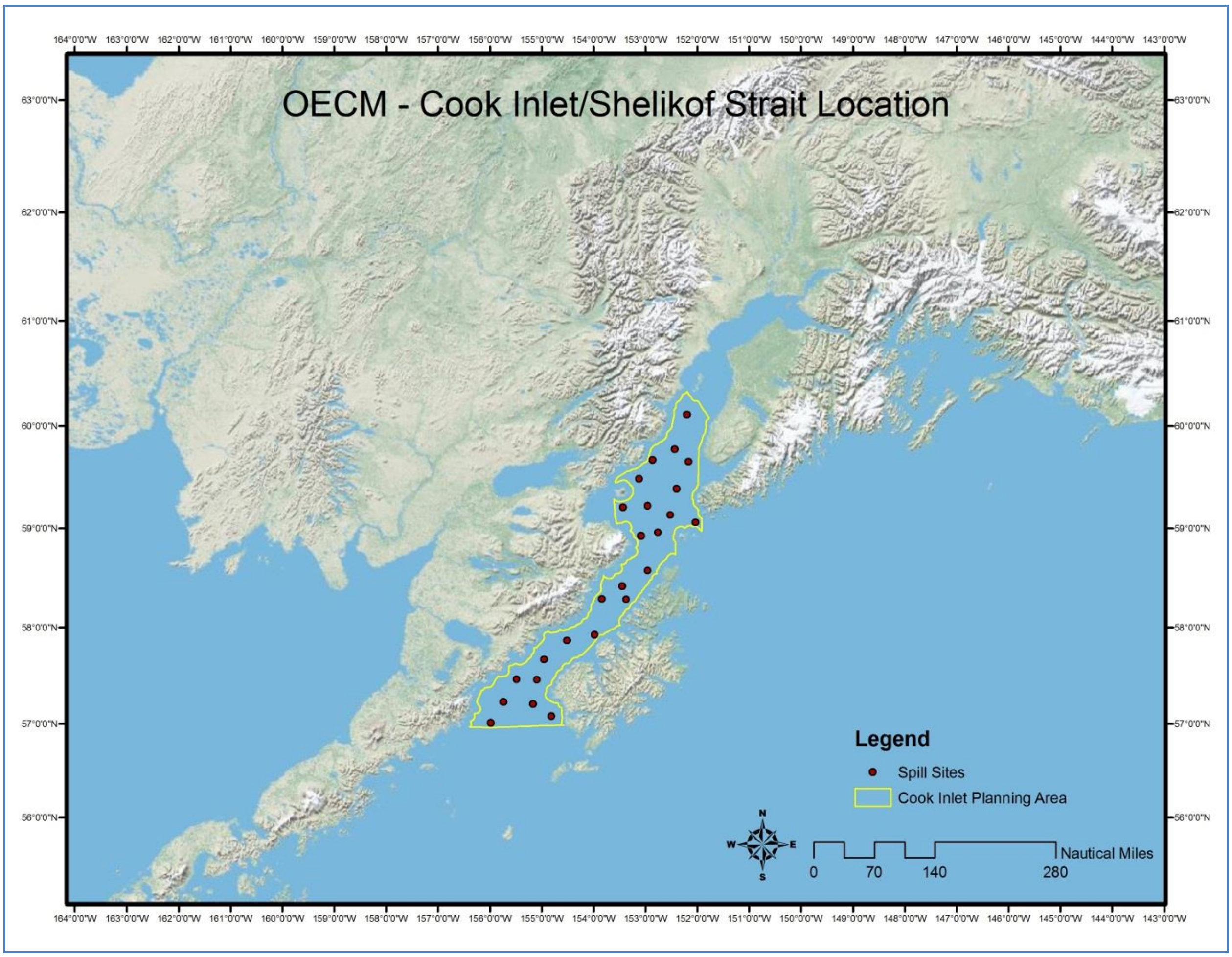


Figure A-28. Spill sites developed for the Cook Inlet/Shelikof Strait region.

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
16	58.92738	-153.08662
17	58.28740	-153.84528
18	57.92627	-153.98005
19	57.46068	-155.09342
20	57.86392	-154.51652
21	60.11031	-152.20362
22	58.28420	-153.37415
23	59.48858	-153.12071
24	57.46238	-155.48558
25	59.13050	-152.52043

Bering Sea

Habitat Grid

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

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

The gridded habitat and depth data are shown in Figures A-29 and A-30. Table A-20 summarizes the dimensions of the habitat grid cells.

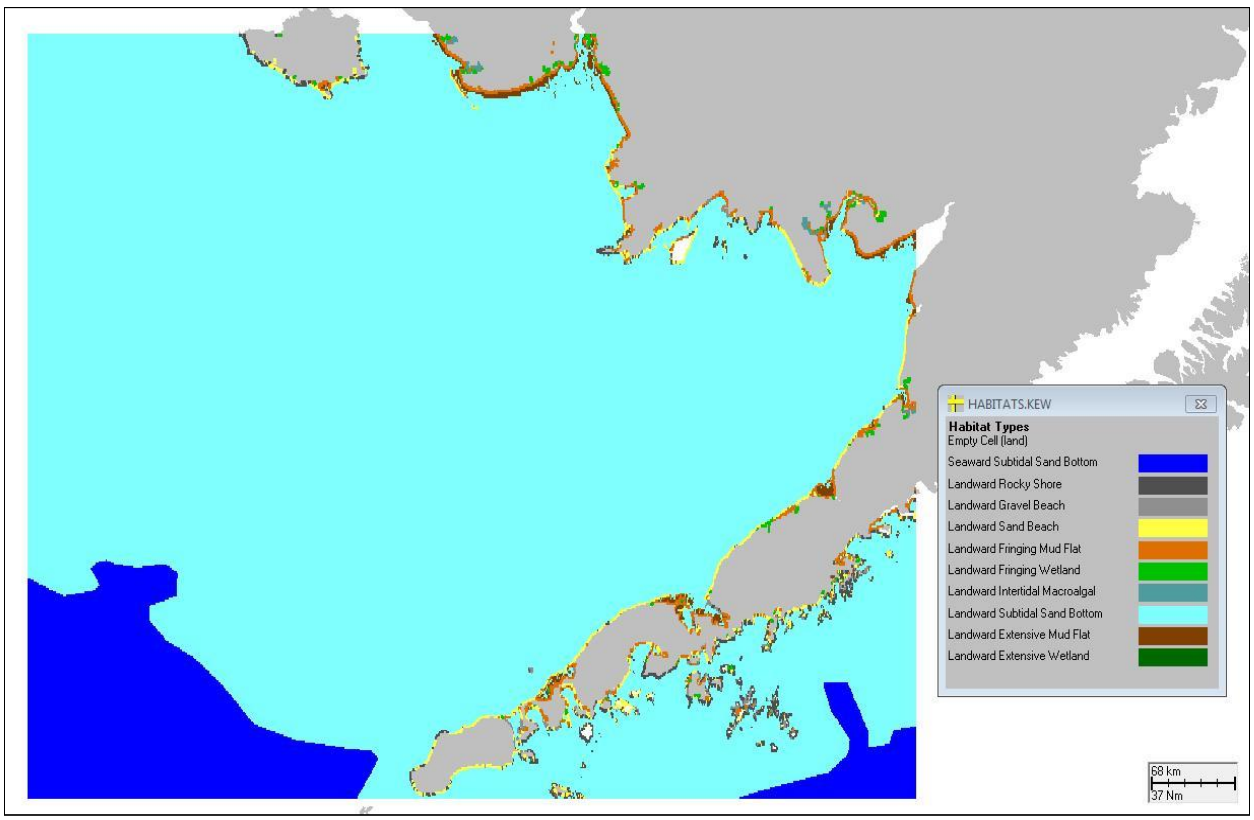


Figure A-29. Habitat grid developed for the Bering Sea region.

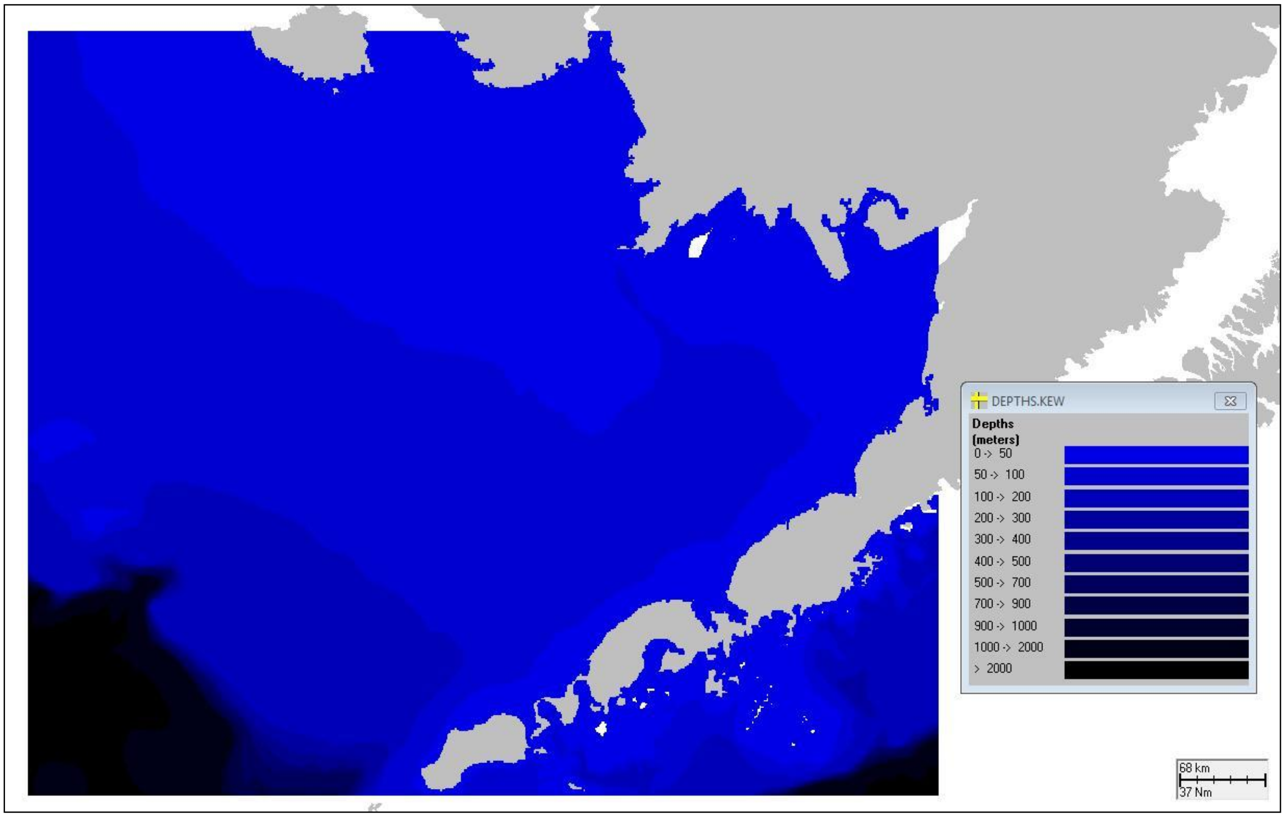


Figure A-30. Depth grid developed for the Bering Sea region.

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

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.

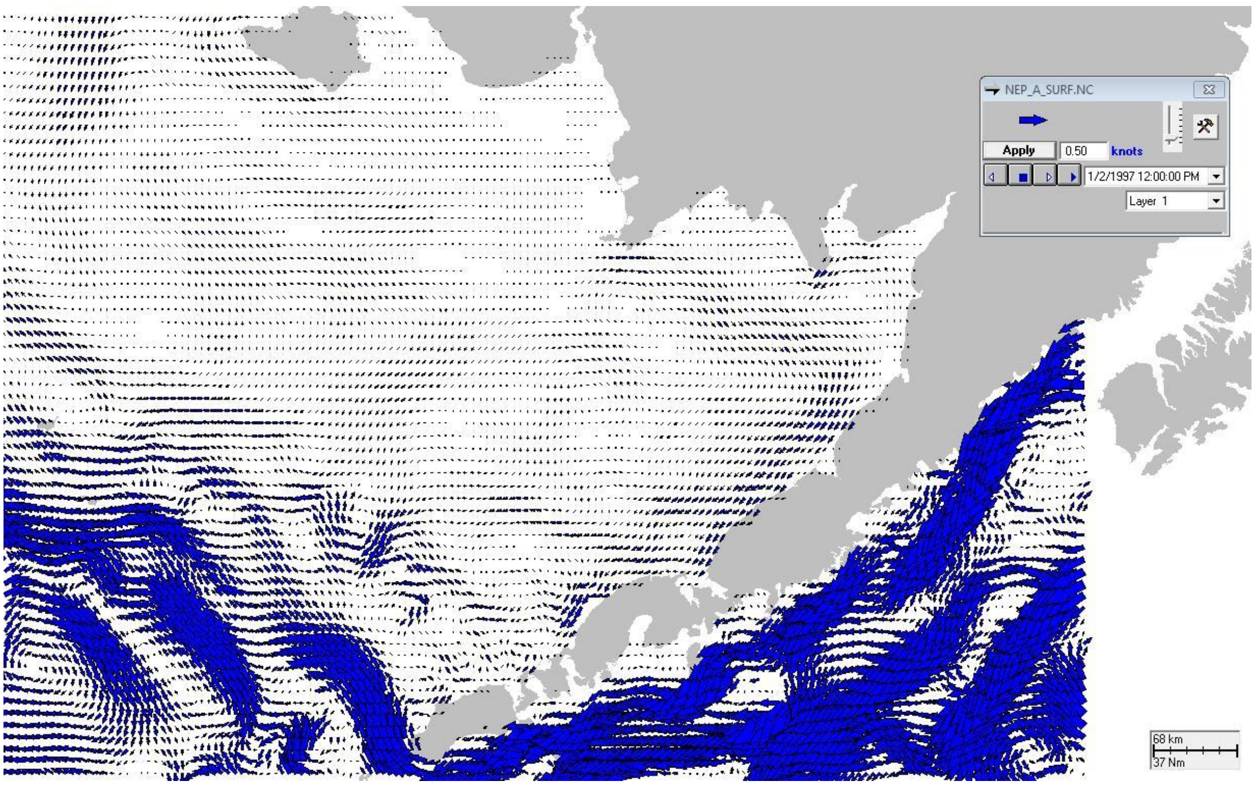


Figure A-31. Example current component data used in modeling for the Bering Sea region. Vector length indicates speed in the indicated direction.

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.

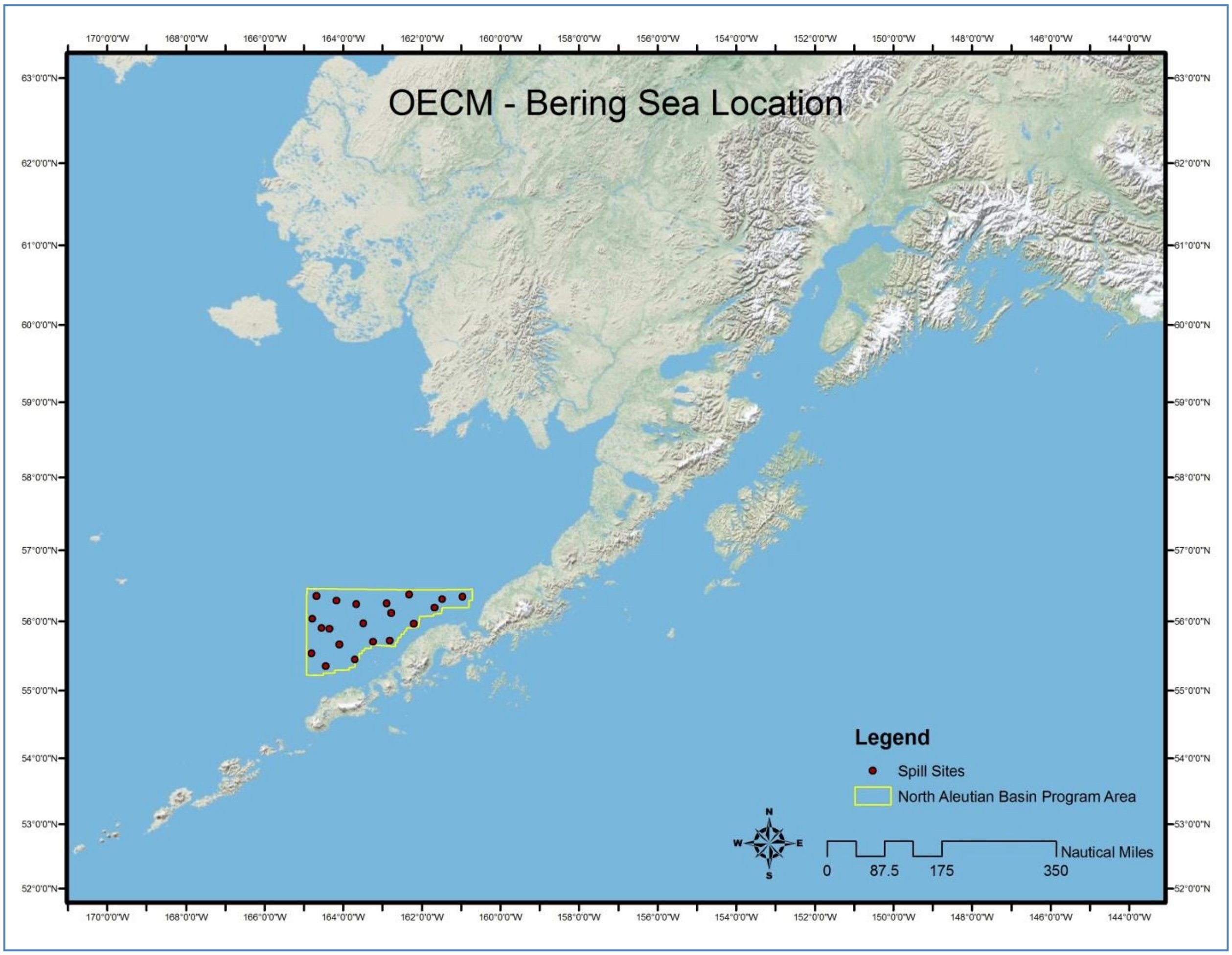


Figure A-32. Spill sites developed for the Bering Sea region.

Table A-21. Bering Sea spill sites.

Spill Site #	Latitude	Longitude
1	55.89743	-164.35828
2	55.71157	-163.23842
3	56.25903	-162.89722
4	56.31636	-161.47658
5	56.19551	-161.68012
6	56.03558	-164.78367
7	55.90328	-164.55477
8	55.35427	-164.44818
9	56.38417	-162.31786
10	56.11979	-162.78089
11	55.54512	-164.80593
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 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. Table A-22 summarizes the dimensions of the habitat grid cells.

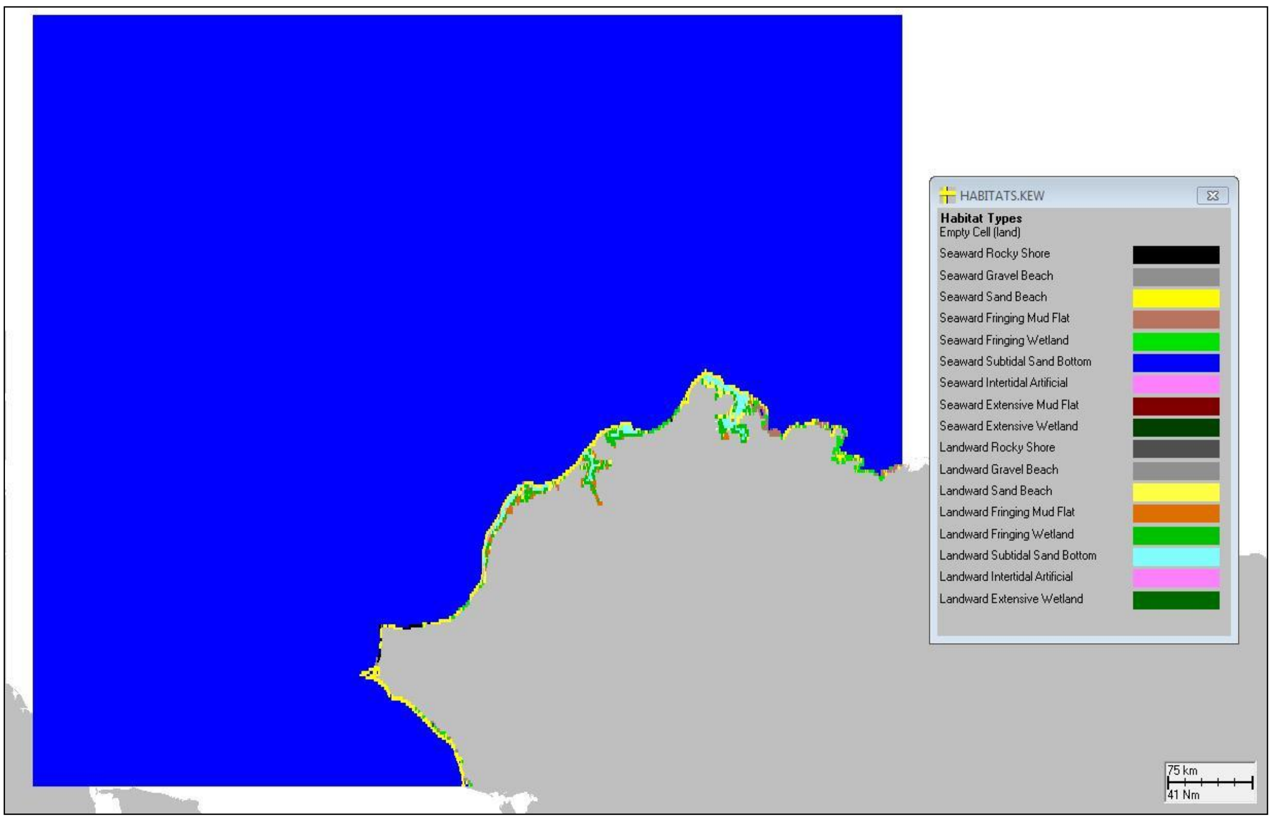


Figure A-33. Habitat grid developed for the Chukchi Sea region.

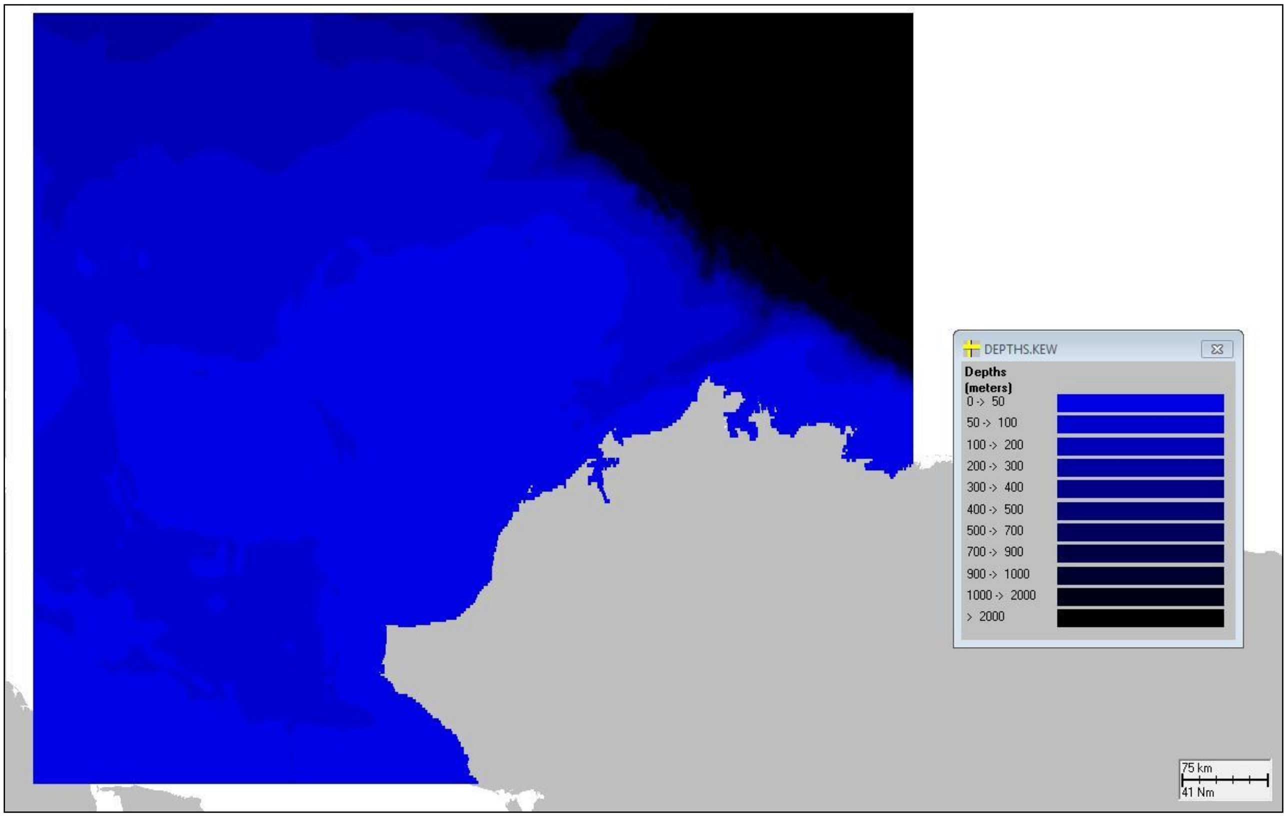


Figure A-34. Depth grid developed for the Chukchi Sea region.

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

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

Currents

Currents were based on data from BOEM's annual means analysis of the Haidvogel et al. (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 et al. 2001). The model is based on the ocean model of Haidvogel et al. (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 et al. (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 et al. 2001).

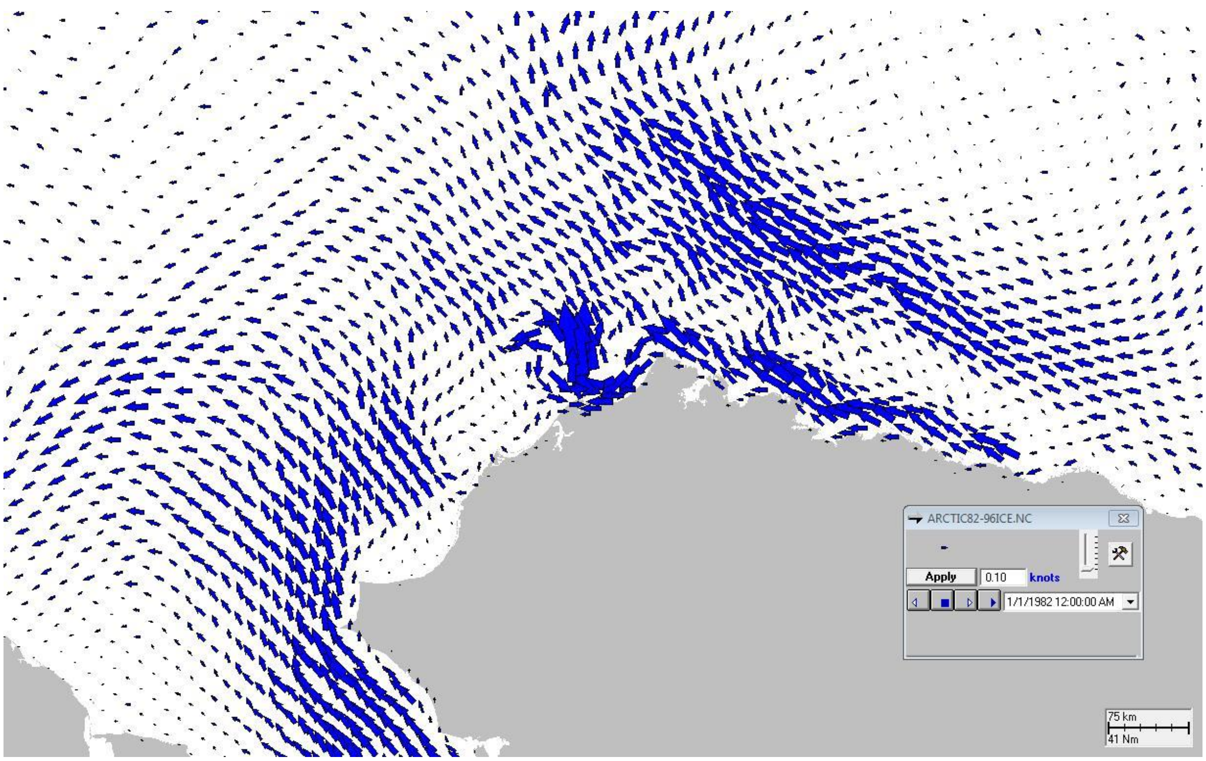


Figure A-35. Example current component data used in modeling for the Chukchi Sea region. Vector length indicates speed in the indicated direction.

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 100 spill sites were placed within the offshore spill area. The coordinates of these points are provided in Tables A-23 and A-24.

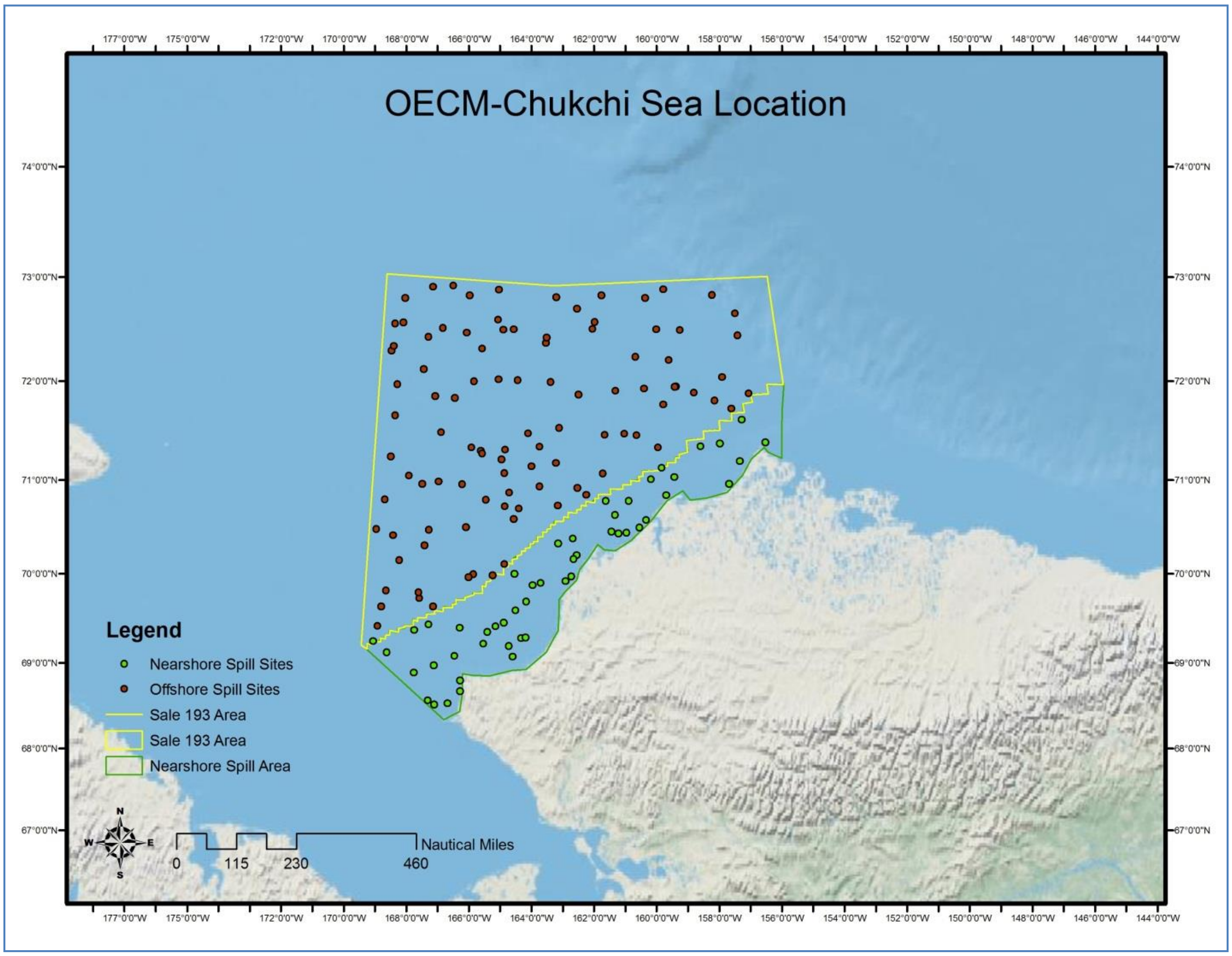


Figure A-36. Spill sites developed for the Chukchi Sea region.

Table A-23. Chukchi Sea nearshore spill sites.

Spill Site #	Latitude	Longitude
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

Spill Site #	Latitude	Longitude
46	68.57023	-167.31760
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.

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

Spill Site #	Latitude	Longitude
39	69.72906	-167.58467
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

Spill Site #	Latitude	Longitude
86	71.04396	-167.91722
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 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 (BODC 2003).

The gridded habitat and depth data are shown in Figures A-37 and A-38. Table A-25 summarizes the dimensions of the habitat grid cells.

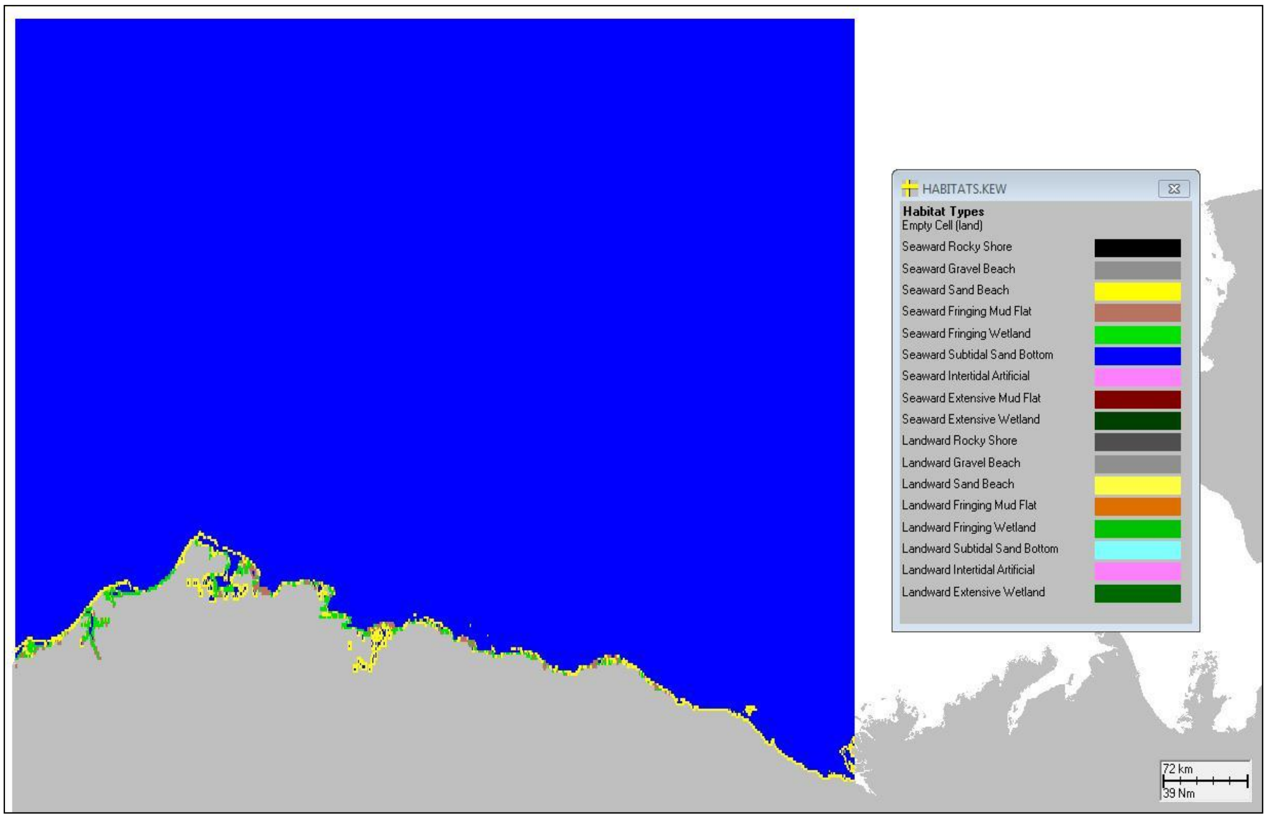


Figure A-37. Habitat grid developed for the Beaufort Sea region.

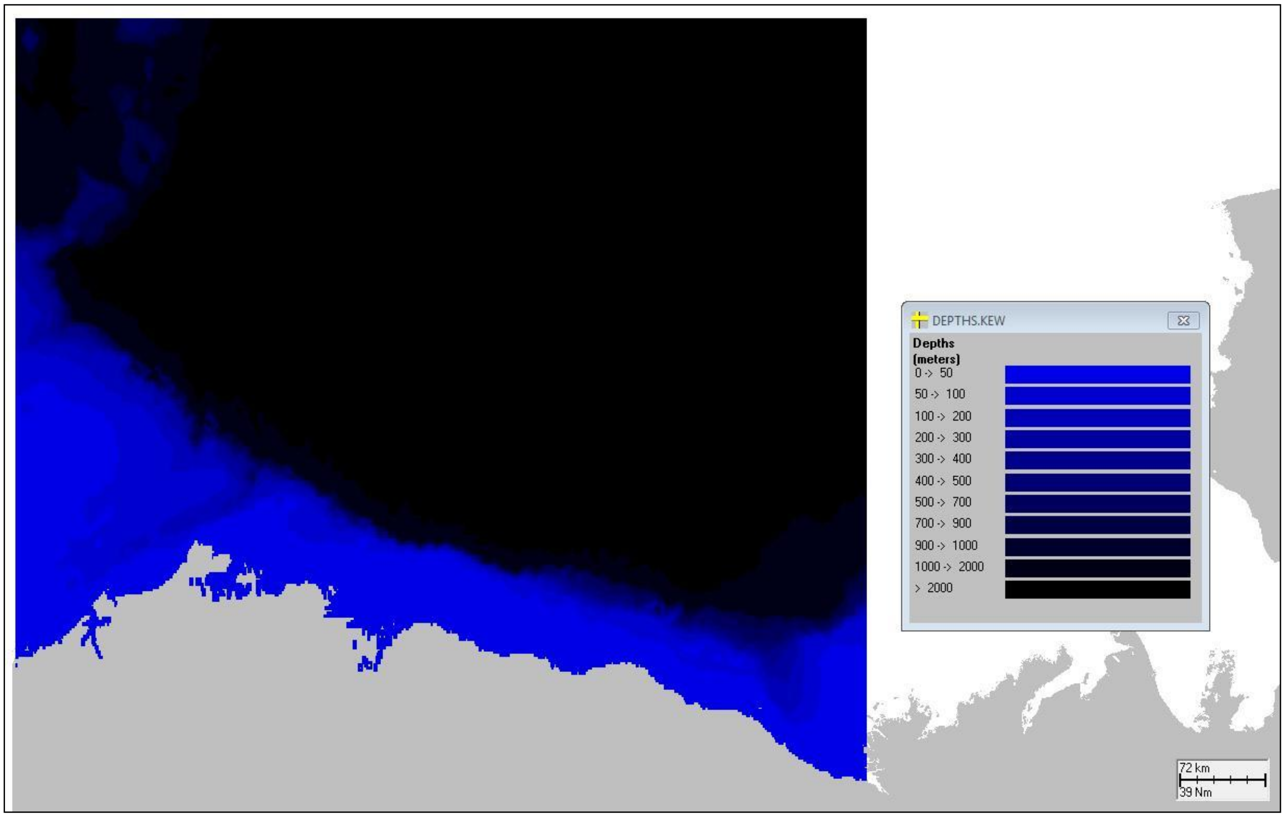


Figure A-38. Depth grid developed for the Beaufort Sea region.

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

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

Currents

Currents were based on data from BOEM's annual means analysis of the Haidvogel et al. (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 et al. 2001). The model is based on the ocean model of Haidvogel et al. (1991) and the ice models of Hibler (1979) and Mellor and Kantha (1989). This model simulates flow properties and sea ice evolution in the western Arctic during the years 1982–1996. The coupled system uses the SCRUM and Hibler viscous-plastic dynamics and the Mellor and Kantha thermodynamics. It is forced by daily surface geostrophic winds and monthly thermodynamic forces. The model is forced by thermal fields for the years 1982–1996. The thermal fields are interpolated in time from monthly fields. The location of each trajectory at each time interval is used to select the appropriate ice concentration. The pack ice is simulated as it grows and melts. The edge of the pack ice is represented on the model grid. Depending on the ice concentration, either the ice or water velocity with wind drift from the stored results of the Haidvogel et al. (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 et al. 2001).

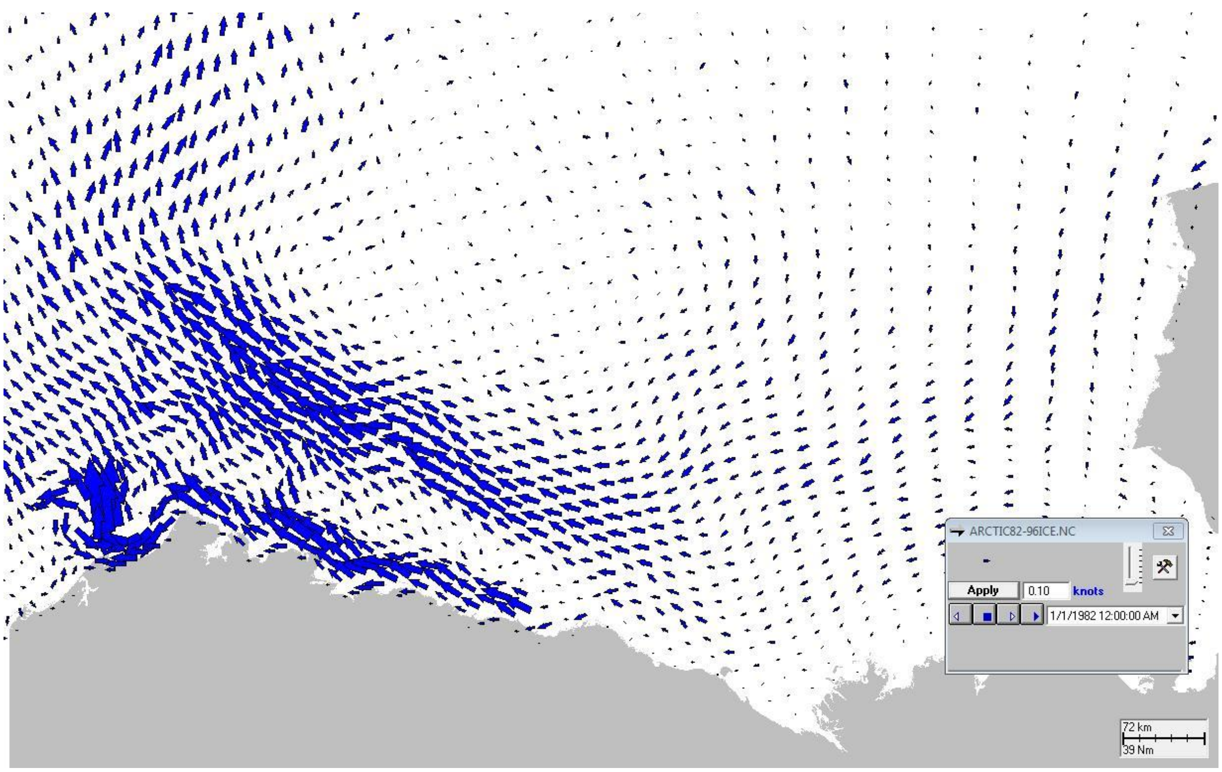


Figure A-39. Example current component data used in modeling for the Beaufort Sea region. Vector length indicates speed in the indicated direction.

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 100 spill sites were placed within the offshore spill area. The coordinates of these points are provided in Tables A-26 and A-27.

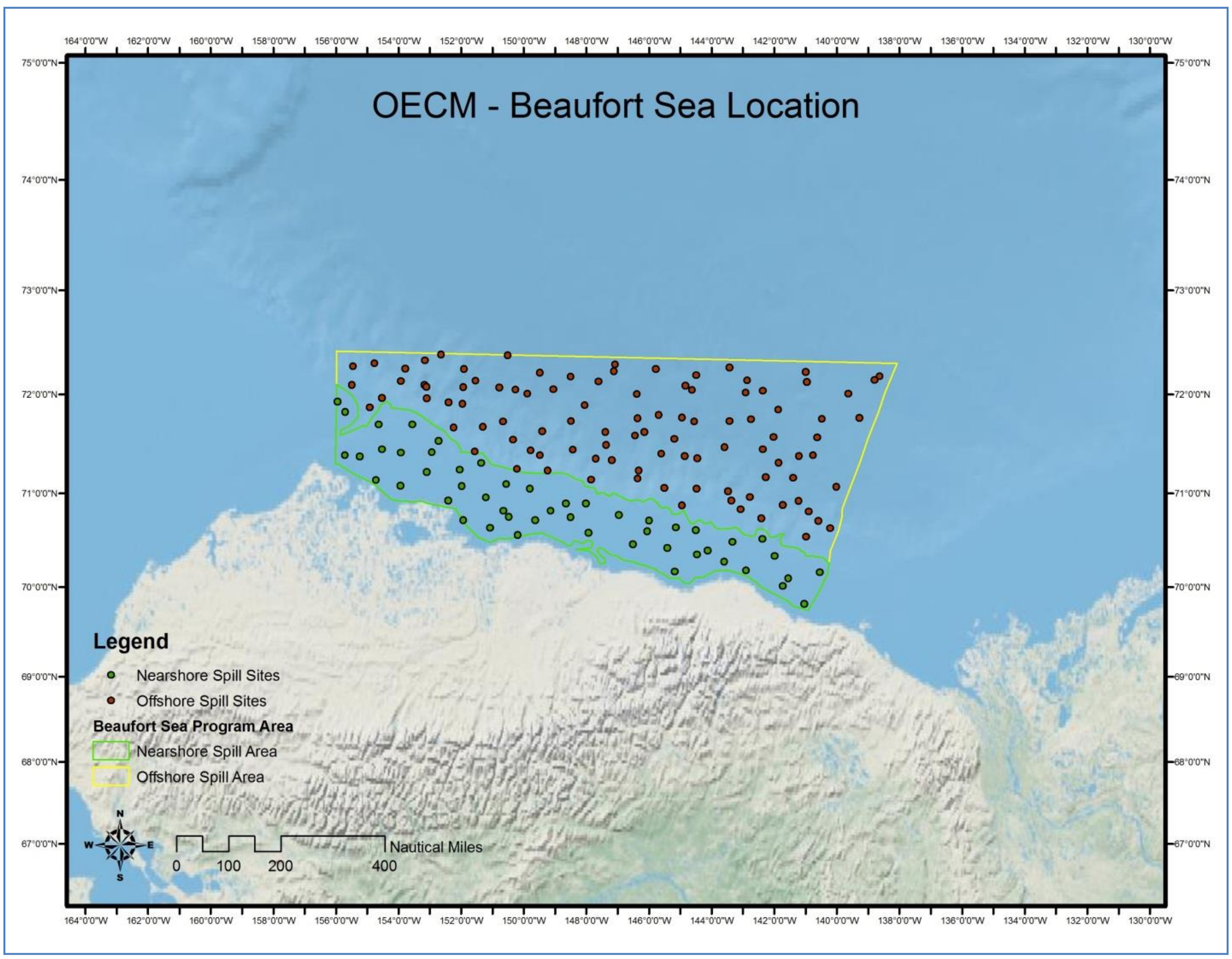


Figure A-40. Spill sites developed for the Beaufort Sea region.
Table A-26. Beaufort Sea nearshore spill sites.

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

Spill Site #	Latitude	Longitude
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.

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

Spill Site #	Latitude	Longitude
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
83	71.77527	-144.94114
84	72.03951	-142.36495

Spill Site #	Latitude	Longitude
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

References

Amante C, Eakins BW. 2009. ETOPO1 1 arc-minute global relief model: procedures, data sources and analysis. Silver Spring (MD): National Oceanic and Atmostpheric Administration. 19 p. Report No.: NOAA Technical Memorandum NESDIS NGDC-24.

[BODC] British Oceanographic Data Centre. 2003. Centenary edition of the General Bathymetric Chart of the Oceans (GEBCO) digital atlas. Liverpool: British Oceanographic Data Centre. https://www.gebco.net/

Clifford M, Horton C, Schmitz J, Kantha L. 1997. An oceanographic nowcast/forecast system for the Red Sea. J. Geophys. Res. 102(25):101–25,122.

Egbert GD, Bennett AF, Foreman MGG. 1994. TOPEX/POSEIDON tides estimated using global inverse model. J. Geophys. Res. 99(C12):24821 –24852.

Haidvogel DB, Hedstrom KS, Francis J. 2001. Numerical simulation of atmosphere/ocean/sea ice interaction in the Arctic Ocean: 1982-1996. Anchorage (AK): U.S. Department of the Interior, Minerals Management Service. Report No.: OCS Study MMS 2001-069.

Haidvogel DB, Arango HG, Hedstrom K, Beckmann A. 2000. Model evaluation experiments in the North Atlantic Basin: simulations in nonlinear terrain-following coordinates. Dynamics of Atmospheres and Oceans. 32(3–4):239–281.

Haidvogel D, Wilkin J, Young R. 1991. A semi-spectral primitive equation ocean circulation model using vertical sigma and orthogonal curvilinear horizontal coordinates. J. Comp. Phys. 94:151–184.

Hibler WD. 1979. A dynamic thermodynamic sea ice model. J. Phys. Oceanogr. 9:815–846.

Hickey BM. 1998. Coastal oceanography of western North America from the tip of Baja California to Vancouver Island. In: The Sea, Vol. 11. Robinson AR, Brink KH, editors. John Wiley & Sons.

Horton C, Clifford M, Schmitz J. 1997. A real-time oceanographic nowcast/ forecast system for the Mediterranean Sea. J. Geophys. Res. 102:25,123–25,156.

Isaji T, Howlett E, Dalton C, Anderson E. 2002. Stepwise-continuous-variable-rectangular grid hydrodynamic model. Proceedings of the Seventh International Conference on Estuarine and Coastal Modeling; Nov 5–7, 2001; St. Petersburg, Florida. p. 519–534.

Kantha L, Choi J-K, Leben R, Cooper C, Vogel M, Feeney J. 1999. Hindcasts and real-time nowcast/forecasts of currents in the Gulf of Mexico. Offshore Technology Conference (OTC ’99); May 3–6, 1999; Houston, TX.

Maltrud ME, Smith RD, Semtner AJ, Malone RC. 1998. Global eddy resolving ocean simulations driven by 1985-1995 atmospheric winds, J. Geophys. Res. 103(C13)30,825–30,853.

Mellor GL, Kantha L. 1979. An ice-ocean coupled model. J. Geophys Res. 94(10)937–10,954.

[NOAA] National Oceanic and Atmospheric Administration. 2009. NOAA NOS hydrographic survey data. Silver Spring (MD): National Oceanic and Atmospheric Administration. http://map.ngdc.noaa.gov/website/mgg/nos_hydro/viewer.htm.

Oey LY, Xu FH. 2011. The origin of along-shelf 1 pressure gradient in the Middle Atlantic Bight. Journal of Physical Oceanography. 41(9): 1720–1740.

State of California Marine Research Committee. 1966. California Cooperative Oceanic Fisheries Investigations Atlas No. 4. 301 p. https://calcofi.org/downloads/publications/atlases/CalCOFI_Atlas_04.pdf

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

SUB-APPENDIX B

Properties of Oils used in SIMAP Modeling

LIST OF TABLES

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

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

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

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

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

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

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

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

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

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

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

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

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

Property	Value	Reference
Density @ 25 deg. C (g/cm^3)	0.8291	Jokuty et al. (1999)*
Viscosity @ 25 deg. C (cp)	4.0	Jokuty et al. (1999)*
Surface Tension (dyne/cm)	26.9	Jokuty et al. (1999)*
Pour Point (deg. C)	-14.0	Jokuty et al. (1999)*
Adsorption Rate to Suspended Sediment	0.01008	Kolpack et al. (1977)
Adsorption Salinity Coef.(/ppt)	0.023	Kolpack et al. (1977)
Fraction monoaromatic hydrocarbons (MAHs)	0.017793	Jokuty et al. (1999)*
Fraction 2-ring aromatics	0.010175	Lee et al. (1992)
Fraction 3-ring aromatics	0.001976	Lee et al. (1992)
Fraction Non-Aromatics: boiling point < 180ºC	0.042207	Jokuty et al. (1999)*
Fraction Non-Aromatics: boiling point 180-264ºC	0.335825	Jokuty et al. (1999)*
Fraction Non-Aromatics: boiling point 264-380ºC	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.

References

Environment Canada. 2004. Spills technology databases. Oil properties database. Ottawa (ON): Environment Canada, Environmental Technology Centre. http://www.etc-cte.ec.gc.ca/databases/OilProperties/Default.aspx.

Environment Canada. 2009. Spills technology database. Oil properties database. Ottawa (ON): Environment Canada, Environmental Technology Centre. http://www.etc-cte.ec.gc.ca/databases/OilProperties/pdf/WEB_Sockeye_(2000).pdf

French, D, Reed M, Jayko K, Feng S, Rines H, Pavignano S, Isaji , Puckett S, Keller A, French III FW, et al. 1996. The CERCLA type A natural resource damage assessment model for coastal and marine environments (NRDAM/CME), technical documentation, Vol. I-V. Final report. Washington (DC): U.S. Dept. of the Interior, Office of Environmental Policy and Compliance.

Henry C. 1997. Louisiana State University. Personal communication, September 3, 1997.

Jokuty P, Whiticar S, Wang Z, Fingas M, Fieldhouse B, Lambert P, Mullin J, 1999. Properties of crude oils and oil products. Ottawa (ON): Environment Canada, Environmental Protection Service. Report No.: Manuscript Report EE-165.

Kolpack RL, Plutchak NB, Stearns RW (University of Southern California). 1977. Fate of oil in a water environment - Phase II, a dynamic model of the mass balance for released oil. Washington (DC): American Petroleum Institute. 53 p. Report No.: API Publication 4313.

Lee LS, Hagwall M, Delfino JJ, Rao PSC. 1992. Partitioning of polycyclic aromatic hydrocarbons from diesel fuel into water. Environ. Sci. Technol. 26:2104–2110.

Mackay D, Shiu WY, Ma DC. 1992. Illustrated handbook of physical-chemical properties and environmental fate for organic chemicals. Chelsea (MI): Lewis Publishers, Inc.

McAuliffe CD. 1987. Organism exposure to volatile/soluble hydrocarbons from crude oil spills – a field and laboratory comparison. In: Proceedings of the 1987 Oil Spill Conference, American Petroleum Institute, Washington, D.C. p. 275–288.

[NOAA] National Oceanic and Atmospheric Administration. 2000. ADIOS oil database. NOAA HAZMAT, Version 2.0. Silver Spring (MD): National Oceanic and Atmospheric Administration. http://response.restoration.noaa.gov

Whiticar S, Bobra M, Fingas M, Jokuty P, Liuzzo P, Callaghan S, Ackerman F, Cao J. 1994. A catalogue of crude oil and oil product properties, 1992 edition with 1994 data files.

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

SUB-APPENDIX C

Habitat Equivalency Analysis and Resource Equivalency Analysis for Injured Habitat and Resources

LIST OF TABLES

HABITAT/RESOURCE EQUIVALENCY ANALYSIS

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. HEA and REA have 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/resource, 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).

Marsh Restoration Approach

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

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

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

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

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

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

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

Consumer	Prey/food	% Efficiency
Invertebrate or finfish	Macrophyte	0.034
Invertebrate or finfish	Microalgae	10
Invertebrate	Microorganisms	20
Invertebrate or finfish	Detritivores	10
Invertebrate or fish	Invertebrate	20
Invertebrate or fish filter feeder	Plankton	20
Sea turtles	Invertebrates	2
Birds, mammals, sea turtles (herbivores)	Macrophyte	0.03
Birds, mammals	Invertebrate	2

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

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

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

Species Category	Trophic Level	Ecological Efficiency Relative to Benthic Detritivores (%)
Fish and Invertebrates:		
Small pelagic fish	planktivorous	20
Demersal fish	bottom feeders	10
Crustaceans	bottom feeders	20
Mollusks (large benthic invertebrates)	filter/bottom feeder	100
Intertidal benthic invertebrates	filter/bottom feeder	100
Birds:		
Waterfowl	bottom feeders	2
Shorebirds	bottom feeders	2
Other Wildlife:		
Herbivorous mammals	herbivores	0.03
Sea turtles	invertebrate feeders	2
Sea otters	plankton/benthos	2
Cetaceans (baleen)	plankton/benthos	0.4

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 NRDA costs.

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 m^{-2} yr^{-1}. In addition, benthic microalgal production provides another 105 g dry weight m^{-2} (Van Raalte, et al. 1976). Thus, estimated total primary production rate in saltmarshes in this region is 605g dry weight m^{-2} yr^{-1}.

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

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

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

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

Supplemental Feeding Restoration Approach

The OECM employs a supplemental feeding restoration assumption for higher trophic level species, including piscivorous fish and birds, piscivorous marine mammals, and polar bears. This model for scaling required compensatory restoration uses REA with a trophic web model to calculate the required biomass of fish to produce the same biomass as lost due to a spill. Scaling methods used here follow those described above for the marsh restoration REA approach.

The resource restoration model is based on food chain transfers, such that equivalent production at the same trophic level as the losses is produced by the supplemental feeding restoration project. The approach uses energetic efficiencies to scale across one or two trophic levels. The concept is that supplemental feeding leads to a net gain in biomass of the lost resource. In a manner similar to the REA described above, the mass of the fish used for supplemental feeding on a weight basis is scaled to compensate for the injury (interim loss). The details of getting the protein (i.e., fish) to trophic level species that incurred losses are not detailed here, as they would depend on the species and location. This restoration method is only used to determine the costs of potential restoration of lost biomass of resources. In this case, the transfer of production up the food web is taken into consideration for one trophic step (or two in the case of polar bears).

The basis for using this model is that restoration should provide equivalent quality fish biomass to compensate for the lost biomass. Equivalent quality implies same or similar species with equivalent ecological role and value for human uses.

Each species group is assigned a trophic level relative to that of the fish, which is only one level except for polar bears. 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) and in Welch et al. (1992). The ecological efficiency assumptions for the OECM are provided in Table C-3.

Table C-3. Assumed ecological efficiencies for one trophic step

Consumer	Prey/food	% Efficiency
Large (>1kg) fish piscivore[1]	Fish	4
Birds, mammals (piscivores)[1]	Fish	2
Polar bear[2]	Seals	5

[1]French McCay and Rowe 2003

[2]Welch et al. 1992

The equivalent compensatory amount of fish biomass of the restored resource is calculated as kilogram of injury divided by ecological efficiency. Ecological efficiency is one step for all piscivorous species, except for the case of polar bears which is a two-step calculation (i.e., the product of the efficiency of transfer from fish to seals and efficiency from seals to polar bears). Table C-4 lists the composite ecological efficiencies relative to fish biomass for each trophic group evaluated in the modeling.

Table C-4 Composite ecological efficiency relative to fish by trophic group.

Species Category	Trophic Level	Ecological Efficiency Used For Restoration Scaling (%)
Fish and Invertebrates:		
Large pelagic fish	piscivores/predators	4
Birds:		
Seabirds	piscivores	2
Waders	piscivores	2
Raptors	piscivores	2
Other Wildlife:		
Pinnipeds	piscivores	2
Cetaceans (piscivores)	piscivores	2
Polar bear	consume piscivores	0.1

Different fish species are used for the supplemental feeding restoration approach depending on the BOEM region. The OECM assumes supplemental feeding using cod for the Arctic planning areas (Chukchi and Beaufort Seas), Pacific herring for other planning areas in the Alaska Region, Pacific herring in the Pacific Region, Gulf menhaden in the GOM Region, and Atlantic menhaden in the Atlantic Region.

Restoration Assumptions for Habitat Injuries

In addition to the quantifiable injuries in water habitats, there also would 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 (> 0.1 mm thickness results in invertebrate injuries). Benthic invertebrate production rates for each habitat type are taken into account when determining injury (Tables C-5 to C-11). Time for recovery for intertidal invertebrates (based on a natural recovery curve) is estimated as 3–5 years (French McCay 2009). The total loss of intertidal invertebrates from shoreline oiling greater than 0.1 mm thick is calculated as a factor of daily production rate, as a function of # years to 99% recovery and annual discount rate (3%).

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

Table C-5. Benthic invertebrate production rates by habitat type for Mid-Atlantic location.

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

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

Table C-6. Benthic invertebrate production rates by habitat type for Straits of Florida location.

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

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

Table C-7. Benthic invertebrate production rates by habitat type for GOM location.

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

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

Table C-8. Benthic invertebrate production rates by habitat type for Southern California location.

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

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

Table C-9. Benthic invertebrate production rates by habitat type for Washington/Oregon location.

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

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

Table C-10. Benthic invertebrate production rates by habitat type for Gulf of Alaska, Cook Inlet/Shelikof Strait, and Bering Sea locations.

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

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

Table C-11. Benthic invertebrate production rates by habitat type for Chukchi Sea and Beaufort Sea locations.

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

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

Table C-12. Natural recovery time (in year) by habitat type based on French McCay (2009).

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

Restoration Factor Assumptions for Species Injuries

Restoration factors are used as multipliers to determine the required amount of restoration (marsh habitat or biomass) to compensate for the oiled habitat or resource (area or biomass). The restoration factors are multiplied by the amount of lost resource and multiplied by the cost per unit area or biomass restored to estimate costs. Tables C-13 and C-14 provide the restoration factors for HEA and REA approaches. As previously described, salt marsh restoration factors vary regionally (Table C-13). The supplemental feeding factors vary by species (based on ecological efficiencies relative to prey fish) but do not vary regionally (Table C-14).

Table C-13. Summary of HEA and REA Saltmarsh Restoration Factors used in the OECM.

Area (m^2) of Saltmarsh Restored per kg of Injury, by OECM Location Code

Grouping	Type	ATL	SFL	CGM	SCA	WAS	GOA	CIS	BER	CHU	BEA
Birds	Waterfowl	82.56	46.37	46.37	16.13	18.75	18.75	18.75	18.75	18.75	18.75
	Shorebirds	82.56	46.37	46.37	16.13	18.75	18.75	18.75	18.75	18.75	18.75
Other Wildlife	Sea Turtles	82.56	46.37	46.37	82.56	82.56	-	-	-	-	-
	Sea Otters	-	-	-	80.63	93.75	52.84	52.84	52.84	52.84	52.84
	Cetaceans (Baleen)	412.82	231.87	231.87	80.63	93.75	52.84	52.84	105.67	105.67	105.67
	Herbivorous Mammals	3,091.60	3,091.60	3,091.60	-	-	-	-	-	-	-
Fish and Invertebrates	Small Pelagic Fish	8.26	4.64	4.64	1.61	1.87	1.87	1.87	1.87	1.87	1.87
	Demersal Fish	16.51	9.27	9.27	3.23	3.75	3.75	3.75	3.75	3.75	3.75
	Crustaceans	8.26	4.64	4.64	1.61	1.87	1.87	1.87	1.87	1.87	1.87
	Molluscs (Large Benthic Invertebrates)	8.26	4.64	4.64	0.32	1.87	1.87	1.87	1.87	1.87	1.87

Area (m^2) of Saltmarsh Restored per Area (m^2) Oiled, by OECM Location Code

OECM Location Code	ATL	SFL	CGM	SCA	WAS	GOA	CIS	BER	CHU	BEA
Intertidal Injury	9.375	15.514	0.725	0.757	2.616	0.378	0.480	0.597	2.243	1.765

Table C-14 Summary of REA Restoration Factor for Supplemental Feeding Restoration Approach used in the OECM.

Group	Type	Biomass (kg) of Fish Required per kg of Injury
Birds	Seabirds	50
	Wading Birds	50
	Raptors	50
Other Wildlife	Pinnipeds	50
	Cetaceans (Piscivores)	50
	Polar Bears	1,000
Fish and Invertebrates	Large Pelagic Fish	25

References

Continental Shelf Associates, Inc. 1991. A comparison of marine productivity among outer continental shelf planning areas. Supplement - An evaluation of benthic habitat primary productivity.

Flint RW. 1985. Long-term estuarine variability and associated biological response. Estuaries 8: 158–169. (from EAI and ASA, 1987).

French, D, Reed M, Jayko K, Feng S, Rines H, Pavignano S, Isaji , Puckett S, Keller A, French III FW, et al. 1996. The CERCLA type A natural resource damage assessment model for coastal and marine environments (NRDAM/CME), technical documentation, Vol. I-V. Final report. Washington (DC): U.S. Dept. of the Interior, Office of Environmental Policy and Compliance.

French DP, Manen CA, Gibson M, Catena J. 2001. Quantifying the scale of restoration required to compensate for the impacts of the North Cape oil spill on fish and invertebrates. In: Proceedings of the 2001 International Oil Spill Conference & Exposition; March 26–29, 2001, Tampa, Florida; American Petroleum Institute; Washington, D.C.

French McCay DP. 2009. State-of-the-art and research needs for oil spill impact assessment modeling. In: Proceedings of the 32nd Arctic and Marine Oil Spill Program Technical Seminar on Environmental Contamination and Response, Emergencies Science Division, Environment Canada, Ottawa, ON, Canada. p. 601-653.

French McCay DP, Rowe JJ. 2003. Habitat restoration as mitigation for lost production at multiple trophic levels. Marine Ecology Progress Series. 264:235–249.

French McCay D, Rowe JJ, Whittier N. 2003a. Final report, estimation of natural resource damages for 23 Florida cases using modeling of physical fates and biological injuries. Tallahassee (FL): Florida Department of Environmental Protection. 23 volumes

French McCay D, Whittier N, Isaji T, Saunders W. 2003b. Assessment of the potential impacts of oil spills in the James River, Virginia. In: Proceedings of the 26th Arctic and Marine Oil Spill Program Technical Seminar. Ottawa (ON): Emergencies Science Division, Environment Canada. p. 857–878.

Greeson PE, Clark JR, and Clark JE, editors. 1979. Wetland functions and values: the state of our understanding. In: Proceedings of the National Symposium on Wetlands held in Disneyworld Village, Lake Buena Vista, FL; November 7–10, 1978. Minneapolis (MN).

[LA DEQ] Louisiana Department of Environmental Quality, et al. 2003. The Louisiana Regional Restoration Planning Program, Draft Regional Restoration Plan, Region 2. Baton Rouge (LA): Department of Environmental Quality, Louisiana Department of Natural Resources, Louisiana Department of Wildlife and Fisheries, Louisiana Oil Spill Coordinator's Office, National Oceanic and Atmospheric Administration, U.S. Department of the Interior.

[LOSCO] Louisiana Oil Spill Coordinator's Office. 2000. Land and water interface of Louisiana coastal region. Baton Rouge (LA): Louisiana Oil Spill Coordinator's Office.

Muscatine L. 1980. Productivity of zooxanthellae. In: Primary Productivity in the Sea. Falkowski PG, editor. New York (NY): Plenum Press. p.381–402.

[NOAA] National Oceanic and Atmospheric Administration. 1997. Natural Resource Damage Assessment guidance document: scaling compensatory restoration actions (Oil Pollution Act of 1990). Silver Spring (MD): NOAA Damage Assessment Center.

NOAA. 1999. Habitat Equivalency Analysis: An Overview. NOAA Damage Assessment Center, Silver Spring, MD, 23p.

Nixon SW, Oviatt CA. 1973. Ecology of a New England salt marsh. Ecolog. Monogr. 43:463–504.

Odum EP. 1971. Fundamentals of ecology, third edition. Philadelphia (PA): W. B. Saunders.

Raymont JE. 1980. Plankton and productivity in the oceans, 2nd edition, Vol. 1 Phytoplankton. Oxford (England): Pergamon Press.

Sibley DA. 2003. The Sibley field guide to birds of eastern North America. New York (NY): Alfred A. Knopf, Inc. 431 p.

Teal JM. 1962. Energy flow in the salt marsh ecosystem of Georgia. Ecology 43:614–624.

Van Raalte CD, Valiela I, Teal JM. 1976. Production of epibenthic salt marsh algae: light and nutrient limitation. Limnol Oceangr. 21:862–872.

Welch HE, Bergmann MA, Siferd TD, Martin KA, Curtis MF, Crawford RE, et al. 1992. Energy flow through the marine ecosystem of the Lancaster Sound region, arctic Canada. Arctic. 1992:343–357.

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

SUB-APPENDIX D

Spill Rate and Volume Data for OECM Modeling

LIST OF TABLES

This sub-appendix summarizes data inputs included in the OECM related to (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 (PDF) of the spill volumes of different oil types (crude, bunker fuel, diesel) should a spill occur from one of these sources. Section 2.1 describes how these data are used in the model. In particular, the analysis requires two sets of spillage rates and spill volume PDFs for spills. The first set is for spills associated with the OCS program (i.e., from offshore platforms/wells [Table D-3], pipelines [Table D-4], and from vessels servicing the platforms [Table D-5]). The PDFs include the following:

- Crude oil spills from OCS platforms/wells (Table D-3);
- Operational diesel spills from OCS platforms/wells (Table D-3);
- Crude oil spills from offshore pipelines (Table D-4);
- Diesel spills from offshore pipelines (Table D-4); and
- Diesel spills[3] from offshore supply or service vessels (Table D-5).

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. These spill size categories, which differ for crude oil spills versus diesel spills, are summarized in Table D-1 below.

Table D-1. Spill size categories for crude oil spills and diesel spills from platforms, offshore pipelines, and offshore supply and service vessels

Size Class	Spill Size Range for Crude Oil Spills (bbls)	Spill Size Range for Diesel Spills (bbl)
Very Small	1 – 10	1
Small	11 – 100	2 – 10
Medium	101 – 1,000	11 - 100
Large	1,001 – 10,000	101 – 1,000
Very Large	10,001 – 100,000	1,001 – 3,600

The second set of PDFs is for the spillage rates and volumes for spills associated with transporting crude and refined products by tanker (i.e., imports, exports, and domestic transport). The PDFs include the following:

- Cargo spills for tankers transporting crude oil (Table D-6);
- Cargo spills for tankers transporting petroleum products (Table D-7);[4] and
- Diesel fuel spills[5] for tankers transporting crude oil (Table D-6).

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.

[3] The smaller vessels that service the offshore platforms are fueled by diesel rather than heavy fuel oil.
[4] Petroleum products will be represented by diesel fuel in the modeling scenarios.
[5] Tankers will most likely be fueled with diesel rather than heavy fuel oil to meet air pollution standards.

These spill size categories, which differ for crude oil spills versus diesel spills, are summarized in Table D-2. The derivation of these oil spill data varies across spill sources, as detailed below.

Table D-2. Spill size categories for tanker spills (crude oil spills and diesel spills)

Size Class	Spill Size Range (bbl)
Very Small	0.1 – 10
Small	10.1 - 100
Medium	101 – 1,000
Large	1,001 – 10,000
Very Large	10,001 – 100,000
Extra Large	Over 100,000

Platform and Pipeline Spills

For OCS platforms and pipelines, the estimated spill rates, distribution of spills across spill size classes, and mean spill size per size class are based largely on BOEM's 2016 report on oil spill occurrence rates (ABS Consulting 2016), which presents platform and pipeline spill data for the 1974–2015 period. To align the estimates of these variables with relatively recent industry practices, only data from the 2001–2015 period were used. The 2004 Taylor Energy oil spill and 2010 *Deepwater Horizon* spill, however, are excluded from these data for the purposes of incorporation into the OECM since the model was not designed to assess spills of the duration and magnitude of these spills. In cases where BOEM's 2016 report lacks sufficient data, data included in the 2018 OECM update are also used (Industrial Economics 2018).

The 2016 study includes data for all petroleum spills from platforms and pipelines, without distinguishing between crude oil and fuel oils (e.g., diesel). It was therefore necessary to parse these data between crude oil and diesel (as is necessary for the OECM). As an initial step in this process, spill rates (bbl spilled/bbl produced), mean spill size, and the distribution of spills across spill size classes were estimated for petroleum directly from the 2016 occurrence report data. Separate oil spill data were then developed for crude oil and diesel as follows:

- ***Mean spill rate:*** The mean spill rate for "petroleum" is assumed to represent the sum of the crude oil spill rate and the diesel spill rate. To distinguish between the two, the proportional relationship between the crude oil spill rate and diesel spill rate was assumed to be the same as determined in the previous OECM update—63.7 percent crude and 36.3 percent diesel for platforms and 99.96 percent crude and 0.04 percent diesel for pipelines (Industrial Economics 2018). The estimated spill rates reflect production of 8 billion barrels of oil on the OCS between 2001 and 2015 (Energy Information Administration 2023).
- ***Distribution of spills across spill size categories:*** The approach for specifying the distribution of spills across spill sizes was somewhat different for platform spills versus pipeline spills:
    - ***Platforms:*** For crude, the distribution of spills between size classes was assumed to be the same as for petroleum overall. For diesel, this same assumption was applied in those cases where the OECM spill size classes match those for

petroleum in the 2016 occurrence rate study (i.e., all spills greater than 10 barrels). However, the classes at the low end are slightly different for diesel in the OECM (1 barrel and 2 to 10 barrels) than for petroleum in the 2016 occurrence rate study (1 to 10 barrels). Thus, within the OECM, the smallest spill size category for diesel from the 2016 occurrence rate study is split into two separate categories of 1 barrel and 2 to 10 barrels. The relative distribution of spills across these two categories is assumed to be the same as in the previous OECM update (Industrial Economics 2018).

  - ***Pipelines:*** For crude, the distribution of spills between size classes was assumed to be the same as for petroleum overall (same as for platforms). For diesel, the distribution from the previous OECM update was applied (Industrial Economics 2018).

- ***Mean spill size:*** The approach for mean spill size also differs for platforms versus pipelines:
  - ***Platforms:*** The mean spill size by spill size class for crude is assumed to be the same as for petroleum overall. For diesel, this same assumption is applied in those cases where the spill size classes in the OECM for diesel are the same as they are for petroleum in the 2016 occurrence rate study. However, the smaller size classes are slightly different for diesel than for petroleum, as noted above. The weighted average spill size for these two classes is assumed to be equal to the spill size for the corresponding petroleum class in the 2016 occurrence rate study (2.79 barrels per spill). This implicitly assumes that the average size of diesel spills in the 1 to 10 barrel range is the same as crude spills in this range.
  - ***Pipelines:*** The mean spill size by spill size class for crude is assumed to be the same as for petroleum overall (same as for platforms). For diesel, there is no mean spill size for the medium, large, and very large categories because there are no spills for those categories. The smaller size classes for diesel are slightly different than those for petroleum overall; as noted above the lowest spill size class in the 2016 occurrence rate report is split into two separate classes in the OECM for diesel. The "very small" class has a spill range of 1 barrel to 1 barrel (i.e., point value rather than a range). The mean spill size for this category is therefore set to 1. The mean spill size for the "small" category (2 to 10 barrels) was calculated such that the weighted average of this value and the value for very small spills (1 barrel) is equal to the mean spill size for the smallest category in the 2016 occurrence rate report (i.e., 3.35 barrel average for spills less than or equal to 10 barrels).

Service Vessel Spills

The oil spill rates and spill sizes used in the OECM for service vessel spills were derived from 1996–2010 spill data documented in Anderson (2012). These are the same data applied in the 2018 version of the OECM. Service vessels were not included in the 2016 occurrence rate study described above for platform and pipeline spills.

Tanker Spills

The tanker spill data in the 2016 occurrence rate study is more limited than the data for platform and pipeline spills. In particular, the data are limited to crude oil spills of at least 1,000 barrels; no data are provided on diesel spills or spills smaller than 1,000 barrels.[6] Taking these limitations into account, oil spill data for inclusion in the OECM were derived as follows:

- ***Distribution of crude spills across spill size categories:*** For the three spill size classes not reflected in the 2016 occurrence rate study (i.e., the three classes < 1,000 barrels), the distribution was left unchanged relative to the previous OECM update. Cumulatively, these classes make up 98.92 percent of spills (Industrial Economics 2018). For the three size classes reflected in the 2016 occurrence rate study (i.e., those representing spills of more than 1,000 barrels), the remaining 1.08 percent was split proportionally based on the distribution in the 2016 occurrence rate data, using data from the 1974–2013 time period rather than just recent years. The more recent data do not include a large enough sample of spills to derive a distribution. As described below, however, only the more recent data were used to derive estimated spill rates (barrels of oil spilled per barrel transported).
- ***Mean spill size for crude spills***: For the three spill size classes not reflected in the ABS data (i.e., the three classes < 1,000 barrels), the same mean spill sizes from the previous OECM update were retained. This leaves three spill classes above 1,000 barrels: Large, Very Large, and Extra Large spills. For the "Large" spill class (1,000 to 10,000 barrels), the mean spill size was calculated directly from the data in the 2016 occurrence report for the years 2001 to 2015. For the "Extra Large" class (> 100,000 barrels), the value of 250,000 barrels per spill was retained from the previous OECM update, as the data in the 2016 occurrence rate report do not distinguish Extra Large spills from Very Large Spills (10,000 to 100,000 barrels). For the Very Large category, the average spill size was calculated such that the weighted average of this value and the 250,000 barrel value for Extra Large spills (> 100,000 bbl) is equal to the value reported for all spills greater than 10,000 barrels in the 2016 occurrence rate report (72,520 barrels).
- ***Mean crude spill rate:*** The 2016 occurrence rate study does not directly report mean spill rates for all spill size classes for tankers, but sufficient data are available in the study to derive estimates based on the following procedure:
    - ***Step 1*** - For each of the three largest spill size classes, tally the number of spills that occurred over the 1974–2013 time period as reported in the 2016 occurrence rate study.
    - ***Step 2*** - Based on the number of spills for the largest three spill size classes (from Step 1) and the distribution of spills across all size categories (estimated per the procedure above), derive the number of spills that occurred in each of the three smallest spill size categories over the 1974–2013 period. This step is necessary

[6] The 2016 occurrence rate study presents data separately for spills greater than or equal to 1,000 barrels and spills greater than or equal to 10,000 barrels. The former category includes all spills in the latter category. To avoid double counting, the number of spills between 1,000 barrels and 10,000 barrels was calculated as the number of spills greater than or equal to 1,000 barrels minus the number of spills greater than or equal to 10,000 barrels. A similar calculation was performed to estimate the total spill volume associated with spills between 1,000 and 10,000 barrels.

because the 2016 occurrence rate data do not include spills for the three smallest spill size categories.

- ***Step 3*** - Multiply the number of spills per spill size category, as estimated in Steps 1 and 2, by the average spill size per category (as estimated per the procedure above) to derive the number of barrels spilled by category over the 1974–2013 period.
- ***Step 4*** – Modify the values from Step 3 to reflect spills only over the most recent 15 years of data, per spill size category. For the largest three categories, the spill volume for the most recent 15 years was taken directly from the 2016 occurrence rate study. Cumulatively, across these three categories, substituting with the more recent data resulted in a 98 percent reduction in spill volume. For the smallest three categories, the spill volumes from Step 3 were scaled in proportion to the change for the largest three categories between Steps 3 and 4 (i.e., a 98 percent reduction).
- ***Step 5*** - The previous step yields the total volume of crude spilled over the most recent 15 years for which data are available for each spill size class. These values were then divided by the total volume transported over that 15-year period to derive the spill rate per size class.

For diesel spills from crude oil tankers, the 2021 updated OECM applies the same oil spill data as applied in the previous iteration of the model, as the 2016 occurrence rate data does not specifically capture diesel spills.

Refined Product Tankers

Updated spill data for refined petroleum product tankers are not available in BOEM's 2016 occurrence study. In the absence of updated data, the mean spill rates used in the previous OECM update are retained, and we assume that the distribution of spills across spill size classes and the mean spill size per size class are the same as updated values for crude oil tankers.

Table D-3. Spill rates and spill size distributions for spills associated with OCS platforms and wells, based upon all OCS spills from 2001–2015 excluding the catastrophic *Deepwater Horizon* event.

Oil Type	Spill Rate (bbl spilled per bbl produced)	Size Class	Spill Size Range (bbl)	Mean bbl[7]	% of Spills
Light crude	0.000002161	Very Small	1 – 10	3	67.18%
		Small	11 – 100	33	22.11%
		Medium	101 – 1,000	277	10.20%
		Large	1,001 – 10,000	1,689	0.51%
		Very Large	10,001 – 100,000	N/A	0.00%
Heavy crude	0.000002161	Very Small	1 – 10	3	67.18%
		Small	11 – 100	33	22.11%
		Medium	101 – 1,000	277	10.20%
		Large	1,001 – 10,000	1,689	0.51%
		Very Large	10,001 – 100,000	N/A	0.00%
Medium crude	0.000002161	Very Small	1 – 10	3	67.18%
		Small	11 – 100	33	22.11%
		Medium	101 – 1,000	277	10.20%
		Large	1,001 – 10,000	1,689	0.51%
		Very Large	10,001 – 100,000	N/A	0.00%
Diesel	0.000001230	Very Small	1	1	22.60%
		Small	2 – 10	4	44.58%
		Medium	11 - 100	33	22.11%
		Large	101 – 1,000	277	10.20%
		Very Large	1,001 – 3,600	1,689	0.51%

[7] Mean spill volume within the spill range.

Table D-4. Spill rates and spill size distributions for spills associated with OCS pipelines, based upon all OCS spills from 2001–2015.

Oil Type[8]	Spill Rate (bbl spilled per bbl produced)	Size Class	Spill Size Range (bbl)	Mean bbl[9]	% of Spills
Light crude	0.0000013051	Very Small	1 – 10	3	56.62%
		Small	11 – 100	28	31.62%
		Medium	101 – 1,000	342	9.56%
		Large	1,001 – 10,000	1,512	2.21%
		Very Large	10,001 – 100,000	N/A	0.00%
Heavy crude	0.0000013051	Very Small	1 – 10	3	56.62%
		Small	11 – 100	28	31.62%
		Medium	101 – 1,000	342	9.56%
		Large	1,001 – 10,000	1,512	2.21%
		Very Large	10,001 – 100,000	N/A	0.00%
Medium crude	0.0000013051	Very Small	1 – 10	3	56.62%
		Small	11 – 100	28	31.62%
		Medium	101 – 1,000	342	9.56%
		Large	1,001 – 10,000	1,512	2.21%
		Very Large	10,001 – 100,000	N/A	0.00%
Diesel	0.000000000497	Very Small	1	1	25.00%
		Small	2 – 10	4	75.00%
		Medium	11 - 100	N/A	0.00%
		Large	101 – 1,000	N/A	0.00%
		Very Large	1,001 – 3,600	N/A	0.00%

[8] No heavy fuel oil spills would be expected from pipelines.
[9] Mean spill volume within the spill range.

Table D-5. Spill rates and spill size distributions for spills associated with OCS service vessels, based upon spills from 1996–2010.

Oil Type	Spill Rate (bbl spilled per bbl produced)	Size Class	Spill Size Range (bbl)	Mean bbl[10]	% of Spills
Light crude	*	Very Small	1 – 10	-	-
		Small	11 – 100	-	-
		Medium	101 – 1,000	-	-
		Large	1,001 – 10,000	-	-
		Very Large	10,001 – 100,000	-	-
Heavy crude	*	Very Small	1 – 10	-	-
		Small	11 – 100	-	-
		Medium	101 – 1,000	-	-
		Large	1,001 – 10,000	-	-
		Very Large	10,001 – 100,000	-	-
Medium crude	*	Very Small	1 – 10	-	-
		Small	11 – 100	-	-
		Medium	101 – 1,000	-	-
		Large	1,001 – 10,000	-	-
		Very Large	10,001 – 100,000	-	-
Diesel	0.0000001218	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 – 3,600	n/a	0.00%

* No crude or heavy fuel oil spills would be expected from offshore supply vessels. Minor spills of other oils (lubricating oil) may occur.

[10] Mean spill volume within the spill range.

Table D-6. Spill rates and spill size distributions for spills associated with tankers transporting crude oil.*

Oil Type	Spill Rate (bbl spilled per bbl transport)	Size Class	Spill Size Range (bbl)	Mean bbl	% of Spills
Light crude	0.0000009497	Very Small	0.1 – 10	4.5	89.10%
		Small	10.1 – 100	35	7.92%
		Medium	101 – 1,000	293	1.90%
		Large	1,001 – 10,000	3,819	0.70%
		Very Large	10,001 – 100,000	31,563	0.31%
		Extra Large	Over 100,000	250,000	0.07%
Heavy crude	0.0000009497	Very Small	0.1 – 10	4.5	89.10%
		Small	10.1 – 100	35	7.92%
		Medium	101 – 1,000	293	1.90%
		Large	1,001 – 10,000	3,819	0.70%
		Very Large	10,001 – 100,000	31,563	0.31%
		Extra Large	Over 100,000	250,000	0.07%
Medium crude	0.0000009497	Very Small	0.1 – 10	4.5	89.10%
		Small	10.1 – 100	35	7.92%
		Medium	101 – 1,000	293	1.90%
		Large	1,001 – 10,000	3,819	0.70%
		Very Large	10,001 – 100,000	31,563	0.31%
		Extra Large	Over 100,000	250,000	0.07%
Diesel	0.00000117	Very Small	0.1 – 10	0.94	92.10%
		Small	10.1 – 100	33	5.74%
		Medium	101 – 1,000	266	1.56%
		Large	1,001 – 10,000	3,790	0.52%
		Very Large	10,001 – 100,000	24,881	0.07%
		Extra Large	Over 100,000	-	-

* Values presented in this table reflect the integration of data from 1974–2013 and data from 2000–2014. See the text above for details.

Table D-7. Spill rates and spill size distributions for spills associated with tankers transporting refined products.

Oil Type	Spill Rate (bbl spilled per bbl transport)	Size Class	Spill Size Range (bbl)	Mean bbl	% of Spills
Diesel	0.00000404	Very Small	0.1 – 10	4.5	89.10%
		Small	10.1 - 100	35	7.92%
		Medium	101 – 1,000	293	1.90%
		Large	1,001 – 10,000	3,819	0.70%
		Very Large	10,001 – 100,000	31,563	0.31%
		Extra Large	Over 100,000	250,000	0.07%

* Data for refined product spills from tankers are assumed to be the same as for crude oil spills from crude tankers. The values reflect the integration of data from 1974–2013 and data from 2000–2014. See the text above for details.

References

ABS Consulting Inc. 2016. 2016 update of occurrence rates for offshore oil spills. Sterling (VA): U.S. Department of the Interior, Bureau of Ocean Energy Management, Bureau of Safety and Environmental Enforcement. 95 p.

Anderson CM, Mayes M, Labelle R. 2012. Update of occurrence rates for offshore oil spills. Herndon (VA): U.S. Department of the Interior, Bureau of Ocean Energy Management, Bureau of Safety and Environmental Enforcement. 87 p. Report No.: OCS Study BOEM 2012-069, BSEE 2012-069.

Industrial Economics Inc. 2018. Forecasting environmental and social externalities associated with Outer Continental Shelf (OCS) oil and gas development, volume 1: 2018 revised Offshore Environmental Cost Model (OECM). Sterling (VA): U.S. Department of the Interior, Bureau of Ocean Energy Management. 360 p. Report No.: OCS Study BOEM 2018-066.

Energy Information Administration. 2023. Crude oil production. [accessed 2023 May 03]. https://www.eia.gov/dnav/pet/pet_crd_crpdn_adc_mbbl_a.htm.

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

SUB-APPENDIX E

Guide to the Digital Regression Files and Biological Databases

LIST OF TABLES

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 the following:

- Regression summaries for each region (coded summary table of coefficients from all individual regressions for the region);
- Supporting graphs for each individual regression, organized by region; and
- Biological data files corresponding to each region (may be one or multiple files per region).

The digital files/regressions are identified by codes for region, oil type, and offshore/nearshore location. Codes are defined in the tables below.

Table E-1. Region Codes

Code	Region
ATL	Mid-Atlantic
BEA	Beaufort Sea
BER	Bering Sea
CGM	Central GOM
CHU	Chukchi Sea
CIS	Cook Inlet/Shelikof Strait
GOA	Gulf of Alaska (North Pacific)
SCA	Southern California
SFL	Straits of Florida
WAS	Washington/Oregon

Table E-2. Offshore/Nearshore Location Codes

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

***Applies to Southern California region only

Table E-3. Oil Type Codes

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

Appendix B: Derivation of Emission Factors for Onshore Oil and Gas Production

To provide additional documentation of the data and methods incorporated into the OECM, this appendix provides a detailed description of the data and methods employed to derive the emission factors for onshore oil and gas production. 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 and gas 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.

B.1 Onshore Oil

Emissions factors for onshore oil production are based on the Western Regional Air Partnership's (WRAP) Oil and Gas Work Group 2014 emissions inventory for oil production activities in 12 western states: Alaska, Arizona, California, Colorado, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, and Wyoming (WRAP 2018). Because the WRAP inventory does not separate onshore and offshore emissions or production, Alaska and California were excluded in order to ensure that only onshore oil production was included. (Note that Idaho, Oregon, and Washington are also included in WRAP, but have no reported oil production in 2014.)

In order to extract oil emissions from the full WRAP inventory (which covered point and nonpoint oil and gas sources), a list of SCC codes associated with oil production was taken from Industrial Economics (2018) and used to categorize each emission source as "Oil," "Gas," "No match," or "Unable to be determined." The total emissions from each source were summed for each state, and the "No match" and "Unable to be determined" emissions were distributed to "Oil" or "Gas" according to the ratio between the two sources for that state. For example, in Arizona, CO_2 emissions were initially categorized as follows in Table B-1:[52]

Table B-1. Example from WRAP Inventory: CO_2 Emissions in Arizona

Source	CO_2 Emissions (tons/year)	Fraction of Oil and Gas Production Emissions Total	Estimated Emissions from Oil Production Sources
Gas Production	932,874	99.853%	N/A
Oil Production	1,373	0.147%	1,373
Total from Oil and Gas	934,247	100%	1,373
No match	36	N/A	0.054
Unable to be determined	248,449	N/A	365
Total of All Sources	1,182,732	N/A	1,738

[52] Unless noted otherwise, all values expressed as tons in this appendix represent short tons (2,000 pounds).

In this example, of the emissions from oil and gas onshore production emission sources, 0.15% were from oil production and 99.85% were from gas production. So, 0.15% of the “No match” and “Unable to be determined” emissions (365 tons) were added to the oil production total. These calculations were performed for every pollutant in each of the WRAP states listed above.

For each pollutant, the total oil production emissions were then divided by the total oil produced in all ten states to obtain emission factors in units of tons of pollutant per million barrels of oil produced. The total emissions can be found in Table B-2. These emissions were divided by the total oil production from these states shown in Table B-3.

Table B-2. Yearly Emissions from Oil Production

Pollutant	Total Emissions (tons)
NO_X	22,282
VOC	698,510
CO	26,498
SO_2	2,930
CO_2	9,050,032
PM_{10}	985
$PM_{2.5}$	985
N_2O	171
CH_4	809,444

Table B-3. 2014 Oil Production in Selected WRAP States

Factor	Value	Units
Total Oil Production	764,283	Thousand bbl/year

Table B-4 shows the resulting onshore oil production emission factors used in the OECM.

Table B-4. Onshore Oil Emission Factors

Emission Factor	CO	$PM_{2.5}$	VOC	NO_X	CO_2	SO_2	CH_4	PM_{10}	N_2O
Onshore Oil Production (tons/million bbl)	34.67	1.29	913.94	29.15	11,841.21	3.83	1,059.09	1.29	0.223

B.2 Onshore Gas

The OECM’s emissions factors for onshore gas production were derived from emissions data from the U.S. Department of Energy’s (DOE’s) National Energy Technology Laboratory (NETL 2019). Data on the gas production by basin are included in this source along with the calculated emissions by basin, representing 2016 data, in units of kg/MJ. Based on these data, separate emission factors were estimated for conventional gas production and unconventional production. The data in the NETL source provided the mean production emissions by basin in units of kg/MJ of delivered gas, with emissions from each basin reported separately for conventional wells, shale wells, and tight gas wells. Gas production data from 2016 were provided for these same basins and well types in units of million cubic feet (mcf) of natural gas produced.

For the OECM, the calculated emission factors for conventional gas represent weighted production emissions of natural gas delivered from conventional wells. The emission factors for unconventional gas represent weighted production emissions of natural gas delivered from shale or tight gas sources. The emissions by basin and well type from the NETL source were weighted according to the fraction of total gas produced for each basin. This fraction of gas production was calculated separately for conventional wells and for unconventional gas wells (tight gas and shale wells). The fraction of U.S. gas produced from each basin was then multiplied by the production emissions from that basin and then the total was summed to obtain emissions weighted by production. This calculation was performed separately for the conventional wells and the unconventional (shale and tight gas) wells. These weighted emission factors are shown in Table B-5. Finally, the emissions were converted from units of kg/MJ to tons per billion cubic feet of gas. The conversion factors used to calculate emission factors using the desired units can be found in Table B-6.

Table B-5. Base Emission Factors for Production of Conventional and Unconventional Gas

Pollutant	Conventional Gas Base Emission Factor (kg/MJ)	Unconventional Gas Base Emission Factor (kg/MJ)
NO_X	$1.83*10^{-5}$	$2.86*10^{-5}$
VOC	$9.53*10^{-8}$	$1.54*10^{-7}$
CO	$3.18*10^{-6}$	$5.46*10^{-6}$
SO_2	$9.22*10^{-8}$	$1.31*10^{-7}$
CO_2	$9.72*10^{-4}$	$1.95*10^{-3}$
PM_{10}	$2.78*10^{-5}$	$4.53*10^{-5}$
$PM_{2.5}$	$2.76*10^{-7}$	$6.01*10^{-7}$
N_2O	$1.08*10^{-9}$	$2.28*10^{-9}$
CH_4	$1.58*10^{-4}$	$6.18*10^{-5}$

Table B-6. Conversion Factors

Factor	Value	Units
Unit Conversion	0.001102311	tons/kg
Heat Content of Natural Gas (EIA 2023)	1.096	MJ/cubic feet
Unit Conversion	1,000,000,000,000	Cubic feet/trillion cubic feet

Table B-7 shows the resulting onshore natural gas production emission factors, from conventional and unconventional wells.

Table B-7. Onshore Natural Gas Emission Factors

Emission Factor	NO_X	SO_2	PM_{10}	$PM_{2.5}$	CO	VOC	CO_2	CH_4	N_2O
Onshore Natural Gas (Conventional) Production (tons/trillion cubic feet)	22,135	111	33,572	333	3,839	115	1,174,163	190,601	1.3
Onshore Natural Gas (Unconventional) Production (tons/trillion cubic feet)	34,606	158	54,742	727	6,591	186	2,360,312	74,653	2.8

B.3 References

[EIA] Energy Information Administration. 2023. Natural gas conversion calculator. Washington (DC): U.S. Department of Energy, Energy Information Administration. [accessed 2023 Apr]. https://www.eia.gov/energyexplained/units-and-calculators/energy-conversion-calculators.php.

Industrial Economics, Inc. 2018. Forecasting environmental and social externalities associated with Outer Continental Shelf (OCS) oil and gas development, volume 1: 2018 revised Offshore Environmental Cost Model (OECM). Sterling (VA): U.S. Department of the Interior, Bureau of Ocean Energy Management. 120 p + appendices. Report No.: OCS Study BOEM 2018-066.

[NETL] National Energy Technology Laboratory. 2019. Life cycle analysis of natural gas extraction and power generation. Washington (DC): U.S. Department of Energy, National Energy Technology Laboratory. 200 p. Report No.: DOE/NETL-2014/1646.

[WRAP] Western Regional Air Partnership Oil & Gas Workgroup. 2018. 2014 base case emission inventory spreadsheet. http://www.wrapair2.org/ogwg.aspx

Appendix C: Modeling the Impacts of Offshore Emissions on Onshore Air Quality

C.1 Introduction and Overview

This appendix documents the methods employed to estimate the impact of offshore criteria pollutant emissions on air quality in the contiguous U.S. 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 GOM. 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 U.S. 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 farther 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.

C.2 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 U.S. 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; therefore, 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):

$$D_{ij} = (((Lat_i - Lat_j)^2 \text{ x } 69) + ((Lon_i - Lon_j)^2 \text{ x } 53))^{0.5} \text{ x } (\cos(Lat_j/57.3))$$

where: Lat_i = latitude in source grid cell (i)

Lon_i = longitude in source grid cell (i)

Because 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):

$$\theta_{ij} = (\text{atan2}(\sin(Lon_j - Lon_i)*\cos(Lat_j),$$

$$\cos(Lat_i)*\sin(Lat_j) - \sin(Lat_i)*\cos(Lat_j)*\cos(Lon_j - Lon_i)))$$

In order to convert the resultant θ_{ij} to degrees, θ_{ij} is multiplied by $180/\Pi$, or 57.3. Finally, because (2) produces values on the interval -180°, 180°, 360° is added to θ_{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 towards 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):

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

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 because 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 (β_{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 U.S.

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.

C.3 Results

Tables C-1 and C-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 C-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 square estimates. First, the large number of observations (>8 million) results in hypothesis tests with high statistical power; note that most of the ordinary least square 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 C-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 NO_x, $PM_{2.5}$, and VOCs, the linear terms are positive, while the quadratic terms are negative. For NO_x, the cubic term also is positive. In contrast, for $PM_{2.5}$ and VOCs the cubic term is negative. Bearing appears to have a somewhat different impact on the T_{ijs} corresponding to SO_2. Specifically, the linear and cubic terms are negative while the quadratic term is positive. The nature of the functional forms for the relationship between bearing and the T_{ijs} for $PM_{2.5}$, NO_x, VOCs, and SO_2 is shown in Figure C-2. This figure indicates that for NO_x, VOCs, and $PM_{2.5}$, T_{ijs} maximizes at between approximately 45^o and 90^o. That is, if the receptor is located from the northeast to due east of the source, the T_{ijs} 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 SO_2, there is not a clear maximum before 90^o. Rather, the T_{ijs} gradually declines from 0^o to 90^o.

Conversely, Figure C-2 indicates that for each pollutant, T_{ijs} minimizes between approximately 250^o and 270^o. 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 C-3 maps (T_{ijs}) for emissions of primary $PM_{2.5}$ corresponding to four different offshore source locations. The top left panel maps the consequences of emissions from a source just offshore of southern California. Intuitively, the largest impact of emissions is concentrated in southern California. This figure clearly displays the impact of wind direction on emissions; the plume spreads from the source in a generally northeasterly direction. Recall that the effect is what Figure C-2 implies because the transfer coefficients for primary $PM_{2.5}$ emissions are greatest between 45° and 90° (northeast and due east).

The top right panel of Figure C-3 shows (T_{ijs}) for a source located off the southeastern U.S. 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 because prevailing winds send the emission to the northeast.

The bottom left panel of Figure C-3 displays the effect of emissions from a source in the Western GOM. This emission has the greatest effect on air quality in Texas and Louisiana. The figure shows that the plume is distorted towards the northeast (again, the impact of prevailing wind direction through bearing), and it also clearly shows the effect that distance between source and receptor has on the magnitude of (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 C-3 shows the impact of an emission from a source in the Eastern GOM. The greatest impact of discharges from this location are in Florida, and the impact spreads northeast over other receptors in the southeastern U.S. This panel, like the others in Figure C-3, shows the influence of both bearing and distance on (T_{ijs}).

Table C-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 C-1 where transfer coefficients reflect the impact of emissions on resulting concentrations of $PM_{2.5}$.

Table C-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 C-1.

Table C-1. Regression analysis results for primary and secondary particulate matter ($PM_{2.5}$). Dependent variable: Log T_{jis}.

	(1)	(2)	(3)	(4)
VARIABLES	NO_x	$PM_{2.5}$	SO_2	VOC
Distance	-4.76e-03***	-5.87e-03***	-4.65e-03***	-5.87e-03***
	(7.34e-06)	(8.07e-06)	(7.00e-06)	(8.07e-06)
Distance^2	3.22e-06***	3.93e-06***	3.08e-06***	3.93e-06***
	(6.96e-09)	(7.65e-09)	(6.64e-09)	(7.65e-09)
Distance^3	-7.37e-10***	-8.85e-10***	-6.92e-10***	-8.85e-10***
	(1.88e-12)	(2.07e-12)	(1.80e-12)	(2.07e-12)
Bearing	8.55e-03***	5.60e-03***	-6.08e-04***	5.60e-03***
	(4.82e-05)	(5.30e-05)	(4.60e-05)	(5.30e-05)
Bearing^2	-9.17e-05***	-7.11e-05***	2.77e-05***	-7.11e-05***
	(3.07e-07)	(3.37e-07)	(2.92e-07)	(3.37e-07)
Bearing^3	1.080e-07***	-1.45e-07***	-7.15e-08***	-1.45e-07***
	(5.62e-10)	(6.17e-10)	(5.36e-10)	(6.17e-10)
Constant	-14.79***	-14.04***	-14.80***	-14.04***
	(2.97e-03)	(3.26e-03)	(2.83e-03)	(3.26e-03)
Observations	8,512,743	8,511,952	8,511,952	8,511,952
R^2	0.183	0.189	0.162	0.189

Results shown in ordinary least squares
Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table C-2. Regression analysis results for NO_x to NO_x and SO_2 to SO_2. Dependent variable: Log T_{jis}.

	(1)	(2)
VARIABLES	NO_x – NO_x	SO_2 – SO_2
Distance	-1.14e-02***	-6.00e-03***
	(1.83e-05)	(1.00e-05)
Distance^2	1.17e-05***	3.91e-06***
	(2.22e-08)	(1.08e-08)
Distance^3	-3.31e-09***	-7.65e-10***
	(7.42e-12)	(3.27e-12)
Bearing	1.38e-02***	-1.23e-02***
	(9.65e-05)	(5.70e-05)
Bearing^2	-9.72e-05***	1.01e-04***
	(6.23e-07)	(3.60e-07)
Bearing^3	1.71e-07***	-1.99e-07***
	(1.14e-09)	(6.53e-10)
Constant	-13.06***	-13.84***
	(5.56e-03)	(3.57e-03)
Observations	2,194,075	6,500,105
R^2	0.191	0.172

Results shown in ordinary least squares
Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

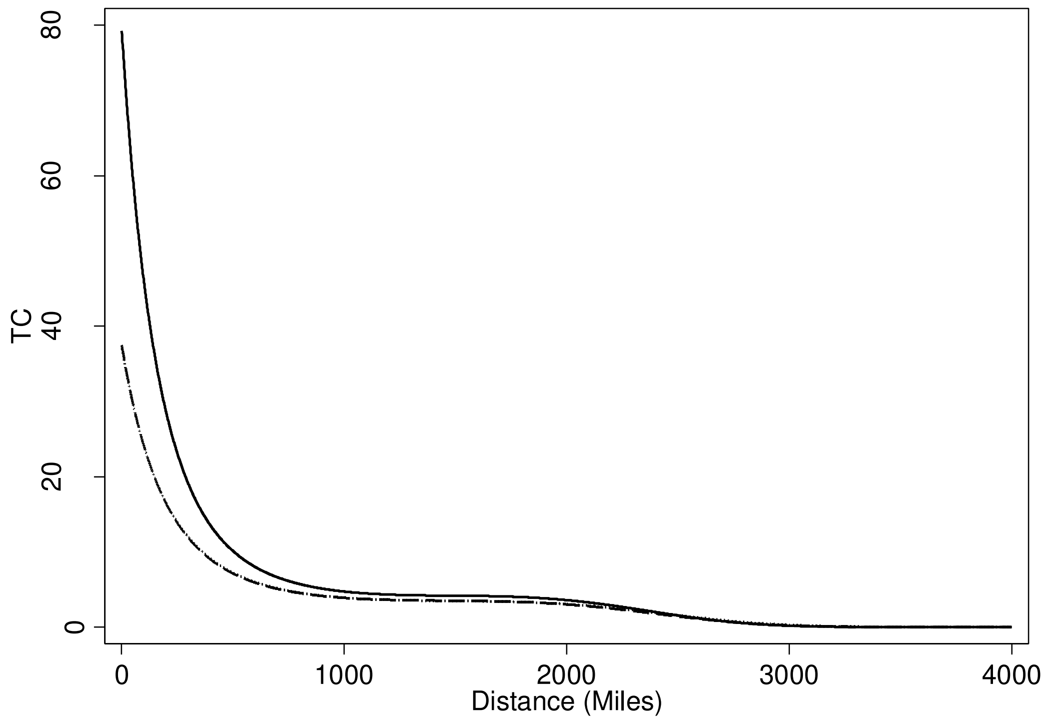


Figure C-1. Effect of distance on T_{JIS}

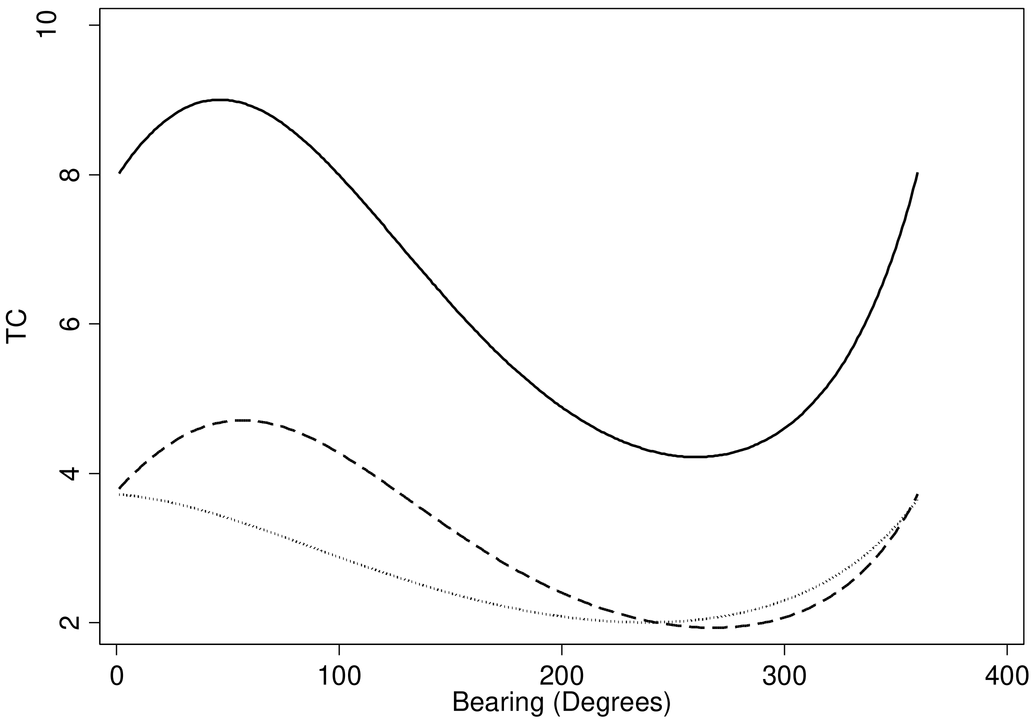


Figure C-2. Effect of direction (bearing) on Tjis

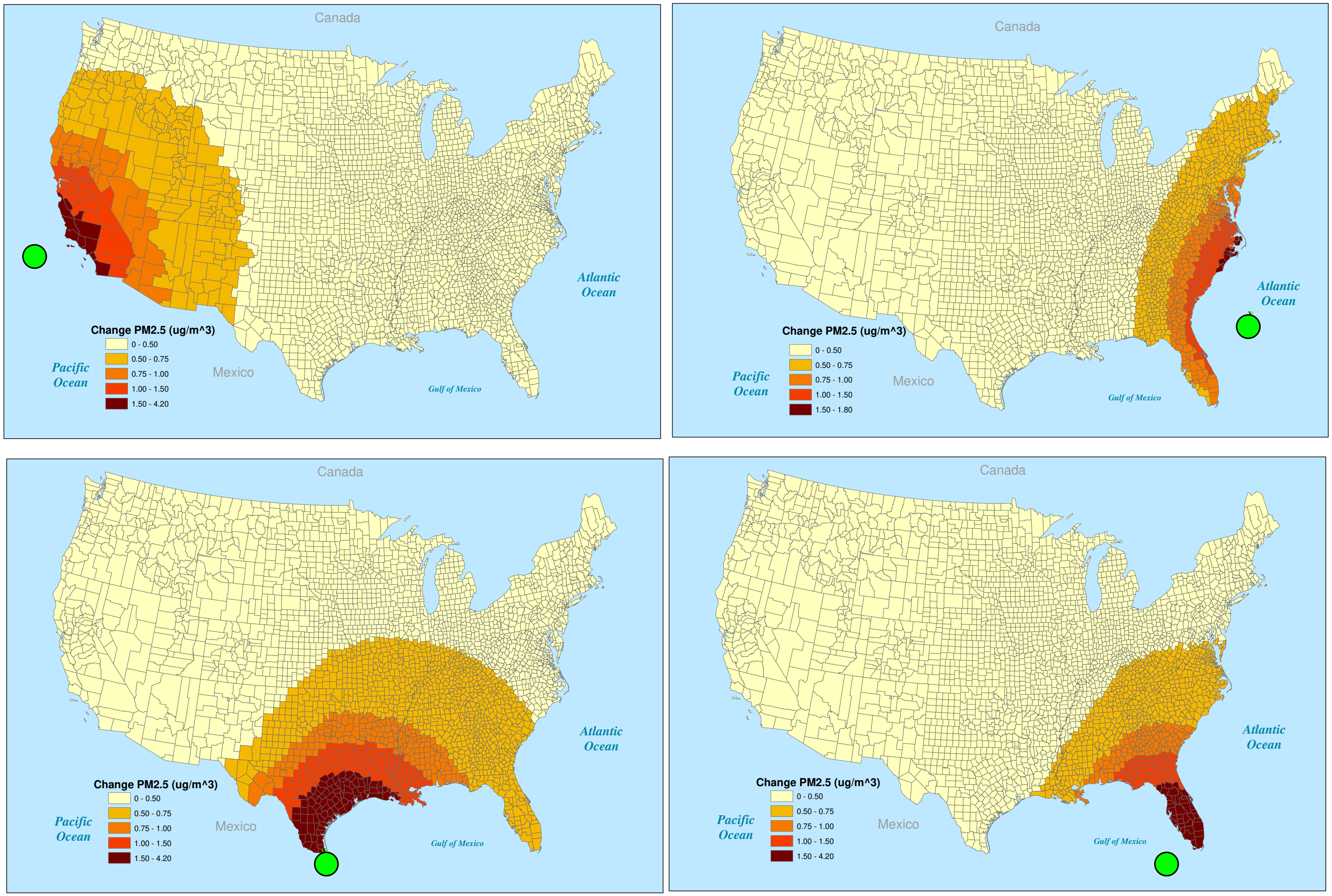


Figure C-3. Transfer coefficients: T_{ijs} for primary $PM_{2.5}$

Note: Locations of offshore emission sources, as represented by green dots in the figure, are for illustrative purposes only.

C.4 References

Muller NZ, Mendelsohn RO. 2007. Measuring the damages due to air pollution in the United States. Journal of Environmental Economics and Management. 54(1):1–14.

Muller NZ, Mendelsohn RO. 2009. Efficient pollution regulation: getting the prices right. The American Economic Review. 99(5):1714–1739.

Muller NZ, Nordhaus WD, Mendelsohn RO. 2011. Environmental accounting: methods with an application to the U.S. economy. The American Economic Review. 101(5):1649–1675.

Turner DB. 1994. Workbook of atmospheric dispersion estimates - an introduction to dispersion modeling, 2nd ed. Ann Arbor (MI): Lewis Publishers.

Appendix D: Physical Effects and Valuation Estimates for the Offshore Environmental Cost Model 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 concentration-response functions employed for each impact category, and valuation information are described.

D.1 Exposure Assessment

To estimate air pollution exposure, the APEEP model relies upon county-level estimates of receptor populations for the contiguous U.S. These receptors vary by impact category based on the exposure metrics used in the concentration-response literature. Because the magnitude of damages associated with air pollution changes over time as receptor population's 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.[53] The U.S. EPA has used BenMAP to assess the human health impacts of air pollution for several regulatory impact analyses (RIAs), 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.[54] To the extent that the U.S. population grows significantly after 2030, this leads to underestimation of impacts.

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

[53] BenMAP is available for download at http://www.epa.gov/air/benmap/.

[54] 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 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.

USDA's 2002 Census of Agriculture (USDA 2004).[55] 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 concentration-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)[56]. 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.[57] 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. Although 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.

D.2 Concentration-Response Functions

To estimate the physical effects of air pollution for exposed populations, the APEEP model will use a series of impact-specific concentration-response (C-R) functions that relate changes in ambient pollutant concentrations to changes in the risk or probability of a given effect. As detailed below, these C-R relationships are derived from several analyses in the peer-reviewed literature.

[55] Data from the 2002 Census of Agriculture are available at http://www.agcensus.usda.gov/Publications/2002/index.asp.

[56] The NAPAP has not been updated since 1991.

[57] 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 C-R functions used by the U.S. EPA in recent RIAs.

In recent years, large epidemiological cohort studies have estimated the relationship between exposure to $PM_{2.5}$ concentrations and premature mortality. The OECM model uses the C-R function from Krewski et al. (2009), a study based on the American Cancer Society cohort. This study reflects a representative range of modeled air quality concentrations relevant to the OECM and indicates that a no-threshold model[58] provides the best estimate of PM-related long-term mortality. The OECM uses Woodruff et al. (1997) concentration-response function for infant mortality. For ozone, the OECM uses Smith et al. (2009) to relate premature mortality with short-term exposure to ozone. This study is used in U.S. EPA's most recent ozone RIA.

Table D-1 summarizes the human health concentration-response information incorporated into the APEEP model to develop dollar-per-ton values for the OECM. For each health endpoint, the table identifies the study(s) used and describes how the studies for a given endpoint were pooled (where applicable).

Note that the health effects incorporated into the APEEP model, as detailed in Table D-1, include most, but not all, of the health impacts typically included in EPA's RIAs[59]. For some health effects, the 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 $PM_{2.5}$ 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[60], 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.[61] Both PM- and ozone-related mortality are reflected in the dollar-per-ton values generated by the APEEP model.

---

[58] A "no-threshold" model assumes there is no $PM_{2.5}$ concentration threshold below which health impacts do not occur. The EPA Science Advisory Board indicates that "[t]his [no-threshold] decision is supported by the data, which are quite consistent in showing effects down to the lowest measured levels. Analyses of cohorts using data from more recent years, during which time PM concentrations have fallen, continue to report strong associations with mortality" (U.S. EPA-SAB 2010).

[59] Chronic bronchitis is included in the APEEP model. In their most recent RIAs, U.S. EPA does not evaluate chronic bronchitis incidence, but because the morbidity-specific portion of the dollar-per-ton values cannot be further disaggregated, chronic bronchitis cannot be removed.

[60] Minor restricted activity days associated with ozone exposure were included in the APEEP model for this analysis. Exposure to $PM_{2.5}$ also increases the risk of experiencing minor restricted activity days, but this change in risk related to $PM_{2.5}$ was not incorporated into the APEEP model for this analysis.

[61] 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 (2010), U.S. EPA (2008), U.S. EPA (2006), and U.S. EPA (1999).

Table D-1. Summary of human health concentration-response information reflected in dollar-per-ton estimates for air quality impacts

Pollutant	Health Effect	Literature Sources For C-R Functions	C-R Coefficient Incorporated Into APEEP	Functional Form	Notes
$PM_{2.5}$	Premature mortality (age 29 and older)	Krewski et al. (2009)	0.005823	Log-linear	• Recent EPA RIAs present separate estimates of the mortality impacts of $PM_{2.5}$ based upon both the Krewski et al. (2009) and Lepeule et al. (2012) C-R functions to provide a range of air quality benefits, with Krewski et al. (2009) at the low and Lepeule et al. (2012) at the high end.[1] The OECM cannot incorporate a range of impacts for PM mortality, so includes only the C-R function from Krewski et al (2009).
$PM_{2.5}$	Infant mortality (age < 1 year)	Woodruff et al. (1997)	0.003922	Logistic	• EPA has estimated infant mortality based on the Woodruff et al. (1997) study in several RIAs.[2]
$PM_{2.5}$	Chronic bronchitis (ages 27 and older)	Abbey et al. (1995)	0.013185	Logistic	• Few studies have examined the impact of air pollution on new cases of chronic bronchitis. Abbey et al. (1995) provides evidence that long-term $PM_{2.5}$ exposure gives rise to the development of chronic bronchitis among U.S. populations.
Ozone	Premature mortality (all ages)[3]	Smith et al (2009)	0.00032	Log-linear	• EPA's RIA for the ozone NAAQS (U.S. EPA, 2015) estimates changes in ozone-related mortality based on Smith et al. (2009) and Zanobetti and Schwartz (2008) to provide low- and high-end benefits estimates, respectively. As noted above, the OECM is unable to provide a range of benefits estimates, so uses Smith et al. (2009). • Because EPA RIAs 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.

Pollutant	Health Effect	Literature Sources For C-R Functions	C-R Coefficient Incorporated Into APEEP	Functional Form	Notes
Ozone	Respiratory hospital admissions (adults aged 65 and older)	Pooled estimate of city-specific C-R coefficients from the following studies, using the random effects pooling procedure described in Abt Associates (2008): • Schwartz (1995): New Haven • Schwartz (1995): Tacoma	0.002994	Log-linear	• The Schwartz (1995) assessments for New Haven and Tacoma examined respiratory hospital admissions associated with all respiratory disease. • EPA RIAs also have used results from the Moolgavkar et al. (1997) Minneapolis and Schwartz (1994b) Detroit studies. Because each of these studies estimate separate C-R coefficients for multiple respiratory conditions that may lead to hospitalization (i.e., they estimate C-R functions for multiple types of respiratory hospital admissions), it was not possible to pool the C-R coefficients from these studies with those from the New Haven, Tacoma, and Minneapolis studies, each of which estimates just one C-R coefficient. • EPA RIAs 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 C-R coefficient from this study with those from Schwartz (1995).
Ozone	Respiratory hospital admissions (age < 2 years)	Burnett et al. (2001)	0.008177	Log-linear	• Several recent EPA RIAs relied upon the Burnett et al. (2001) study to estimate ozone-related changes in respiratory hospital admissions among children less than 2 years old.[4]
Ozone	Asthma-related emergency room visits (all ages)	Pooled estimate of C-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	• This is consistent with the C-R functions employed in the U.S. EPA (2010).
Ozone	Minor restricted activity days (ages 18–64)	Pooled estimate (using fixed effects weighting) of year-specific C-R coefficients estimated in Ostro and Rothschild (1989)	0.002596	Log-linear	• Ostro and Rothschild (1989) estimate separate C-R parameter values for the years 1976 through 1981. Consistent with several EPA RIAs, the weighted average of these values was used, using the inverse of the variance of each parameter estimate as weights.[4]

Pollutant	Health Effect	Literature Sources For C-R Functions	C-R Coefficient Incorporated Into APEEP	Functional Form	Notes
Ozone	School loss days (children age 5 to 17)	Chen et al. (2000)	0.015763	Linear	• Chen et al. (2000) focused on children between the ages of 6 and 11. Based upon recommendations issued by the National Research Council (2002) and the Health Effects Subcommittee of the U.S. EPA SAB'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. • Recent EPA RIAs have developed pooled estimates of school loss days based on both Chen et al. (2000) and Gilliland et al. (2001). It was not possible to pool the C-R coefficients from these two studies because Chen et al. (2000) uses a linear specification while Gilliland et al. (2001) uses a log-linear specification.

Notes:

1. Examples of EPA RIAs that have used both the Krewski et al. (2009) and Lepeule et al. (2012) C-R functions include U.S. EPA (2012) and U.S. EPA (2015).
2. For example, see U.S. EPA (2008) and U.S. EPA (2006).
3. The ozone mortality studies referenced here use the 24-hour or 1-hour maximum ozone levels as metrics of exposure. Neither of these metrics, however, is the most relevant for characterizing population-level exposure. Because most people tend to be outdoors only during daylight hours, which is when ozone concentrations are highest, the 24-hour metric is not appropriate. In addition, the 1-hour maximum ozone metric is inconsistent with that used for the current ozone NAAQS. The most biologically relevant metric is the 8-hour maximum standard, which has been used in the ozone NAAQS since 1997. For this analysis, 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).

For example, see U.S. EPA (2010) and U.S. EPA (2008).

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

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

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)

γ = statistically estimated shape parameter

σ = statistically estimated parameter

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

Manmade Materials

The APEEP model uses C-R functions for manmade 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 C-R functions for (1) galvanized steel, (2) painted surfaces, and (3) carbonate stone surfaces.

Atteraas and Haagenrud (1982) estimate a linear C-R function relating ambient concentrations of SO_2 to the corrosion of galvanized steel. This function is based on an analysis of mass loss data from 22 field sites in Norway and is specified as follows.

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

where: ΔM = mass loss of material,

β_0, β_1 = statistically estimated parameters (6.05 and 0.22, respectively, as estimated in Atteraas and Haagenrud (1982)),

SO_2 = ambient concentration of SO_2, and

M_b = existing material quantity

Table D-2. Summary of baseline incidence rates for human health effects (rate per 100 people per year by age group)

Endpoint	<1	<2	<18	18–24	25–29	30–34	35–44	45–54	55–64	65–74	75–84	85+	Notes/Source
Mortality (all causes)	-	-	0.045	0.093	0.119	0.119	0.211	0.437	1.056	2.518	5.765	15.16	Center for Disease Control (CDC) compressed mortality file, accessed via CDC Wonder (1996–1998)
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)	0.7037	-	-	-	-	-	-	-	-	-	-	-	Derived from 2002 mortality data, CDC multiple cause-of-death public-use data files
Chronic Bronchitis	-	-	-	-	0.378	-	-	-	-	-	-	-	Abbey et al. (1993), for ages 27+
Respiratory Hospital Admissions (all respiratory, ages 65 and older)	-	-	-	-	-	-	-	-	-	5.2	5.2	5.2	1999 NHDS public-use data files
Respiratory Hospital Admissions (all respiratory, ages 0 and 1) – West	-	6.059	-	-	-	-	-	-	-	-	-	-	1999 NHDS public-use data files
Same as above – South	-	5.709	-	-	-	-	-	-	-	-	-	-	1999 NHDS public-use data files
Same as above – Northeast	-	4.785	-	-	-	-	-	-	-	-	-	-	1999 NHDS public-use data files
Same as above – Midwest	-	4.938	-	-	-	-	-	-	-	-	-	-	1999 NHDS public-use data files
Asthma Emergency Room Visits	-	-	1.011	1.087	0.751	0.751	0.438	0.352	0.425	0.232	0.232	0.232	2000 NHAMCS public-use data files; 1999 NHDS public-use data files
Minor Restricted Activity Days	-	-	-	780	-	-	-	-	-	-	-	-	Ostro and Rothschild (1989)
School Loss Days	-	-	990	-	-	-	-	-	-	-	-	-	U.S. Department of Education National Center for Education Statistics (1996)

Notes:
NHDS: National Hospital Discharge Survey, see ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHDS/.
NHAMCS: National Hospital Ambulatory Medical Care Survey, see ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHAMCS/.
Northeast: Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania
Midwest: Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, Kansas
South: Delaware, Maryland, District of Columbia, Virginia, West Virginia, North Carolina, South Carolina, Georgia, Florida, Kentucky, Tennessee, Alabama, Mississippi, Arkansas, Louisiana, Oklahoma, Texas
West: Montana, Idaho, Wyoming, Colorado, New Mexico, Arizona, Utah, Nevada, Washington, Oregon, California, Alaska, Hawaii
*Cells with dashes indicate that no value was necessary, as the C-R function for that health endpoint applies only to a limited number of age groups.

For painted surfaces, the APEEP model relies upon the C-R relationship estimated by Haynie (1986), which was developed from erosion data for painted specimens exposed to both SO_2 and moisture. This function is specified as follows.

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

where: ΔM_C = mass loss of material,

β_0, β_1 = statistically estimated parameters

SO_{2C} = ambient concentration of SO_2,

pH = average pH by region, as measured by the National Atmospheric Deposition Program (NADP),

F_C = frequency exposed surface area is wet by county (C), and

R_C = annual rainfall

The model predicts the increase in erosion relative to a baseline under which pH is 5.2 and the SO_2 concentration is zero or representative of a clean environment.

The APEEP model uses the C-R function from ICP (1998) to estimate the effect of ambient SO_2 on carbonate stone surfaces. ICP's concentration-response function is based upon an extensive field exposure program in which data on materials corrosion, gaseous pollutants, precipitation, and climate parameters were collected at 39 exposure sites in 12 European countries, the U.S., and Canada. The C-R function estimated from these data is as follows.

$$\Delta S = \left(\beta_0 SO_2^{\kappa}\right) \exp^{\gamma T_C} + \left(\beta_1 R_C\right) H^+$$

where: ΔS = surface recession of material,

β_0, β_1, γ, κ = statistically estimated parameters,

SO_2 = ambient concentration of SO_2,

T_C = ambient temperature,

R_C = annual rainfall, and

H^+ = hydrogen concentration of precipitation.

In using the ICP concentration-response function, the APEEP model holds ambient temperature, annual rainfall, and the hydrogen concentration of precipitation constant.

D.3 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 applied to GDP per capita, as projected in DOE's Annual Energy Outlook (AEO) (EIA 2018).[62] The DOE data go through 2050. 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 2050 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 D-3a and D-3b contain estimates for the intervening years, and out to 2100.

[62] Mortality-related WTP estimates are adjusted for income growth using GDP per capita from the DOE's AEO for 2018. Because morbidity-related estimates are aggregated within dollar-per-ton values developed for previous versions of the OECM, morbidity-related WTP estimates could not be updated based on 2018 data and remain consistent with income growth as projected by the AEO in 2010 (i.e., from the 2015 version of the OECM).

Table D-3a. Income-Adjusted Values Per Statistical Case, by Health Endpoint: 2010–2050 (2010$).

Health Endpoint	2010	2015	2020	2025	2030	2035	2040	2045	2050
Premature mortality	$8,900,000	$9,100,000	$9,400,000	$9,600,000	$9,900,000	$10,000,000	$10,000,000	$11,000,000	$11,000,000
Chronic bronchitis	$480,000	$500,000	$530,000	$550,000	$570,000	$590,000	$610,000	$630,000	$650,000
Respiratory hospital admissions (65+)	$26,000	$26,000	$26,000	$26,000	$26,000	$26,000	$26,000	$26,000	$26,000
Respiratory hospital admissions (< 2)	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000
Asthma-related emergency room visits	$390	$390	$390	$390	$390	$390	$390	$390	$390
Minor restricted activity days	$66	$67	$68	$68	$69	$70	$71	$72	$73
School loss days	$95	$95	$95	$95	$95	$95	$95	$95	$95

Table D-3b. Income-adjusted values per statistical case, by health endpoint: 2045–2100 (2010$)

Health Endpoint	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100
Premature mortality	$11,000,000	$12,000,000	$12,000,000	$12,000,000	$13,000,000	$13,000,000	$13,000,000	$14,000,000	$14,000,000	$15,000,000
Chronic bronchitis	$680,000	$700,000	$730,000	$750,000	$780,000	$810,000	$840,000	$870,000	$900,000	$930,000
Respiratory hospital admissions (65+)	$26,000	$26,000	$26,000	$26,000	$26,000	$26,000	$26,000	$26,000	$26,000	$26,000
Respiratory hospital admissions (<2)	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000	$11,000
Asthma-related emergency room visits	$390	$390	$390	$390	$390	$390	$390	$390	$390	$390
Minor restricted activity days	$73	$74	$75	$76	$77	$78	$79	$80	$81	$82
School loss days	$95	$95	$95	$95	$95	$95	$95	$95	$95	$95

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 D-4.

Table D-4. Summary of crop prices (2010$)

Crop	Price
Corn	$4.36 per bushel
Cotton	$0.63 per pound
Peanut	$0.21 per pound
Grain Sorghum	$7.56 per hundredweight
Soybeans	$10.48 per bushel
Spring Wheat	$7.80 per bushel
Tobacco	$1.76 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 manmade materials. Based on this maintenance schedule, the model calculates the present value of materials maintenance costs using the following formula.

$$M_{rb} = \delta \text{ x } (RC_{rb}(e^{-rt}))/(1 - e^{-rt})$$

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

δ = market interest rate

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

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

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 below.

$$t^* = 5 \text{ x } (I_p/I_b)$$

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 (shown above). 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. These values are incorporated into the OECM in 2010$.

D.4 References

Abbey DE, Petersen F, Mills PK, Beeson WL. 1993. Long-term ambient concentrations of total suspended particulates, ozone, and sulfur dioxide and respiratory symptoms in a nonsmoking population. Archives of Environmental Health. 48(1):33–46.

Abbey DE, Hwang BL, Burchette RJ, Vancuren T, Mills PK. 1995. Estimated long-term ambient concentrations of PM_{10} and development of respiratory symptoms in a nonsmoking population. Archives of Environmental Health. 50(2):139–152.

Abt Associates, Inc. 2008. Environmental Benefits Mapping and Analysis Program (BenMAP) user's manual appendices (September). Research Triangle Park (NC): U.S. Environmental Protection Agencyt, Office of Air Quality Planning and Standards.

Atteraas H, Haagenrud S. 1982. Atmospheric corrosion testing in Norway. In: Atmospheric corrosion. Ailor WH, editor. New York (NY): Wiley-Interscience. p. 873–892.

Berger MC, Blomquist GC, Kenkel D, Tolley GS. 1987. Valuing changes in health risks: a comparison of alternative measures. The Southern Economic Journal. 53:967–984.

Burnett RT, Smith-Doiron M, Stieb D, Raizenne ME, Brook JR, Dales RE, Leech JA, Cakmak S, Krewski D. 2001. Association between ozone and hospitalization for acute respiratory diseases in children less than 2 years of age. American Journal of Epidemiology. 153(5):444–452.

Chen L, Jennison BL, Yang W, Omaye ST. 2000. Elementary school absenteeism and air pollution. Inhalation Toxicology. 12(11):997–1016.

[EIA] Energy Information Administration. 2018. Annual Energy Outlook 2018. Washington (DC): U.S. Energy Information Administration.

Gilliland FD, Berhane K, Rappaport EB, Thomas DC, Avol E, Gauderman WJ, London WJ, Margolis HW, McConnell R, Islam KT, Peters JM. 2001. The effects of ambient air pollution on school absenteeism due to respiratory illnesses. Epidemiology. 12(1):43–54.

Harrington W, Portney PR. 1987. Valuing the benefits of health and safety regulation. Journal of Urban Economics. 22:101–112.

Haynie FH. 1986. Atmospheric acid deposition damage to paints. Research Triangle Park (NC): Atmospheric Science Research Laboratory. Report No.: Environmental Research Brief EPA 600/M-85/019.

[ICP] International Cooperative Programme on Effects on Materials, Including Historic and Cultural Monuments. 1998. Report no 30: statistical analysis of 8 year materials exposure and acceptable deterioration and pollution levels. Stockholm (Sweden): Swedish Corrosion Institute.

Krewski D, Jerrett M, Burnett RT, Ma R, Hughes E, Shi Y, et al. 2009. Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality. Res Rep Health Eff Inst. 2009(140):5–136.

Lepeule J, Laden F, Dockery D, Schwartz J. 2012. Chronic exposure to fine particles and mortality: an extended follow-up of the Harvard Six Cities study from 1974 to 2009. Environ Health Perspect. 120(7):965–70.

Lesser VM, Rawlings JO, Spruill SE, and Somervile MC. 1990. Ozone effects on agricultural crops: statistical methodologies and estimated dose-response relationships. Crop Science. 30(1):148–155.

Moolgavkar SH, Luebeck EG, Anderson EL. 1997. Air pollution and hospital admissions for respiratory causes in Minneapolis-St. Paul and Birmingham. Epidemiology. 8(4):364–370.

[NAPAP] National Acid Precipitation Assessment Program. 1991. Acidic deposition: state of science and technology, volume III (P.M. Irving, PhD, ed.). Washington (DC): Government Printing Office.

National Research Council. 2002. Estimating the public health benefits of proposed air pollution regulations. Washington (DC): The National Academies Press. 192 p.

Ostro BD, Rothschild S. 1989. Air pollution and acute respiratory morbidity: an observational study of multiple pollutants. Environmental Research. 50(2):238–247.

Peel JL, Tolbert PE, Klein M, Metzger KB, Flanders WD, Todd K, Mulholland JA, Ryan PB, Frumkin H. 2005. Ambient air pollution and respiratory emergency department visits. Epidemiology. 16(2):164–174.

Schwartz J. 1994a. PM_{10}, Ozone, and hospital admissions for the elderly in minneapolis-St Paul, Minnesota. Archives of Environmental Health. 49(5):366–374.

Schwartz J. 1994b. Air pollution and hospital admissions for the elderly in Detroit, Michigan. American Journal of Respiratory and Critical Care Medicine. 150(3):648–655.

Schwartz J. 1995. Short term fluctuations in air pollution and hospital admissions of the elderly for respiratory disease. Thorax. 50(5):531–538.

Smith RL, Xu B, Switzer P. 2009. Reassessing the relationship between ozone and short-term mortality in U.S. urban communities. Inhalation Toxicology. 21:37–61.

[USDA] U.S. Department of Agriculture. 2004. 2002 Census of agriculture, volume 1, geographic area series, part 51. Washington (DC): U.S. Department of Agriculture, National Agricultural Statistics Service. Report No.: AC-02-A-51.

[USDA/NASS] U.S. Department of Agriculture, National Agricultural Statistics Service. 2009. Agricultural prices 2008 summary (August 2009). http://usda01.library.cornell.edu/usda/current/AgriPricSu/AgriPricSu-08-05-2009.pdf.

U.S. Department of Education National Center for Education Statistics. 1996. The condition of education 1996, Indicator 42: student absenteeism and tardiness. Washington, DC.

[U.S. EPA] U.S. Environmental Protection Agency. 1999. The benefits and costs of the Clean Air Act: 1990 to 2010: EPA report to Congress. Washington (DC): U.S. Environmental Protection Agency. Report No.: EPA 410-R-99-001.

U.S. EPA. 2006. Final PM NAAQS regulatory impact analysis. Washington (DC): U.S. Environmental Protection Agency.

U.S. EPA. 2008. Final ozone NAAQS regulatory impact analysis. Washington (DC): U.S. Environmental Protection Agency.

U.S. EPA. 2010. Summary of the updated regulatory impact analysis (RIA) for the reconsideration of the 2008 ozone National Ambient Air Quality Standard (NAAQS). Washington (DC): U.S. Environmental Protection Agency.

U.S. EPA. 2012. Regulatory Impact Analysis for the final revisions to the National Ambient Air Quality Standards for particulate matter. Research Triangle Park (NC): U.S. Environmental Protection Agency.

U.S. EPA. 2015. Regulatory Impact Analysis of the final revisions to the National Ambient Air Quality Standards for ground-level ozone. Research Triangle Park (NC): U.S. Environmental Protection Agency.

[U.S. EPA SAB] U.S. Environmental Protection Agency Science Advisory Board Health Effects Subcommittee of the Advisory Council on Clean Air Compliance Analysis. 2004. Advisory plans for health effects analysis in the analytical plan for EPA's second prospective analysis – benefits and costs of the Clean Air Act, 1990-2020. Washington (DC): U.S. Environmental Protection Agency. Report No.: EPA-SAB-COUNCIL-ADV-04-002.

U.S. EPA SAB. 2010. Review of EPA's draft health benefits of the second Section 812 Prospective Study of the Clean Air Act. Washington (DC): U.S. Environmental Protection Agency. Report No.: EPA-COUNCIL-10-001.

Wilson AM, Wake CP, Kelly T, Salloway JC. 2005. Air pollution, weather, and respiratory emergency room visits in two northern New England cities: an ecological time-series study. Environmental Research. 97(3):312–321.

Woodruff TJ, Grillo J, Schoendorf KC. 1997. The relationship between selected causes of postneonatal infant mortality and particulate air pollution in the United States. Environmental Health Perspectives. 105(6):608–612.

Zanobetti A, Schwartz J. 2008. Mortality displacement in the association of ozone with mortality: nn analysis of 48 cities in the United States. American Journal of Respiratory and Critical Care Medicine. 177(2):184-9.

Appendix E: 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 National OCS Program activity (i.e., no lease sales are scheduled for the five-year period).[63] 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.[64]

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 version used for the 2012–2017 Program 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).[65] The U.S. is divided into five PADDs: PADD 1 (East Coast), PADD 2 (Midwest), PADD 3 (GOM area), PADD 4 (Rocky Mountains), and PADD 5 (West Coast, AK, HI) (See Figure E-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 GOM 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 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.

---

[63] In practice, National OCS 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.

[64] 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.

[65] Although 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.

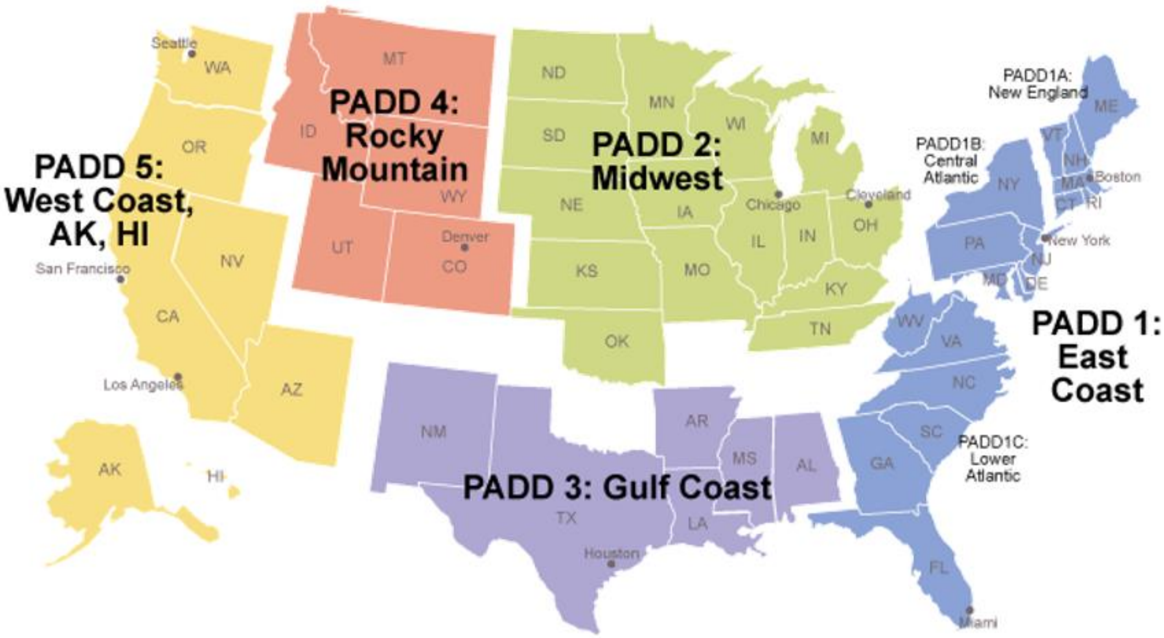


Figure E-1. Map of Petroleum Administration for Defense Districts (PADDs)

E.1 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 GOM is sent to refineries in the GOM 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 GOM 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 GOM 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 GOM ports. Based on these assumptions, 78 percent ($0.3\times0.5 + 0.7\times0.9$) of the oil imports that displace OCS production in the Central GOM would be replaced by imports to the GOM 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.[66] 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.

E.2 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. Because the majority of shipments by rail originate from North Dakota's Bakken formation[67] (located in PADD 2), it is reasonable to infer that all refinery receipts of crude oil by rail represent deliveries from PADD 2. [68]

E.3 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.[69] 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 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 E-1).

---

[66] 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

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

[67] 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#

[68] Following the completion of the analysis presented in this appendix, the EIA released a dataset which tracks movements of crude oil by rail. Although 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

[69] 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.

Table E-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
PADD 1 (East Coast)	283,040	287,076	4,036
PADD 2 (Midwest)	683,916	671,163	(12,753)
PADD 3 (Gulf Coast)	1,347,373	1,373,682	26,309
PADD 4 (Rocky Mountains)	107,879	90,009	(17,870)
PADD 5 (West Coast)	399,272	399,550	278
Total	2,821,480	2,821,480	-

Sources:

1. 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_mbbl_a.htm
2. 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_mbbl_a.htm

Additional 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 E-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 (USACE) indicate that PADD 3 received approximately 890,000 barrels of crude from Canada via waterborne methods of transportation in 2012. [70] This represents less than 2 percent of all Canadian imports processed in PADD 3 in that year.

Table E-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
Total	941,236	1,880,244

Source:

1. 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_mbbl_a.htm
2. 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_mbbl_a.htm

[70] USACE Navigation Data Center, Waterborne Commerce Statistics Center. "Foreign Cargo Inbound and Outbound." Accessed November 4, 2014, at http://www.navigationdatacenter.us/data/dataimex.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. Because PADD 2 is landlocked, this crude must have been transported from PADD 1 or PADD 3. Because 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. Because 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 E-3 displays the transport of all crude oil (both foreign and domestic) between PADDs.

Table E-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 E-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 E-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 E-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. Although 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 E-2).

Table E-4. Inter-PADD transport of foreign 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)	-	-		-	-
PADD 2 (Midwest)	-	-	45,927	-	-
PADD 3 (Gulf Coast)	4,036	15,582	-	-	-
PADD 4 (Rocky Mountains)	-	17,592	-	-	278
PADD 5 (West Coast)	-	-	-	-	-

- 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. Although 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 E-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 E-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).[71]
- 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 E-1 and the other assumptions stated above.[72]

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 E-5 provides a summary of domestic inter-PADD transfers.

[71] 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 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

[72] 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 E-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.

Table E-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)	-	-	-	-	-

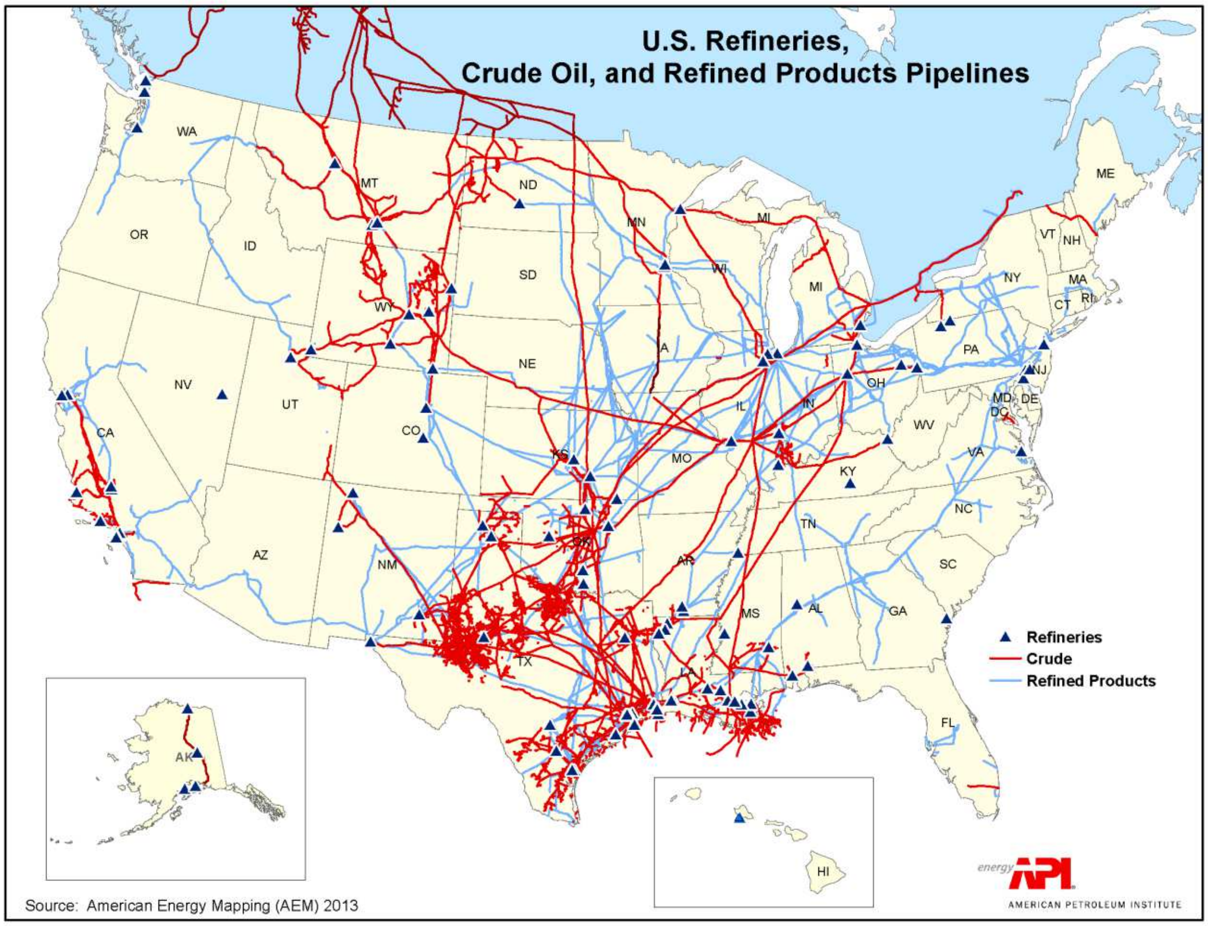


Figure E-2. Map of U.S. crude oil pipelines

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

E.4 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 E-5). Consequently, 65.3% of incremental imports resulting from forgone production in the OCS planning areas within PADD 1 (9,369 thousand barrels / 14,353 thousand barrels = 0.653), will be delivered to PADD 3, and the remaining 34.7% will be delivered to PADD 1. Table E-6 presents the allocation of incremental imports resulting from forgone production in each coastal PADD.

Table E-6. Allocation of incremental crude oil imports by PADD

PADD/OCS Region With Forgone Production	Replaced by Imports into PADD 1 (Atlantic Region)	Replaced by Imports into PADD 3 (GOM Region)	Replaced by Imports into PADD 5 (Pacific and Alaska Regions)	Total
PADD 1 (Atlantic Region)	34.7%	65.3%	0%	100%
PADD 3 (GOM Region)	0.3%	99.7%	0%	100%
PADD 5 (Pacific and AK Regions)	0%	0%	100%	100%

E.5 Distribution of Imports Within PADDs

Table E-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 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 E-7 presents the crude oil import tonnage and the percent of total PADD imports associated with each planning area.

Table E-7. Crude oil imports to U.S. ports, organized by planning area and PADD

PADD	Planning Area	Crude Oil Tonnage	Percent of PADD Imports
PADD 1	North Atlantic	40,042,470	83.9%
	Mid-Atlantic	7,274,415	15.3%
	South Atlantic	383,815	0.8%
PADD 3	Central GOM	103,701,134	40.7%
	Western GOM	151,294,769	59.3%
PADD 5	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%

Notes: PADD 1 = East Coast, corresponds to the Atlantic Region; PADD 3 = Gulf Coast, corresponds to the GOM Region; PADD 5 = West Coast, corresponds to the Pacific Region

Table E-8 combines the information in Tables F-6 and F-7 to estimate the allocation of incremental imports by planning area. The values in Table E-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 E-6 shows that 65.3% of incremental imports resulting from forgone production in PADD 1 will be delivered to PADD 3, and Table E-7 shows that 40.7% of imports into PADD 3 arrive in the Central GOM Planning Area. As a result, 26.5% (65.3% x 40.7%) of incremental imports resulting from forgone production in PADD 1 are assumed to be delivered to the Central GOM.

The values in Table E-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 1 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 GOM, 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 GOM, and 100,000 barrels for the Pacific/Alaska. Using these data in conjunction with the values in Table E-8, the estimated increase in imports to the Western GOM Planning Area is 471,000 barrels (300,000 × 0.387 + 600,000 × 0.592 + 100,000 × 0).

Table E-8. Allocation of incremental crude oil imports by planning area

PADD/OCS Region With Forgone Production	PADD 1 (Atlantic Region) North Atlantic	PADD 1 (Atlantic Region) Mid-Atlantic	PADD 1 (Atlantic Region) South Atlantic	PADD 3 (GOM Region) Central Gulf of Mexico	PADD 3 GOM (Region) Western Gulf of Mexico	PADD 5 (Pacific and Alaska Regions) Central California	PADD 5 (Pacific and Alaska Regions) Cook Inlet	PADD 5 (Pacific and Alaska Regions) Southern California	PADD 5 (Pacific and Alaska Regions) Washington/ Oregon	Total
PADD 1 (Atlantic Region)	29.1%	5.3%	0.3%	26.5%	38.7%	0.0%	0.0%	0.0%	0.0%	100%
PADD 3 (GOM 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 Regions)	0.0%	0.0%	0.0%	0.0%	0.0%	32.4%	0.5%	55.8%	11.3%	100%

E.6 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.

E.6.1 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 E-9 presents the regions of the country served by OCS production. For example, the data in Table E-9 show that nearly 20 percent of the production in the Gulf Coast region (PADD 3) is sent to the Midwest (PADD 2). Although the data in Table E-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 E-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
PADD 1 (Atlantic Region) production	15.7%	19.0%	65.3%	0.0%	0.0%	100%
PADD 3 (GOM Region) production	0.28%	19.8%	79.9%	0.0%	0.0%	100%
PADD 5 (Pacific and AK Regions) production	0.0%	0.0%	0.0%	0.0%	100.0%	100%

Source: 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_mbbl_m.htm and http://www.eia.gov/dnav/pet/pet_move_tb_dc_R20-R10_mbbl_m.htm

E.6.2 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 E-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 E-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 E-10 shows the sources of domestic crude for each region (PADD) of the U.S.

Table E-10: Sources of domestic crude for each region (PADD)

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)
Sources of crude for PADD 1 (East Coast)	4.5%	86.6%	8.8%	0.0%	0.0%
Sources of crude for PADD 2 (Midwest)	0.4%	42.7%	46.7%	10.2%	0.00%
Sources of crude for PADD 3 (Gulf Coast)	0.7%	10.3%	88.6%	0.4%	0.0%
Sources of crude for PADD 4 (Rocky Mountains)	0.0%	21.8%	0.0%	78.2%	0.0%
Sources of crude for PADD 5 (West Coast)	0.0%	0.0%	0.0%	5.9%	94.1%

Source: 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_mbbl_m.htm and http://www.eia.gov/dnav/pet/pet_move_tb_dc_R20-R10_mbbl_m.htm

Combining the information presented in Tables F-9 and F-10 yields the percentage of incremental onshore production that would be expected in each region (PADD) absent program activity (see Table E-11). For instance, Table E-11 indicates that absent program activity in the GOM 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 E-9), and PADD 2 produces 86.6% of the crude supplied to PADD 1 (Table E-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 E-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
PADD 1 (Atlantic Region)	1.2%	28.5%	68.1%	2.2%	0.0%	100%
PADD 3 (GOM Region)	0.6%	17.0%	80.1%	2.3%	0.0%	100%
PADD 5 (Pacific and Alaska Regions)	0.0%	0.0%	0.0%	5.9%	94.1%	100%

The values in Table E-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.

E.7 Geographic Distribution of Incremental Natural Gas Imports

In the absence of program activity, the U.S. may import a greater quantity of natural gas. There are only 11 natural gas import terminals in the U.S., so any increase in imports must be divided between these terminals.[73] Six of the import terminals are located along the Gulf Coast (PADD 3) and five are located along the East Coast (PADD 1).[74] 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 E-3). The quantity of LNG imports, by terminal, is presented in Table E-12.

[73] Although 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.

[74] 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.

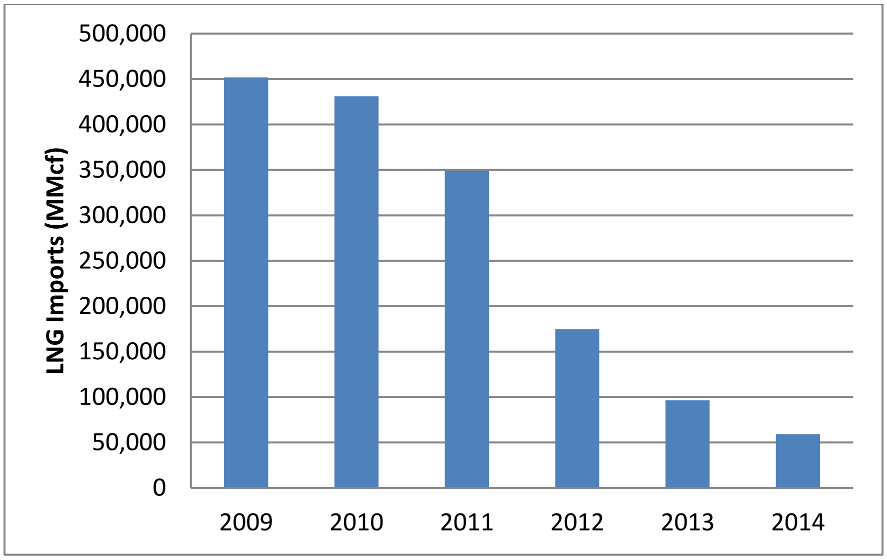


Figure E-3. U.S. LNG Imports 2009–2014

Table E-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 GOM	Cameron, LA	9,654	7,011	12,662	5,716	-	-
	Central GOM	Pascagoula, MS	-	-	5,774	-	-	-
	Central GOM	Lake Charles, LA	31,348	39,037	2,282	2,514	-	-
	Central GOM	Sabine, LA	29,097	44,819	45,610	11,902	5,750	5,880
	Western GOM	Freeport, TX	5,789	12,236	21,427	5,851	5,627	5,698
	Western GOM	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)

Because only PADD 1 (East Coast/Atlantic Region) and PADD 3 (Gulf Coast/GOM 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 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/GOM 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 GOM 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.[75]

- All natural gas produced in the Pacific and Alaska Regions (PADD 5) is either consumed within the PADD, or transported to PADD 4 (Rocky Mountains). However, PADD 5 cannot 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 Regions to PADD 3 (Gulf Coast), because PADD 3 borders PADD 5 (unlike PADD 1).

Table E-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).[76]

Table E-13: Distribution of incremental LNG imports between PADDs (MMcf, 2012)

PADD/OCS Region with Forgone Production	Replaced by Imports to PADD 1 (Atlantic Region)	Replaced by Imports to PADD 3 (Gulf of Mexico Region)	Total
PADD 1 (Atlantic Region)	100.0%	0.0%	100%
PADD 3 (GOM Region)	25.70%	74.30%	100%
PADD 5 (Pacific and Alaska Regions)	0%	100%	100%

The allocation of incremental LNG imports can be further disaggregated by combining the information in Table E-13 with the information on the distribution of imports by planning area from Table E-12. More specifically, each value in Table E-13 can be disaggregated to the individual planning areas within each PADD in proportion to current import patterns. Table E-14 summarizes the distribution of incremental LNG imports resulting from these calculations. For example, based on the data in Table E-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 GOM OCS production replaced by imports to the Atlantic Region, we estimate that approximately 16 percent ($.257 \times .61 = .157$) of the imports that displace forgone OCS production in the GOM would be shipped to ports in the North Atlantic Planning Area.

[75] 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.

[76] 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

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_mmcf_a.htm

Table E-14. Distribution of incremental LNG imports between planning areas (MMcf, 2012)

PADD/OCS Region with Forgone Production	PADD 1 (Atlantic Region) North Atlantic	PADD 1 (Atlantic Region) Mid-Atlantic	PADD 1 (Atlantic Region) South Atlantic	PADD 3 (Gulf of Mexico Region) Central Gulf of Mexico	PADD 3 (Gulf of Mexico Region) Western Gulf of Mexico	Total
PADD 1 (Atlantic Region)	61%	24%	15%	0%	0%	100%
PADD 3 (GOM Region)	16%	6%	4%	38%	37%	100%
PADD 5 (Pacific and Alaska Regions)	0%	0%	0%	51%	49%	100%

The values in Table E-14 are incorporated directly into the OECM 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 GOM, 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 GOM, and 1 trillion cubic feet for the Pacific/Alaska. Using these data in conjunction with the values in Table E-14, the estimated increase in natural gas tanker imports to the North Atlantic Planning Area is 2.34 trillion cubic feet (tcf) (2 tcf × 0.61 + 7 tcf × 0.16 + 1 tcf × 0).

E.8 Geographic Distribution of Onshore Natural Gas Production

In the absence of OCS program activity, onshore natural gas production may increase. The OECM 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.

E.8.1 Regions Served by OCS Natural Gas Production

Data on the transport of natural gas within the U.S. 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 E-15 presents PADD level production and transfers of natural gas.

Table E-15: PADD level natural gas production and transfers of natural gas (MMcf, 2012)

PADD	Production	Transfers to PADD 1	Transfers to PADD 2	Transfers to PADD 3	Transfers to PADD 4	Transfers to PADD 5
PADD 1 (East Coast)	2,965,220	-	284,260	-	-	-
PADD 2 (Midwest)	2,654,532	903,383	-	1,130,868	841,622	-
PADD 3 (Gulf Coast)	13,785,715	2,960,757	3,611,945	-	-	1,256,916
PADD 4 (Rocky Mtns)	4,087,396	-	2,790,462	462,284	-	1,838,894
PADD 5 (West Coast)	564,747	-	-	-	9,031	-

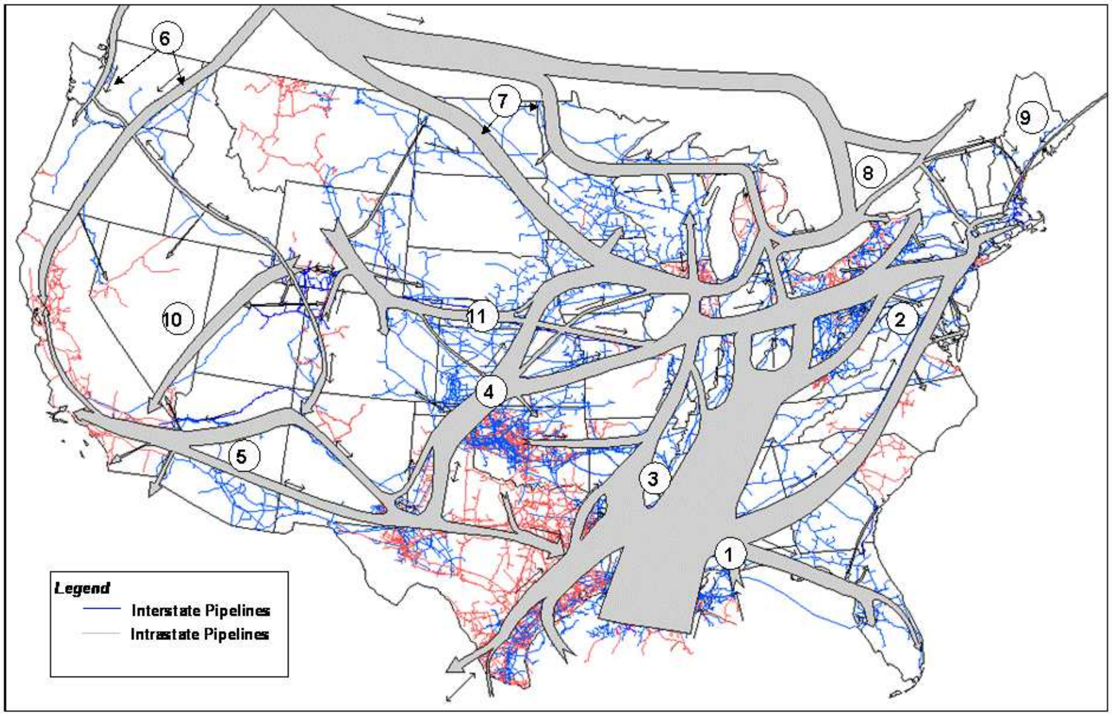
Sources:

1. 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
2. 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_mmcf_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 E-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. Although 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 E-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.



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*.

Figure E-4. Major U.S. natural gas transportation corridors (2008)[77]

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. Although 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 E-16 presents inter-PADD transfers of domestic natural gas, after subtracting transfers of imported natural gas and adjusting for intermediary transfers.

[77] 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

Table E-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
PADD 1 (East Coast)	-	284,260	-	-	-
PADD 2 (Midwest)	321,550	-	1,130,868	841,622	-
PADD 3 (Gulf Coast)	3,542,590	3,611,945	-	-	1,256,916
PADD 4 (Rocky Mountains)	-	2,036,404	462,284	-	1,220,070
PADD 5 (West Coast)	-	-	-	9,031	-

Source*:* 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

Combining the data on inter-PADD transfers of domestic natural gas (Table E-16) with PADD level production data (from Table E-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 E-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 E-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 E-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 Region)	90.4%	9.6%	0.0%	0.0%	0.0%	100%
PADD 3 (GOM Region)	25.7%	26.2%	39.0%	0.0%	9.1%	100%
PADD 5 (Pacific and Alaska Regions)	0.0%	0.0%	0.0%	1.6%	98.4%	100%

E.8.2 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 E-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 E-19).

For instance, Table E-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 E-18. Sources of domestic natural gas for each PADD

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 E-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 Region)	37.5%	5.0%	54.4%	3.1%	0.0%
PADD 3 (GOM Region)	11.7%	9.1%	62.8%	14.7%	1.7%
PADD 5 (Pacific and Alaska Regions)	0.0%	1.1%	40.8%	40.1%	18.0%

The values in Table E-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 GOM 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 F: A Comparison of Ecosystem Service Valuation and Habitat Equivalency Analysis Frameworks

F.1 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
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.

F.2 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 (U.S. EPA) defines ecosystem services as, "…the direct or indirect contributions that ecosystems make to the well-being of human populations" (U.S. EPA 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 (U.S. EPA SAB 2009; NRC 2005).[78] 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.

[78] The National Research Council distinguishes between ecosystem functions and services, as follows (NRC 2005, p. 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, 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.[79] 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?

Although 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
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 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

[79] 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).

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
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).[80] 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 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."

[80] 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; Shaw and Wlodarz 2013.

F.3 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. EPA 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 (U.S. EPA 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., viewscapes)
- 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
- **Subsistence harvest:** replacement costs for spill-related loss of marine life of cultural and subsistence value

These functions of the OECM, though 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. Table F-1 provides a comparison of the general methodological approaches, highlighting how they diverge after this first step.

Although 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). Although 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. Although 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 F-1. Comparison of general HEA and ecosystem service valuation methods

Step	HEA/REAA	Ecosystem Service Valuation
1	**Quantify the changes in ecological functions or processes associated with the injury.** 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)).	**Quantify the changes in ecological functions or processes associated with the injury.** 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	**Identify appropriate restoration project and evaluate it in terms of the degree and duration of ecological benefits that it is likely to provide.** Given the need to generalize for the purposes of the OECM, this HEA/REA step is not included.	**Identify the full suite of ecosystem services associated with the injured resources (inclusive of use and non-use values).** 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	**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.** 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.	**Quantify the ecosystem service losses for each type of service.** 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.
4	**Quantify costs of implementing the restoration project.** The OECM applies average, area-specific, per-acre coastal marsh restoration costs.	**Monetize the quantified ecosystem service losses and discount over time.** 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.

[a] HEA/REA method adapted from Zafonte and Hampton (2007) to be descriptive of the steps followed in the current OECM model.

- **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 (U.S. EPA, 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 U.S. EPA, in its September 2000 guidance document on cost-benefit analysis (U.S. EPA 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)."

F.4 Implications for the OECM

Overall, although 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.

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.[81] 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 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.

F.5 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 forgone 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.

[81] 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.

F.5 References

Batker D, de la Torre I, Costanza R, Swedeen P, Day J, Boumans R, Bagstad K. 2010. Gaining ground: wetlands, hurricanes, and the economy – the value of restoring the Mississippi Delta. Tacoma (WA): Earth Economics.

Bockstael N, Freeman AM, Kopp R, Portney P, Smith VK. 2000. On measuring economic values for nature. Environmental Science and Technology. 34(8):2000.

[CEQ] Council on Environmental Quality. 2014. Final principles, requirements and guidelines for federal investments in water resources. https://www.whitehouse.gov/administration/eop/ceq/initiatives/PandG.

Dunford RW, Ginn TC, Devousges WH. 2004. The use of habitat equivalency analysis in natural resource damage assessments. Ecological Economics. 48:49–70.

Freeman AM III, Herriges JA, Kling CL. 2014. The measurement of environmental and resource values: theory and methods, third edition. New York (NY): RFF Press.

Holland, et al. 2010. Economic analysis for ecosystem-based management, applications to marine and coastal environments, 1st edition. New York (NY): RFF Press.

[NOAA] National Oceanic and Atmospheric Administration. 2006. Habitat equivalency analysis: an overview. Silver Spring (MD): National Oceanic and Atmospheric Administration, Damage Assessment and Restoration Program. http://www.darrp.noaa.gov/economics/pdf/heaoverv.pdf.

[NRC] National Research Council. 2005. Valuing ecosystem services: toward better environmental decision-making. Washington (DC): National Academies Press.

[OMB] Office of Management and Budget. 2003. Regulatory analysis. Report No.: Circular A-4.

Roach B, Wade WW. 2006. Policy evaluation of natural resource injuries using habitat equivalency analysis. Ecological Economics. 58 421–433.

Shaw WD, Wlodarz M. 2013. Ecosystems, ecological restoration, and economics: does habitat or resource equivalency analysis mean other economic valuation methods are not needed? AMBIO. 42: 628–643.

Unsworth RE, Bishop RC. 1995. Assessing natural resource damages using environmental annuities. Ecological Economics. 11(1):35–41.

[U.S.EPA] U.S. Environmental Protection Agency. 2000. Guidelines for preparing economic analyses. http://yosemite.epa.gov/EE/epa/eed.nsf/webpages/Guidelines.html/$file/Guidelines.pdf

[U.S. EPA SAB] U.S. Environmental Protection Agency Science Advisory Board. 2009. Valuing the protection of ecological systems and services: a report of the EPA Science Advisory Board. Report No.: EPA-SAB-09-012.

Vincent, et al. 1995. Passive-use values of public forestlands: a survey of the literature. Washington (DC): U.S. Forest Service.

Zafonte M, Hampton S. 2007. Exploring welfare implications of resource equivalency analysis in natural resource damage assessments. Ecological Economics. 61(134–145).

Appendix G: Geographic Origin of Crude Oil Exports and Refined Petroleum Product Exports

G.1 Approach

Following the 2015 repeal of the U.S. ban on crude oil exports that had been in place since 1973, oil producers are now free to export U.S. crude oil, including crude oil produced on the OCS, to markets outside the U.S. To ensure that BOEM's estimates of the environmental and social costs associated with National OCS Program activity are as comprehensive as possible, the OECM estimates the environmental and social costs related to the changes in both crude oil exports and refined petroleum product exports expected under a user-defined E&D scenario.

To estimate the environmental impacts of these exports, the OECM requires information on the spatial distribution of exports (i.e., where in the U.S. exports are produced). Although MarketSim calculates total crude oil and refined product exports at the *national* level, the OECM requires estimates of exports by planning area. Therefore, MarketSim's national export estimates are allocated to individual OCS planning areas based on OCS production in each planning area and the recent historical percentage of total production that is exported from each associated OCS region. Specifically, exports are allocated according to Equation 1.

$$(1)\quad OCS\_Exports_{p,c,t} = MarketSim\_Exports_{c,t} \times Weight_{p,c,t}$$

Where:

$OCS\_Exports_{p,c,t}$ = estimated OCS exports of commodity *c* (crude oil or refined petroleum) from planning area *p* in year *t*.

$MarketSim\_Exports_{c,t}$ = total national exports of commodity *c* projected by MarketSim in year *t*.

$Weight_{p,c}$ = percentage of MarketSim exports of commodity *c* originating from planning area *p* in year *t*.

This equation estimates exports of OCS crude or refined products from each planning area by multiplying the national export quantity from MarketSim by a planning area- and commodity- (crude vs refined petroleum product) specific weight ($Weight_{p,c,t}$). The weights shown in Equation 1 are estimated based on (1) each planning area's OCS oil production for a given year (i.e., the more a planning area produces relative to other areas, the greater the share of exports allocated to that planning area), and (2) the percentage of the region's (i.e., the region where the planning area is located) crude or refined petroleum production that is exported. Equation 2 illustrates the procedure for estimating these weights.

$$(2)\quad Weight_{p,c,t} = \frac{OCS\_Production_{p,t} \times \left(\frac{State\_Exports_{r,c}}{State\_Production_{r,c}}\right)}{\sum_{p,t}\left[OCS\_Production_{p,t} \times \left(\frac{State\_Exports_{r,c}}{State\_Production_{r,c}}\right)\right]}$$

Where:

$OCS\_Production_{p,t}$ = OCS crude oil production in planning area *p* and year *t* from the E&D scenario

$State\_Exports_{r,c}$ = exports of commodity *c* from states located near OCS region *r*, based on recent data

$State\_Production_{r,c}$ = production of commodity *c* from states located near OCS region *r*, based on recent data

Equation 2 is structured such that the sum of $Weight_{p,c,t}$ across all planning areas is equal to 100 percent. Planning areas with the greatest OCS crude production and the greatest propensity for export are assigned the greatest weights according to this equation. The numerator of Equation 2 represents a synthetic estimate of OCS crude exports from a planning area, without any constraint based on the export projections from MarketSim. The denominator normalizes the numerator to ensure that the weights across planning areas sum to 100 percent.

G.2 Data Sources

Applying the approach depicted in Equations 1 and 2 above will require information on (1) crude production by planning area and (2) the percentage of each region's crude and refined petroleum production that is exported. For the former, the OECM relies on the production estimates included in a given E&D scenario. To derive the latter, the OECM uses data on the production of crude oil and refined products in the states located near each OCS region and exports of crude oil and refined petroleum products from each region.[82] The U.S. Census Bureau's USA Trade Online database provides information on monthly historical exports of crude oil and petroleum products.[83] Specifically, the "State Exports by HS Commodities" dataset tracks exports by "State of Origin of Movement" (i.e., the state from which a product begins its transport to the port of export). Additionally, the EIA provides information on monthly production of crude oil by state and net refinery and blender production by refinery district.[84] The most recent 12 months with available data was used for this analysis (March 2017 to February 2018) to capture recent trends following the lifting of the export ban.

Prior to estimating exports as a percentage of production, an adjustment to the production dataset was made. The documentation for the Census Bureau export dataset indicates that the state of transportation origin is not always tracked accurately, particularly for commodities that are consolidated by intermediaries prior to export.[85] This is an issue for the petroleum export data in particular because the dataset includes exports only for coastal states, even in the GOM Region where several adjacent states

---

[82] For the purposes of this analysis, states were assigned to OCS regions as follows:

- GOM: Alabama, Louisiana, Mississippi, and Texas
- Atlantic: Connecticut, Delaware, Georgia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, North Carolina, Pennsylvania, Rhode Island, South Carolina, and Virginia
- Pacific: California, Oregon, and Washington
- Alaska: Alaska

[83] For crude exports, HS code 2709 "Crude Oil from Petroleum and Bituminous Minerals" was used. For refined product exports, two HS codes were used: HS code 2710 "Oil (not Crude) from Petroleum and Bituminous Minerals etc." and HS Code 2711 "Petroleum Gases and other Gaseous Hydrocarbons."

[84] For the purposes of this analysis, net refinery production near each OCS region was estimated based on the following refinery districts:

- GOM: Texas Gulf Coast and Louisiana Gulf Coast refinery production
- Atlantic: East Coast refinery production
- Pacific: West Coast (incl. Alaska and Hawaii) refinery production, multiplied by the percentage of total West Coast refinery capacity in California, Washington, and Oregon
- Alaska: West Coast (incl. Alaska and Hawaii) refinery production, multiplied by the percentage of total West Coast refinery capacity in Alaska.

[85] See U.S. Census Bureau (2018c).

produce a significant amount of crude oil (e.g., Oklahoma, New Mexico). As a result, a portion of the exports attributed to coastal Gulf states in the Census Bureau dataset likely reflect oil produced and refined in neighboring non-coastal states. To calculate a more accurate percentage of production that is exported, production from neighboring non-coastal states was added to the GOM Region production total. To revise the GOM production total, data that the EIA publishes on movements of crude oil between Petroleum Administration for Defense Districts (PADDs) was used (EIA 2018b). More specifically, to calculate the percentage of crude oil and refined products exported from the GOM Region, the denominator for this calculation (see Equation 2 above) includes the total amount of crude oil and refined products produced in PADD 3 (Gulf Coast) as well as crude oil and refined products produced in PADD 2 (Midwest) that is transported to PADD 3.

Based on these adjustments to the available production and export data, Tables H-1 and H-2 below present the derivation of recent historical exports as a percentage of production for crude oil and refined petroleum products, respectively. These data are used to derive the right-hand expression in the numerator of Equation 2 and the denominator of Equation 2.

Table G-1. Crude oil production and exports by OCS region

OCS Region	Crude Production (Coastal States)	Crude Exports (Coastal States)	Exports as Percent of Production
Atlantic	6,800	626	9.21%
GOM	2,729,689	355,223	13.01%
Pacific	172,395	2,344	1.36%
Alaska	185,919	1,751	0.94%

Notes:
1. Production data reflect activity from March 2017 to February 2018 from EIA (2018a).
2. Exports data also for March 2017 to Feb 2018 from U.S. Census Bureau (2018b).
3. Crude production for the GOM Region reflects production in PADD 3 (Gulf Coast) and production from PADD 2 (Midwest) that is transported to PADD 3 from EIA (2018b).

Table G-2. Refined product production and exports by OCS region

OCS Region	Refinery Production (Coastal States)	Product Exports (Coastal States)	Exports as Percent of Production
Atlantic	1,308,219	61,617	4.71%
GOM	3,327,331	1,326,316	39.86%
Pacific	1,118,788	87,113	7.79%
Alaska	28,294	3,747	13.24%

Notes:
1. Refinery production from EIA (2018c).
2. Exports from U.S. Census Bureau (2018b).
3. Refinery production for the GOM Region reflects production in PADD 3 (Gulf Coast) and production from PADD 2 (Midwest) that is transported to PADD 3 from EIA (2018b).

G.3 Illustration

Table G-3 demonstrates the derivation of planning area-specific weights for ***crude oil*** exports. Specifically,

- Columns A and B present total production and exports for the states near each OCS region from March 2017 to February 2018 based on the EIA and Census Bureau data described above.
- Column C in the exhibit displays the percent of total crude or refined product production in states near each OCS region that was exported in the past 12 months. The percentages in this column are fixed across E&D scenarios.
- Column D presents OCS crude production for each planning area, as specified in user-defined E&D scenarios. The values included here are hypothetical and presented for illustrative purposes only.
- Column E displays the product of Columns C and D, reflecting the numerator of Equation 2 above.
- Column F displays the planning area-specific weights, calculated by dividing the value for each planning area estimated in Column E (i.e., the numerator of Equation 2) by the sum of all values in Column E (i.e., the denominator of Equation 4). This weight represents the percent of total exports from MarketSim assigned to each planning area.

Table G-4 presents the corresponding calculations for refined petroleum product exports.

G.4 Export Shipping Distance

Related to the spatial distribution of exports, the OECM requires assumptions about export shipping distances to estimate the criteria pollutant and greenhouse gas emissions associated with exports. The OECM estimates the impact of criteria pollutants based on emissions within U.S. waters only. Consistent with the model's estimation of air quality impacts related to imports, the OECM assumes that the distance that exports travel within U.S. waters is equivalent to the distance to traverse a given planning area.

Table G-3. Hypothetical distribution of crude exports by OCS planning area for a given year

OCS Region	Planning Area	Crude Production (States Near each OCS Region) [A]	Crude Exports (States Near each OCS Region) [B]	Exports as A Percent of Production [C = B / A]	E&D Scenario Crude Production (OCS) [D]	Equation 2 Numerator [E = C × D]	Percent of Total Crude Exports [F = E/ΣE]
Atlantic	North Atlantic	6,800	626	9.2%	10,000	921	1.0%
	Mid-Atlantic	6,800	626	9.2%	75,000	6,908	7.8%
	South Atlantic	6,800	626	9.2%	5,000	461	0.5%
	Straits of Florida	6,800	626	9.2%	-	-	0.0%
GOM	Eastern GOM	2,729,689	355,223	13.0%	-	-	0.0%
	Central GOM	2,729,689	355,223	13.0%	500,000	65,067	73.8%
	Western GOM	2,729,689	355,223	13.0%	100,000	13,013	14.8%
Pacific	Southern California	172,395	2,344	1.4%	50,000	680	0.8%
	Central California	172,395	2,344	1.4%	10,000	136	0.2%
	Northern California	172,395	2,344	1.4%	-	-	0.0%
	Washington/Oregon	172,395	2,344	1.4%	5,000	68	0.1%
Alaska	Cook Inlet	185,919	1,751	0.9%	50,000	471	0.5%
	Chukchi Sea	185,919	1,751	0.9%	30,000	471	0.3%
	Beaufort sea	185,919	1,751	0.9%	15,000	471	0.2%
	Every other Alaska Planning Area	185,919	1,751	0.9%	0	0	0.0%

Notes:
1. Production and export data reflect activity from March 2017 to February 2018.
2. Production for the GOM Region reflects production in PADD 3 (Gulf Coast) and production from PADD 2 (Midwest) that is transported to PADD 3.

Sources:
1. EIA (2018a).
2. U.S. Census Bureau (2018b).

Table G-4. Hypothetical distribution of refined product exports by OCS planning area for a given year

OCS Region	Planning Area	Refined Petroleum Production (States Near Each OCS Region) [A]	Refined Petroleum Exports (States Near Each OCS Region) [B]	Exports as A Percent of Production [C = B / A]	E&D Scenario Crude Production (OCS) [D]	Equation 2 Numerator [E = C × D]	Percent of Total Crude Exports [F = E/ΣE]
Atlantic	North Atlantic	1,308,219	61,617	4.7%	10,000	471	0.2%
	Mid-Atlantic	1,308,219	61,617	4.7%	75,000	3,532	1.4%
	South Atlantic	1,308,219	61,617	4.7%	5,000	235	0.1%
	Straits of Florida	1,308,219	61,617	4.7%	-	-	0.0%
GOM	Eastern GOM	3,327,331	1,326,316	39.9%	-	-	0.0%
	Central GOM	3,327,331	1,326,316	39.9%	500,000	199,306	76.3%
	Western GOM	3,327,331	1,326,316	39.9%	100,000	39,861	15.3%
Pacific	Southern California	1,118,788	87,113	7.8%	50,000	3,893	1.5%
	Central California	1,118,788	87,113	7.8%	10,000	779	0.3%
	Northern California	1,118,788	87,113	7.8%	-	-	0.0%
	Washington/Oregon	1,118,788	87,113	7.8%	5,000	389	0.1%
Alaska	Cook Inlet	28,294	3,747	13.2%	50,000	6,621	2.5%
	Chukchi Sea	28,294	3,747	13.2%	30,000	3,973	1.5%
	Beaufort sea	28,294	3,747	13.2%	15,000	1,986	0.8%
	Every other Alaska Planning Area	28,294	3,747	13.2%	-	-	0.0%

Notes:
1. Production and export data reflect activity from March 2017 to February 2018.
2. Production for the GOM Region reflects production in PADD 3 (Gulf Coast) and production from PADD 2 (Midwest) that is transported to PADD 3.

Sources:
1. EIA (2018c).
2. U.S. Census Bureau (2018b).

The OECM estimates the impacts of greenhouse gas emissions based on total shipping distances in U.S. and international waters. As a result, estimating greenhouse gas emissions from exports requires assumptions about the distances between each planning area and foreign ports. The Census Bureau's USA Trade Online database includes a dataset that tracks petroleum exports by port of export and destination country (U.S. Census Bureau 2018a). Using this database, the port in each planning area with the largest quantity of oil exports was identified. This was the assumed point of origin for each planning area. The receiving port for individual countries was assumed to be the port in each country that receives the largest quantity of petroleum imports, as identified in U.S. Army Corps of Engineers (2018).

Shipping distances were estimated between origin and destination ports using the Distances & Time tool available from SeaRates.[86] The SeaRates Distances & Time tool incorporates information from shipping lanes and various nautical agencies to estimate the shipping distances between ports. Using these data, Table G-5 displays the average shipping distances for crude oil and refined petroleum products associated with each planning area. For crude oil, the distances shown in Table G-5 reflect an average across all export destinations, weighted by the quantity of crude exported to each country from the OCS region associated with each planning area. The distances were weighted by exports from OCS regions instead of planning areas because some planning areas do not have historical crude exports to use as weights. The average shipping distance by planning area for refined product exports is based on the same methodology. However, due to the much larger number of destinations for refined product exports (175 countries), shipping distances were calculated based on the top 10 destination countries.

Table G-5. Average distance that exports are transported in international waters, by planning area of origin (miles)

Planning Area	Average Crude Oil Shipping Distance, Net of Planning Area Diameter	Average Refined Petroleum Product Shipping Distance, Net of Planning Area Diameter
North Atlantic	790	3,892
Mid-Atlantic	929	3,951
South Atlantic	1,456	4,320
Straits of Florida	1,867	4,555
Eastern GOM	5,861	4,149
Central GOM	6,172	4,244
Western GOM	6,461	4,394
Southern California	3,930	2,490
Central California	4,337	2,717
Northern California	4,541	2,784
Washington/Oregon	4,781	2,894
Alaska Planning Areas	4,439	5,354

[86] SeaRates. Distances & Time Tool. Accessed May 2018 at: https://www.searates.com/services/distances-time/

G.5 Export-Related Impacts Under the National Allocation and Regional Allocation

After estimating export-related impacts, the OECM assigns these impacts to individual planning areas, depending on whether the user has chosen the regional allocation or the national allocation. For the regional allocation, export-related impacts are allocated to the planning area(s) where these impacts occur, which is consistent with the regional allocation for all other impacts.

As described in the main body of this document, the OECM assigns impacts associated with the development of oil and gas to the planning area(s) where the oil was produced under the national allocation. Therefore, if oil is produced in the Chukchi Sea Planning Area, the oil spill impacts associated with that oil are assigned to the Chukchi Sea Planning Area, regardless of where the spill occurs (e.g., even if the oil is spilled en route to the Port of Long Beach). Applying the national allocation to export-related impacts, however, is slightly more complicated because the total change in exports is a function of E&D production across all planning areas. MarketSim does not consider the planning area(s) where oil is produced when estimating the change in exports. Thus, the standard approach of allocating impacts to where the impact-generating oil (or gas) is produced is not feasible. The OECM instead allocates export-related impacts to planning areas in proportion to the allocation of exports across planning areas. For example, if the approach described above indicates that 15 percent of crude oil exports are shipped from the Mid-Atlantic Planning Area, the OECM allocates 15 percent of all impacts associated with crude oil exports to the Mid-Atlantic Planning Area. The model performs this allocation of export-related impacts separately for crude oil exports and refined petroleum product exports.

G.6 References

[EIA] Energy Information Administration. 2018a. Crude oil production. [accessed 2018 May]. https://www.eia.gov/dnav/pet/pet_crd_crpdn_adc_mbbl_a.htm

EIA. 2018b. Movements by pipeline, tanker, barge and rail between PAD Districts. [accessed 2018 May]. https://www.eia.gov/dnav/pet/pet_move_ptb_a_EP00_TNR_mbbl_a.htm

EIA. 2018c. Refinery and blender net production. [accessed 2018 May]. https://www.eia.gov/dnav/pet/pet_pnp_refp_a_ep00_ypr_mbbl_a.htm

U.S. Army Corps of Engineers. 2018. Foreign waterborne transportation: foreign cargo inbound and outbound vessel entrances and clearances, exports 2016. [accessed 2018 May]. https://usace.contentdm.oclc.org/digital/collection/p16021coll2/id/2774/rec/7.

U.S. Census Bureau. 2018a. USA Trade Online, port-level exports. [accessed 2018 May]. https://usatrade.census.gov/

U.S. Census Bureau. 2018b. USA Trade Online, state exports by HS commodities. [accessed 2018 May]. https://usatrade.census.gov/

Department of the Interior (DOI)

The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the Nation’s trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

Bureau of Ocean Energy Management (BOEM)

The mission of the Bureau of Ocean Energy Management is to manage development of U.S. Outer Continental Shelf energy and mineral resources in an environmentally and economically responsible way.

BOEM Environmental Studies Program

The mission of the Environmental Studies Program is to provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments. The proposal, selection, research, review, collaboration, production, and dissemination of each of BOEM’s Environmental Studies follows the DOI Code of Scientific and Scholarly Conduct, in support of a culture of scientific and professional integrity, as set out in the DOI Departmental Manual (305 DM 3).