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The Potential Benefits Of Effluent Limitation Guidelines For Coastal Oil And Gas Facilities In Cook Inlet, Alaska

THE POTENTIAL BENEFITS OF EFFLUENT LIMITATION GUIDELINES FOR COASTAL OIL AND GAS FACILITIES IN COOK INLET, ALASKA

Final Report

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CONTENTS

EXECUTIVE SUMMARY

S.1 INTRODUCTION

This report provides preliminary insights into the types of benefits that are likely to result from the proposed effluent limitations guidelines for the coastal subcategory of the oil and gas extraction industry in Cook Inlet, Alaska. The proposed rulemaking will impact discharges of produced water, and drilling fluids and drill cuttings from coastal oil and gas facilities in Upper Cook Inlet. Reductions in loadings of oil and grease, total suspended solids (TSS), hydrocarbons, and metals to the inlet are anticipated as a result.

The benefits analysis provided in this report is qualitative in nature, and is not intended to provide precise benefits estimates. Additional research is necessary to quantify the potential benefits of the proposed regulation. However, the analysis shows that Cook Inlet's resources are highly valued, and that the benefits of water pollution controls in the inlet may be significant. The following sections provide a description of Cook Inlet's resources, the proposed guidelines, and potential benefits of proposed guidelines in Cook Inlet.

S.2 DESCRIPTION OF THE RESOURCES

Cook Inlet is a large tidal estuary located in southcentral Alaska. There are a wide variety of biological resources in the inlet, including microbial populations, phytoplankton, pelagic fish, groundfish, aquatic invertebrates, marine mammals, and avian species. Several endangered species may also occur in or near the inlet. And, as shown below, this ecosystem supports highly valued commercial, recreational, personal use, and subsistence fisheries.

Commercial Fisheries

Cook Inlet supports commercial finfisheries for salmon, halibut, herring, and pacific cod. The salmon fishery in Upper Cook Inlet accounts for the majority of the harvest and value. In 1993, the upper inlet commercial salmon harvest was about 5.3 million salmon while the lower inlet harvest was about 1.1 million salmon (Simpson, 1994). Sockeye salmon was the most important species in Upper Cook Inlet while halibut and herring were the most important species in Lower Cook Inlet. Cook Inlet commercial shellfisheries include clam, crabs, and shrimp. About 84% of the shellfishing value is from tanner crabs, shrimp, green urchins, and razor clams.

The total value of Cook Inlet commercial fisheries (finfish and shellfish) is estimated at approximately **$46.5 million** (in 1992 dollars). Upper Cook Inlet salmon fisheries comprise about 63% of this total.

Recreational Fisheries

Cook Inlet also supports a large and diverse recreational fishery. Cook Inlet area waters provide over 50% of the total (saltwater and freshwater) sport fishing days in Alaska (Mills, 1993). In 1992, there were an estimated 375,993 saltwater recreational fishing days in Cook Inlet (Mills, 1993). Much of this activity is focused on catching halibut and chinook salmon. Shellfishing in the inlet is mainly for razor clams. Razor clams are harvested along the eastern beaches of the Kenai Peninsula and at Polly Creek Beach and Crescent River Bar on western Cook Inlet. There were also an estimated 725,348 freshwater recreational fishing days for anadromous species (salmon, steelhead, and smelt) in the area. Local populations of these targeted species are dependent on the marine environment of Cook Inlet.

Research shows that recreational fishing opportunities in southcentral Alaska are highly valued. In one travel cost study, the authors estimated a mean willingness to pay (WTP) per choice occasion for sport fishing at various sites (Hanemann et al., 1987). In Cook Inlet, the WTP for halibut fishing at Kachemak bay was estimated at $27.2 (1986 dollars). Freshwater salmon fishing in the Cook Inlet area was especially highly valued (e.g., $53.83 for King (chinook) salmon in the Kenai River). Razor clam harvesting (all sites) was somewhat lower valued at $2.70 per choice occasion.

Multiplying the estimated site- and species-specific WTP by the number of saltwater and freshwater recreational fishing days results in baseline values of the fisheries of approximately $9.1 million and $16.8 million per year, respectively (updated to 1992 dollars). Thus, the combined baseline value of the recreational fishery is approximately **$25.9 million per year** (1992 dollars).

Personal Use Fisheries

Personal use fisheries allow Alaskan residents more liberal catch limits and harvest techniques than recreational fisheries. Approximately 50,072 salmon were harvested in Cook Inlet personal use fisheries in 1992. Although there are no estimates of the economic value of personal use fisheries in Cook Inlet, personal use fisheries provide Alaskan citizens with a food source that would otherwise have to be purchased elsewhere.

Subsistence Fisheries

Cook Inlet also provides subsistence fishery resources to Native American populations. Alaska has a unique property rights structure in which hunting and fishing rights are prioritized by law, and subsistence harvesters are given priority over both sport and commercial harvesters

(Brown and Burch, 1992). Cook Inlet was designated as a "nonsubsistence area" in 1992 by the Alaska Board of Fisheries. However, exceptions were provided to the Alaska Native Villages of Tyonek, Port Graham, and English Bay (Nelson, 1994). Tyonek is located on the northwestern shore of Cook Inlet and has a population of 121. The villages of Port Graham and English Bay, with populations of 145 and 161 respectively, are located near the mouth of Cook Inlet on Kachemak Bay.

The three Cook Inlet subsistence fisheries had a total harvest of 6,583 salmon. Tyonek, English Bay, and Port Graham also have subsistence shellfisheries. The Tyonek people utilize clamming beds south of their village on the western shore of Cook Inlet. Tyonek clamming parties harvest about 3,000 razor clams, butter clams, and cockles annually. English Bay and Port Graham villagers have traditionally harvested shellfish from areas near the mouth of Kachemak Bay. Shellfish resources harvested at English Bay and Port Graham include clams, chiton, cockles, mussels, crabs, shrimp, octopus, and snails.

There are no estimates of the economic value of the Cook Inlet subsistence fisheries. However, Cook Inlet's subsistence fisheries provide a food source to Alaskan Native populations that would otherwise have to be purchased elsewhere. In addition, subsistence fisheries are of cultural value to Alaskan Native populations in that they allow the continuance of a traditional lifestyle dependent on the natural resources of the Inlet.

Total Baseline Fishery Value

Table S-1 provides a summary of the baseline fishery values. In 1992 dollars, the estimated value of Cook Inlet's commercial and recreational fisheries is approximately $72.4 million per year. In addition, personal use and subsistence fisheries provide a food source and cultural values to Alaskan residents and Alaskan native populations.

S.3 IMPACT OF THE PROPOSED REGULATION

Regulatory options for Cook Inlet were considered in conjunction with all areas of the Gulf of Mexico. Options were developed separately for drilling fluids (muds) and drill cuttings and for produced water, as shown in Tables S-2 and S-3. EPA is co-proposing three options for the control of drilling fluids and drill cuttings, and has selected Option 4 for produced water.

Reductions in loadings of oil and grease, total suspended solids, aromatic hydrocarbons, and metals from eight facilities in Cook Inlet are anticipated as a result of the proposed guidelines.[1] For drilling fluids and drill cuttings, loadings are expected to be reduced by 3,868,896 pounds (17%) under Option 2. Under Option 3, reductions total 22,739,018 pounds

[1] Reductions in radionuclides are also expected in produced waters.

(100%). (No loadings reductions are associated with Option 1.) For produced water, reductions in loadings of 1,502,566 pounds (43%) are anticipated under selected Option 4.

Of the contaminants found in coastal oil and gas effluents, aromatic hydrocarbons and metals are of special concern to aquatic organisms. The anticipated reductions in loadings of these two pollutant groups from the eight facilities resulting from combinations of alternative and selected options are summarized in Table S-4.

Table S-1
Annual Baseline Value of Cook Inlet[1] Fisheries (1992 dollars)

Fishery	Value ($ Millions)
Commercial[2] (Finfisheries and Shellfisheries)	**$46.5**
Recreational[3]	
Saltwater	$9.1
Freshwater	$16.8
Total Recreational	**$25.9**
Personal Use	++
Subsistence	++
TOTAL	**> $72.4**

1 Refers to the entire Cook Inlet
2 Commercial revenues from fishing. Revenues may overstate producer surplus as they do not account for costs.
3 Consumer surplus.
++ Value is positive but not quantified.

Table S-2
Coastal Oil and Gas Effluent Limitations Guidelines for Cook Inlet
Options Considered for Drilling Fluids and Drill Cuttings[1]

Option 1	Offshore limitations (including 30,000 ppm toxicity limit in the suspended particulate phase (SPP))
Option 2	Offshore limitations with a more stringent toxicity limit (between 100,000 and one million ppm (SPP))
Option 3	Zero discharge

1 All options require zero discharge in the Gulf of Mexico.
Note: Option 2 is more stringent that Option 1.

Table S-3
Coastal Oil and Gas Effluent Limitations Guidelines for Cook Inlet: Options Considered for Produced Water

Option 1	BPT[1] for Gulf of Mexico and Cook Inlet
Option 2	Offshore limitations for Gulf of Mexico and Cook Inlet
Option 3	Zero discharge for Gulf of Mexico and BPT[1] for Cook Inlet
Option 4*	Zero discharge for Gulf of Mexico and offshore limitations for Cook Inlet
Option 5	Zero discharges for Gulf of Mexico and Cook Inlet

1 Best Practicable Technology (limitations for oil and grease of: (1) 48 mg/l as a monthly per-day average; and (2) 72 mg/l as a daily maximum).
* Selected option.

Table S-4
Summary of Anticipated Loadings Reductions for Aromatic Hydrocarbons and Metals from Impacted Facilities in Cook Inlet

Guideline Reduction Options	Aromatic Hydrocarbons - pounds reduced (% Reduction*)	Metals - pounds reduced (% Reduction*)
Drilling Fluids and Drill Cuttings (Option 2)	157 (100%)	176,070 (17%)
Drilling Fluids and Drill Cuttings (Option 3)	157 (100%)	1,035,705 (100%)
Produced Water (Option 4)	109,151 (61%)	548,154 (36%)
Combined (Option 2 for Drilling Fluids and Drill Cuttings)	109,308 (61%)	724,224 (28%)
Combined (Option 3 for Drilling Fluids and Drill Cuttings)	109,308 (61%)	1,583,859 (62%)

* Percent reduction reflects reduction of loadings from facilities, not total loadings reductions for Cook Inlet.

S.4 POTENTIAL BENEFITS OF THE PROPOSED REGULATION

The continuous long-term release of contaminants found in coastal oil and gas effluents may have a negative impact upon Cook Inlet's natural resources. Aquatic organisms, in particular, may be adversely affected by exposure to these pollutants, and detrimental impacts may occur even at low concentration levels. Thus, ecologic improvements may result from reductions in current loadings. Because Alaska appeals to the American public as an unspoiled wilderness and the fact that the inlet supports many important species, society is likely to value these improvements.

This section describes the potential ecologic impacts of the contaminants found in coastal oil and gas effluents and the potential improvements resulting from the proposed guidelines. Then, general concepts applicable to the benefits analysis and the potential nonuse values resulting from the proposed guidelines are discussed.

Potential Impacts of Contaminants found in Coastal Oil and Gas Effluents on Cook Inlet's Biotic Resources

The continuous, long-term release of low levels of contaminants present in drilling fluids and drill cuttings and produced waters is of particular concern for the natural resources in marine and estuarine habitats, such as Cook Inlet. Chronic pollution of such areas should be carefully evaluated with respect to the maintenance of the coastal and offshore fishing grounds, and the abiotic and biotic resources that sustain the fisheries. Knowledge of the fates, exposure pathways, and effects of the contaminants found in coastal oil and gas effluents is necessary for understanding the potential impacts of the discharges and the potential benefits of the proposed guidelines.

Fate: Physical, Chemical, Biotic Transformation. The fate of contaminants associated with coastal oil and gas discharges in Cook Inlet is a function of the Inlet's unique physical, chemical, and biological characteristics that influence the weathering processes and distribution of the contaminants. Following discharge into coastal waters, the chemical composition of the effluents are transformed by combinations of physical, chemical, and biological processes that disperse the pollutants in the environment. Eventually, it should be expected that these contaminants will be widely distributed among sediments, soils, water, air, and biota in the marine/estuarine environment in which the discharge takes place. It should be noted that the biodegradation of certain hydrocarbons does not necessarily result in products (or metabolites) that are less toxic than the parent pollutant. In fact, the biodegradation of a small proportion of aromatic hydrocarbons (e.g., benzo(a)pyrene) produces metabolites that are more toxic than the parent compound, resulting in mutagenic and carcinogenic chemicals (NRC, 1985).

Exposure Pathways. Contaminants present in coastal oil and gas discharges to marine environments can effect the natural resources either through direct or indirect pathways of exposure. Direct pathways of exposure occur when natural resources come in direct contact, either singularly or in combination, with the contaminants coastal in the water column, sediments, or diet. Indirect pathways of exposure occur when habitat resources (e.g., spawning beds, prey sources) have been reduced or otherwise altered by the contaminants.

Biotic Effects. Biological organisms are effective receptors for the contaminants found in coastal oil and gas effluents through the uptake, accumulation, and eventual metabolic degradation of the various contaminants. In aquatic resources, it is critical to evaluate the effects of low concentrations of the contaminants because even low concentrations in water, sediment, or diet are likely to impair fitness, produce adverse-physiological effects that lead to death or that, at least, lower long-term survivability in the wild. There is extensive documentation on the long-term, injurious effects of oil substances at relatively low concentrations to aquatic biota in shielded or enclosed waters. Therefore, a continued need exists to evaluate the chronic toxicities of the contaminants found in coastal oil and gas effluents to help evaluate how low level exposures can reduce the viability of Cook Inlet's resident and migratory biota.

Exposure to contaminants found in coastal oil and gas effluents can impact various biological levels of organization which result in four identified biotic responses (Table S-5). The four biotic responses -- lethal toxicity, sublethal toxicity, bioaccumulation, and habitat alteration -- provide broad categorization for a multitude of specific biotic responses. The observed effects of contaminants found in coastal oil and gas pollutants on the various biological levels include a list of quantifiable endpoints ranging from lethality endpoints (death or moribundity, due to direct exposure to acutely toxic concentrations or indirect exposure to sublethal concentrations that eventually cause death) to sub-lethal endpoints due to direct or indirect exposures that cause physiological or behavioral abnormalities, including genetic mutations, behavioral changes, disease, cancer, and growth or physiological impairments.

Table S-5
Responses to Contaminants found in Coastal Oil and Gas Effluents

Biotic Response	Sub-cellular	Cellular	Organism	Population	Community	Ecosystem
Lethal Toxicity	X	X	X	X	X	X
Sublethal Toxicity	X	X	X	X	X	X
Bioaccumulation	X	X	X	X	X	X
Habitat Alteration			X	X	X	X

Evaluation of the Potential Ecologic Improvements Associated with the Effluent Guidelines in Cook Inlet

There is limited quantitative data for evaluating the potential impacts and therefore the potential benefits from the proposed effluent limitation guidelines. A complete analysis of the risks of exposing the biotic resources of Cook Inlet to the contaminants found in coastal oil and gas effluents, even at "low levels", would include the following:

1. Inventories describing resident biotic and abiotic resources of ecological, commercial, and recreational value,

2. An assessment of migratory biota utilizing Cook Inlet habitats and an assessment of the ecological interactions between resident and migratory species,

3. Development of fate and transport models to describe the biotic and abiotic uptake, distribution, transformation, and accumulation of coastal oil and gas pollutants in Cook Inlet, and

4. Knowledge of the chronic toxicity and associated biotic responses caused by exposure of ecologically important species and habitats to contaminants found in coastal oil and gas effluents.

Although a complete analysis of the potential water quality improvements in Cook Inlet from the proposed guidelines is not available, research indicates that the contaminants present in coastal oil and gas effluents have the potential to impact biological resources in the manner described above. The present concentrations of these contaminants in Cook Inlet surface waters are unlikely to cause acute, sudden lethality. Yet the current discharges provides exposure levels that could cause sublethal effects in the aquatic resources.

For example, low concentrations of the contaminants (including metals) will cause avoidance behaviors in salmon that may lead to changes in their migration patterns (e.g., Rice, 1974; Babcock, 1985). Changes in behavior or impaired physiology of the organisms may influence the production and recruitment strategies in the important fisheries resources of Cook Inlet.[2] By limiting or eliminating discharges of the contaminants, the fisheries would be less likely to avoid contaminated areas of Cook Inlet. Reducing the risk of avoidance by fishes in Cook Inlet may improve the stock production of important salmonids.

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2 Sockeye salmon runs in bays near the lower portions of Cook Inlet have been severely depressed since 1984 to the extent that the Alaska Department of Fish and Game has closed commercial, sport, and subsistence fishing to protect returning adults (in English Bay and Port Graham) (see Bucher and Hammarstrom, 1994).

Additional Cook Inlet resources that would potentially benefit from the regulation include those species and lifestages that are particularly sensitive and susceptible to contaminants found in coastal oil and gas effluents. Planktonic organisms (including planktonic fish eggs and shellfish larvae) would benefit from the regulations by reducing the risk of exposure to pollutants dispersed and transported by tides and currents in Cook Inlet. Benthic organisms (including organisms in the intertidal zone) would benefit from reduced exposures to pollutants being deposited and accumulating in the sediments. Finfish and shellfish would benefit through reductions in risk of direct exposure to water-soluble fractions of the contaminants and reductions in the risk of exposure to contaminated-food sources.

Overview of Concepts Applicable to the Benefits Analysis

The Economic Concept of Benefits. The general term benefits refers to any and all outcomes of the regulation that are considered positive; that is, that could contribute to an enhanced level of social welfare. The term "economic benefits" refers to the dollar value associated with all the expected positive impacts of the regulation (not all ecological improvements necessarily result in substantial economic benefits). Conceptually, the monetary value of benefits is embodied by the sum of the predicted changes in "consumer (and producer) surplus." These "surplus" measures are standard and widely accepted terms of applied welfare economics, and reflect the degree of well-being enjoyed by people given different levels of goods and prices (including those associated with environmental quality). These measures also reflect the standard anthropocentric approach to estimating benefits -- that all values arise from how environmental changes are perceived and valued by humans.

Overview of Benefit Categories. The benefits typically observed as a result of changes in the water resource environment are divided into use and nonuse benefits. Use benefit categories can embody both direct and indirect uses of affected waters, and the direct use category embraces both consumptive and nonconsumptive activities. In most applications to water quality improvement scenarios, the most prominent use benefit categories are those related to human health risk reductions, and those related to enhanced recreational fishing, boating and/or swimming. Recreational activities have received considerable empirical attention from economic researchers over the past two decades because they are amenable to various nonmarket valuation techniques (e.g., travel cost models). Thus, there is a considerable body of knowledge relating to recreational fishing and associated activities, and these generally indicate that water-based recreation is a highly valued activity in today's society.

Improved environmental quality can also be valued by individuals apart from any past, present or anticipated future use of the resource in question. Such nonuse values may be of a highly significant magnitude; however, the benefit value to assign to these motivations often is a matter of considerable debate. Whereas human uses of a resource can be observed directly and valued with a range of technical economic techniques, nonuse values can only be ascertained from asking survey respondents to directly reveal their values. The inability to rely on revealed behavior to ascertain nonuse values has led to considerable debate as to how to best measure such intrinsic values for applicable changes in environmental quality.

Among the more relevant nonuse values associated with the proposed effluent limitations are "ecologic benefits." The potential ecologic benefits from the proposed regulations in Cook Inlet may also ultimately translate into measurable use benefits.

Potential Nonuse Values

There is insufficient data on the expected ecologic improvements in Cook Inlet or society's willingness to pay for water quality improvements in Cook Inlet to quantify the benefits of the proposed guidelines. Nonetheless, as suggested by McCollum et al. (1992), because Alaska's resources are unique and viewed as "the last bastion of unspoiled wildlife habitat," it is probable that nonuse values (including existence and bequest values) held by nonresidents are very large, and may even outweigh use values.

The baseline value of Cook Inlet's commercial and recreational fisheries is approximately $72.4 million per year (1992 dollars); in addition, there are important personal use and subsistence fisheries in the Inlet. Therefore, nonuse values for the inlet may be large, and even small positive changes in these values (benefits) may be significant.

Research associated with the Exxon Valdez oil spill in Alaska's Prince William Sound shows that society holds very high nonuse values for Alaska's resources. A study of the lost nonuse value associated with the spill indicated that households were willing to pay $31.90 per household, or $2.9 billion nationwide (in 1992 dollars) to avoid an oil spill of similar magnitude in the future (Carson et al., 1992). Given the magnitude of nonuse values held by the non-Alaskan public for Prince William Sound, it is probable that nonuse values for Cook Inlet are also high.

S.5 CONCLUSIONS

In conclusion, although there is limited information with which to assess the benefits of the proposed effluent limitations guidelines for Cook Inlet, research shows that even low levels of contaminants found in coastal oil and gas discharges have the potential to impact the inlet's aquatic resources. Loadings reductions associated with the proposed guidelines may ultimately result in measurable improvements in uses of the resources; society may also value these improvements apart from any past, present, or anticipated use of the resources.

There are no available estimates of WTP for the anticipated loadings reductions. However, evidence suggests that nonuse values for Cook Inlet are likely to be very large. Thus, even small changes in these values may be significant. Based on the estimated annual baseline use value of Cook Inlet's commercial and recreational fisheries alone ($72.4 million, 1992 dollars) and the estimated costs of the co-proposed and selected options ($2.24 million, $3.6 million, and $6.1), changes in baseline fishery-related values attributable to the proposed guidelines of 3.1%, 5.0%, and 8.5%, respectively, would be required for the monetized portion of benefits to equal costs. This comparison considers only increases in baseline values for a portion of the total use value of the Inlet, and does not include changes in some use and all nonuse values that are likely to result from the rulemaking. As discussed above, there is reason to believe that nonuse values may be as large or larger than use values.

CHAPTER 1
INTRODUCTION

1.1 SCOPE AND PURPOSE OF THE REPORT

This report is intended to provide preliminary insight into the types of benefits likely to accrue from proposed effluent limitation guidelines for coastal oil and gas facilities in Cook Inlet, Alaska. The proposed rulemaking is anticipated to impact discharges of produced waters and drilling fluids and drill cuttings from eight produced water outfalls and 36 new drilling wells[1] in Upper Cook Inlet. Reduced loadings of oil and grease, TSS, hydrocarbons, and metals to Cook inlet are anticipated as a result.

Because no new scientific research was conducted in Cook Inlet, the analysis of benefits from the regulation provided below is primarily qualitative, and is not intended to provide precise benefit estimates. The emphasis is on the potential impacts of coastal oil and gas discharges to biotic resources, and how the regulation may generate benefits by reducing these discharges. Further research is required to more accurately quantify these benefits. Nonetheless, as described in the body of this report, Cook Inlet's resources are highly valued. Thus, the potential benefits from water pollution controls in the inlet may be significant.

1.2 ORGANIZATION OF THE REPORT

This report is organized as follows. Chapter 2 provides a general description of the resources and estimated baseline values of important fisheries dependent on Cook Inlet's aquatic environment. Chapter 3 provides information on the anticipated impact of the proposed regulation on coastal oil and gas discharges in Cook Inlet. Finally, Chapter 4 provides a qualitative description of the potential benefits of the proposed regulation.

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[1] Nineteen recompletions are also anticipated.

CHAPTER 2
DESCRIPTION OF THE RESOURCES

This chapter provides a description of the natural resources in Cook Inlet, and the estimated baseline values for these resources. Section 2.1 describes the physical characteristics of the inlet and the recreational opportunities it provides. Section 2.2 discusses the biological resources of the inlet, including endangered and sensitive populations. Section 2.3 describes important fisheries dependent on the aquatic environment, and where possible, the estimated value of these fisheries.

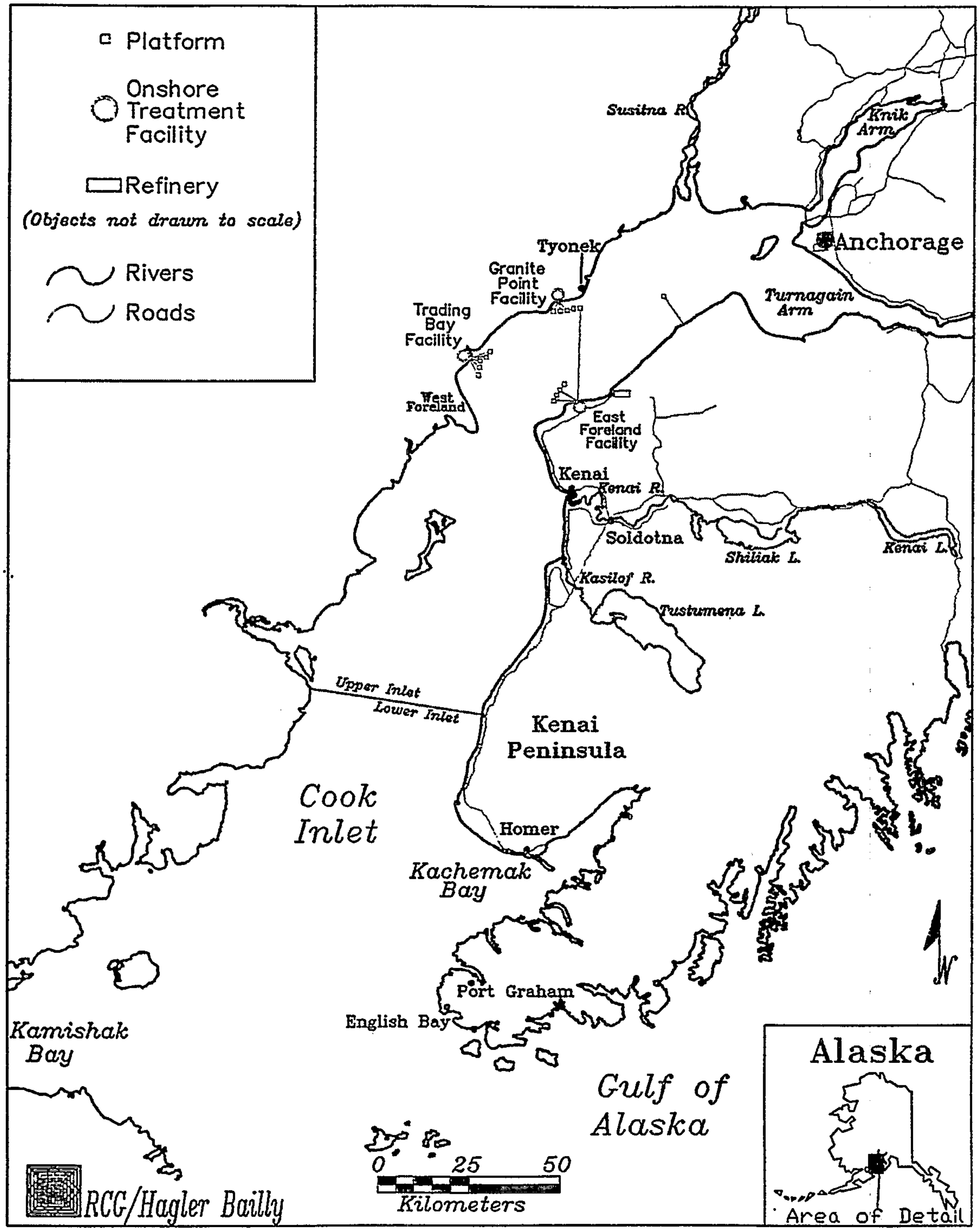
2.1 PHYSICAL CHARACTERISTICS

Cook Inlet is a tidal estuary located in southcentral Alaska. It is approximately 175 miles long and ranges in width from 12 to 55 miles. Cook Inlet is divided into two regions: Upper Cook Inlet and Lower Cook Inlet. Upper Cook Inlet begins north of Anchor Point at the Forelands and extends northeast towards Anchorage. Lower Cook Inlet extends from the Forelands south to the Gulf of Alaska. The Kenai Peninsula forms the eastern shore of the inlet, while the Lake Clark and Katmai National Parks and Preserves lie on much of the western border. The eight produced water outfalls in Cook Inlet impacted by the proposed effluent guidelines are located in the upper portion of the inlet. A map of Cook Inlet is provided in Figure 2-1.

Cook Inlet is an extremely dynamic estuarine system and its physical characteristics influence the fate and transport of contaminants in its waters (Hyland et al., 1993). These effects are described in greater detail in Chapter 4. Water movement in Cook Inlet is dominated by the tidal cycle. Normal tidal heights in the inlet vary from 5.5 meters at Kachemak Bay to 8.8 meters at Anchorage with extreme tides of over 11 meters, giving Cook Inlet some of the largest tidal ranges in the world (Hyland et al., 1993). The extreme tidal ranges produce strong tidal currents in the inlet (Minerals Management Service, 1984; Hyland et al., 1993). Due to freshwater inputs from rivers and precipitation, there is an overall outflow of water from Cook Inlet into the Gulf of Alaska.

Anchorage, Alaska's largest city, is located at the head of Cook Inlet. Population centers on the Kenai Peninsula include Kenai, Soldotna, and Homer. Route 1 on the Kenai Peninsula provides access to the Cook Inlet area's unique recreational opportunities for both Alaska residents and nonresidents. The Cook Inlet area offers opportunities for fishing, wildlife viewing, and wilderness experiences. For example, there are eleven state recreation areas along the eastern shore of Cook Inlet on the Kenai Peninsula, as well as the Kachemak Bay State Park/Wilderness Park, which is accessible by boat or plane from Homer. The state

Figure 2-1
Map of Cook Inlet, Alaska



recreation areas provide campsites, picnic areas, trails, fishing opportunities and access areas, and boat launch facilities.

2.2 BIOLOGICAL RESOURCES

There are a wide variety of biological resources in the Cook Inlet area. These resources and their viability are interrelated, and all are necessary components of the Cook Inlet ecosystem. These biological resources include microbial populations, phytoplankton, pelagic fish, groundfish, aquatic invertebrates, marine mammals, and avian species. Several endangered species may also occur in or near Cook Inlet. The following discussion is based on Minerals Management Service (1984) and Hood and Zimmerman (1987).

Intertidal and Subtidal Communities

Protected habitats, composed of unconsolidated cobble, gravel, sand, or silt, dominate this coastline. Salt marshes occur in the upper part of the Inlet. Overall standing stock biomass of kelp beds at sites in Cook Inlet were 1.98 kg/m^2. Subtidal invertebrates are rare in the turbid waters of upper Cook Inlet; however, in lower Cook Inlet, invertebrate biomass and species diversity is high. Total benthic production of lower Cook Inlet is 2.5 to 10.0 gC/m^2y. Lower Cook Inlet supports populations of Tanner, red king, and Dungeness crabs as well as shrimp. Mollusks may also be found in the area, including the chiton, weathervane scallop, razor clam, butter clam, cockle, geoduck clam, pinto abalone, and octopus. As described in Sections 2.3.1 and 2.3.2, commercial and recreational shellfisheries are very important to Cook Inlet.

Fisheries

Over 100 species of fish inhabit the Cook Inlet area. Several rivers and streams in the area (e.g., the Kasilof, Kenai, and Susitna) are critical pelagic fish spawning areas. Pelagic fish found in Cook Inlet include salmon (e.g., chinook, sockeye, coho, pink, and chum), trout (e.g., steelhead), and herring. Groundfish species include roundfish (e.g., pollock and pacific cod), rockfish (e.g., ocean perch), and flatfish (e.g., halibut). Sections 2.3.1 and 2.3.2 describe the importance of commercial and recreational fisheries in Cook Inlet.

Marine and Coastal Birds

There are a wide variety of seabirds, waterfowl, and shore birds that use the area for breeding and nesting. These include petrels, gulls, puffins, bald eagle, cackling Canada goose, Tule goose, Emperor goose, and Pacific black brant.

Marine Mammals

Nonendangered marine mammals are resident or occur seasonally in Cook Inlet, including the sea lion, fur seal, harbor seal, sea otter, and beluga whale. Most of the Gulf of Alaska population of beluga whales inhabit Cook Inlet, where they are present year-round. Several endangered cetacean (whale) species including the humpback whale, fin whale, sei whale, and gray whale may migrate to areas in or near Cook Inlet.

Zooplankton

Zooplankton in Cook Inlet serve as food for higher trophic levels including fishes, birds, and mammals. Copepods, in particular, are a critical food source for larval fish and their presence or absence affects fish production in the Gulf of Alaska. Copepods make up the majority of zooplankton biomass and are the dominant taxa in the Gulf of Alaska. There are approximately 30 other species of zooplankton that also occur with regularity in the Gulf.

Zooplankton grazing seems to control both the stock and production of phytoplankton in the open ocean. Shelf and coastal zooplankton exhibit seasonal variation in standing stock that appears to be a response to phytoplankton production. Zooplankton biomass is greatest in the summer and fall, ranging from 30 g/m^2 in the open ocean to 1,600 g/m^2 in deep inside waters. Biomass decreases in winter, with the greatest reductions occurring in the open ocean (values decline to 1.5 g/m^2), and lesser reductions in the deep inside waters (1,320 g/m^2).

Zooplankton production may reach up to 30 g C/m^2y in the upper 150 meters of the open ocean. Estimates of production over the shelf and in the inside waters range from 27 to 50 g C/m^2y.

Phytoplankton

Phytoplankton species present in abundant numbers in lower Cook Inlet include chrysophytes, diatoms, dinoflagellates, green algae, and microflagellates.

The Gulf of Alaska shelf is quite productive with respect to primary photosynthesis; annual primary production in the lower Cook Inlet is approximately 300 gC/m^2. Production may be associated with upwelling that is induced by both coastal and near-shelf water movements. In the lower Cook Inlet, this upwelling appears to play an important role in maintaining the large daily production (> 1 gC/m^2) throughout the summer.

Annual production in coastal areas is estimated to range from 140 to over 200 gC/m^2, compared to Cook Inlet production of 300 gC/m^2. Large standing crops of phytoplankton build up near the shore. Dense chlorophyll *a* concentrations usually appear briefly in surface waters, although subsurface chlorophyll *a* layers may persist throughout the summer.

Microbial Populations

Microbial populations in the Gulf of Alaska are taxonomically and physiologically diverse, and comparable in population levels to communities in other regions of the Pacific Ocean. As an important base component of food webs, microorganisms contribute to overall productivity via important roles in carbon and nitrogen cycling. For example, chum salmon fry feed heavily on harpacticoid copepods during their first few weeks in saltwater, and bacteria are the primary food of harpacticoid copepods. Microbial productivity is critical to salmonid productivity.

High rates of microbial productivity in nearshore waters appear directly related to river inputs. This occurrence was observed on a large scale in Cook Inlet. Relatively high numbers of microorganisms also occur in the top few centimeters of most marine sediments. Microbial numbers decrease in pelagic waters and in deeper sediment layers. This further supports the notion that healthy microbial communities are vital resources of Cook Inlet.

Endangered and Threatened Species

The Endangered Species Act of 1973 defines an endangered species as any species which is in danger of extinction throughout all or a significant portion of its range. The act defines a threatened species as one which is likely to become endangered within the foreseeable future. There are no animal species officially listed as threatened in the area. Neither are there any listed endangered plants in areas adjacent to Cook Inlet. The following is a list of endangered species which may occur within or near Cook Inlet.

There are at least four endangered cetacean species which may occur in or near Cook Inlet. These include the humpback whale, fin whale, sei whale, and gray whale. Other endangered cetacean species, including the blue whale and right whale, were historically abundant in or near these waters, have now become so rare (in the case of the right whale, possibly biologically extinct) as to be unlikely to found in the area.

Endangered avian species which may occur as migrants in or near Cook Inlet include the short-tailed albatross, American peregrine falcon, and Arctic peregrine falcon.

2.3 FISHERIES DEPENDENT ON COOK INLET'S AQUATIC ENVIRONMENT

Cook Inlet provides important commercial, recreational, personal use, and subsistence fisheries. Important species include salmon, halibut, herring, trout, and razor clams. A description of these fisheries is provided below. Estimated baseline values are provided for the commercial and recreational fisheries. Unless noted otherwise, the baseline values provided for Cook Inlet refer to the entire Cook Inlet.

2.3.1 Commercial Fisheries

Finfisheries

Cook Inlet supports commercial finfisheries for salmon, halibut, herring, and pacific cod. The salmon fishery in Upper Cook Inlet accounts for the majority of the commercial finfish harvest and value. In 1993, the upper inlet commercial salmon harvest was about 5.3 million salmon while the lower inlet harvest was about 1.1 million salmon (Simpson, 1994). As shown in Table 2-1, sockeye salmon was the most important commercial species in Upper Cook Inlet. Halibut and herring were the most important species in Lower Cook Inlet in 1993.

Shellfisheries

Cook Inlet supports commercial shellfisheries for a wide variety of species including clam, crabs, and shrimp. As shown in Table 2-2, about 84% of the total value of 1993 Cook Inlet commercial shellfisheries is from tanner crabs, shrimp, green urchins, and razor clams (in order of value).

Table 2-1
Cook Inlet[1] 1993 Commercial Finfisheries

Fishery	Total Harvest (lbs)	Ex-vessel Value[2] (millions)	Upper Inlet Percentage of Harvest
Chinook salmon	552,754	$0.57	95%
Sockeye salmon	29,071,042	$29.75	97%
Coho salmon	1,887,224	$0.95	96%
Pink salmon	2,665,059	$0.31	12%
Chum salmon	139,318	$0.04	97%
Halibut[3]	6,058,396	$7.06	na
Herring[3]	2,196,004	$7.06	0%
Pacific Cod	2,195,764	$0.35	0%
TOTAL	44,765,561	$46.10	

Note: Detail may not add due to rounding.
na = not available
1 Refers to the entire Cook Inlet.
2 Calculated by multiplying the pounds harvested by value per pound from Simpson, 1994.
3 Harvest from catcher/processor vessels not included.
Source: All information is from Simpson, 1994, except pounds of pacific cod harvested which is from Bectol, 1994.

Table 2-2
Cook Inlet[1] 1993 Commercial Shellfisheries

Fishery	Pounds Harvested	Ex-vessel Value (millions)
Tanner crab	284,676	$0.61
Dungeness crab	na[2]	$0.02
Razor clams	310,000	$0.16
Hardshell clams & mussels	63,676[2]	$0.13
Green urchins	195,403	$0.23
Sea cucumbers	32,005	$0.03
Scallops	20,115	$0.12
Octopus	1,292	$0.001
Shrimp (pot)	8,356	$0.03
Shrimp (trawl)	na[2]	$0.50
TOTAL		$1.83

1 Refers to the entire Cook Inlet.
2 Dungeness crab, mussel, and trawl shrimp were not reported by the Alaska Dept. of Fish and Game because 2 or less fishermen participated in the fishery.
Source: Kimker et al., 1994.

Total Commercial Value

The Alaska Department of Fish and Game estimated that the total value of Cook Inlet commercial fisheries (finfish and shellfish) in 1993 was $47.9 million ($46.1 million + $1.8 million). (For comparison to estimated values shown elsewhere in this report, the 1993 value represents **$46.5 million** in 1992 dollars.) Approximately 63% of this total was from Upper Cook Inlet salmon fisheries (Simpson, 1994).

2.3.2 Recreational Fisheries

Cook Inlet also supports a large and diverse recreational fishery. The Alaska Department of Fish and Game has found that Cook Inlet area waters provide over 50% of the total (saltwater and freshwater) sport fishing days in Alaska (Mills, 1993). The total value of these resources depends in part on active use of the fishery, measured in fishing effort, outings, or days spent fishing. Recreational use values are found by multiplying the estimated value per outing by the total number of outings taken.

Saltwater Finfishing and Shellfishing

As shown in Table 2-3, an estimated 375,993 saltwater recreational fishing days were spent in Cook Inlet in 1992 (Mills, 1993). Much of the recreational activity in the inlet is focused on catching halibut and chinook salmon. Shellfishing in the inlet is mainly for razor clams. Razor clams are harvested along the eastern beaches of the Kenai Peninsula and at Polly Creek Beach and Crescent River Bar on western Cook Inlet.

Table 2-3
Cook Inlet[1] Saltwater Sport Fishing Days by Area -- 1992

Area	Finfishing	Shellfishing	Total
Knik Arm Drainage[2]	1,540	0	1,540
Anchorage[3]	3,271	0	3,271
West Cook Inlet-West Susitna River Drainages[4]	3,267	683	3,950
Kenai Peninsula[5]	306,256	60,976	367,232
TOTAL	314,334	61,659	375,993

1 Refers to the entire Cook Inlet.
2 Coho and sockeye salmon were about 72% of total saltwater sport fish harvest.
3 Smelt were about 81% of total saltwater sport fish harvest.
4 Halibut were about 49% while chinook, coho, sockeye, and pink salmon were about 48% of total saltwater sport fish harvest. The entire shellfish harvest is comprised of razor clams.
5 Halibut were about 56% while chinook, coho, sockeye, and pink salmon were about 22% of total saltwater sport fish harvest. Razor clams and dungeness crab dominant the shellfish harvest.

Source: Mills, 1993.

Freshwater Recreational Salmon Fishing

Freshwater recreational angling for anadromous species in the rivers and streams feeding into Cook Inlet yields among the highest values for all types of recreation (Walsh et al., 1988). The salmon caught at freshwater sites are dependent on the marine environment of Cook Inlet. Table 2-4 shows the number of *freshwater* fishing days by area.

Table 2-4
Cook Inlet[1] Freshwater Anadromous Sport Fishing Days by Area -- 1992

	Fishing Days[2]	
Area	**Salmon**	**Steelhead and Smelt**
Knik Arm Drainage	57,949	0
Anchorage	23,082	47,282
West Cook Inlet-West Susitna River Drainages	74,831	24,167
Kenai Peninsula (except Kenai River main channel)	173,719	8,317
Kenai River	301,682	14,319
TOTAL	631,263	94,085

1 Refers to the entire Cook Inlet.
2 For each area, angler days calculated by allocating the total freshwater angler days using the percentage of salmon harvested.
Source: Mills, 1993.

Recreational Fishing Values

Recreational fishing opportunities in Alaska are highly valued. In one travel cost study of recreational fishing in Southcentral Alaska, the authors estimated a mean willingness to pay (WTP) per choice occasion for sport fishing at various sites (Hanemann et al., 1987). These WTP represent consumer surplus associated with recreational fishing, and vary by location and type of species, as shown in Table 2-5.

For all sport fishing in Southcentral Alaska, the average WTP is $305 per choice occasion (1986 dollars). This value represents the average angler's maximum WTP to prevent losing access to the *entire* Southcentral Alaska fishery. In comparison, the site-specific values, which are lower, represent the WTP to prevent the loss of a single fishery (which still allows the angler to substitute to other species and sites).

In Cook Inlet, the WTP for halibut fishing at Kachemak bay was estimated at $27.2 (1986 dollars). Freshwater salmon fishing in the Cook Inlet area was especially highly valued (e.g., $53.83 for King (chinook) salmon in the Kenai River). Razor clam harvesting (all sites) was somewhat lower valued at $2.70 per choice occasion.

Table 2-5
Parameter and Net Willingness to Pay (WTP)[1] Estimates from the Nonresident Angler Demand Model

Area/Site/Species	Mean WTP per Choice Occasion[2]
Southcentral Alaska	
All sport fishing	$305.13
King salmon (all sites)	$88.49
Halibut (all sites)	$35.41
Razor clams (all sites)	$2.70
Kenai River:	
King (chinook) salmon	$53.83
Silver (coho) salmon	$16.12
Other species	$10.50
Russian River:	
Red (sockeye) salmon	$9.11
Lower Streams in the Kenai Peninsula:	
All species	$4.98
Deep Creek Marine:	
King (chinook) salmon	$4.06
Halibut	$2.70
Kachemak Bay:	
Halibut	$27.20
Other species	$4.07
Resurrection Bay:	
Silver (coho) salmon	$4.52
Other species	$8.19
Other Kenai Peninsula	
All species	$5.89
Little Susitna River	
All salmon	$4.52
West Side Susitna Streams	
King (chinook) salmon	$5.87
Other species	$4.96
East Side Susitna Roadside Streams	
All salmon	$2.70
Glennallen Area	
All species	$4.52

Table 2-5 (Continued)
Parameter and Net Willingness to Pay (WTP)[1] Estimates from the Nonresident Angler Demand Model

Area/Site/Species	Mean WTP per Choice Occasion[2]
Anchorage Area All species	$5.89
Prince William Sound All species	$10.50
Southeast Alaska	
Juneau Area Marine - All species Roadside - All species	$18.20 $4.19
Other Southeast (including other freshwater - Juneau) - All species	$104.37
Southwest Alaska	
All sport fishing	$43.53
Other Alaska	
Fairbanks Area - All species	$11.45
Other - All species	$15.27

1 Consumer surplus estimates.
2 Based on 99,581 household trips (i.e., "choice occasions") made in 1986.
NA = Not applicable because no parameter is estimated.
Source: Hanemann et al., 1987.

Total Recreational Fishing Value

Saltwater. Multiplying the estimated site- and species-specific WTP from Table 2-5 and the finfishing and shellfishing days shown in Table 2-3 results in a baseline value of the saltwater recreational fishery of approximately $9.1 million per year (in 1992 dollars, updated using the CPI).[1] This total value may appear high, but in 1986, the total WTP associated with the Kachemak Bay halibut fishery alone was estimated at $8.1 million (Hanemann et al., 1987).

Freshwater. Multiplying the estimated site- and species-specific WTP from Table 2-5 by the freshwater fishing days shown in Table 2-4 results in a baseline value of approximately $16.8 million per year (in 1992 dollars, updated by the CPI).[2]

Total. Combining the saltwater and freshwater fisheries values results in an estimated baseline value of the recreational fishery of approximately **$25.9 million per year** (1992 dollars).

2.3.3 Personal Use Fisheries

Personal use fisheries allow Alaskan residents more liberal catch limits and harvest techniques than recreational fisheries. The Cook Inlet area supports both gill net and dip net personal use salmon fisheries. As shown in Table 2-6, in 1992, the Cook Inlet personal use dip net fisheries harvest (primarily salmon) totaled 38,585 salmon. The Cook Inlet personal use gill net fisheries harvested 11,487 salmon.

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1 Knik Arm Drainage and Anchorage finfishing days were valued at $5.89 per day, the WTP for fishing for all species in the Anchorage area. The West Cook Inlet/West Susitna River Drainages days were valued by a weighted average, with 50% valued at the WTP for halibut fishing at all sites ($35.41) and 50% valued at the WTP for King (chinook) salmon at West side Susitna streams ($5.87). The Kenai Peninsula days were valued by a weighted average with 56% valued by the WTP for halibut fishing at all sites ($35.41) and 44% valued at the WTP for fishing all species at other Kenai Peninsula sites ($5.89).

2 Knik Arm Drainage and Anchorage days were valued at $5.89, the WTP to fish for all species in the Anchorage area. West Cook/West Side Susitna salmon and steelhead and smelt days were valued at $5.87 and $4.96, the WTP to fish for King (chinook) salmon and other species in Westside Susitna Streams, respectively. Kenai River salmon days were valued by an average of the WTP to fish for King and Silver salmon in the Kenai River ($53.83 and $16.12, respectively). Kenai River steelhead trout and smelt days were valued at $10.50, the WTP for fishing for other species in the Kenai River. Kenai Peninsula days were valued at $5.89, the WTP for fishing for all species in other Kenai Peninsula areas.

Table 2-6
Cook Inlet[1] Personal Use Fisheries

Dip Net[2]				
Fishery	**Anglers**	**Days Fished**	**Target Species Harvest**	**Total Harvest**
Fish Creek 1992 (a)	6,681	12,249	19,002[3]	20,287
China Poot 1992 (a)	810	1,525	3,468[3]	3,727
Kenai River 1992 (a)	6,270	10,371	12,189[3]	14,125
Fox Creek 1992 (a)	199	235	437[4]	446
Total	13,960	24,380	35,096	38,585

Gill Net		
Fishery	**Target Species Harvest**	**Total Harvest**
Kasilof River 1993 (c)	7,942[3]	7,989
Fall Coho 1993 (c)	1,168[4]	1,191
Kachemak Bay 1993 (b)	1,873[4]	2,307
Total	10,983	11,487

1 Refers to the entire Cook Inlet.
2 The Kasilof River personal use dip net fishery did not occur in 1992 as abundance targets for opening the fishery were not reached (Nelson, 1994).
3 Sockeye salmon
4 Coho salmon
Sources: (a) Mills, 1993; (b) Nelson, 1994; and (c) Ruesch and Fox, 1994.

Total Personal Use Fishery Value

There are no estimates of the economic value of personal use fisheries in Cook Inlet. However, personal use fisheries provide Alaskan citizens with a food source that would otherwise have to be purchased elsewhere. Therefore, the value of the fishery could be calculated by the replacement cost of lost meals. There may also be some recreational and/or cultural value for some residents associated with these fisheries.

2.3.4 Subsistence Fisheries

Cook Inlet also provides subsistence fishery resources to Native American populations. Alaska has a unique property rights structure in which hunting and fishing rights are prioritized by law, and subsistence harvesters are given priority over both sport and commercial harvesters (Brown and Burch, 1992). Cook Inlet was designated as a "nonsubsistence area" in 1992 by the Alaska Board of Fisheries. However, exceptions were provided to the Alaska Native Villages of Tyonek, Port Graham, and English Bay (Nanwalek) (Nelson, 1994). Tyonek is located on the northwestern shore of Cook Inlet and has a population of 121. The villages of Port Graham and English Bay (Nanwalek), with populations of 145 and 161 respectively, are located near the mouth of Cook Inlet on Kachemak Bay.[3]

Finfisheries

As shown in Table 2-7, in 1993, the three Cook Inlet subsistence fisheries had a total harvest of 6,583 salmon. The Tyonek and Port Graham fisheries harvested about 11 salmon per village resident while English Bay's (Nanwalek) per capita harvest was almost twice that at 21 fish per village resident. The English Bay (Nanwalek) fishery also harvested the most salmon per permit, at about 163 fish per permit, while Port Graham harvested about 67 fish per permit and Tyonek harvested 25 fish per permit.

Shell Fisheries

Tyonek, English Bay (Nanwalek), and Port Graham also have subsistence shellfisheries. The Tyonek people utilize clamming beds south of their village on the western shore of Cook Inlet. Tyonek clamming parties harvest about 3,000 razor clams, butter clams, and cockles annually, with razor clams making up about 90% of the harvest (Stanek et al., 1982). English Bay (Nanwalek) and Port Graham villagers have traditionally harvested shellfish from areas near the mouth of Kachemak Bay. Following the Exxon Valdez oil spill, residents of these villages began utilizing areas further into Kackemak Bay and razor clam beaches across Kachemak Bay and the inlet (Stanek, 1994). Shellfish resources harvested at English Bay (Nanwalek) and Port Graham include clams, chiton, cockles, mussels, crabs, shrimp, octopus, and snails with chiton, butter clams, razor clams, and cockles being the most important (Stanek et al., 1982; Stanek, 1994).

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[3] In addition, several scientific/educational permits have been issued recently for Cook Inlet waters. In 1993 the Kenaitze Tribal Fishery harvested 2,156 salmon (about 71% sockeye), the Ninilchik Traditional Council Fishery harvested 227 salmon (about 85% coho), the Native Village of Eklutna Fishery harvested 200 salmon, and the Knik Tribal Council Fishery harvest 200 salmon (Ruesch and Fox, 1994).

Table 2-7
Cook Inlet[1] Subsistence Salmon Fisheries -- 1993

	Tyonek (a)	English Bay (Nanwalek)[2] (b)	Port Graham[2] (b)
No. of Permits	53	21	27
Salmon Harvest			
Chinook	1,247	20	248
Sockeye	43	1,018	153
Coho	36	570	302
Pink	11	1,703	978
Chum	9	115	130
Total Salmon	1,346	3,426	1,811

1 Refers to the entire Cook Inlet.
2 Traditionally, this fishery has targeted sockeye salmon returning to the English Bay Lakes system. Minimum escapement goals have not been met since 1984. In 1993 this area was closed to fishing from June 7 to July 12 to protect returning sockeye adults.
Sources: (a) Ruesch and Fox, 1994 and (b) Bucher and Hammarstrom, 1994.

Total Subsistence Fishery Value

There are no estimates of the economic value of the Cook Inlet subsistence fisheries. Several national studies of subsistence fishing are underway, but none have produced estimates of value at this stage. Like the personal use fishery, Cook Inlet's subsistence fisheries provide a food source to Alaskan Native populations that would otherwise have to be purchased elsewhere. This value could also be estimated by the cost of replacement meals. In addition, subsistence fisheries are of cultural value to Alaskan Native populations in that they allow the continuance of a traditional lifestyle dependent on the natural resources of the Inlet.

2.4 CONCLUSIONS

Cook Inlet is rich in natural resources that are highly valued by both Alaskan residents and nonresidents. Table 2-8 provides a summary of baseline fishery values. In 1992 dollars, the estimated value of Cook Inlet's commercial fishery is approximately $46.5 million. The total recreational fishery dependent on the inlet (saltwater fishing and freshwater anadromous fishing) is valued at approximately $25.9 million per year. In addition, personal use and subsistence fisheries provide a food source and cultural values to Alaskan residents and Alaskan native populations.

Table 2-8
Annual Baseline Value of Cook Inlet[1] Fisheries
(1992 dollars)

Fishery	**Value ($ Millions)**
Commercial[2] (Finfisheries and Shellfisheries)	**$46.5**
Recreational[3]	
Saltwater	$9.1
Freshwater	$16.8
Total Recreational	**$25.9**
Personal Use	++
Subsistence	++
TOTAL	**> $72.4**

1 Refers to the entire Cook Inlet
2 Commercial revenues from fishing. Revenues may overstate producer surplus as they do not account for costs.
3 Consumer surplus.
++ Value is positive but not quantified.

CHAPTER 3
IMPACT OF THE PROPOSED REGULATION

This chapter discusses the development and effects of the proposed effluent limitations for the coastal subcategory of the oil and gas extraction industry as they apply to Cook Inlet, Alaska. Section 3.1 describes the regulatory options considered and the options selected. Section 3.2 reports the outfalls in Cook Inlet that will be affected by the proposed guidelines. Finally, Section 3.3 addresses pollutant loadings, and how loadings are expected to be reduced by the proposed guidelines.

3.1 REGULATORY OPTIONS

Regulatory options for Cook Inlet were considered in conjunction with all areas of the Gulf of Mexico. In this section, we discuss these options as they pertain to Cook Inlet. Options were developed separately for drilling fluids (muds) and drill cuttings and for produced waters.

3.1.1 Options Proposed for Drilling Fluids and Cuttings

The Agency is co-proposing three options for the control of drilling fluids and drill cuttings. The three options considered contain zero discharge for all areas, except two of the options contain allowable discharges for Cook Inlet. One of these options, which would allow discharges meeting a more stringent toxicity limitation if selected for the final rule, would require an additional notice for public comment since the specific toxicity limitation has not been determined at this time. The three options are described in Table 3-1.

Options 1 and 2, which allow some discharge, include the following limitations or restrictions:

- No discharge of free oil (static sheen) or diesel oil
- Limitations of 1 mg/kg of mercury and 3 mg/kg of cadmium in the stock barite

Table 3-1
Coastal Oil and Gas Effluent Limitations Guidelines for Cook Inlet
Options Considered for Drilling Fluids and Drill Cuttings[1]

Option 1	Offshore limitations (including 30,000 ppm toxicity limit in the SPP)
Option 2	Offshore limitations with a more stringent toxicity limit (between 100,000 and one million ppm (SSP))
Option 3	Zero discharge

1 All options require zero discharge in the Gulf of Mexico.
Note: Option 2 is more stringent that Option 1.

The first two restrictions listed for these options are components of offshore limitations. These options also disallow discharges of the dewatering effluent (i.e., drill water) that can be produced by drilling fluids solids control systems. Zero discharge technologies for Option 3 include:

- Recycling and re-using waste mainly accomplished through the use of closed loops
- Delivering waste to onshore disposal facilities
- Grinding and injection of waste in a Class II disposal well.

3.1.2 Proposed Option for Produced Water

Five options were considered for produced water; these options are described in Table 3-2. The selected option for Cook Inlet allows coastal discharge limitations for produced waters to equal offshore limitations. This option was chosen because it is technologically and economically feasible; zero discharge of produced water in Cook Inlet is not considered economically achievable. Offshore limits utilize improved gas flotation and consist of two components for oil and grease: (1) 29 mg/l as a 30-day maximum average; and (2) 42 mg/l as a daily maximum.

Table 3-2
Coastal Oil and Gas Effluent Limitations Guidelines for Cook Inlet: Options Considered for Produced Water

Option 1	BPT[1] for Gulf of Mexico and Cook Inlet
Option 2	Offshore limitations for Gulf of Mexico and Cook Inlet
Option 3	Zero discharge for Gulf of Mexico and BPT[1] for Cook Inlet
Option 4*	Zero discharge for Gulf of Mexico and offshore limitations for Cook Inlet
Option 5	Zero discharges for Gulf of Mexico and Cook Inlet

1 Best Practicable Technology (limitations for oil and grease of: (1) 48 mg/l as a 30-day maximum average; and (2) 72 mg/l as a daily maximum).
* Selected option.

3.2 COOK INLET FACILITIES AFFECTED BY THE PROPOSED GUIDELINES

Eight produced water outfalls in Cook Inlet will be affected by the proposed effluent limitations guidelines. These outfalls are listed in Table 3-3. The proposed guidelines will also impact 36 projected new drilling wells and 19 recompletions in Cook Inlet.

3.3 ESTIMATED LOADINGS REDUCTIONS

Baseline pollutant loadings from the impacted facilities and loadings reductions expected under the proposed effluent limitations guidelines are reported and discussed in this section. Baseline loadings and reductions in loading are from Cook Inlet's coastal oil and gas facilities only, and do not include other point or nonpoint sources of loadings. Tables 3-4 and 3-5 report baseline loadings and reductions in loadings from drilling fluids and drill cuttings for Options 2 and 3 (no loadings reductions are associated with Option 1). Under Option 2, reductions in loadings from drilling fluids and drill cuttings total 3,868,896 pounds (17%). Under Option 3, reductions total 22,739,018 pounds (all loadings are eliminated). Table 3-6 reports baseline loadings and reductions for produced water for selected Option 4. Under Option 4, reductions in loadings from produced water total 1,502,566 pounds (43%). Toxic weighted loadings are also included in these tables.

Table 3-3
Cook Inlet Produced Water Outfalls

Operator	Facility	Discharge Distance from Shore (miles)	Average Discharge (bpd)
Marathon	Trading Bay	1.9	126,072
Shell Western	East Foreland	0.15	3,100
Amoco	Dillon	3.7	2,650
Unocal	Anna	2.5	1,500
Marathon	Granite Point	1.9	300
Phillips	NCIU Tyonek A	5.5	170
Unocal	Bruce	1.5	160
Unocal	Baker	7.5	30
Facility Count			8
Total Alaska Volume (bpd)			133,982
Total Alaska Volume (bpy)			48,903,430
Average Alaska Discharge Rate (bpd)			16,748
Source: Avanti, 1994.			

The pollutants present in drilling fluids and drill cuttings and produced waters can be grouped as follows:[1]

- Oil and grease
- Total suspended solids
- Aromatic hydrocarbons
- Metals

Of these pollutant groups, aromatic hydrocarbons and metals are of special concern to aquatic organisms. The potential loading reductions for these two pollutant groups are discussed below and summarized in Table 3-7.

[1] Radionuclides are also found in produced waters.

Table 3–4
Annual Baseline Loadings and Loadings Reductions for Impacted Facilities for Drilling Fluids and Drill Cuttings: Option 2

	Unweighted				Toxic Weighted			
Pollutant	Baseline Loadings (lbs)	Proposed Guidelines Loadings (lbs)	Reduction (lbs)	Percent Change	Baseline Loadings (lbs)	Guidelines Loadings (lbs)	Reduction (lbs)	Percent Change
Metals and Metaloids								
Aluminum	64,765.7	53,755.6	11,010.2	−17%	4,145.0	3,440.4	704.7	−17%
Antimony	40.7	33.8	6.9	−17%	0.5	0.4	0.1	−17%
Arsenic	50.7	42.1	8.6	−17%	212.9	176.8	36.2	−17%
Barium	856,888.2	711,217.2	145,671.0	−17%	1,713.8	1,422.4	291.3	−17%
Beryllium	5.0	4.2	0.8	−17%	21.0	17.5	3.5	−17%
Cadmium	7.9	6.5	1.3	−17%	5.3	4.4	0.9	−17%
Chromium	1,713.8	1,422.4	291.3	−17%	188.5	156.5	32.0	−17%
Copper	133.5	110.8	22.7	−17%	253.7	210.6	43.1	−17%
Iron	109,569.6	90,942.7	18,626.8	−17%	230.1	191.0	39.1	−17%
Lead	250.6	208.0	42.6	−17%	165.4	137.3	28.1	−17%
Mercury	0.7	0.6	0.1	−16%	185.7	156.0	29.7	−16%
Nickel	96.4	80.0	16.4	−17%	65.6	54.4	11.1	−17%
Selenium	7.9	6.5	1.3	−17%	0.6	0.5	0.1	−17%
Silver	5.0	4.2	0.8	−17%	30.5	25.4	5.1	−17%
Thallium	8.6	7.1	1.5	−17%	0.2	0.2	0.0	−17%
Tin	104.3	86.5	17.7	−17%	31.3	26.0	5.3	−17%
Titanium	624.8	518.6	106.2	−17%	18.1	15.0	3.1	−17%
Zinc	1,431.7	1,188.3	243.4	−17%	93.1	77.2	15.8	−17%
Total Metals and Metaloids	1,035,705.0	859,635.2	176,069.8	−17%	7,361.3	6,111.9	1,249.5	−17%
Aromatic Hydrocarbons								
Alkylated benzenes (a)	133.1	0.0	133.1	−100%	0.7	0.0	0.7	−100%
Alkylated fluroenes (b)	7.7	0.0	7.7	−100%	0.7	0.0	0.7	−100%
Alkylated naphthalenes (b)	2.2	0.0	2.2	−100%	0.1	0.0	0.1	−100%
Alkylated phenanthrenes (b)	0.9	0.0	0.9	−100%	0.1	0.0	0.1	−100%
Fluorene	3.6	0.0	3.6	−100%	2.0	0.0	2.0	−100%
Naphthalene	0.2	0.0	0.2	−100%	0.0	0.0	0.0	−100%
Phenanthrene	0.5	0.0	0.5	−100%	10.0	0.0	10.0	−100%
Total biphenyls (b)	8.6	0.0	8.6	−100%	0.3	0.0	0.3	−100%
Total dibenzothiophenes	0.0	0.0	0.0	−100%	0.0	0.0	0.0	−100%
Total Aromatic Hydrocarbons	156.9	0.0	156.9	−100%	14.1	0.0	14.1	−100%
TSS	21,699,381.2	18,010,486.4	3,688,894.8	−17%	0.0	0.0	0.0	NA
Total Oil	3,774.6	0.0	3,774.6	−100%	0.0	0.0	0.0	NA
Total	22,739,017.7	18,870,121.6	3,868,896.1	−17%	7,375.4	6,111.9	1,263.5	−17%

Source: SAIC, 1994; ERG, 1994.

Table 3–5
Annual Baseline Loadings and Loadings Reductions for Impacted Facilities
for Drilling Fluids and Drill Cuttings: Option 3

Pollutant	Unweighted Baseline Loadings (lbs)	Unweighted Proposed Guidelines Loadings (lbs)	Unweighted Reduction (lbs)	Unweighted Percent Change	Toxic Weighted Baseline Loadings (lbs)	Toxic Weighted Guidelines Loadings (lbs)	Toxic Weighted Reduction (lbs)	Toxic Weighted Percent Change
Metals and Metaloids								
Aluminum	64,765.7	0.0	64,765.7	−100%	4,145.0	0.0	4,145.0	−100%
Antimony	40.7	0.0	40.7	−100%	0.5	0.0	0.5	−100%
Arsenic	50.7	0.0	50.7	−100%	212.9	0.0	212.9	−100%
Barium	856,888.2	0.0	856,888.2	−100%	1,713.8	0.0	1,713.8	−100%
Beryllium	5.0	0.0	5.0	−100%	21.0	0.0	21.0	−100%
Cadmium	7.9	0.0	7.9	−100%	5.3	0.0	5.3	−100%
Chromium	1,713.8	0.0	1,713.8	−100%	188.5	0.0	188.5	−100%
Copper	133.5	0.0	133.5	−100%	253.7	0.0	253.7	−100%
Iron	109,569.6	0.0	109,569.6	−100%	230.1	0.0	230.1	−100%
Lead	250.6	0.0	250.6	−100%	165.4	0.0	165.4	−100%
Mercury	0.7	0.0	0.7	−100%	185.7	0.0	185.7	−100%
Nickel	96.4	0.0	96.4	−100%	65.6	0.0	65.6	−100%
Selenium	7.9	0.0	7.9	−100%	0.6	0.0	0.6	−100%
Silver	5.0	0.0	5.0	−100%	30.5	0.0	30.5	−100%
Thallium	8.6	0.0	8.6	−100%	0.2	0.0	0.2	−100%
Tin	104.3	0.0	104.3	−100%	31.3	0.0	31.3	−100%
Titanium	624.8	0.0	624.8	−100%	18.1	0.0	18.1	−100%
Zinc	1,431.7	0.0	1,431.7	−100%	93.1	0.0	93.1	−100%
Total Metals and Metaloids	1,035,705.0	0.0	1,035,705.0	−100%	7,361.3	0.0	7,361.3	−100%
Aromatic Hydrocarbons								
Alkylated benzenes (a)	133.1	0.0	133.1	−100%	0.7	0.0	0.7	−100%
Alkylated fluroenes (b)	7.7	0.0	7.7	−100%	0.7	0.0	0.7	−100%
Alkylated naphthalenes (b)	2.2	0.0	2.2	−100%	0.1	0.0	0.1	−100%
Alkylated phenanthrenes (b)	0.9	0.0	0.9	−100%	0.1	0.0	0.1	−100%
Fluorene	3.6	0.0	3.6	−100%	2.0	0.0	2.0	−100%
Naphthalene	0.2	0.0	0.2	−100%	0.0	0.0	0.0	−100%
Phenanthrene	0.5	0.0	0.5	−100%	10.0	0.0	10.0	−100%
Total biphenyls (b)	8.6	0.0	8.6	−100%	0.3	0.0	0.3	−100%
Total dibenzothiophenes	0.0	0.0	0.0	−100%	0.0	0.0	0.0	−100%
Total Aromatic Hydrocarbons	156.9	0.0	156.9	−100%	14.1	0.0	14.1	−100%
TSS	21,699,381.2	0.0	21,699,381.2	−100%	0.0	0.0	0.0	NA
Total Oil	3,774.6	0.0	3,774.6	−100%	0.0	0.0	0.0	NA
Total	22,739,017.7	0.0	22,739,017.7	−100%	7,375.4	0.0	7,375.4	−100%

Source: SAIC, 1994; ERG, 1994.

Table 3-6
Annual Baseline Loadings and Loadings Reductions for Impacted Facilities for Produced Water: Option 4

	Unweighted				Toxic Weighted			
Pollutant	Baseline Loadings (lbs)	Proposed Guidelines Loadings (lbs)	Reduction (lbs)	Percent Change	Baseline Loadings (lbs)	Guidelines Loadings (lbs)	Reduction (lbs)	Percent Change
Metals and Metaloids								
Aluminum	1,334	854	480	-36%	85	55	31	-36%
Arsenic	1,953	1,250	703	-36%	8,203	5,250	2,953	-36%
Barium	950,318	608,203	342,115	-36%	1,901	1,216	684	-36%
Boron	440,240	281,753	158,487	-36%	79,243	50,716	28,528	-36%
Cadmium	387	248	139	-36%	259	166	93	-36%
Copper	7,605	4,867	2,738	-36%	14,450	9,247	5,202	-36%
Iron	84,077	53,809	30,268	-36%	177	113	64	-36%
Lead	3,337	2,136	1,201	-36%	2,202	1,410	793	-36%
Manganese	1,982	1,269	713	-36%	1,110	711	399	-36%
Nickel	29,169	18,668	10,501	-36%	19,835	12,694	7,141	-36%
Titanium	120	77	43	-36%	3	2	1	-36%
Zinc	766	0	766	-100%	50	0	50	-100%
Total Metals and Metaloids	1,521,288	973,134	548,154	-36%	127,518	81,580	45,938	-36%
Aromatic Hydrocarbons								
2-Butanone	17,599	7,040	10,559	-60%	8	3	5	-60%
2,4-Dimethyl phenol	8,803	4,276	4,527	-51%	21	10	11	-51%
Anthracene	432	127	305	-71%	151	44	107	-71%
Benzene	57,914	20,967	36,947	-64%	927	335	591	-64%
Benzo(a)pyrene	181	80	101	-56%	760,200	336,000	424,200	-56%
Chlorobenzene	138	134	4	-3%	2	1	0	-3%
Di-n-butylphthalate	275	110	165	-60%	440	176	264	-60%
Ethyl benzene	2,698	1,064	1,634	-61%	351	138	212	-61%
n-Alkanes	28,075	11,230	16,845	-60%	121	48	72	-60%
Naphthalene	15,967	1,574	14,393	-90%	750	74	676	-90%
p-Chloro-m-cresol	432	173	259	-60%	2	1	1	-60%
Phenol	7,380	0	7,380	-100%	1,624	0	1,624	-100%
Steranes	1,325	530	795	-60%	6	2	3	-60%
Toluene	25,782	14,158	11,624	-45%	28	16	13	-45%
Triterpanes	1,334	534	800	-60%	6	2	3	-60%
Total Xylenes	9,278	6,465	2,813	-30%	158	110	48	-30%
Total Aromatic Hydrocarbons	177,613	68,462	109,151	-61%	764,793	336,962	427,831	-56%
TSS	1,154,465	513,095	641,370	-56%	0	0	0	NA
Total Oil and Grease	605,816	401,925	203,891	-34%	0	0	0	NA
Radionuclides								
Radium 226	0.000025	0	0.000025	-100%	4	0	4	-100%
Radium 228	0.000050	0	0.000050	-100%	17,500	0	17,500	-100%
Total Radionuclides	0.000075	0	0.000075	-100%	17,504	0	17,504	-100%
Total	3,459,182	1,956,616	1,502,566	-43%	909,815	418,542	491,273	-54%

Source: SAIC, 1994; ERG 1994.

Table 3-7
Summary of Anticipated Loadings Reductions for Aromatic Hydrocarbons and Metals from Impacted Facilities in Cook Inlet

Guideline Reduction Options	Aromatic Hydrocarbons - pounds reduced (% Reduction*)	Metals - pounds reduced (% Reduction*)
Drilling Fluids and Drill Cuttings (Option 2)	157 (100%)	176,070 (17%)
Drilling Fluids and Drill Cuttings (Option 3)	157 (100%)	1,035,705 (100%)
Produced Water (Option 4)	109,151 (61%)	548,154 (36%)
Combined (Option 2 for Drilling Fluids and Drill Cuttings)	109,308 (61%)	724,224 (28%)
Combined (Option 3 for Drilling Fluids and Drill Cuttings)	109,308 (61%)	1,583,859 (62%)

* Percent reduction reflects reduction of loadings from the impacted facilities, not total loadings reductions for Cook Inlet.

Aromatic Hydrocarbons. Annual baseline loadings of aromatic hydrocarbons from drilling fluids and drill cuttings and from produced waters are 157 and 177,613 pounds, respectively. The proposed effluent limitations guidelines are anticipated to reduce loadings of these compounds by 157 pounds (100%) annually for drilling fluids and drill cuttings (for both Options 2 and 3) and by 109,151 pounds (61%) annually for produced water (Option 4).

Metals. Annual baseline loadings of metals from drilling fluids and drill cuttings and from produced water are 1,035,705 and 1,521,288 pounds, respectively. For drilling fluids and drill cuttings, Option 2 would reduce annual metal loadings by 176,070 pounds (17%) and Option 3 would eliminate annual metal loadings (100% reduction). The selected Option 4 for produced water will reduce the annual loadings of metals by 548,154 pounds (36%).

CHAPTER 4
POTENTIAL BENEFITS OF THE PROPOSED REGULATION

This chapter provides a description of the types of benefits anticipated to result from the proposed effluent limitation guidelines in Cook Inlet, Alaska. As described in Chapter 2, Cook Inlet's aquatic resources are highly valued. However, the continuous long-term release of petroleum hydrocarbons and associated pollutants may have a negative impact upon the Inlet's natural resources. Aquatic organisms, in particular, may be adversely affected by exposure to these pollutants. As shown in Chapter 3, the proposed rulemaking is expected to reduce loadings of these substances from drilling muds and drill cuttings and produced water discharges to the inlet.

Because information on total loadings (i.e., from all sources) to the inlet is not available, the loadings impact evaluation presented in Chapter 3 is incomplete. Nonetheless, detrimental impacts to aquatic biota from the contaminants present in coastal oil and gas discharges may occur even at low concentration levels, and thus ecologic improvements may result from reductions in current loadings. In addition, because of Alaska's appeal as an unspoiled wilderness, and the fact that the inlet supports many important species, the public is likely to value these improvements.

This chapter is organized as follows. Section 4.1 provides a discussion of the potential ecologic impacts of current discharges and potential benefits of the proposed rulemaking. Section 4.1.1 is a detailed scientific description of the potential impacts of the contaminants present in drilling fluids and cuttings and produced waters on biotic resources, including discussions of fate, exposure pathways, and biotic effects. Section 4.1.2 discusses the potential for ecologic improvements associated with the proposed rulemaking in Cook Inlet. Section 4.2 provides an overview of concepts applicable to the benefits analysis. Finally, Section 4.3 provides a qualitative discussion of potential nonuse benefits of the proposed regulation, and presents quantitative research which may shed light on the potential magnitude of these benefits.

4.1 POTENTIAL ECOLOGIC IMPACTS OF COASTAL OIL AND GAS DISCHARGES AND IMPROVEMENTS ASSOCIATED WITH THE PROPOSED REGULATION

This section describes the adverse impacts that contaminants found in drilling fluids and drill cuttings and produced waters can have on biotic resources in Cook Inlet. Once discharged, low concentrations of these pollutants may pose substantial risk to resident and migratory biota through direct and indirect pathways of exposure in the surface waters, diets, or sediments. It appears that these pollutants may be widely distributed throughout the inlet which increases the likelihood that many of the resources are exposed to the contaminants at low levels. Exposure to chronic, low levels of contaminants found in coastal oil and gas effluents can adversely affect the resources by causing physiological and behavioral impairments in organisms, contamination or reduction of food-web resources, and alteration of habitats. By reducing the toxicity of drilling fluids and drill cuttings and produced water discharges into Cook Inlet, the ecological and biological resources would be put at less risk of exposure. Loading reductions would also reduce the risk of disturbances to the ecological integrity and important habitats of biological resources in Cook Inlet.

A key to understanding the potential impacts of the proposed effluent limitations guidelines on the ecologic and biologic resources of Cook Inlet involves a knowledge of the fates, exposure pathways, and effects of the coastal oil and gas pollutants. These factors are discussed below.

4.1.1 Potential Impacts of Contaminants found in Coastal Oil and Gas Effluents on Biotic Resources

The continuous, long-term release of low levels of contaminants present in drilling fluids and drill cuttings and produced water is of particular concern for the natural resources in marine and estuarine habitats, such as Cook Inlet. Chronic pollution of such areas should be carefully evaluated for the maintenance of the coastal and offshore fishing grounds and the abiotic and biotic resources that sustain the fisheries.

Discharges from different coastal oil and gas platforms are not likely to have equal impacts on the same biota. This is largely due to the site-specific physicochemical factors influencing the fate or dispersion of the contaminants present in these effluents in the marine environment. It is likely that the supratidal, intertidal, and subtidal communities of Cook Inlet are prime targets for exposure to chronic pollution due to the physical transport of coastal oil and gas effluents to these habitats of Cook Inlet (see below). Depending on the extent of contamination and penetration at an impacted site, organisms in addition to the most obvious species (e.g., fish) can be adversely impacted.

Fate: Physical, Chemical, Biotic Transformation

The fate of contaminants associated with coastal oil and gas discharges in Cook Inlet is a function of the Inlet's unique physical, chemical, and biological characteristics that influence the weathering processes and distribution of the contaminants. Following discharge into coastal waters, the chemical composition of the effluents are transformed by combinations of physical, chemical, and biological processes that disperse the pollutants in the environment. The physical transformations include evaporation, dissolution, vertical dispersion, emulsification, and sedimentation; and these physical transformations also involve chemical factors (e.g., photooxidation, degradation) determined by the specific compositions of the effluents being discharged (NRC, 1985). The physical and chemical processes that disperse and transform the various contaminants are important for determining the eventual spatial and temporal distribution of chemicals in the environment. Eventually, it should be expected that these contaminants will be widely distributed among sediments, soils, water, air, and biota in the marine/estuarine environment in which the discharge takes place.

Cook Inlet is an extremely dynamic, high-energy estuarine environment due to its extreme tidal fluxes and resulting turbulent and well-mixed waters, and it has high loads of suspended sediments from riverwater inputs (Hyland et al., 1993). The unusual current patterns and high suspended sediments within Cook Inlet are likely to be significant factors controlling the dispersal and deposition of contaminants found in coastal oil and gas effluents. A study by Feely and Massoth (1982) showed that the suspended materials from lower Cook Inlet were capable of accommodating (adsorbing) up to 11% of their weight in particles associated with these contaminants in Cook Inlet. These results along with the use of a settling model suggested that these particles (adsorbed to suspended materials within Cook Inlet) could be thoroughly distributed throughout the inlet prior to deposition along the shore. The environmental factors increasing dispersal and distribution are important for evaluating the specific biotic resources affected by these discharges into Cook Inlet.

Cook Inlet also provides habitat for a variety of biota, including plants, invertebrates, fishes, birds, and mammals, which likely (in addition to the physical and chemical forces) influence the fate and distribution of drilling fluids and cuttings and produced water discharges. All of the physical, chemical, and biological processes influencing the fate of contaminants found in coastal oil and gas discharges are important to an evaluation of the potential impact these effluents have on the environment and the exposed biota.

Biological processes can dramatically influence the fate of contaminants found in coastal oil and gas effluents because many of the compounds and elements are taken up by biological organisms. It has been estimated that the biodegradable portion of crude oils is between 11-90% (Colwell and Walker, 1977, cited in NRC, 1985). In general, the simpler hydrocarbons (i.e., alkanes, alkenes, and monoaromatics; NRC, 1985) and many of the non-hydrocarbons (i.e., metals, nitrogen-, sulfur- and oxygen-compounds) found in coastal oil and gas effluents may be taken up and biodegraded by many different biological organisms. Biodegradation (via micro- and macroorganisms) is a major mechanism for the transformation and elimination of certain hydrocarbons.

Following uptake, biodegradation involves the oxidation of lipophilic hydrocarbons (rendering hydrocarbons more water soluble), which facilitates their excretion back into the environment. However, the enzymatic processes of micro- and macroorganisms used to metabolize or otherwise biodegrade many of the contaminants found in coastal oil and gas effluents will have slower or restricted degradation rates in colder (arctic) waters of marine environments compared to that in warmer (temperate or tropical) waters (Collier et al., 1978; Varanasi et al., 1981; NRC, 1985). Microorganisms (bacteria, yeasts, fungi) can biodegrade most of the compounds in the surface, water column, and sediments of aquatic environments; yet the biodegradation rate varies widely depending on the specific compound and on the enzymatic pathways used by different organisms. Less is known about phytoplankton biodegradation of coastal oil and gas effluents. Through ingestion, compounds associated with particulate organic matter, zooplankton and benthic invertebrates aid in their sedimentation and resuspension, respectively. Fish, marine mammals, and birds are also important in the biodegradation and distribution of these contaminants following exposure.

It should be noted that the biodegradation of certain hydrocarbons does not necessarily result in products (or metabolites) that are less toxic than the parent pollutant. In fact, the biodegradation of a small proportion of aromatic hydrocarbons (for example, benzo(a)pyrene) produces metabolites that are more toxic than the parent compound, resulting in mutagenic and carcinogenic chemicals (NRC, 1985).

Exposure Pathways

Contaminants present in drilling fluids and drill cuttings and produced water discharges to marine environments can effect the natural resources either through direct or indirect pathways of exposure. Direct pathways of exposure occur when natural resources come in direct contact, either singularly or in combination, with the contaminants in the water column, sediments, or diet. Indirect pathways of exposure occur when habitat resources (e.g., spawning beds, prey sources) have been reduced or otherwise altered by the contaminants. The extent to which the biota are impacted largely depends upon the pathway and duration of exposure and also depends on the concentration and type of contaminant present in the pathway.

Biotic Effects

Biological organisms are effective receptors for contaminants found in coastal oil and gas effluents through the uptake, accumulation, and eventual metabolic degradation (see above) of the various contaminants. Uptake of these contaminants results from various exposure pathways, singularly or in combination: diet, water, and sediment. Accumulated contaminants associated with oil and gas effluents may concentrate in various tissues and organs of biota, and the specific tissues/organs affected depend upon the exposure pathways, the exposure concentrations, and the ability to metabolize the accumulated contaminants. Metabolic degradation of the contaminants occurs through enzymatic pathways, and the rate/ability of metabolic degradation largely depends upon the presence/absence and relative abundance of various enzymes necessary to transform different components into excretable compounds.

In aquatic resources, it is critical to evaluate the effects of low concentrations of the contaminants found in coastal oil and gas effluents (i.e., PAH) because even low concentrations in water, sediment, or diet are likely to impair fitness, produce adverse-physiological effects that lead to death or that, at least, lower long-term survivability in the wild. There is extensive documentation on the long-term, injurious effects of oil substances at relatively low concentrations to aquatic biota in shielded or enclosed waters. Therefore, a continued need exists to evaluate the chronic toxicities of the contaminants found in coastal oil and gas effluents to help evaluate how low level exposures can reduce the viability of Cook Inlet's resident and migratory biota.

Exposure to contaminants found in coastal oil and gas effluents can impact various biological levels of organization which result in four identified biotic responses (Table 4-1). The four biotic responses -- lethal toxicity, sublethal toxicity, bioaccumulation, and habitat alteration -- provide broad categorization for a multitude of specific biotic responses.

Lethal toxicity refers to the direct disruption of sub-cellular or cellular physiological activities that result in death of the organism. The death of individuals from populations can influence the future reproductive viability of populations, and in turn may influence even the higher levels of biological organization. Sub-lethal toxicity also involves interference of sub-cellular and cellular processes but does not result in immediate death, although death may follow due to impaired behavior or physiology. Short of death, it is the impaired behavioral or physiological activities of the organism, especially those necessary for feeding, growth, and reproduction, that are most influential on the higher levels of biological organization.

Bioaccumulation of contaminants found in coastal oil and gas effluents is of importance because the physiological health of organisms is affected (e.g., reducing growth, reproduction), and as well, bioaccumulation provides additional pathways for contaminant transfer throughout the food chain. Impaired physiology or contaminant transfer through food chains due to bioaccumulation can have dramatic impacts on all levels of biological organization. For instance, accumulated contaminants (or metabolites of these contaminants) transferred through food webs may concentrate in food sources for piscivorous fishes, which can adversely affect important recreational or commercial fisheries.

Table 4-1
Biological Organization Levels Associated with Responses to Coastal Oil and Gas Effluents

Biotic Response	Sub-cellular	Cellular	Organism	Population	Community	Ecosystem
Lethal Toxicity	X	X	X	X	X	X
Sublethal Toxicity	X	X	X	X	X	X
Bioaccumulation	X	X	X	X	X	X
Habitat Alteration			X	X	X	X

Habitat alteration includes effects on the physical and chemical environment that can result in unsuitable habitat for both resident and migratory biota, at the level of the organism and the population. The physical and chemical alteration of particular habitats can shift species composition, abundance, and diversity. Any change in species composition directly reflects altered community structure, and can extensively impact ecosystem function.

The observed effects of contaminants found in coastal oil and gas discharges on the various biological levels include a list of quantifiable endpoints ranging from lethality endpoints (death or moribundity, due to direct exposure to acutely toxic concentrations or indirect exposure to sublethal concentrations that eventually cause death) to sub-lethal endpoints due to direct or indirect exposures that cause physiological or behavioral abnormalities. A brief discussion of several of these endpoints describing biotic effects due to coastal oil and gas pollution follows.

Death. Death can result from direct and indirect exposure to contaminants found in coastal oil and gas effluents (e.g., Morrow, 1973; Rice et al., 1976; Nunes and Benville, 1978). The loss of individual organisms through death can cause reductions in the populations and disrupt the species composition in a biotic community. Dead or dying organisms can cause reductions in populations due to the loss of reproductively fit individuals.

Growth and Physiology. Contaminants found in coastal oil and gas effluents affect many aspects of cellular metabolism and physiology that can reduce normal growth in organisms. Exposure to the contaminants can affect biological activities, such as feeding, respiration, and enzymatic pathways, that are necessary for the physiological maintenance (homeostasis) and growth (e.g., Rice et al., 1976; Kiceniuk and Khan, 1987). Reduced physiological fitness or reduced growth in organisms bears directly on the ability of an organism to survive and reproduce in the environment.

Genetic Mutation. Exposure to the contaminants contained in coastal oil and gas effluents, including several aromatic hydrocarbons, metabolites of hydrocarbons, and heavy metals, can increase the rate of genetic mutations by impairing DNA synthesis, increasing DNA-strand exchanges, and altering chromosome number (NRC, 1985; Longwell, 1978). Increased rates of genetic mutations can reduce the fitness of individuals and populations, especially in contaminated areas providing breeding or spawning habitat because there would be even more risk to embryonic life stages undergoing rapid development.

Disease or Cancer. Exposure to certain contaminants found in coastal oil and gas effluents can result in an increase in the prevalence of pathogens causing disease or outbreaks of cancers in populations (NRC, 1985; Meyer et al., 1994). Increased susceptibility to diseases or cancers due to exposure to pollutants can reduce growth and reproductive potentials and survivability of individual organisms, and thus may reduce the overall growth or productivity of populations.

Behavior. Behavioral effects of exposure to contaminants found in coastal oil and gas effluents include such responses as avoidance of polluted waters, chemoreception, and feeding (Smith et al., 1983; Blundo, 1978). These adverse effects on behaviors may reduce the fitness of individual organisms, and in turn, have influences at higher levels of biological organization, such as the population.

4.1.2 Evaluation of the Potential Ecologic Improvements Associated with the Proposed Effluent Guidelines in Cook Inlet

As described above, the drilling fluids and drill cuttings and produced water discharges released by the coastal oil and gas facilities in Cook Inlet have the potential to cause adverse effects to ecological/biological resources. However, there is limited quantitative data for evaluating the potential impacts, and therefore, the potential benefits of the proposed guidelines. As summarized by Peterson (1993), the National Research Council presently considers that there is insufficient information gathered about the environments (e.g., physical, chemical, biological data) to support evaluations of environmental risks of oil and gas developments in coastal areas.

A complete analysis of the risks of exposing the biotic resources of Cook Inlet to the contaminants found in coastal oil and gas effluents, even at "low levels", would include the following:

1. Inventories describing resident biotic and abiotic resources of ecological, commercial, and recreational value,

2. An assessment of migratory biota utilizing Cook Inlet habitats and an assessment of the ecological interactions between resident and migratory species,

3. Development of fate and transport models to describe the biotic and abiotic uptake, distribution, transformation, and accumulation of coastal oil and gas pollutants in Cook Inlet, and

4. Knowledge of the chronic toxicity and associated biotic responses caused by exposure of ecologically important species and habitats to coastal oil and gas effluents.

Reference or control sites should be evaluated concurrently with any assessment of Cook Inlet resources to assist with the analyses. These types of information (data) would need to be gathered in order to make well informed assessments of the potential risks. Once collected, it would be necessary to use a model containing hydrological information specific to Cook Inlet (e.g., currents, dilution factors, sediment adsorption factors) to determine whether impacts would occur and/or whether pollutant-specific criteria thresholds would be exceeded based on loadings reductions.[1]

Although a complete analysis of the potential water quality improvements in Cook Inlet from the proposed guidelines is not available, research indicates that the contaminants present in coastal oil and gas effluents have the potential to impact biological resources in the manner described in Section 4.1.1, that is, the potential to cause genetic mutations, behavioral changes, disease, or cancer, or to impair growth and physiology. Chronic exposure to these contaminants (including the metals) also may lead to death in organisms. Reducing the chronic, low-level input of these substances into Cook Inlet waters will ameliorate the effects of contamination and exposure on biological resources.

The present concentrations of the contaminants found in coastal oil and gas effluents in Cook Inlet surface waters are unlikely to cause acute, sudden lethality. Yet the current discharges provides exposure levels that could cause sublethal effects in the aquatic resources. For example, low concentrations of the contaminants (including metals) will cause avoidance behaviors in salmon that may lead to changes in their migration patterns (e.g., Rice, 1974; Babcock, 1985). Changes in behavior or impaired physiology of the organisms may influence the production and recruitment strategies in the important fisheries resources of Cook Inlet.[2] By limiting or eliminating discharges of the contaminants, the fisheries would be less likely to avoid contaminated areas of Cook Inlet. Reducing the risk of avoidance by fishes in Cook Inlet may improve the stock production of important salmonids.

Additional Cook Inlet resources that would potentially benefit from the regulation include those species and lifestages that are particularly sensitive and susceptible to contaminants

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[1] One water quality analysis used a waste load allocation model to assess compliance with water quality standards under baseline loadings and the anticipated guidelines-reduced loadings of petroleum-related effluents from produced waters in Cook Inlet (Avanti, 1994). A dilution factor is used to extrapolate loadings from daily pounds to ug/L; the methods used to derive these dilutions factors were not described. This analysis does not assess compliance based on total loadings of pollutants from all sources to Cook Inlet, or even drilling fluid loadings. Therefore, the results are described merely as an example of the type of information a water quality model could provide.

Loadings from eight outfalls were analyzed using a 50 and 200 foot mixing zone. The analysis found the following compounds exceeded standards at baseline conditions at the 50 foot mixing zone, and did not exceed standards following reductions in loadings: anthracene, arsenic, benzene, cadmium, iron, manganese, and nickel. Not all of these exceeded criteria at all platforms, nor were criteria exceedences decreased at all platforms.

[2] Sockeye salmon runs in bays near the lower portions of Cook Inlet have been severely depressed since 1984 to the extent that the Alaska Department of Fish and Game has closed commercial, sport, and subsistence fishing to protect returning adults (in English Bay and Port Graham) (see Bucher and Hammarstrom, 1994).

found in coastal oil and gas effluents. Planktonic organisms (including planktonic fish eggs and shellfish larvae) would benefit from the regulations by reducing the risk of exposure to pollutants dispersed and transported by tides and currents in Cook Inlet. Benthic organisms (including organisms in the intertidal zone) would benefit from reduced exposures to pollutants being deposited and accumulating in the sediments. Finfish and shellfish would benefit through reductions in risk of direct exposure to water-soluble fractions of the contaminants and reductions in the risk of exposure to contaminated-food sources.

Appendix A presents water quality criteria and a summary of observed effects associated with the two major groups of compounds found in coastal oil and gas effluents -- aromatic hydrocarbons and metals. These observed effects are not related to specific contaminant concentrations, however. A comprehensive list of potential toxic effects to marine organisms expected at specific contaminant concentrations should be developed in conjunction with water quality modeling results.

4.2 OVERVIEW OF CONCEPTS APPLICABLE TO THE BENEFITS ANALYSIS

This section provides an overview of the general concepts applicable to the benefits analysis. Although there is insufficient information to quantify the potential benefits of the regulation, a qualitative discussion of potential nonuse values is provided in Section 4.3.

4.2.1 The Economic Concept of Benefits

The general term benefits refers to any and all outcomes of the regulation that are considered positive; that is, that could contribute to an enhanced level of social welfare. The term "economic benefits" refers to the dollar value associated with all the expected positive impacts of the regulation (not all ecological improvements necessarily result in substantial economic benefits). Conceptually, the monetary value of benefits is embodied by the sum of the predicted changes in "consumer (and producer) surplus." These "surplus" measures are standard and widely accepted terms of applied welfare economics, and reflect the degree of well-being enjoyed by people given different levels of goods and prices (including those associated with environmental quality).

This conceptual economic foundation raises several relevant issues and potential limitations for the benefits analysis of the regulation. First, the standard economic approach to estimating environmental benefits is anthropocentric — all values arise from how environmental changes are perceived and valued by humans. A related second point is that the benefits of all future outcomes are often discounted at a positive rate, such that future benefits are worth less in "present value" terms than are near-term benefits. Thus, all near-term as well as temporally distant future physical outcomes associated with reduced pollutant loadings are translated into the framework of present day human activities and concerns.

4.2.2 Overview of Benefit Categories

To implement a benefits analysis, the types or categories of benefits that apply need to be defined. The benefits typology shown in Figure 4-1 summarizes, as an example, benefits typically observed as a result of changes in the water resource environment. As reflected in Figure 4-1, benefits typically are categorized according to whether or not they involve some form of direct use of, or contact with, the resource. Although there are important embellishments and appreciable semantic distinctions that can be made to enhance this figure, it can be used as a convenient starting point.

Use Benefits

Use benefit categories can embody both direct and indirect uses of affected waters, and the direct use category embraces both consumptive and nonconsumptive activities. In most applications to water quality improvement scenarios, the most prominent use benefit categories are those related to human health risk reductions, and those related to enhanced recreational fishing, boating and/or swimming. Recreational activities have received considerable empirical attention from economic researchers over the past two decades because they are amenable to various nonmarket valuation techniques (e.g., travel cost models).[3] Thus, there is a considerable body of knowledge relating to recreational fishing and associated activities, and these generally indicate that water-based recreation is a highly valued activity in today's society.

Nonuse (Intrinsic or Passive Use) Benefits

Improved environmental quality can also be valued by individuals apart from any past, present or anticipated future use of the resource in question. Such nonuse values may be of a highly significant magnitude; however, the benefit value to assign to these motivations often is a matter of considerable debate. Whereas human uses of a resource can be observed directly and valued with a range of technical economic techniques, nonuse values can only be ascertained from asking survey respondents to directly reveal their values. The inability to rely on revealed behavior to ascertain nonuse values has led to considerable debate as to how to best measure values for applicable changes in environmental quality.

Among the more relevant nonuse values associated with the proposed effluent limitation guidelines are "ecologic benefits," as discussed in Section 4.1. Whether such "ecologic benefits" fall within the traditional economic rubric of nonuse values is an unresolved semantic issue. Some ecologic changes will have positive impacts on use values (e.g., recreational angling, bird watching, etc.). But of greater relevance is the applicability of

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[3] Note that travel cost models capture use values only.

Figure 4-1
The Benefits of Water Quality Improvements

USE BENEFITS	
In-Stream	• Human health risk reductions • Recreation (fishing, boating, swimming, etc.) • Subsistence fishing (including human health risks) • Commercial fisheries and navigation
Near Stream	• Water enhanced noncontact recreation (picnicking, photography, jogging, camping, etc.) • Nonconsumptive use (e.g. wildlife observation)
Option Value	• Premium for uncertain future demand • Premium for uncertain future supply
Diversionary	• Industry/commercial (process and cooling waters) • Agriculture/silviculture (crop growth rates) • Municipal drinking water (treatment cost savings and/or human health risk reductions)

NONUSE (INTRINSIC) BENEFITS	
Aesthetic	• Residing, working, traveling and/or owning property near affected lands and water, etc.
Bequest	• Intergenerational equity
Existence	• Stewardship/preservation • Ecologic • Vicarious consumption

values for "ecologic changes" under the traditional nonuse categories of existence (stewardship or preservation) and bequest values.

The key distinction may be that nonuse values are anthropocentric, whereas "ecologic" benefits are viewed by some as distinct from human valuation — making them somehow additive to nonuse values. The issue is whether there ought to be some accounting for ecological benefits over and above any connection to human beings (though the removal of these benefits from the anthropocentric realm begs the question of how we assign values to ecologic benefits for the purpose of setting priorities in policy making). Therefore, for the purposes of this analysis, ecologic benefits are assumed to be included within traditional nonuse values.

4.2.3 Causality: Linking the Regulation to Beneficial Outcomes

Conducting a benefits analysis for anticipated changes in pollutant loadings to receiving waters requires that a chain of events be specified and understood. These steps are shown in Figure 4-2. The final "steps" (6 and 7) in Figure 4-2 illustrate the point at which anthropocentric benefit concepts begin to apply, such as illustrated by the link between improved fisheries and the enhanced enjoyment realized by recreational anglers. Ecologic improvements can also result in changes in nonuse values, as discussed below.

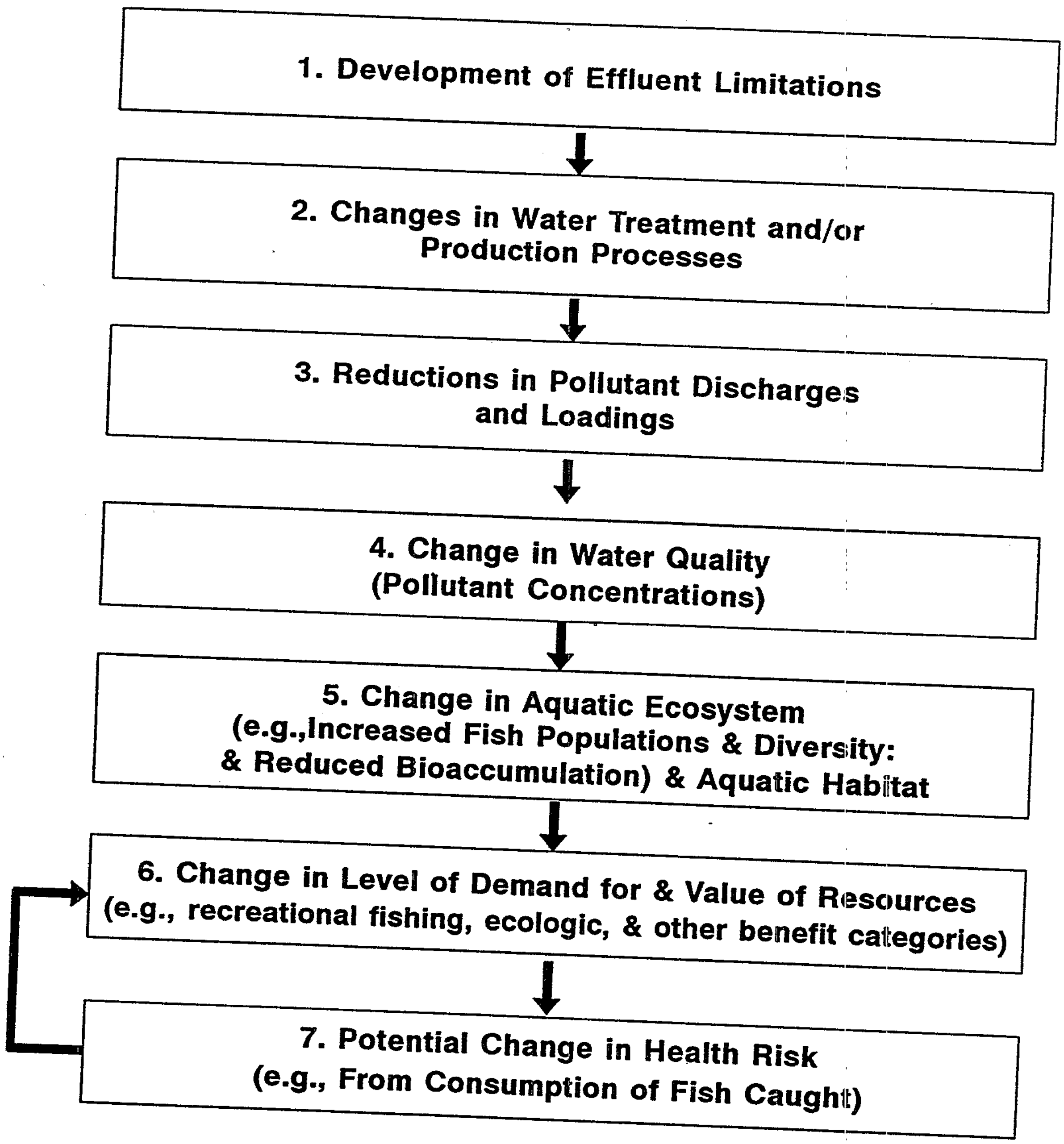
4.3 POTENTIAL BENEFITS OF THE PROPOSED REGULATION

There is insufficient data on the expected ecologic improvements in Cook Inlet, or society's willingness to pay for water quality in Cook Inlet, to quantify the benefits of the proposed guidelines. However, research is available indicating that nonuse values held by society for other areas of Alaska (Prince William Sound) are large. As described below, there is reason to believe that nonuse values for Cook Inlet may also be large. Thus, even small changes in these values (benefits) may be significant.

Evidence of Nonuse Values for Alaska's Coastal Resources

There is no research available to quantify the nonuse values that society holds for Cook Inlet or how these values would be increased through more stringent control of coastal oil and gas facilities. Nonetheless, as suggested by McCollum et al. (1992), because Alaska's resources are unique and viewed as "the last bastion of unspoiled wildlife habitat," it is probable that nonuse values (including existence and bequest values) held by nonresidents are very large, and may even outweigh use values. As shown in Chapter 2, the baseline use value of Cook Inlet's commercial and recreational fisheries alone is approximately $72.4 million per year. Therefore, nonuse values for the inlet may be large.

Figure 4-2
Steps in a Benefits Assessment



Research supports the contention that society holds very high nonuse values for Alaska's resources. A study of the lost nonuse value resulting from the Exxon Valdez oil spill in Alaska's Prince William Sound indicated that households were willing to pay $31.90 per household, or $2.9 billion nationwide (1992 dollars, updated from 1991 dollars using the CPI) in a single year payment to avoid an oil spill of similar magnitude in the future (Carson et al., 1992).[4] These damages were estimated using the contingent valuation (CV) method, an approach in which hypothetical markets are constructed and presented to individuals in a survey format.[5] The values estimated in the study were determined to be almost exclusively nonuse values because no Alaskan households were included in the sample and impacts that would affect use were not included in the injury scenario.[6] Given the magnitude of nonuse values held by the non-Alaskan public for Prince William Sound, it is probable that nonuse values for Cook Inlet are also high.[7]

Potential for Regulatory Nonuse Benefits for Cook Inlet

As discussed above, even low levels of contaminants found in coastal oil and gas discharges have the potential to impact the aquatic resources of Cook Inlet. The proposed effluent guidelines are expected to reduce annual pollutant loadings from eight facilities in Cook Inlet, with pollutant loading reductions including 3,800 pounds of oil from drilling fluids and cuttings; 204,000 pounds of oil and grease in produced waters; 109,000 pounds of aromatic hydrocarbons; and 724,000 pounds of metals under Option 2 for drilling fluids or 1.6 million pounds of metals under Option 3 for drilling fluids. These reductions may ultimately result in measurable improvements in uses of the resources. Additionally, society may value these

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4 The estimated values for Prince William Sound may represent an upper bound on potential benefits of the proposed regulation because the severity of the injury caused by the spill is considered greater than that caused by the ongoing incremental loadings from coastal oil and gas production and exploration in Cook Inlet that will be reduced by the proposed guidelines. It should be noted, however, that the injury scenario valued in the Exxon Valdez study did not include any long-term population impacts which may result from ongoing exposure to the contaminants found in coastal oil and gas discharges.

5 A detailed description of the CV method can be found in Mitchell and Carson (1989).

6 Damages were calculated for english speaking households only. In addition, the damage estimate was based on median WTP, which is lower than mean WTP, and thus is considered to be a lower bound of the true WTP (Carson et al., 1992).

7 Because Cook Inlet is more accessible than Prince William Sound, it may have higher use levels. Higher use and greater awareness may result in larger nonuse values for those who do not use the resource, since friends and relatives of the users are more likely to be knowledgeable about the site and hold value for it. Alternatively, society may hold larger nonuse values for more pristine areas than for those that are exposed to greater use.

improvements apart from any past, present, or anticipated use of the resources. This latter value is considered a potential nonuse benefit of the regulation.

Potential Use Benefits Relative to Costs

Although there are no available estimates of WTP for the anticipated loadings reductions, there is evidence to suggest that total nonuse values for Cook Inlet are likely to be very large and, thus, even small changes in these values (benefits) may be significant. Based on the annual baseline use values of Cook Inlet's commercial and recreational fisheries alone (approximately $72.4 million) and the estimated costs of the combined co-proposed and selected options,[8] changes in baseline fishery-related values attributable to the proposed guidelines of 3.1%, 5.0% and 8.5%, respectively, would be required for benefits to equal costs. This comparison considers only increases in baseline values for a portion of the total use value of the Inlet (personal use and subsistence fisheries are not included), and does not include changes in nonuse values that are likely to result from the rulemaking. And, as discussed above, there is reason to believe that nonuse values may be as large or larger than use values.

[8] Estimated annual costs for options 1, 2, and 3 for drilling fluids and cuttings are $0.0, $1.37 million, and $3.89 million, respectively. The estimated annual cost of selected option 4 for produced waters is $2.24 million. Therefore, the combined annual costs for drilling fluids and cuttings and produced waters are $2.24 million, $3.6 million, and $6.1 million.

CHAPTER 5
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APPENDIX A
SUMMARY OF TOXIC EFFECTS OF AROMATIC HYDROCARBONS AND METALS ON MARINE ORGANISMS

A.1 AROMATIC HYDROCARBONS

Exposure to aromatic hydrocarbons may potentially have a negative effect on biological resources. The Ambient Water Quality Criteria (AWQC) for aromatic hydrocarbons are shown in Table A-1. These criteria are for the protection of marine organisms.

The following lists some LC-50s (the concentration under which 50% of organisms die) observed following exposure of marine organisms to aromatic hydrocarbons, specifically polycyclic aromatic hydrocarbons (PAHs):

The pink salmon, *Oncorhynchus gorbuscha*, had an LC-50 (24 hours) of 920 ppb naphthalene (Eisler, 1987a); Dungeness crab, *Cancer magister*, and Coho salmon, *Onchorhynchus kisutch*, had LC-50s (96 hour) of 2,000 and 3,200 ppb, respectively (Eisler, 1987a).

A comprehensive list of potential toxic effects to marine organisms from aromatic hydrocarbon exposure should be developed following comparison of modeling results to AWQC.

A.2 METALS

The AWQC for metals are shown in Table A-2; these criteria are for the protection of marine aquatic organisms.

Depending upon the exposure concentration, metals have the potential to adversely impact biological resources. The following are examples of some toxic responses potentially caused by metal exposure. A comprehensive review of studies describing metal toxicity should be performed following comparison of modeling concentration results to AWQC.

Arsenic. Arsenic may be bioaccumulated to toxic levels in the tissues of marine organisms, and has the potential to concentrate in the food chain (U.S. EPA, 1992a). A decline in growth and metabolic rates of microorganisms may follow exposure to arsenic; more tolerant species can withstand arsenic levels up to 1,000 ppm, while the most sensitive organisms succumb to levels less than 375 ppm (U.S. EPA, 1992b). Phytoplankton populations showed a biomass reduction after four days of exposure to concentrations of 0.075 ppm (Eisler, 1988a). The

Table A-1
Marine AWQC for Aromatic Hydrocarbons

Compound	Acute AWQC (ug/L)	Chronic AWQC (ug/L)
n-Alkanes	see PAHs	none
Anthracene	see PAHs	none
Benzene	5,100*	700*
Benzo(a)pyrene	see PAHs	none
Biphenyls	none	none
2-Butanone	none	none
Chlorobenzene	160*	129*
p-Chloro-m-cresol	none	none
Dibenzothiophenes (total)	none	none
2,4-Dimethylphenol	none	none
Di-n-butylphthalate	none	none
Ethylbenzene	430*	none
Fluorene	see PAHs	none
Naphthalene	2,350*	none
Phenanthrene	7.7 (proposed)	4.6 (proposed)
Phenol	5,800*	none
Polynuclear Aromatic Hydrocarbons (PAHs)	300*	none
Steranes	none	none
Toluene	6,300*	5,000*
Triterpanes	none	none
Xylenes	none	none

* Insufficient data to develop criteria. Value presented is the LOEL (Lowest Observed Effect Level)

Source: U.S. EPA, 1991; U.S. EPA, 1994.

Table A-2
Marine AWQC for Metals

Compound	Acute AWQC	Chronic AWQC
Aluminum	pH dependent	pH dependent
Antimony	1,500 (proposed)	500 (proposed)
Arsenic (V)	2,319*	none
Arsenic (III)	69	36
Barium	none	none
Beryllium	none	none
Boron	none	none
Cadmium	43	9.3
Chromium (VI)	1,100	50
Chromium (III)	10,300*	none
Copper	2.9	none
Iron	none	none
Lead	140	5.6
Manganese	none	none
Mercury	2.1	0.025
Nickel	75	8.3
Selenium	300	71
Silver	2.3	0.92 (proposed)
Thallium	2,130*	none
Tin	none	none
Titanium	none	none
Zinc	95	86

*Insufficient data to develop criteria. Value presented is the LOEL.
Source: U.S. EPA, 1991; U.S. EPA, 1994.

Dungeness crab had an LC50 (96 hours) of 0.23 ppm (Eisler, 1988a). The median lethal concentration of arsenic for the Black Sea mussel was 10 ppm. These mussels were quite sensitive to sublethal concentrations of arsenic, as reflected by physiological changes (i.e., oxygen consumption respiration, trophic activity of yearlings) (U.S. EPA, 1992b). Pink salmon had an LC54 (10 days) of 3.8 ppm (Eisler, 1988a).

Cadmium. Cadmium has been found to bioaccumulate in the tissues of marine organisms, and has the potential to concentrate in the food chain (U.S. EPA, 1992a). Decreased growth occurs in algae (*Phaeodactylum tricornutum* and *Skeletonema costatum*) following exposure to 10 ppb cadmium (Eisler, 1985). Mysid shrimp, *Mysidopisis* spp., showed molt inhibition following exposure to 10 ppb cadmium for 23 to 27 days (Eisler, 1985).

Chromium. Acute toxicity studies show clearly that hexavalent chromium (Cr VI) is more toxic than trivalent chromium, and that organisms are more sensitive during their younger life stages. The organisms most sensitive to Cr VI, as judged by 96-hour LC-50 values, were marine crustaceans, for which LC-50 values ranged from 445 to 3,100 ppb (Eisler, 1986). Exposures of 28 to 84 days produced LC-50 values of 200 to 500 ppb (Eisler, 1986). Chromium was additive in toxicity when present in a complex mixture of cadmium, zinc, and hexavalent chromium salts (Eisler, 1986).

Lead. Reduced biomass was observed in phytoplankton (mixed populations) exposed to 21 ppb lead for 4 days (Eisler, 1988b). The American lobster, *Homarus americanus*, showed reduced ALAD activity following 30 days exposure to 50 ppb lead (Eisler, 1988b). Dungeness Crab had an LC-50 (96 hours) of 575 ppb lead (Eisler, 1988b).

Mercury. Mysid shrimp had an LC-50 (96 hour) of 3.5 ppb inorganic mercury, and Dungeness Crab larva had an LC-50 (96 hours) of 6.6 ppb inorganic mercury (Eisler, 1987b). Copepods, *Acartia tonsa*, and prawn, *Penaeus indicus*, had LC-50s (96 hour) of 10 and 15.3 ppb, respectively (Eisler, 1987b). Haddock, *Melanogrammus aeglefinus*, had an LC-50 (96 hour) of 98 ppb (Eisler, 1987b).