Injury Assessment

Guidance Document for Natural Resource Damage Assessment Under the Oil Pollution Act of 1990

Damage Assessment
and Restoration Program

August 1996

INJURY ASSESSMENT

GUIDANCE DOCUMENT FOR NATURAL RESOURCE DAMAGE ASSESSMENT UNDER THE OIL POLLUTION ACT OF 1990

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DISCLAIMER

This guidance document is intended to be used as a tool in injury assessments for Natural Resource Damage Assessment (NRDA) activities under the Oil Pollution Act of 1990 (OPA). This document is not regulatory in nature. Trustees are not required to use this document in order to receive a rebuttable presumption for NRDAs under OPA.

NOAA would appreciate any suggestions on how this document could be made more practical and useful. Readers are encouraged to send comments and recommendations to:

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PREFACE

Given the numerous and varied oil spill incidents that have occurred to date, it is abundantly clear that such incidents are difficult to characterize. Therefore, a universal assessment strategy for all incidents is inappropriate. The Oil Pollution Act of 1990 (OPA) recognized this fact, and the regulations implementing Natural Resource Damage Assessments (NRDA) under the Oil Pollution Act of 1990 (OPA) provide for a logical, flexible, and cost-effective approach that can accommodate such varied circumstances.

In accordance with OPA and the NRDA regulations under OPA, the guidance provided in this document serves to describe the approach that trustees may apply to injury assessments. This document does not direct the user in the selection of specific procedures (or methods) and should be viewed only as a starting point for the design of injury assessments for NRDAs under OPA.

LIST OF ACRONYMS

ASTM	American Society for Testing and Materials
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended
EMAP	Environmental Monitoring and Assessment Program
GC	Gas Chromatography
LAT	Lead Administrative Trustee
MFO	Mixed Function Oxygenase
MS	Mass Spectroscopy
NIST	National Institute of Standards and Technology
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NOAA	National Oceanic and Atmospheric Administration
NRDA	Natural Resource Damage Assessment
NRDAM/GLE	Natural Resource Damage Assessment Model/Great Lakes Environment
NRDAM/CME	Natural Resource Damage Assessment Model/Coastal Marine Environment
OPA	Oil Pollution Act of 1990
QA	Quality Assurance
QC	Quality Control
PSEP	Puget Sound Estuary Program
RP	Responsible Party
RPI	Research Planning Institute
SAV	Submerged Aquatic Vegetation
SOP	Standard Operating Procedure
USCG	U.S. Coast Guard
USDOI	U.S. Department of the Interior
USEPA or EPA	U.S. Environmental Protection Agency

INTRODUCTION CHAPTER 1

1.1 Background

A major goal of the Oil Pollution Act of 1990 (OPA)[1] is to make the environment and public whole for injury to or loss of natural resources and services as a result of a discharge or substantial threat of a discharge of oil (referred to as an "incident"). This goal is achieved through returning injured natural resources and services to the condition they would have been in if the incident had not occurred (otherwise referred to as "baseline" conditions), and compensating for interim losses from the date of the incident until recovery of such natural resources and services through the restoration, rehabilitation, replacement, or acquisition of equivalent natural resources and/or services.

The U.S. Department of Commerce, acting through the National Oceanic and Atmospheric Administration (NOAA), issued final regulations providing an approach that public officials (trustees) may use when conducting Natural Resource Damage Assessments (NRDA) under OPA.[2] These NRDA regulations (the OPA regulations) describe a process by which trustees may:

- Identify injuries to natural resources and services resulting from an incident;
- Provide for the return of injured natural resources and services to baseline conditions and compensation for interim lost services; and
- Encourage and facilitate public involvement in the restoration process.

The OPA regulations are included in Appendix A of this document for reference. The preamble discussion of the OPA regulations, along with a summary of and response to public comments received on the proposed regulations, is published at 61 Fed. Reg. 440 (January 5, 1996).

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1 33 U.S.C. §§ 2701 *et seq.*

2 The OPA regulations are codified at 15 CFR part 990 and became effective February 5, 1996.

1.2 Purpose and Scope of this Document

The purpose of the Injury Guidance Document is to provide general approaches for identifying and evaluating injuries to natural resources resulting from incidents involving oil. The focus of this document is on natural resources. Although services provided by natural resources are an important aspect of injury assessment and are discussed where appropriate, detailed identification and evaluation of services is outside the scope of the document. Refer to Appendix B for a listing of other related guidance documents in support of the OPA regulations.

The extent of injury assessment efforts is dependent on the information developed in the early stages of an NRDA (i.e., Preassessment Phase) and the ultimate goal to make the environment and public whole. Therefore, a strong link between preassessment, injury assessment, and restoration planning is necessary. Injury assessment studies should not be initiated without careful consideration of preassessment information and the need to restore natural resources and compensate for interim lost services.

1.3 Intended Audience

This document was prepared primarily to provide guidance to natural resource trustees using the OPA regulations. However, other interested persons may also find the information contained in this document useful and are encouraged to use this information.

1.4 The NRDA Process

The NRDA process shown in Exhibit 1.1 in the OPA regulations includes three phases outlined below: Preassessment; Restoration Planning; and Restoration Implementation.

1.4.1 Preassessment Phase

The purpose of the Preassessment Phase is to determine if trustees have the jurisdiction to pursue restoration under OPA, and, if so, whether it is appropriate to do so. This preliminary phase begins when the trustees are notified of the incident by response agencies or other persons.

Once notified of an incident, trustees must first determine the threshold criteria that provide their authority to initiate the NRDA process, such as applicability of OPA and potential for injury to natural resources under their trusteeship. Based on early available information, trustees make a preliminary determination whether natural resources or services have been injured. Through coordination with response agencies, trustees next determine whether response actions will eliminate the threat of ongoing injury. If injuries are expected to continue, and feasible restoration alternatives exist to address such injuries, trustees may proceed with the NRDA process.

NATURAL RESOURCE DAMAGE ASSESSMENT
Oil Pollution Act of 1990
Overview of Process

PREASSESSMENT PHASE

- Determine Jurisdiction
- Determine Need to Conduct Restoration Planning

RESTORATION PLANNING PHASE

- Injury Assessment
    - Determine Injury
    - Quantify Injury
- Restoration Selection
    - Develop Reasonable Range of Restoration Alternatives
    - Scale Restoration Alternatives
    - Select Preferred Restoration Alternative(s)
    - Develop Restoration Plan

RESTORATION IMPLEMENTATION PHASE

- Fund/Implement Restoration Plan

Exhibit 1.1 NRDA process under the OPA regulations.

1.4.2 Restoration Planning Phase

The purpose of the Restoration Planning Phase is to evaluate potential injuries to natural resources and services and use that information to determine the need for and scale of restoration actions. The Restoration Planning Phase provides the link between injury and restoration. The Restoration Planning Phase has two basic components: injury assessment and restoration selection.

1.4.2.1 Injury Assessment

The goal of injury assessment is to determine the nature, degree, and extent of any injuries to natural resources and services. This information is necessary to provide a technical basis for evaluating the need for, type of, and scale of restoration actions. Under the OPA regulations, injury is defined as an observable or measurable adverse change in a natural resource or impairment of a natural resource service. Trustees determine whether there is:

- Exposure, a pathway, and an adverse change to a natural resource or service as a result of an actual discharge; or

- An injury to a natural resource or impairment of a natural resource service as a result of response actions or a substantial threat of a discharge.

To proceed with restoration planning, trustees also quantify the degree, and spatial and temporal extent of injuries. Injuries are quantified by comparing the condition of the injured natural resources or services to baseline, as necessary.

1.4.2.2 Restoration Selection

(a) Developing Restoration Alternatives

Once injury assessment is complete or nearly complete, trustees develop a plan for restoring the injured natural resources and services. Under the OPA regulations, trustees must identify a reasonable range of restoration alternatives, evaluate and select the preferred alternative(s), and develop a Draft and Final Restoration Plan. Acceptable restoration actions include any of the actions authorized under OPA (restoration, rehabilitation, replacement, or acquisition of the equivalent) or some combination of those actions

Restoration actions under the OPA regulations are either primary or compensatory. Primary restoration is action taken to return injured natural resources and services to baseline, including natural recovery. Compensatory restoration is action taken to compensate for the interim losses of natural resources and/or services pending recovery. Each restoration alternative considered will contain primary and/or compensatory restoration actions that address one or more specific injuries associated with the incident. The type and scale of compensatory restoration may depend on the nature of the primary restoration action, and the level and rate of recovery of the injured natural resources and/or services given the primary restoration action.

When identifying the compensatory restoration components of the restoration alternatives, trustees must first consider compensatory restoration actions that provide services of the same type and quality, and of comparable value as those lost. If compensatory actions of the same type and quality and comparable value cannot provide a reasonable range of alternatives, trustees then consider other compensatory restoration actions that will provide services of at least comparable type and quality as those lost.

(b) Scaling Restoration Actions

To ensure that a restoration action appropriately addresses the injuries resulting from an incident, trustees must determine what scale of restoration is required to return injured natural resources to baseline levels and compensate for interim losses. The approaches that may be used to determine the appropriate scale of a restoration action are the resource-to-resource (or service-to-service approach) and the valuation approach. Under the resource-to-resource or service-to-service approach to scaling, trustees determine the appropriate quantity of replacement natural resources and/or services to compensate for the amount of injured natural resources or services.

Where trustees must consider actions that provide natural resources and/or services that are of a different type, quality, or value than the injured natural resources and/or services, or where resource-to-resource (or service-to-service) scaling is inappropriate, trustees may use the valuation approach to scaling, in which the value of services to be returned is compared to the value of services lost. Responsible parties (RPs) are liable for the cost of implementing the restoration action that would generate the equivalent value, not for the calculated interim loss in value. An exception to this principle occurs when valuation of the lost services is practicable, but valuation of the replacement natural resources and/or services cannot be performed within a reasonable time frame or at a reasonable cost. In this case, trustees may estimate the dollar value of the lost services and select the scale of the restoration action that has the cost equivalent to the lost value.

(c) Selecting a Preferred Restoration Alternative

The identified restoration alternatives are evaluated based on a number of factors that include:

- Cost to carry out the alternative;
- Extent to which each alternative is expected to meet the trustees' goals and objectives in returning the injured natural resources and services to baseline and/or compensating for interim losses;
- Likelihood of success of each alternative;
- Extent to which each alternative will prevent future injury as a result of the incident, and avoid collateral injury as a result of implementing the alternative;
- Extent to which each alternative benefits more than one natural resource and/or service; and
- Effect of each alternative on public health and safety.

Trustees must select the most cost-effective of two or more equally preferable alternatives.

(d) Developing a Restoration Plan

A Draft Restoration Plan will be made available for review and comment by the public, including, where possible, appropriate members of the scientific community. The Draft Restoration Plan will describe the trustees' preassessment activities, as well as injury assessment activities and results, evaluate restoration alternatives, and identify the preferred restoration alternative(s). After reviewing public comments on the Draft Restoration Plan, trustees develop a Final Restoration Plan. The Final Restoration Plan will become the basis of a claim for damages.

1.4.3 Restoration Implementation Phase

The Final Restoration Plan is presented to the RPs to implement or fund the trustees' costs of implementing the Plan, therefore providing the opportunity for settlement of the damage claim without litigation. Should the RPs decide to decline to settle the claim, OPA authorizes trustees to bring a civil action for damages in federal court or to seek an appropriation from the Oil Spill Liability Trust Fund (FUND) for such damages.

1.5 Basic Terms and Definitions

Legal and regulatory language often differ from conventional usage. This section defines and describes a number of important terms used in this document and in the OPA regulations. Trustees should also refer to the OPA regulatory language of Appendix A (at § 990.30), and Appendix C for additional, related definitions.

1.5.1 Baseline

> "*Baseline* means the condition of the natural resources and services that would have existed had the incident not occurred. Baseline data may be estimated using historical data, reference data, control data, or data on incremental changes (e.g., number of dead animals), alone or in combination, as appropriate." (OPA regulations at § 990.30)

Baseline refers to the condition of natural resources and services that would have existed had the incident not occurred. Although injury quantification requires comparison to a baseline condition, site-specific baseline information that accounts for natural variability and confounding factors prior to the incident may not be required. In many cases, injuries can be quantified in terms of incremental changes resulting from the incident, rather than in terms of absolute changes relative to a known baseline. In this context, site-specific baseline information is not necessary to quantify injury. For example, counts of oiled bird carcasses can be used as a basis for quantifying incremental bird mortality resulting from an incident, thereby providing the basis for planning restoration.

The OPA regulations do not distinguish between baseline, historical, reference, or control data in terms of value and utility in determining the degree and spatial and temporal extent of injuries. These forms of data may serve as a basis of a determination of the conditions of the natural resources and services in the absence of the incident.

Types of information that may be useful in evaluating baseline include:

- Information collected on a regular basis and for a period of time from and prior to the incident;
- Information identifying historical patterns or trends on the area of the incident and injured natural resources and services;
- Information from areas unaffected by the incident, that are judged sufficiently similar to the area of the incident with respect to the parameter being measured; or
- Information from the area of the incident after particular natural resources or services have been judged to have recovered.

1.5.2 Exposure

> "*Exposure* means direct or indirect contact with the discharged oil." (OPA regulations at § 990.30)

Exposure is broadly defined to include not only direct physical exposure to oil, but also indirect exposure (e.g., injury to an organism as a result of disruption of its food web). However, documenting exposure is a prerequisite to determining injury only in the event of an actual discharge of oil. The term *exposure* does not apply to response-related injuries and injuries resulting from a substantial threat of a discharge of oil.

1.5.3 Incident

> "*Incident* means any occurrence or series of occurrences having the same origin, involving one or more vessels, facilities, or any combination thereof, resulting in the discharge or substantial threat of discharge of oil into or upon navigable waters or adjoining shorelines or the Exclusive Economic Zone, as defined in section 1001(14) of OPA (33 U.S.C. 2701(14))." (OPA regulations at § 990.30)

When a discharge of oil occurs, natural resources and/or services may be injured by the actual discharge of oil, or response activities related to the discharge. When there is a substantial threat of a discharge of oil, natural resources and/or services may also be injured by the threat or response actions related to the threat.

1.5.4 Injury

> "*Injury* means an observable or measurable adverse change in a natural resource or impairment of a natural resource service. Injury may occur directly or indirectly to a natural resource and/or service. Injury incorporates the terms "destruction," "loss," and "loss of use" as provided in OPA." (OPA regulations at § 990.30)

Section 1002(b)(2)(A) of OPA authorizes natural resource trustees to assess damages for "injury to, destruction of, loss of, or loss of use of" natural resources. The definition of *injury* incorporates these terms. The definition also includes the injuries resulting from the actual discharge of oil, a substantial threat of a discharge of oil, and/or related response actions.

Injury can include adverse changes in the chemical or physical quality, or viability of a natural resource (i.e., direct, indirect, delayed, or sublethal effects). Potential categories of injuries include adverse changes in:

- Survival, growth, and reproduction;
- Health, physiology and biological condition;

- Behavior;
- Community composition;
- Ecological processes and functions;
- Physical and chemical habitat quality or structure; and
- Services to the public.

Although injury is often thought of in terms of adverse changes in biota, the definition of injury under the OPA regulations is broader. Injuries to non-living natural resources (e.g., oiled sand on a recreational beach), as well as injuries to natural resource services (e.g., lost use associated with a fisheries closure to prevent harvest of tainted fish, even though the fish themselves may not be injured) may be considered.

1.5.5 Natural Resources and Services

> "*Natural resources* means land, fish, wildlife, biota, air, water, ground water, drinking water supplies, and other such resources belonging to, managed by, held in trust by, appertaining to, or otherwise controlled by the United States (including the resources of the Exclusive Economic Zone), any State or local government or Indian tribe, or any foreign government, as defined in section 1001(20) of OPA (33 U.S.C. 2701(20))." (OPA regulations at § 990.30)

Natural resources provide various services to other natural resources and to humans, and loss of services is included in the definition of injury under the OPA regulations.

> "*Services* (or *natural resource services*) means the functions performed by a natural resource for the benefit of another natural resource and/or the public." (OPA regulations § 990.30)

Natural resource services may be classified as follows:

- Ecological services - the physical, chemical, or biological functions that one natural resource provides for another. Examples include provision of food, protection from predation, and nesting habitat, among others; and
- Human services - the human uses of natural resources or functions of natural resources that provide value to the public. Examples include fishing, hunting, nature photography, and education, among others.

In considering both natural resources and services, trustees are addressing the physical and biological environment, and the relationship of people with that environment.

1.5.6 Oil

> "*Oil* means oil of any kind or in any form, including, but not limited to, petroleum, fuel oil, sludge, oil refuse, and oil mixed with wastes other than dredged spoil. However, the term does not include petroleum, including crude oil or any fraction thereof, that is specifically listed or designated as a hazardous substance under 42 U.S.C. 9601(14)(A) through (F), as defined in section 1001(23) of OPA (33 U.S.C. 2701(23))." (OPA regulations at § 990.30)

Under the OPA regulations, the definition of "oil" includes petroleum, as well as non-petroleum oils (i.e., fats and oils from animal and vegetable sources). However, in assessing injury resulting from non-petroleum oils, trustees should consider the differences in the physical, chemical, biological, and other properties, and in the environmental effects of such oils on the natural resources of concern.

1.5.7 Pathway

> "*Pathway* means any link that connects the incident to a natural resource and/or service, and is associated with an actual discharge of oil." (OPA regulations at § 990.30)

Pathway is the medium, mechanism, or route by which the incident has resulted in an injury. Pathways may include movement/exposure through the water surface, water column, sediments, soil, groundwater, air, or biota.

Pathway determination may include, but is not limited to, an evaluation of the sequence of events by which the discharged oil was transported from the incident and either:

- Came into direct physical contact with the exposed natural resource (e.g., oil transported from an incident by ocean currents, wind, and wave action directly to shellfish); or

- Caused an indirect injury to a natural resource and/or service (e.g., oil transported from an incident by ocean currents, wind, and wave action cause reduced populations of bait fish, which in turn results in starvation of a fish-eating bird; or, oil transported from an incident by currents, wind, and wave action causes the closure of a fishery to prevent potentially tainted fish from being marketed).

Pathway determination does not require that injured natural resources and/or services be directly exposed to oil. In the example provided above, fish-eating birds are injured as a result of decreases in food availability. However, if an injury is caused by direct exposure to oil, the pathway linking the incident to the injury should be determined.

As with exposure, establishing a pathway is a prerequisite to determining injury, except for response-related injuries and injuries resulting from a substantial threat of a discharge of oil.

1.5.8 Restoration

> "*Restoration* means any action (or alternative), or combination of actions (or alternatives), to restore, rehabilitate, replace, or acquire the equivalent of injured natural resources and services. Restoration includes: (a) Primary restoration, which is any action, including natural recovery, that returns injured natural resources and services to baseline; and (b) Compensatory restoration, which is any action taken to compensate for interim losses of natural resources and services that occur from the date of the incident until recovery." (OPA regulations at § 990.30)

Section 1006(c) of OPA requires natural resource trustees to develop and implement a plan for the "restoration, rehabilitation, replacement, or acquisition of the equivalent," of the natural resources under their stewardship. The OPA regulations have addressed this requirement by defining restoration to encompass all the preceding terms.

The OPA regulations also include the concepts of primary and compensatory restoration. Primary restoration is any action that returns injured resources and services to baseline conditions, including natural recovery. Natural recovery refers to the taking of no human intervention to directly restore the injured natural resources and services. Depending on the injury of concern, primary restoration actions may include actions to actively accelerate recovery or simply to remove conditions that would make recovery unlikely. For each injury (or loss), trustees must consider compensatory restoration actions to compensate for the interim loss of natural resources and services pending recovery.

1.6 Injury Assessment Process

The injury assessment process described schematically in Exhibit 1-2 provides the basis for the organization of this document. The injury selection and study design process often will be iterative. The ability to conduct effective assessment studies should influence the trustees' decision to include a particular injury in the assessment program. It also is helpful for trustees to have access to information about typical oil pathways and routes of exposure, and about common types of injury to natural resources that result from exposure to oil. This information is included in Appendices C and D of this document, respectively.

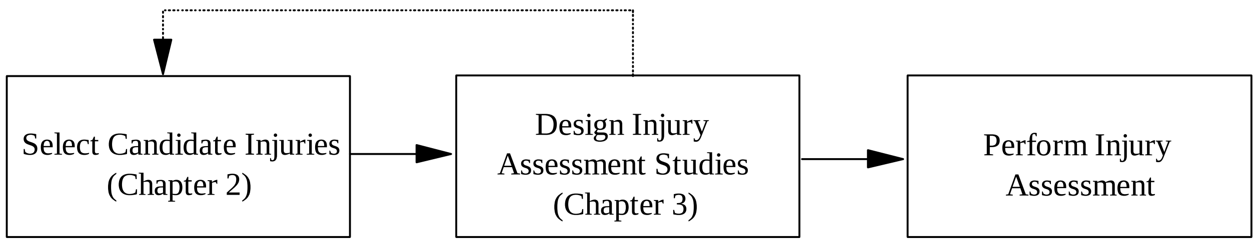

Exhibit 1.2 Injury assessment process.

DECISIONMAKING FRAMEWORK FOR INJURY ASSESSMENT — CHAPTER 2

2.1 Introduction

The purpose of this chapter is to develop a decisionmaking framework to assist trustees in designing the injury assessment component of an NRDA. The framework includes five steps.

- Review information on potential injuries from the Preassessment Phase.

  Trustees review all of the information and preliminary conclusions relevant to injury developed during the Preassessment Phase.

- Construct inventory of possible injuries.

  Trustees organize and structure what is known about possible injuries resulting from the incident. A list of important types of information is provided in this chapter to suggest a way to organize information using a common framework and identify important gaps in knowledge.

  In completing this step, trustees will find it important to carefully differentiate between what is known and what is suspected.

- Evaluate injuries for strength of evidence.[1]

  Trustees evaluate possible injuries based on the strength of information for the injury, relative to what is known and what could be learned from additional injury assessment efforts.

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1 The term *evidence* refers to scientific, not legal, information.

- Establish preliminary restoration objectives.

  Trustees set forth a set of preliminary restoration objectives.

  These objectives might be based upon a number of factors including knowledge of the incident gained during the Preassessment Phase, additional information developed as part of the injury assessment design process, and the knowledge of experts.

- Evaluate injuries for relevance to restoration.

  Trustees evaluate possible injuries based on the relevance (significance and correspondence) of each injury to restoration.

Although these five steps are presented in a sequential fashion, trustees may find it useful to review the process several times as information becomes available and trustee deliberations continue.

Exhibit 2.1 presents a schematic of the decisionmaking framework and includes references to Section 2.4 of this chapter where each element is discussed in greater detail. An example application of the decisionmaking framework is provided in Section 2.5.

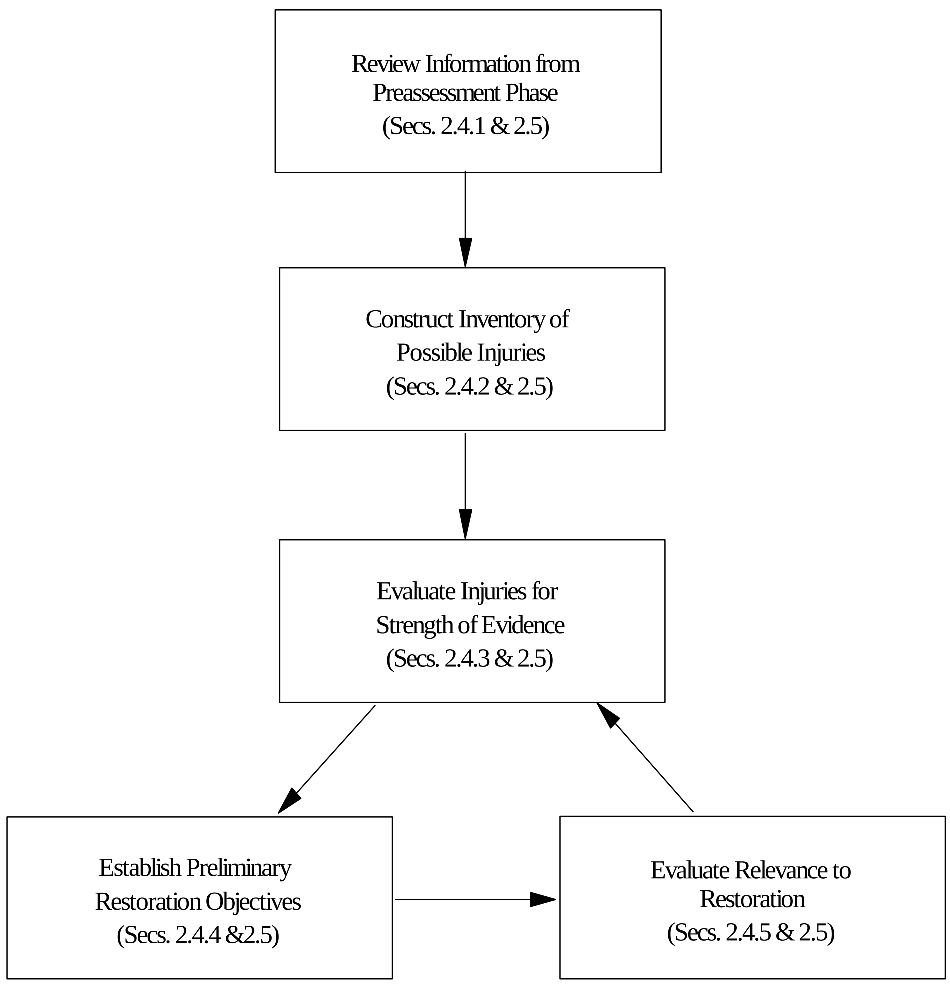
The decisionmaking framework may be more useful to trustees once the Preassessment Phase is completed. During the Preassessment Phase trustees develop initial documentation about the incident, pathways and exposures resulting from the incident, the natural resources and services affected and the specific injuries suffered, and the overall basis for the restoration actions they are contemplating.[2] This information provides the initial direction for designing the injury assessment.

Before turning to a detailed discussion of the decisionmaking framework and the example application, the next two sections explain the concepts of injury and restoration.

2 The reader is referred to the Preassessment Phase Guidance Document, cited in Appendix B.

Exhibit 2.1

DECISIONMAKING FRAMEWORK



2.2 Concept of Injury

2.2.1 Definition of Injury

Under the OPA regulations, trustees must determine if the definition of *injury* has been met. *Injury* is defined as an observable or measurable adverse change in a natural resource or impairment of a service and is described in section 1.5.4 of Chapter 1. The list of potential adverse changes described in the OPA regulations and this document is not intended to be inclusive of all injuries that trustees may evaluate.

2.2.2 Direct and Indirect Injury

An injury can be direct or indirect. Under the OPA regulations, such a distinction is not important. However, when designing an injury study, such distinctions may be quite useful in setting priorities and selecting appropriate methodologies.

Direct injuries can occur when natural resources come into physical contact with the incident (i.e., discharged oil or response-related activities). Examples include the death of a fish exposed to the discharged oil, or restriction of boat activities for the purposes of cleanup along a waterbody affected by the discharge of oil. Indirect injuries may occur when the presence of the discharged oil interferes with a physical, chemical, or biological process important to the natural resource. An example of indirect injury would be a reduction in growth or reproduction in a population of fish-eating birds when prey (e.g., fish abundance) is reduced because of direct injury to the prey from the incident. Indirect injury also may occur from loss or reduction of services provided by a natural resource (e.g., when a fishery is closed because of the potential for oil-tainted fish).

2.2.3 Injury Causality

OPA emphasizes the need for trustees to establish that the identified injuries resulted from the incident. In the event of an actual discharge of oil, injury determination involves:

- Establishing a *pathway* from the discharge in question to the resource;
- Establishing that the resource was *exposed* to the discharge (where applicable); and
- Demonstrating that the adverse change in the resource relative to baseline was caused by exposure to the discharge.[3]

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3 OPA regulations at § 990.51(b).

To evaluate causality, trustees may wish to consult the criteria set forth in Fox (1991). The Fox paper provides a detailed discussion of the many considerations important in establishing causality for environmental changes and sets forth seven specific criteria that should be evaluated.

These criteria are summarized briefly below.

- *Probability*: Is the relationship statistically significant? The demonstration of a statistical relationship between exposure and an adverse change is an important factor in evaluating causality, provided that the statistical power is adequate. A statistically significant correlation between exposure and an adverse change does not, in and of itself, prove causality, but a causal relationship is very unlikely without such a correlation. However, as discussed in detail in Section 3.4.3, statistical significance should not be equated with biological or environmental significance.

- *Time Order*: What is the temporal nature of the association? Does the cause precede the effect in time or was the adverse change already occurring? For example, was the population of a particular species declining prior to the incident? Although the timing of cause and effect may be obscured, the injury should occur during a reasonable time frame following the incident. For example, did the fish kill occur immediately after the discharge or two months later?

- *Strength of Association*: What is the degree to which the cause is associated with the effect (i.e., severity, frequency, extent). Is the exposed population 200 times or 2 times more likely to suffer the injury than the baseline occurrence of that effect? Are all organisms affected by the exposure or is only a fraction of the exposed population affected?

- *Specificity*: How precise is the cause and effect relationship? Does the adverse change occur only in the exposed population relative to baseline information? For example, a decline in reproductive success may be observed following an incident. If that association is limited to the exposed population, the causation argument would be strengthened. If, however, similar declines in reproductive success are consistently found elsewhere (i.e., at reference sites), the association would be weakened.

- *Consistency on Replication*: Has the association been repeatedly observed under different conditions? The occurrence of an association in more than one population or species, in different areas, by different researchers, is strong evidence of a causal relationship.

- *Predictive Performance*: Is the association strong enough to allow for prediction of consequences? Such predictions are based on hypothesis formulation and observation.

- *Coherence*: Does the cause-effect hypothesis conflict with knowledge of natural history, biology, and toxicology? Is there a plausible mechanism? Is there a dose-response relationship?

2.3 Concept of Restoration

2.3.1 Definition of Restoration

Trustees must identify a reasonable range of restoration alternatives[4] for consideration, as defined in section 1.5.8 of Chapter 1. Each alternative is composed of primary and/or compensatory restoration components that address one or more specific injuries associated with the incident. Primary restoration refers to any actions taken to return the injured natural resources and services to baseline on an accelerated time frame. Natural recovery, in which no human intervention is taken to accelerate recovery of the injured natural resource and service, is included under the primary restoration component. Compensatory restoration refers to any actions taken to compensate for the interim losses of natural resources and services, from the time of the incident until recovery is achieved.

Each alternative must be designed so that, as a package of one or more actions, the alternative would satisfy OPA's goal to make the environment and public whole for injuries resulting from an incident. Acceptable restoration alternatives include any of the actions authorized under OPA (i.e., restoration, rehabilitation, replacement, or acquisition of the equivalent) or any combination of those actions.

In general, both primary and compensatory restoration of services must be accomplished through actions to restore natural resources or to preserve or enhance the amount, quality, and/or availability of natural resources that provide the same or similar services. This may include actions to improve access to natural resources, although in selecting such actions, the trustees must carefully evaluate the direct and indirect impacts of the improved access on natural resource quality and productivity. In the natural resource damages context, a service may not be viewed as an abstract economic unit or activity that may be restored independently of the natural resources from which the service flows.

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4 OPA regulations at § 990.53(a).

2.3.2 Primary Restoration

Trustees must consider primary restoration actions,[5] including a natural recovery alternative. Alternative primary restoration actions can range from actions that prevent interference with natural recovery (e.g., closing an area to human traffic) to more intensive actions expected to return injured natural resources and services to baseline faster or with greater certainty than natural recovery.

When identifying primary restoration actions to be considered, trustees should consider whether:

- Activities exist that would prevent or limit the effectiveness of restoration actions (e.g., residual sources of contamination);

- Any primary restoration actions are necessary to return the physical, chemical, and biological conditions necessary to allow recovery or restoration of the injured natural resources (e.g., replacement of sand or vegetation, or modifying hydrologic conditions); and

- Restoration actions focusing on certain natural resources and services would be an effective approach to achieving baseline conditions (e.g., replacing essential species, habitats, or public services that would facilitate the replacement of other, dependent natural resource and service components).

2.3.3 Compensatory Restoration

In addition to primary restoration, trustees must consider compensatory restoration actions[6] in the restoration alternatives. The extent of interim natural resource or service losses that must be addressed by a particular restoration alternative may vary depending on the level and speed of recovery generated by the primary restoration component of the restoration alternative.

To the extent practicable, when identifying the compensatory restoration components of the restoration alternatives, trustees should consider compensatory restoration actions that provide services of the same type and quality, and of comparable value as those injured. This is the preferred approach to identifying compensatory restoration actions. If such actions do not provide a reasonable range of alternatives, trustees should identify actions that, in the judgment of the trustees, will provide services of at least comparable type and quality as those injured. Where the injured and replacement natural resources and services are not of comparable value, the scaling process will involve valuation of injured and replacement services.

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5 OPA regulations at § 990.53(b).

6 OPA regulations at § 990.53(c).

In general, both primary and compensatory restoration of services must be accomplished through actions to restore natural resources or to preserve or enhance the amount, quality, and/or availability of natural resources that provide the same or similar services. This may include actions to improve access to natural resources, although in selecting such actions, the trustees must carefully evaluate the direct and indirect impacts of the improved access on natural resource quality and productivity. In the natural resource damages context, a service may not be viewed as an abstract economic unit or activity that may be restored independently of the natural resources from which the service flows.

2.3.4 Relationship between Primary and Compensatory Restoration

The concept of scaling compensatory restoration actions is illustrated in Exhibit 2.2. The first graph characterizes the level of services provided by an injured resource, and the second graph characterizes the level of services provided at a compensatory restoration project site. Time is represented on the horizontal axis, and the level of services is represented on the vertical axis. The baseline level of services is indicated by the horizontal line labeled "baseline."

If no primary restoration is undertaken, the combined areas A and B would represent the total services lost from the time of injury until the return of the resources to baseline through natural recovery. However, a primary restoration program would promote the recovery and reduce the interim loss of services by the amount represented in area B. In other words, the compensatory restoration project would need to compensate for the loss of A.

Trustees would compensate for the loss in services due to the injury by implementing an on-site compensatory restoration project generating additional services represented by area C. The public will be compensated when the area of C equals the area of A. Alternatively, if natural recovery were the preferred option, then area C should equal the sum of areas A and B.

It should be clear from this discussion that the selection of a metric to characterize service levels is critical.

A range of primary restoration activities may be considered by the trustees. Active primary restoration would achieve a quicker return to baseline, relative to natural recovery, and generally would reduce the interim loss of services. However, in some situations, active primary restoration may not be feasible or desirable and the trustees would develop only a compensatory restoration program in conjunction with natural recovery.

Exhibit 2.2 assumes that baseline remains constant over time. This may not always be the case (refer to Exhibit 2.3). Trustees should consider whether the baseline level is changing when planning and conducting an injury assessment.[7]

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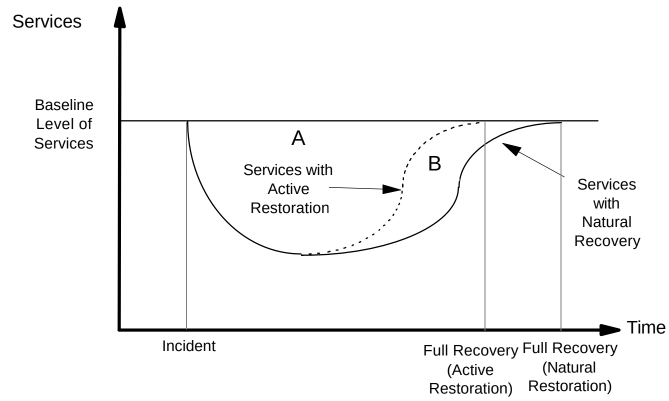
[7] The plots in Exhibit 2.3 were developed by John Cubit, NOAA, Damage Assessment Center, Long Beach, CA.

Exhibit 2.2

THE RELATIONSHIP BETWEEN PRIMARY AND COMPENSATORY RESTORATION

Level of Services Provided by Injury Site



Increment in Services at Site of Compensatory Restoration Project

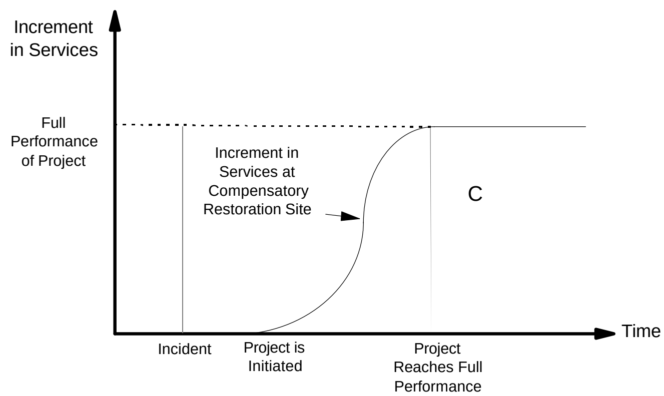
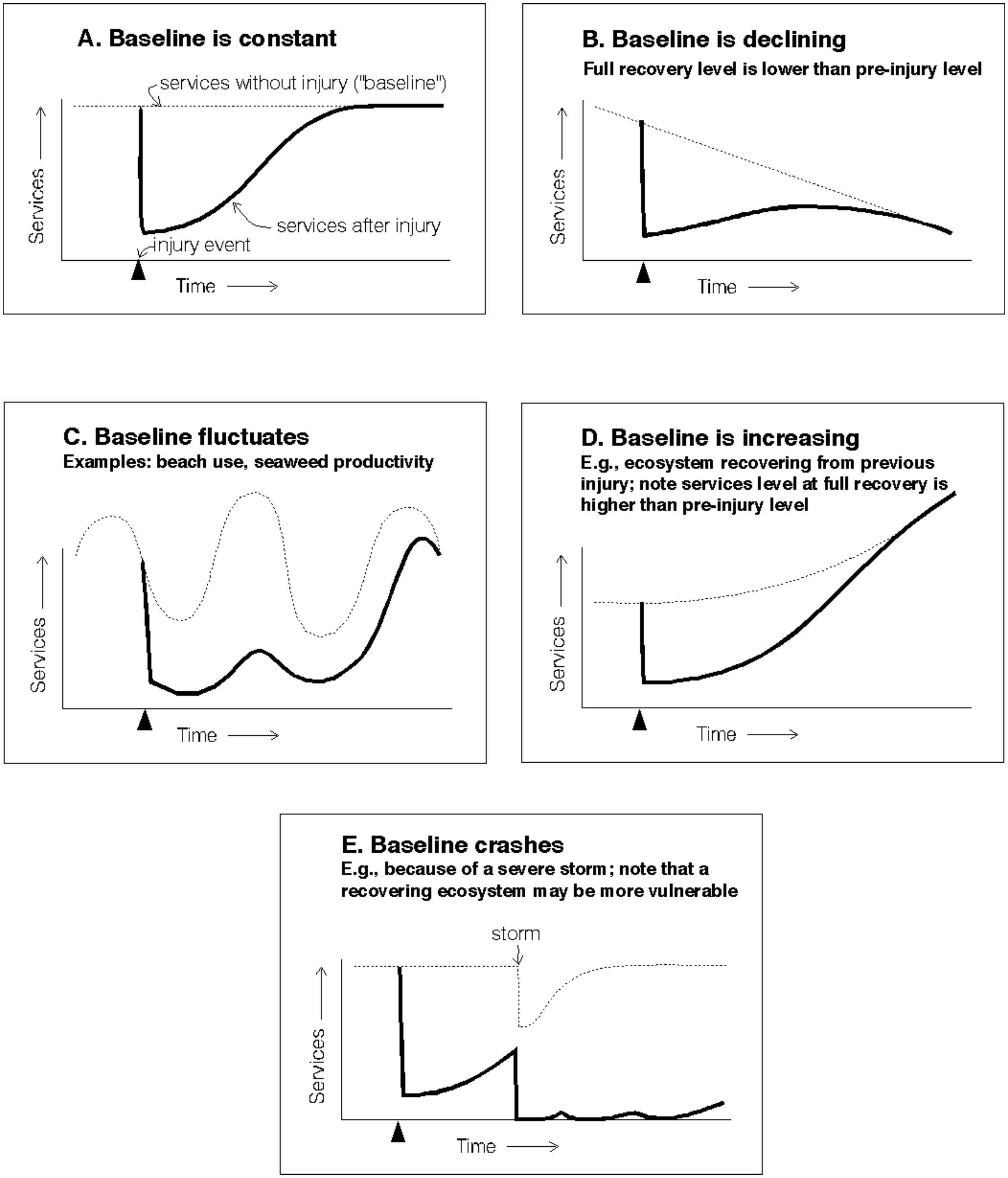


Exhibit 2.3

EXAMPLES OF A FEW BASELINE FORMS



2.4 The Decisionmaking Framework

The decisionmaking framework for injury assessment is structured to ensure that restoration considerations are an integral part of the injury assessment planning process. Natural resource trustees may wish to use this framework to assist in designing an integrated and cost-effective injury assessment that will support restoration.

2.4.1 Review Information from Preassessment Phase

Trustees may wish to begin by carefully reviewing all information and preliminary conclusions generated during the Preassessment Phase, including the Notice of Intent to Conduct Restoration Planning as well as other information generated during preassessment activities. In most cases, trustees already will be very familiar with preassessment information as they begin to design the injury assessment. The purpose of this review is to ensure the trustees are familiar with all available information about the incident and environmental characteristics prior to the incident.

2.4.2 Construct Inventory of Possible Injuries

To ensure that the evaluation of possible injuries is as complete as possible, trustees should consolidate knowledge about all suspected injuries prior to evaluating the injuries for inclusion in the assessment. To compile the inventory, trustees should answer the following types of questions for each suspected injury.[8]

- What are the natural resources and services of concern?
- What are the procedures available to evaluate and quantify injury and the associated cost and time requirements?
- What is the evidence indicating exposure?
- What is the pathway from the incident to the natural resource and/or service of concern?
- What is the adverse change or impairment that constitutes injury?
- What is the evidence indicating injury?
- What is the mechanism by which injury occurred?

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8 OPA regulations at § 990.51(f).

- What is the potential degree and spatial and temporal extent of the injury?

- What is the potential natural recovery period?

- What are the kinds of primary and/or compensatory restoration actions that are feasible?

When completing the inventory, the trustees should critically examine all observations, data, and assumptions that indicate that specific injuries have occurred or will occur. Trustees should give careful consideration to contradictory evidence, alternative hypotheses, and possible confounding factors.

Constructing the inventory of possible injuries should not require an extensive research effort, but should instead be based on the knowledge of the trustees and outside experts, and the information collected during response and preassessment. It may be useful to review the relevant scientific and damage assessment literature as the inventory is constructed. To be most useful, the inventory should not be a list of possible *studies* that might be conducted in support of an injury assessment program, but rather should focus on what is known and suspected about *injuries* from the incident.

Exhibit 2.4 presents an example of a tabular format that trustees might use to consolidate this information. The columns in the exhibit are keyed to the questions listed above. This example format can be varied to meet the particular requirements of an incident. For example, an additional column could be added to summarize information about baseline trends or two columns could be used to consider pathway and exposure issues separately. A separate table could be generated for each type of natural resource (e.g., fish, birds, wetlands). The paragraphs below provide a brief discussion of each of the questions listed above and in the exhibit.

Exhibit 2.4

INVENTORY OF POTENTIAL INJURIES

Resource	Injury	Services	Evidence for Injury	Mechanism	Pathway and Exposure	Time to Natural Recovery	Possible Primary Restoration Activities	Possible Compensatory Restoration Activities

What are the natural resources and services of concern?

Trustees should identify the specific natural resources of concern using precise language to describe the area, habitat, plant, or animal at whatever level is appropriate. To complete this first step, trustees may consider the spatial and temporal extent of the incident, pathways from the incident to resources, likely exposures, and observed or suspected adverse effects. Appendix D describes a wide range of natural resources that could be injured by oil. The information in Appendix D can be used as a check on the completeness of the list of injured natural resources.

Trustees should also list the specific ecological and human services affected by the injury. The trustees should consider the important services provided by the affected natural resources, with particular attention to the role of those natural resources in the overall ecosystem (e.g., source of clean food, habitat for rearing of young).

What are the procedures available to evaluate and quantify injury, and the associated cost and time requirements?

The OPA regulations allow for a wide range of assessment procedures,[9] from field or laboratory procedures, to model- or literature-based procedures, to a combination of procedures. When practicable, injury assessment procedures should be chosen that provide information of use in determining the most appropriate alternative for restoring the injury resulting from the incident. In addition, when selecting injury assessment procedures, trustees should consider factors such as the time and cost to implement the procedure, nature, and spatial and temporal extent of injury, information needed to determine and quantify injury, possible restoration actions for expected injuries, and information needed to determine appropriate restoration. If more than one procedure providing the same type and quality of information is available, the most cost-effective procedure must be used.

Under the OPA regulations, injury assessment procedures must meet all of the following standards:

- The procedures provide assessment information of use in determining the type and scale of restoration appropriate for a particular injury;

- The additional cost of a more complex procedure is reasonably related to the expected increase in the quantity and/or quality of relevant information provided by the more complex procedure; and

- The procedures are reliable and valid for the particular incident.

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9 OPA regulations at § 990.27.

What is the evidence indicating exposure? What is the pathway from the oil to the natural resource and/or service of concern?

For incidents involving an actual discharge, trustees should describe the specific pathway and mechanism thought responsible for exposing the resource in question to the incident. Trustees will need to evaluate whether there is a pathway from the oil to the resource in question and the natural resource in question was, in fact, exposed to the discharge.

What is the adverse change or impairment that constitutes injury?

Trustees should list the specific injury of concern. Known or suspected adverse change should be defined as precisely as possible.

What is the evidence indicating injury?

Trustees should list the basic facts and hypotheses that suggest that injury has or is likely to have occurred. Data and observations collected during response to the incident will provide information, for example, about the extent of animal and plant mortality and perhaps other injuries. There also may be data on oil concentrations in various media such as water and sediments, and information on the degree of oiling of shorelines, wetlands, etc. This information can be combined with the knowledge of experts and with information found in the published literature to provide the initial line of reasoning supporting injury.

What is the mechanism by which injury occurred?

Trustees should list the mechanism of action thought to have caused the observed or suspected injury. The trustees may wish to review the relevant toxicological literature and consult with biologists and environmental toxicologists knowledgeable about the mechanisms (e.g., suffocation, acute/chronic toxicity, tissue or cellular damage) of action that cause adverse effects in resources exposed to oil.

What is the potential degree, and spatial and temporal extent of the injury?

In order to adequately assess injury to natural resources and services, trustees must evaluate the degree (severity or magnitude) of the injury, and the spatial (geographical) and temporal (duration) extent of that injury.[10] Such information allows the trustees not only to prioritize their concerns relative to various injuries, but ultimately to define the scale of restoration possible given those prioritized injuries.

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10 OPA regulations at § 990.52(b).

Degree of injury may be expressed in terms such as percent mortality, incremental mortality, proportion of habitat affected, and extent of oiling. Spatial extent may include quantification of the total area or volume of injury. Temporal extent may be expressed as the total length of time that the natural resource and/or service is adversely affected, starting at the time of the incident and continuing until the natural resources and services return to baseline.

What is the potential natural recovery period?

Trustees must determine not only whether natural recovery[11] is possible, but also the rate of such recovery. Analysis of recovery times may include such factors as the:

- Nature, degree, and spatial and temporal extent of injury;
- Sensitivity and vulnerability of the injured natural resource and/or service;
- Reproductive and recruitment potential;
- Resistance and resilience (stability) of the affected environment;
- Natural variability; and
- Physical/chemical processes of the affected environment.

Although it is desirable to account for these factors and produce a rigorous quantitative natural recovery estimate for a particular natural resource, this may not be practicable for many injuries. Where quantitative procedures are lacking, inadequate, or unnecessarily costly to precisely estimate natural recovery times, trustees may use appropriate qualitative procedures to develop estimates where needed.

What are the kinds of primary and/or compensatory restoration actions that are feasible?

Trustees should list actions by which primary restoration of the natural resources and services might be accomplished.[12] Trustees should also list actions that could replace services lost due to the injured natural resource. These actions might include activities such as acquisition of additional habitat, provision of food while restoration or natural recovery is ongoing, improvements to facilities to allow enhanced public uses of the resource, etc.

[11] OPA regulations at § 990.52(c).

[12] Trustees should refer to the Restoration Guidance Document cited in Appendix B for a list of possible restoration actions.

2.4.3 Evaluate Possible Injuries for Strength of Evidence

The strength of evidence for each possible injury should be evaluated based on what is presently known about the incident and could be learned from additional work during injury assessment. Exhibit 2.5 provides four questions to guide evaluation of strength of evidence, both with current knowledge and with additional studies. The paragraphs following Exhibit 2-5 provide a brief discussion of each of the questions.

Exhibit 2.5

QUESTIONS TO EVALUATE STRENGTH OF EVIDENCE

- Can the injury be stated in terms that comply with the definition of injury in the OPA regulations.
- Can the injury be reliably documented under appropriate quality assurance procedures?
- Can the pathway of exposure be established through empirical observations, modeling, or a combination of observations and models?
- Is it reasonable to conclude that the injury was caused by the incident in question or do other plausible explanations exist?

- **Can the injury be stated in terms that comply with the definition of injury in the OPA regulations?**

Trustees should begin evaluating the strength of the information by determining whether they are able to clearly define the injury in terms consistent with the OPA regulations. That is, is there an *injury* as defined by the OPA regulations? Is the injury related to an actual discharge of oil, response actions, or a substantial threat of a discharge of oil?

- **Can the injury be reliably documented under appropriate quality assurance protocols?**

Trustees should evaluate the quality of the data that support the finding of injury and should carefully consider limitations in these data. In cases where a model-based assessment (e.g., type A model) is appropriate, field observations and literature searches may generate important corroborative information. If additional assessment effort is needed, trustees should consider the quality of the findings likely to be generated by these efforts. Chapter 3 provides information trustees should consider when designing and evaluating injury assessment studies. To be scientifically defensible, any assessment efforts undertaken by the trustees should be designed with a strong quality assurance component.[13]

- **Can the pathway of exposure be established through empirical observations, modeling, or a combination of observations and models?**

In the event of an actual discharge, trustees should evaluate the quality of the data indicating that injured natural resources have been exposed to the discharge or affected by the incident. If additional assessment efforts are needed to further document the pathway of exposure, trustees should consider the quality of the findings likely to be generated by these studies.

- **Is it reasonable to conclude that the injury was caused by the incident in question or do other plausible explanations exist?**

Trustees should evaluate the quality of the data that supports the finding that the injury was caused by the incident in question. Adverse effects can occur for a variety of reasons and natural resources sometimes are affected by other substances or perturbations.

2.4.4 Establish Preliminary Restoration Objectives

Trustees should further develop a set of preliminary restoration objectives. Because these objectives are tentative at this stage, trustees can expect to revise the objectives as the design for the injury assessment is developed and finalized. The preliminary objectives will be based on information gathered during the incident, response, and preassessment efforts, the knowledge of experts, and the results of the first three steps of the decisionmaking framework.

The restoration objectives should set forth a brief list of the restoration endpoints that the trustees seek to achieve. Trustees should consider listing restoration actions with each objective to make the objectives more tangible and useful and ordering the objectives by overall importance to the trustees.

13 Chapter 3 provides an overview of quality assurance procedures for injury assessments.

For example, imagine that a large discharge of oil has occurred in a coastal area, resulting in extensive oiling of the intertidal zone, including salt marshes. Bird, fish, and shellfish mortality are documented, as is tissue contamination in large areas of shellfish beds. The area was closed to beach use, fishing, shellfishing, and boating for a three-week period. Some shellfish beds are not expected to be reopened for several months and will suffer from reduced populations for approximately three years. Oiled salt marshes will be impaired for approximately five years.

In this situation, the trustees might develop the following list of preliminary objectives to guide the injury assessment process.

Objective 1. Clean up, isolate, or remediate any continuing sources of oil that would inhibit natural recovery or limit the success of further restoration efforts. Actions might include removal of buried oil in a gravel beach that continues to generate sheens.[14]

Objective 2. Restore or rehabilitate injured habitats to baseline conditions. Actions might include replanting of salt marsh vegetation and protection of oiled areas from erosion during vegetation recovery.

Objective 3. Enhance the recovery of specific injured natural resources and services that are important to the environment or public. Actions might include replacement of killed birds by encouraging recolonization of the area (e.g., nesting sites), reseeding of shellfish beds, and placement of clean sand on degraded public beaches.

Objective 4. Create or enhance habitat or human facilities to provide equivalent services as compensation for services lost from the onset of injury to full recovery to baseline. For example, such actions might include rehabilitation of additional areas of degraded salt marsh near the discharge area (but not caused by the discharge).

Compensatory restoration actions are typically considered after primary restoration actions have been developed because the scope of compensatory restoration is dependent upon the speed and effectiveness of primary restoration.

2.4.5 Evaluate Possible Injuries for Relevance to Restoration

The final part of the decisionmaking framework is the evaluation of possible injuries for relevance to restoration. Exhibit 2.6 provides a checklist to aid the evaluation of relevance of possible injuries. The paragraphs following Exhibit 2.6 provide a brief discussion of each of the questions.

[14] Often, significant sources of oil will be removed during the response action. In this example, we assume that buried oil was discovered after clean-up actions were terminated.

Exhibit 2.6

QUESTIONS TO EVALUATE RELEVANCE TO RESTORATION

(1) Relevance to Primary Restoration

- Can the injury be remedied by direct restoration of chemical, physical, or biological attributes of the environment?
- Do the trustees conclude, on a tentative basis, that active primary restoration is preferable to natural recovery?
- Can the injury be quantified in a way that allows the scale of primary restoration to be determined?

(2) Relevance to Compensatory Restoration

- Can the environment or public be compensated for lost services through compensatory restoration such as habitat construction, stocking, or other activities, to replace lost services?
- Can the injury be quantified in terms that allow the scale of compensatory restoration to be estimated?

(1) Relevance to Primary Restoration

- **Can the injury be remedied by direct restoration of chemical, physical, or biological attributes of the environment?**

Trustees should list possible primary restoration actions considered in the Preassessment Phase and further evaluate whether these actions are technically feasible and likely to be cost-effective. While a variety of actions may appear possible at first consideration, experts should carefully evaluate the likely effectiveness of these actions.

- **Do the trustees conclude, on a tentative basis, that active primary restoration is preferable to natural recovery?**

Trustees should evaluate whether primary restoration actions will result in a more rapid return to baseline. The time needed to return the injured natural resource to baseline depends not only on the speed with which the restoration action affects the environment, but also on the time required to initiate the restoration action given the status of the overall assessment of injury, the need for detailed planning and environmental permitting, and other factors. The total time required to plan, gain regulatory and public approval, and then implement a primary restoration action can be significant.

- **Can the injury be quantified in a way that allows the scale of primary restoration to be determined?**

Trustees should consider how the degree and spatial/temporal extent of primary restoration might be determined and how the trustees might demonstrate that the primary restoration under consideration will accelerate the recovery of the injured natural resources. Trustees should be able to link the primary restoration to the baseline condition of the natural resource developed in the injury assessment.

(2) Relevance to Compensatory Restoration

- **Can the environment or public be compensated for lost services through compensatory restoration, such as habitat construction, stocking, or other activities, to replace lost services?**

Trustees should list possible compensatory restoration actions and consider the feasibility, costs, and ecological and human services to be gained from each possible compensation action. Compensatory restoration actions should generate services that are as similar as practicable to the services lost as a result of the incident.

- **Can the injury be quantified in terms that allow the scale of compensatory restoration to be estimated?**

Trustees should consider how the appropriate amount or scale of compensatory restoration will be determined and how this will be shown to be commensurate with the natural resources and services lost. In the case of compensation actions, duration as well as degree of replacement services is important.

2.4.6 Consider the Strength of Evidence on Injury and its Relevance to Restoration

Evaluation of strength of evidence and relevance to restoration for each possible injury can assist trustees in selecting injuries to include in the injury assessment and identifying additional injury assessment efforts to pursue, if any. Trustees may decide not to include injuries with low relevance regardless of the strength of evidence on injury. Injuries with high relevance and strong evidence are obvious candidates for inclusion in the injury assessment. Injuries with high relevance, but weaker information will need to be carefully considered by the trustees.

The primary value of the strength of evidence on injury and relevance concepts and of the overall decisionmaking framework is to provide a structure for discussions and deliberations among trustees and other interested persons. Trustees may find it helpful during these deliberations to use some simple tables or graphs to visualize the relationship between strength of evidence and relevance to restoration for each possible injury. Trustees could use a simple table to summarize strength of evidence and relevance, as shown in Exhibit 2.7, using either terms such as "high" and "low" or numerical rankings. When trustees use such subjective terms such as "high" and "low," they should define the parameters of these terms so that there is a common understanding of their use.

Exhibit 2.7

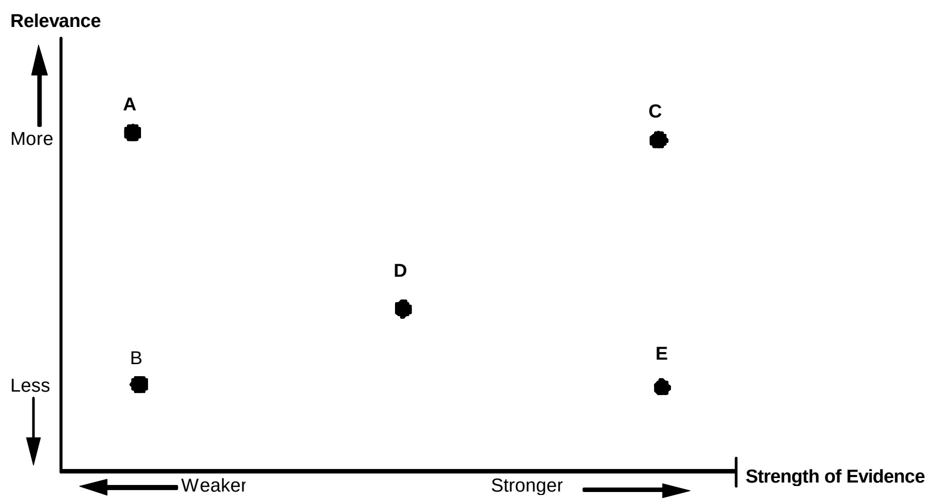
CONSIDERING INJURIES BASED ON THE STRENGTH OF EVIDENCE ON INJURY AND RELEVANCE TO RESTORATION

Injury	Strength of Evidence		Relevance
	Now	**With More Study**	
A	Weak	Moderate	High
B	Weak	Weak	Low
C	Strong	Very Strong	High
D	Moderate	Moderate	Medium
E	Strong	Strong	Low

Exhibit 2.8 provides one possible graphical technique. Strength of evidence for each injury under consideration is plotted along the horizontal axis, with injuries with greater strength of evidence to the right and injuries with weaker evidence on the left. The relevance of each possible injury is

Exhibit 2.8

CONSIDERING INJURIES BASED ON STRENGTH OF EVIDENCE AND RELEVANCE



plotted on the vertical axis, with more relevant injuries found above less relevant injuries.

Exhibits 2.7 and 2.8 include five example injuries labeled A through E. Injuries A and C both are judged highly relevant, and Injury C is judged to have strong evidence. Trustees might elect to include both A and C in the injury assessment. Limited additional studies might be needed to finalize the evidence for C, while significant additional assessment effort appears needed for A given the relatively weak evidence at present. Trustees would need to carefully consider the cost and time requirements of possible additional efforts for injury A.

Injury D is judged to fall in the middle of both the relevance and strength of evidence scales. Trustees will often find possible injuries in this middle area. Decisions to include these types of injuries in the assessment may depend on whether additional assessment effort can be completed within a reasonable time period and budget.

Injuries B and E both are judged to have low relevance. Injury B also is judged to have weak evidence and would likely be dropped from further consideration by the trustees. Injury E is judged to have relatively strong evidence and might be included in the injury assessment if little or no further study of the injury were required.

As trustees consider the strength of evidence of possible injuries they will need to carefully review additional studies needed to evaluate injuries. Trustees may wish to clearly set forth information about each additional study by developing brief answers to the following questions.

- What questions regarding injury and its relevance to restoration will the study answer?
- How will the study be conducted?
- Who will perform the study and what are the qualifications of the investigators?
- How much time and funding will be required?
- Is the study likely to generate valid data and conclusions?

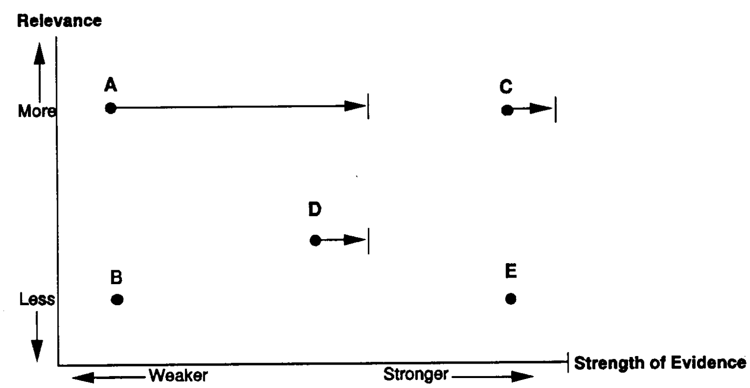
If useful, trustees can include information about the expected change in strength of evidence shown in Exhibit 2.7 or can plot this information shown in Exhibit 2-9. The horizontal arrows in Exhibit 2.9 associated with each injury represent the trustees' estimate of how the strength of evidence for an injury might change after further study.

Continuing the example used above, Exhibit 2.9 indicates the trustees' judgment that additional assessment effort would significantly strengthen evidence for injury A but would have little effect on the evidence for injury D. Additional effort was not considered for injuries B and E in view of their low relevance. Little additional effort is judged necessary for injury C.

The example table or graphs described above are methods that trustees might use to facilitate discussion and decisionmaking about the interaction of relevance and strength of evidence. It is important for trustees to understand that the selection and evaluation of injuries will be an iterative rather than sequential process. As new information becomes available and trustee deliberations continue, restoration objectives may evolve and the evaluation of some injuries may change.

Exhibit 2-9

CONSIDERING INJURIES AFTER ADDITIONAL ASSESSMENT EFFORTS



2.5 Example Application of the Decisionmaking Framework

The following example of a hypothetical incident and the accompanying evaluation of potential injuries using the decisionmaking framework are intended to illustrate the type of process trustees might use during the development of an injury assessment program. The list of injuries for the example is not meant to be exhaustive, rather, it is intended to include a range of natural resource injuries and service losses. Similarly, the evaluation of injuries is illustrative only and is not intended to indicate any preferred approach to injury assessment.

On June 1, an oil tanker lodged onto a submerged rock ledge while approaching a harbor in a coastal area. Tank measurements and reconnaissance flights indicated at least 1,000,000 gallons of crude oil had been discharged. Initial reports indicated that salt marshes, recreational beaches, boating, fish and shellfish, birds, and commercial and recreational fishing were most likely to suffer adverse effects from the discharge.

Nearby beaches were threatened with oiling. The beaches provide sunbathing, picnicking, hiking, surfing, fishing, and shellfishing as recreational activities, along with boat ramps for launching small vessels. The beaches also provide nesting habitat for several shorebirds.

The oil also threatened extensive salt marshes that provide habitat for birds as well as a rearing area for fish and shellfish. These wetlands also provided flood control and erosion protection to the area. Bird watchers frequently visit the salt marsh.

The wind and currents carried the oil onshore and oiled large sections of the beaches, intertidal zone, and salt marshes. Beaches were closed for three weeks immediately after the discharge. Additionally, small sections of beach were closed throughout the summer to allow for beach cleaning operations. Several boat launching areas also were closed to public use during the response action phase of the incident. The launching areas were not oiled, but the closure was necessary to provide staging areas for clean-up contractors.

The State Department of Health issued a closure for all recreational and commercial harvests of fish and shellfish for one week. The closure was then partially lifted to allow for finfishing, but remained in effect for the harvest of clams, mussels, oysters, and crabs for an additional two weeks. Some heavily oiled shellfish beds were not reopened for several months and experienced significant mortality. Shellfish populations in these beds were expected to require three years to recover.

Recreational and commercial boating activity was restricted by the safety zone established by the U.S. Coast Guard (USCG) around the damaged tanker, but no further area closures were implemented. Continued clean-up activity caused a reduction in boating activity for three weeks after the discharge.

The natural resource trustees determined to conduct a NRDA based upon information collected during the Preassessment Phase. Within the first two days of the discharge, trustees formed a working trustee council to coordinate early sampling and develop a plan for identifying, documenting, and quantifying the effects of the discharge.

To develop an injury assessment program, the trustees decided to use the decisionmaking framework described in this chapter. The trustees have summarized their knowledge and judgment about the effects of the discharge into an inventory of possible injuries. Exhibit 2.10 includes a portion of the inventory developed by the trustees.

Exhibit 2.10

EXAMPLE INVENTORY OF POTENTIAL INJURIES

Resource	Injury	Services	Evidence for Injury	Mechanism	Pathway and Exposure	Time to Natural Recovery	Primary Restoration Alternatives	Compensatory Restoration Alternatives
Shorebirds (A)	mortality, reproductive impairment	bird watching, passive use	dead shorebirds, oiled and broken eggs, destroyed nests	direct contact with oil, habitat destruction by oil and response crews	oil washed ashore	unknown	attraction of replacement nesting pairs to the area, improve nesting sites and foraging.	Provide additional bird refuges at nearby beaches.
Shellfish (B)	mortality, tainting resulting in closure	recreational and commercial fishery, clean food	dead shellfish, samples of shellfish tissue contain oil	ingestion of oil-contaminated water, direct contact with oil	oil floats ashore, dissolves in the water column	3 years	Remediate sediments to provide new clean habitat, monitor water quality data.	Provide additional shellfishing opportunities at alternate nearby sites.
Salt marsh (C)	loss of vegetation, loss of productivity	habitat, clean food, erosion control	large oiled and devegetated areas	uptake of oil by plants and/or smothering	oil entered salt marsh and oiled the vegetation	10 years	Remove heavy contamination, replace with clean-fill and replant.	Purchase and rehabilitate degraded wetland nearby.
Fish (D)	mortality, behavioral abnormalities, closure	food, contributes to standing stock of fishery	dead fish, lower populations of juvenile fish	ingestion of oil	oil entered salt marsh	4 years	stocking of juvenile fish, enhance habitat	Provide additional recreational fishing opportunities.
Beaches (E)	oiling of beaches	human use, shorebird habitat	closure	direct contact with oil, *spill* response	oil washed ashore	1 year	additional cleanup, replacement of sand	provide additional beach habitat or access

Using the information summarized in Exhibit 2.10, the trustees first evaluate the strength of evidence for each possible injury. Existing evidence for the shorebird and beach injuries is judged to be very strong. Evidence for immediate adverse effects on shellfish and salt marshes also is strong, but evidence for continuing effects and time to natural recovery for these resources is less conclusive. Evidence for the possible injury to fish is judged to be weak.

Next, the trustees set forth preliminary restoration objectives for the injured natural resources. These objectives are described in section 2.4.4.

The trustees then consider the relevance to restoration for each possible injury. They conclude that the possible injuries to shorebirds and shellfish are most relevant to the tentative restoration objectives, followed closely by the salt marsh injury. The trustees judge the relevance to restoration of the possible injuries to fish and beaches to be substantially lower than the first three injuries.

The trustees summarize their evaluation of the strength of evidence and relevance to restoration by means of the plot shown in Exhibit 2.11.

The trustees also consider the additional assessment effort that might be conducted to strengthen evidence for the shellfish and salt marsh injuries and prepare final documentation of the shorebird and beach injuries. The possible injury to fish is dropped from further consideration by the trustees in view of the weak evidence and low relevance to restoration for this injury.

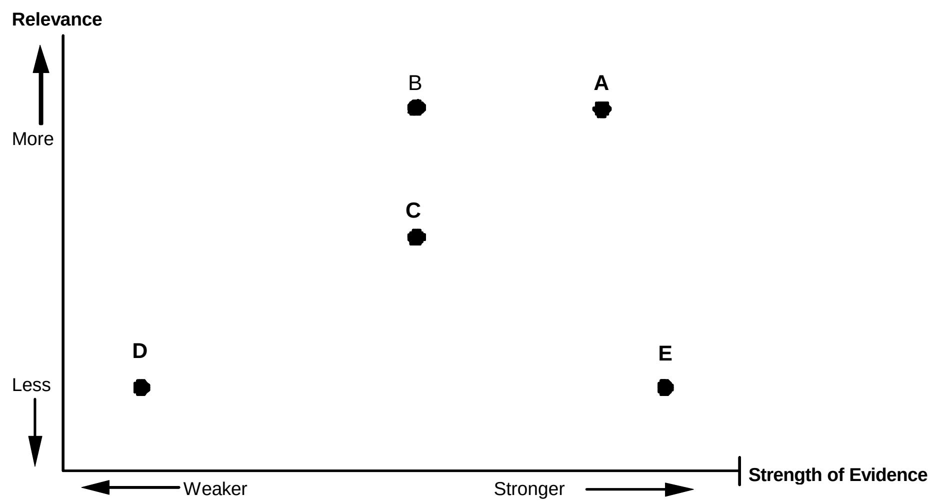
After considering a variety of assessment approaches and specific studies, the trustees reach a consensus concerning the best approach for additional study of the four injuries remaining for consideration. During these discussions, the trustees assess the likely change in the strength of evidence for each injury if additional studies are conducted and plot this information on Exhibit 2.12.

As Exhibit 2.12 indicates, the trustees judge that additional injury studies would significantly improve the evidence for salt marsh injury, but would have less effect on the evidence for shellfish injury. The evidence for shorebird injury already is strong, but would be further strengthened by modest additional work.

On the basis of the considerations outlined above as well as a variety of other factors, the trustees decide to pursue injury to shorebirds, shellfish, salt marshes, and beaches. To support this claim the trustees elect to rely on existing documentation plus additional injury assessment effort for shorebirds and salt marshes. Shellfish injury will be included based on existing documentation of closures and mortality, but no additional research on long term effects will be pursued. Beach injury will be included based on lost services documented during response.

Exhibit 2.11

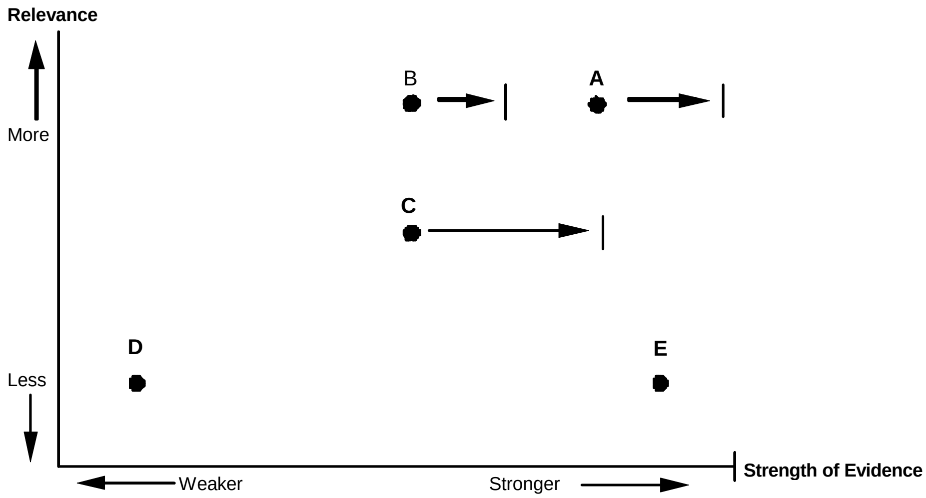
EXAMPLE OIL SPILL INJURIES



A: shorebirds B: shellfish C: salt marshes D: fish E: beaches

Exhibit 2.12

EXAMPLE OIL SPILL INJURIES AFTER ADDITIONAL ASSESSMENT EFFORT



A: shorebirds B: shellfish C: salt marshes D: fish E: beaches

2.6 References

Conner, W.G. 1993. "The Injury/Restoration Handshake." Coastal Zone '93 - Proceedings of the 8th Symposium on Coastal and Ocean Management.

Fox, G. A. 1991. "Practical Causal Inference for Ecoepidemiologists." Journal of Toxicology and Environmental Health 33:359- 373.

NOAA. 1995. Habitat Equivalency Analysis: An Overview. NOAA, Damage Assessment and Restoration Program, Silver Spring, Maryland, Policy and Technical Paper Series, Number 95-1.

3.1 Introduction

This chapter provides basic guidance on program management, quality assurance, and statistics, and introduces four general injury assessment methods (procedures), literature reviews, field studies, laboratory studies, and modeling studies. The general methods listed here are not meant to be an exhaustive list, nor are they mutually exclusive. Methods may be combined within an injury assessment study. Trustees often may find that results obtained during the early stages of an assessment suggest changes in the type or extent of ongoing assessment activities. Thus, the methods being used should be reviewed throughout the study to ensure that findings are being developed in the most efficient manner possible.

3.2 Injury Determination and Quantification

An injury assessment evaluates whether adverse effects resulted from an incident and the severity, geographic extent, and duration of those effects. Injury determination and injury quantification, respectively, are terms used to describe these two inter-related components of an injury assessment.

Determination of injury caused by direct exposure to a discharge of oil requires the trustees to demonstrate that:

- A pathway exists between the discharge and the natural resource of concern;
- The resource was exposed to the discharge; and
- Exposure has caused an adverse effect on the resource.

If an injury was not caused by direct exposure to the discharged oil, trustees should document an adverse effect and demonstrate that the effect resulted from the incident.

Injury quantification involves determining the severity, extent, and duration of the adverse effect. Trustees have the option of quantifying the adverse effect directly and/or quantifying the reduction in services provided by a natural resource caused by the incident. The natural resource or service change is defined as the difference between post-incident conditions and baseline conditions.

It is important to quantify injury in ways that allow the scale of restoration actions to be determined. For example, benthic injury may be quantified by determining the area of sediment where oil concentrations are, or have been, above a threshold concentration sufficient to cause injury. Restoration actions may then be scaled based on the area of sediment that must be restored and/or compensated.

Although the OPA regulations describe injury determination and injury quantification as separate steps, they often are performed together. Trustees should design a suite of studies that serve this dual purpose and that ultimately allow trustees to scale restoration activities to match the extent and severity of injuries. In addition, thinking about injury determination and quantification issues concurrently will result in studies that do not require additional data collection or study revision. For convenience, injury determination and injury quantification issues are discussed together throughout this chapter.

3.3 Program Management

The NRDA process can be a complex undertaking, involving a variety of technical and administrative activities, trustee staff from multiple jurisdictions, and experts from a range of technical disciplines. These various activities and personnel must be coordinated to ensure that:

- Relevant and high quality assessment information is collected;
- Critical decisions are made in a timely manner with input from all co-trustees; and
- The overall assessment is conducted in an efficient and cost-effective manner.

The level of effort necessary for program management will vary according to the complexity and significance of the incident, but regardless of the complexity, trustees should consider developing a management plan that structures both the overall injury assessment and individual components of the assessment. Planning and organizational considerations should be addressed early in the process, ideally evolving from the management structure established as part of pre-incident planning or during the preliminary assessment. Details of the individual studies should be developed by the specific investigators, but the trustees should provide overall guidance and a management framework that assigns clear responsibilities to the investigators. Common elements of a program management plan are discussed below.

3.3.1 Overall Administrative Structure

The management plan should address the overall coordination and conduct of the NRDA by establishing an organizational structure and decisionmaking process. In most cases, the trustees will develop a Memorandum of Understanding (MOU) to address basic coordination and decisionmaking. The roles of each trustee should be clearly specified. Trustee coordination is crucial to an effective NRDA because most incidents involve multiple trustees with overlapping interests. Coordination of trustee activities will avoid redundant assessment activities.

Activities that may be considered in establishing an overall structure include:

- Forming a co-trustee council;
- Selecting a lead administrative trustee (LAT);
- Determining roles of the various co-trustees and specific personnel;
- Establishing overall budgetary and cost-accounting procedures;
- Allocating assessment activities among co-trustees, including contract management;
- Scheduling; and
- Determining and facilitating participation by the RPs.

3.3.2 Lead Administrative Trustee (LAT)

The lead administrative trustee (LAT) is the agency responsible for coordinating and managing the NRDA process. This coordination is essential to the efficient and timely completion of the assessment. When an incident involves more than one trustee agency, the trustees, by consensus, should select a LAT to coordinate the assessment. The LAT does not need to be a Federal agency, nor does the LAT responsibility need to stay with one trustee over the entire assessment.

In designating a LAT, trustees may wish to consider such factors as:

- Jurisdictional or natural resource oversight (e.g., which agency has the preponderance of affected resources);
- Demonstrated technical and administrative capability and willingness to manage the NRDA process;
- Current workloads; and
- Availability of staff and supporting infrastructure.

The specific role of the LAT may be determined on a case-by-case basis. However, it is important that the role be clearly defined because of the LAT's central role. Examples of LAT duties may include:

- Coordinating the co-trustees;
- Coordinating with the RPs and response agencies;
- Scheduling regular meetings and preparing agendas;
- Overseeing completion of critical documents and distributing documents, data, and information;
- Facilitating co-trustee review and comment on draft documents;
- Maintaining the administrative record, tracking samples and evidence;
- Monitoring assessment progress and scheduling critical elements; and
- Managing recovered damages.

3.3.3 Establishment of a Technical Team

Depending upon the size and complexity of the NRDA, a technical team may be established. The management plan should include the establishment of such a team to design and implement technical aspects of the assessment. Each trustee agency should participate and, in a cooperative assessment, the RPs also may be represented. The roles of each person on the technical team should be clearly specified.

The technical team would generally have the responsibility for:

- Interpreting preassessment information;
- Establishing the scope of the injury assessment, including selection of candidate injuries for evaluation;
- Developing assessment goals, objectives, and strategies;
- Identifying specific studies and anticipated findings;
- Defining data quality management;
- Selecting contractors and experts;
- Determining appropriate assessment methods;
- Reviewing study proposals;
- Providing technical oversight of studies and interpreting study results;
- Providing site safety planning; and
- Identifying overall restoration objectives.

3.3.4 Logistical Considerations

The management plan should address logistical responsibilities by making specific assignments to trustees. Certain activities may be consolidated under one trustee's jurisdiction (e.g., the LAT may manage the administrative record) while other activities may be conducted by each trustee agency (e.g., cost accounting). Logistical considerations may include:

- Scheduling assessment activities and deliverables, including critical decision-points and key points for input from or output to other studies;
- Scheduling regular trustee and peer review meetings;
- Establishing and maintaining an information management system, including distribution of documents, maintenance of the administrative record, and evidence tracking and storage;
- Financial management;
- Facilitating public involvement; and
- Complying with statutory and regulatory requirements.

3.3.5 Litigation Requirements

The results of injury assessment studies ultimately may be used in litigation against the parties responsible for the incident. The possibility of litigation requires that trustees take additional steps in development, conduct, and management of NRDA studies. All parties involved should be aware of the relevant regulations and litigation considerations, including:

- **Scientific requirements for evidence.** Information collected during the assessment process may be used as evidence. Therefore, appropriate quality assurance and chain-of-custody procedures must be identified and followed to ensure that data and analyses are technically sound, legally defensible, and cost-effective.

- **Data and Information Management.** Data and information management are critical throughout the NRDA process. Samples, data, and other evidence must be maintained pending the final resolution of the incident and expiration of the time period allowed for any changes to, or appeals, of that resolution.

- **Cost Accounting.** Assessment costs are one element of a claim. In order to recover these costs, all persons participating in the assessment should be aware of cost documentation procedures.

3.4 General Assessment Considerations

A key element in the design and conduct of injury assessment studies (regardless of the general method selected) is a clear understanding of how the data generated during the study will be used. This section addresses three important factors related to the collection and ultimate use of assessment data:

- Use of appropriate expertise;

- Development of explicit questions that can be evaluated during the assessment; and

- Determination of the most effective techniques for analyzing and presenting the data.

3.4.1 Use Appropriate Expertise

Injury assessments are based on scientific data that often are limited and subject to conflicting interpretations. Appropriate expertise is necessary to:

- Focus and design the assessment;
- Evaluate and select assessment procedures;
- Determine the relevance and quality of available data;
- Develop hypotheses based on logic and scientific principles; and
- Interpret the significance of observed, measured or predicted impacts.

Because appropriate expertise is critical, an experienced interdisciplinary team enhances the likelihood of a successful injury assessment.

3.4.2 Develop Explicit Questions

To focus the design of each injury assessment study, trustees should clearly formulate the questions to be evaluated by the study. To do this, trustees may find it helpful to ask a number of questions.

- What are the basic facts regarding the injury?
- What additional information would contribute to the injury assessment?
- What must be measured or observed in order to obtain this additional information?
- Will it be possible to gather this information in an efficient and effective manner?
- How confident are we that the study can be carried out successfully?
- What utility will the information provide to our restoration efforts? (i.e., Will we be able to quantify the injury in a way that allows us to scale restoration actions?)

Through a careful consideration of these questions, trustees can focus each study on clear and explicit questions, thereby increasing the possibility of obtaining useful data. See chapter 2 of this guidance for a more thorough discussion of these considerations.

3.4.3 Develop Valid Study Designs[1]

Trustees should seek experienced statistical experts and consider data analysis and statistical issues at the beginning of the study design process. This section describes some of the general statistical techniques that trustees may need to consider in the design of an assessment study, but is not a complete presentation of all of the analytical and statistical techniques that could be used in an injury assessment. Trustees may wish to consult Eberhardt and Thomas (1991), Gilbert (1987), Hurlbert (1984), and Zar (1984) for additional information.

Typically, the analysis of injury assessment data requires the application of descriptive and inferential statistical methods to assess the likelihood that a change has occurred in a natural resource. These techniques can be used to describe conditions at the assessment site and at reference sites and to determine whether there are any statistically significant differences between the sites with respect to the distribution and concentration of oil and level of adverse effects that can be attributed to exposure to oil. These techniques also may be used to predict the degree of a specific response given a particular level of contamination.

The primary objective of statistical analysis is to infer the characteristics of a group based on examination of a sample from the group. The process of sampling introduces uncertainty because only partial information is acquired and observations vary from sample to sample. The variability in samples is attributable to several sources, including natural variability, chance or sampling variability, and measurement variability (also called measurement error). A primary goal of almost all statistical analyses is to identify and understand systematic effects (e.g., effects from the incident) while accounting for the influences of these sources of variability.

1 The portions of this section that describe statistical concepts are drawn from MacDonald et al., 1992.

The logic of statistical inference is based on evaluating a particular question, formulated as a testable hypothesis or null hypothesis, on the basis of results from a sample. The hypothesis is assumed to be true and is evaluated on the basis of the statistical evidence contained in the obtained sample. It also is assumed that the sample is randomly selected so that the laws of probability may be invoked to evaluate the sample data with respect to the hypothesis. The null hypothesis is tested against an alternative hypothesis that represents an alternative explanation. A decision will be made by a test of the null hypothesis against the alternative hypothesis assuming a possible error level (significance or alpha level) of the test. Based on the value of a test statistic computed from the sample and whose distribution is determined by the null hypothesis, a measure of likelihood of the particular sample, called the significance probability (p-value), can be computed. This value is a measure of how likely the obtained sample is if the null hypothesis is true, assuming the particular assumptions of the statistical test are valid. Because of the nature of inductive inference, it is generally desirable to define the alternative hypothesis as the conclusion for which one would like to test for validity. Technically, the null hypothesis should never actually be accepted, rather it should only be concluded that there is insufficient reason to reject it.

There are two general types of statistical methods, parametric and nonparametric, that provide the primary means of testing null hypotheses. Parametric methods are employed to test hypotheses formulated about the characteristics of population parameters, such as the population mean and variance. All parametric methods are based on certain assumptions pertaining to the parent population(s). These assumptions may differ depending on the specific method.

These assumptions might include:

- Samples are collected from a population of normal distribution;
- Parent populations have the same variance;
- The size of the variance is independent of the size of the mean; and
- The samples are independent.

Sample sizes permitting, these assumptions should be tested prior to the formal application of parametric statistical tests.

Populations in environmental studies frequently provide data that do not meet the assumptions of parametric tests. One solution in such a case is to transform the data using a transformation such as the logarithmic transformation so that the data to be analyzed meet the required assumptions of the statistical method. The use of transformations, however, complicates the interpretation and presentation of the results, so this technique should be used with caution. An alternative that is becoming more widely adopted by investigators is to employ nonparametric methods in cases where parametric methods involve assumptions not apparently met by the data. Nonparametric methods involve ranking the data and do not require such stringent assumptions regarding the parent population. Thus, they are less affected by departures from assumptions than parametric methods.

Additionally, because they are based on ranks of the data, they are not seriously affected by extreme values, real or artifacts, in the data. While nonparametric methods are generally not quite as powerful in rejecting a null hypothesis as parametric methods when the assumptions of parametric methods are met, they are nearly as powerful in such circumstances, and when the conditions of parametric procedures are not met, they are clearly preferable. Statistical analysis merely provides a means of evaluating the likelihood of an hypothesis based on information generated through sampling. There are two types of significance to consider: statistical and biological. It is important for trustees to keep in mind that statistically significant results are not necessarily "meaningful" in the sense that they demonstrate the injury trustees are trying to measure. This point is made clear by the National Research Council in "Managing Troubled Waters" (NRC, 1990):

> Virtually any change can be statistically significant, depending in part on the sampling effort. Thus . . . a small sampling effort will detect only large changes, but one with an intensive sampling effort could find even extremely small changes statistically significant. Whether changes in the environment are statistically significant has no bearing on the extent to which the changes may be either meaningful or important...

The OPA regulations do not mandate that results of injury assessments meet any pre-determined level of statistical significance. In the most general sense, valid injury determination and quantification requires only the use of accepted scientific practices by competent investigators so that the results clearly indicate an adverse change in a resource or service. Statistical significance should be viewed as one tool that could help demonstrate injury.

3.5 Quality Assurance[2]

An injury assessment can include many individual studies conducted by a team of investigators using different methods and generating a variety of physical, biological and chemical data. Because these data are used to draw conclusions with respect to injury determination and quantification and may be used in litigation, all of the data must be of known, acceptable, and defensible quality and be properly documented.

A quality assurance program provides the framework for developing data with these attributes. The program should be developed and implemented at the start of the NRDA process to allow the inclusion of all of the injury determination components, including field sampling and data collection. All generated data (e.g., analytical chemistry, bioassays, field counts) are subject to the same quality assurance process.

Development of the quality assurance program is most successful if undertaken as an interactive and iterative process. The leaders of the various studies should work cooperatively with the Quality Assurance (QA) Coordinator to design and implement a realistic quality assurance plan for their work. The oversight and coordination of these various plans is the responsibility of the QA Coordinator, who ensures that the data quality needs of the NRDA are met. The size and complexity of the quality assurance program depends on the needs of the particular assessment. Trustees should keep in mind that it may be just as important to have defensible data for a spill of 5,000 gallons as it is for a spill of 500,000 gallons. The following guidance provides an outline and brief description of the components of the quality assurance program.

As described by Taylor (1987), each quality assurance program should consist of:

- **Quality Assurance:** A system of activities that provide to the producer or user of a product or a service the assurance that it meets defined standards of quality with a stated level of confidence.

- **Quality Control**: The overall system of activities that control the quality of a product or service so that it meets the needs of the users. The aim is to provide quality that is satisfactory, adequate, dependable, and economic.

- **Quality Assessment:** The overall system of activities that provide assurance that the overall quality control job is being done effectively. This involves a continuing evaluation of products produced and the performance of the production system.

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2 This section was drafted by Carol-Ann Manen, NOAA, Damage Assessment Center, Silver Spring, MD.

In practice, a quality assurance program consists of a:

- Document describing the objectives of the injury assessment process (i.e., data quality objectives) and the QA practices to be implemented;

- Development and implementation of a set of practices that will result in data meeting the objectives (this should include compliance with Good Laboratory Practice Standards, as described in the Toxic Substances Control Act, 40 CFR Part 792, for Standard Operating Procedures (SOPs) and physical/chemical and biological test systems and specific steps or responsibilities for correcting any deviations from the desired data quality); and

- Development and implementation of a method(s) for assessing whether the program is functioning as planned.

These program elements should be documented and available for review and inclusion in the Administrative Record for the assessment.

3.5.1 Quality Assurance Practices

There are a variety of quality assurance practices currently in use; some of these practices are more useful for one type of measurement than others. Because injury assessment studies may use a variety of measurements, the quality assurance practices outlined in this guidance document represent an integration of Good Laboratory Practice Standards (GLPS), Contract Laboratory Program requirements, and experience gained from the USEPA's Puget Sound Estuary and Environmental Monitoring and Assessment (EMAP) Programs and NOAA's National Status and Trends Program.

3.5.2 Quality Assurance Project Plan

Every Principal Investigator of a data-generating study should prepare and follow a plan that defines explicitly what is to be done in each measurement situation. This plan may be referred to as a Quality Assurance Project Plan (QAPP), a QA Plan or a Sampling and Analysis Plan (SAP). Each plan should be prepared by the Principal Investigator or his(her) designee and include the data quality requirements for that study.

The plan should specify the:

- Methodology to be followed in collecting or generating the samples and data (e.g., standard operating procedures or SOPs);

- Number and types of samples and quality control materials, including procedures to be used in generating or collecting the data; and

- In-house quality assessment procedures to be used in evaluating the data.

The USEPA has developed guidance (Stanley and Verner, 1983) for what information should be included in these plans and how the information should be organized. This guidance is summarized in Exhibit 3.1. This guidance may not be applicable in total to all injury determination and quantification studies. Several of the topics included in Exhibit 3.1 are discussed below.

Project Description: If possible, the study goals should be stated as a quantitative, testable hypothesis. An example of such a statement, taken from EMAP:

> Over a decade, for each indicator of condition and resource class, on a regional scale detect, at a minimum, a linear trend of 2% (absolute) per year (i.e. a 20% change for a decade), in the percent of the resource class in degraded condition. The test for trend will have a maximum significance level of alpha = 0.2 and a minimum power of 0.7 (i.e. beta = 0.3).

This statement provides the criteria to design a sampling and analysis program within the cost and resource constraints or technology limitations that may be imposed upon the study. Also, with this statement, the uncertainty that can be accepted in the measurement data can be defined.

Project Organization: Responsibilities for field and laboratory personnel should be clearly indicated. Include phone and fax numbers.

Quality Assurance Objectives for Measurement Data: Representativeness, completeness, and comparability are difficult to quantify (Taylor 1987). They relate primarily to the study design, the selection of sampling and analytical methodologies, and the resulting data base. Precision and accuracy are quantifiable criteria that are developed for the different collection and measurement systems (and the individual components within those systems) being used in the study.

Exhibit 3-1

DESCRIPTION OF THE SUGGESTED SUBJECT AREAS OF A QUALITY ASSURANCE PROJECT PLAN

Subject Area	Description
Project Description	Each specific project description should contain a brief introduction containing relevant background information. This section also should contain a general statement of project goals.
Project Organization and Responsibility	This section should summarize the overall project organization and the responsibilities of cooperating organizations. A figure illustrating the organizational structure is usually included.
Quality Assurance Objectives for Measurement Data	This section should specify the intended use of the data, and the questions to be answered or the decisions to be made as a result of the data. This section also should spell out the data quality objectives for five aspects of the data quality representativeness, completeness, comparability, accuracy, and precision for each indicator.
Sampling Procedures and Sample Handling	This section should provide specific guidelines and protocols regarding preservation, holding times, labeling, and collection of samples for each major indicator. A description of the site selection rationale also can be included in this section.
Sample Custody, Transportation, and Storage	All samples collected should be labeled according to date of collection, sample type, sample location and sample class, and each sample should have its own unique identification.
Calibration Procedures and Frequency	This section usually describes instrument maintenance and calibration, and performance (QC) checks on instruments. Performance checks should be done on a regular, specified basis, and results should be recorded.
Experimental Design and Analytical Procedures	This section details the analytical methods to be used for each indicator. This section also discusses changes in methods (if necessary) as the project progresses.
Data Reduction, Validation, and Reporting	This section should include the criteria that will be used to validate the quality of data, the methods to be used for the treatment of outliers, equations for calculation or value of the indicator to be measured, the reporting units to be used, and a description of data verification and validation phases for the project.
Internal Quality Control Checks and Frequency	A description of internal quality control (both laboratory and field), including a description of the QC sample design and samples (i.e., splits replicates, matrix spikes), should be given in this section. If control charts are used, they should be described here.
Performance and Systems Audits and Frequency	This section describes the performance system audits (both internal and external) used to monitor the performance of the measurement systems being used for the project. If laboratories will be expected to participate in a performance evaluation program of any sort, this should be described here.
Preventive Maintenance Procedures and Schedule	Preventive maintenance to be performed on instruments on a scheduled basis, and any critical parts (those that either have to be replaced on a frequent basis, or that require extra time ordering and shipment) that should be kept on hand should be included in this section.
Specific Routine Procedures to be Used to Assess Data Quality	Specific procedures to be used for the assessment of accuracy and precision of the data for each indicator, including confidence limits, central tendency, dispersion, bias, and the five aspects of data quality should be detained in this section.
Corrective Action	The limits for data acceptability, the point at which corrective action should be initiated, and a description of the corrective action to be taken for each indicator should be included here. Corrective actions also can be a result of other QA activities; such as performance audits, systems audits, and laboratory comparison studies.
Quality Assurance Reports to Management	This section should describe the type and schedule for documents reporting on data accuracy, completeness, and precision, the results of performance or systems audits, and any significant QA or methods problems and the corrective action taken for resolution of problems.

Source: Stanley and Verner, 1983.

Accuracy is the difference between a measured value and the true or expected value and represents an estimate of systematic error or net bias. Precision is the degree of mutual agreement among individual measurements and represents an estimate of sampling, measurement, or other sources of error. Collectively, accuracy and precision can provide an estimate of the total error or uncertainty associated with an individual measured value.

Measurement quality objectives for accuracy, precision and completeness should be expressed in a quantitative manner. The Principal Investigator establishes these objectives based on the study methods and the hypothesis being tested. These objectives may not be definable for all parameters due to the nature of the measurement type. Accuracy measurements are difficult for toxicity testing or for histopathology (tissue lesions) for example, because "true" or expected values do not exist for these measurement parameters. Example measurement quality objectives are presented in Exhibit 3.2.

Objectives for accuracy and precision may be met through several mechanisms. These mechanisms are similar for field and laboratory procedures and rely upon replication, training and SOPs. Examples of field and laboratory mechanisms are given below.

Field: Counting murres nesting on rocky islands provides a good example of mechanisms to assure accuracy and precision. In this case, because the birds feed at a certain tidal height, care was taken to time the counts with the tide to count the maximum number of birds. The counts were taken while circling the islands in a ZODIAC, each ZODIAC contained 3 people, one to run the boat and two to count. The "counters" were trained in the field by the PI to recognize and identify the birds of interest. Using photographs, the islands had been divided into approximately equal zones by natural markers. The two counters counted the birds in sequential zones for 15 minutes and then traded zones. If the two sets of counts were within ±15% agreement the counters moved on to the next two zones. If the two sets did not agree, the zones were recounted. If they still did not agree, the data were marked with a qualifier. These procedures were described in SOPs that were used to guide field personnel and document how the procedure was performed.

Exhibit 3.2

EXAMPLE OF MEASUREMENT QUALITY OBJECTIVES

Sample Type	Analytical Measurement	Precision (±%)	Accuracy (±%)	Completeness (%)	Detection Limit/Unit	QC Samples and frequency (#s=no. of samples)	Acceptance Criteria	Corrective Action
Blood plasma	Testosterone Estradiol Progesterone	±15 ±15 ±15	±25 ±25 ±25	95 95 95	<20pg/100µ1 <20pg/100µ1 <20pg/100≤1	B,S,M,ES @ 3-4/assay B,S,M,ES @ 3-4/assay B,S,M,ES @ 3-4/assay	Rec. ES ≥ 60%, M(see caption), B≤ 10 pg/100µl E, Rec. S ± 25%	B, Es, S, M Recalibrate and/or reanalyze
Blood Plasma	Protein bound phosphorus Gonadotropin	±15 ±15	n/a ±25	95 95	<10pg/100µl <50pg/100µl	B,D @ 3-4/assay B,D,S @ 3-4 assay	RPD of D ≤ 20%; B record data S ± 20%; RFD of D ≤ 20%; B ≤ 50 pg/100µl	Recalibrate /re-analyze; B; correction factor B,D,S; Recalibrate and/or reanalyze
Liver	Estraduik receptor assay E-2 Competition assay	n/a n/a	n/a n/a	95 95	n/a n/a	D,SD D,SD w competitor	SD; realistic Kd; RFD of D ≤20% SD competitor, shows displacement, RPD of D ≤ 29%	D, SD; Recalibrate and/or reanalyze –
Pituitary	Gonadotropin release	±15	±25	95	<50 pg/100µl	B,C,D,S	S ± 25%; RPD of D ≤ 20%; B ≤ 50 pg/100µl, C < Stimulated samples	B, C ,D, S Recalibrate and/or reanalyze
Gonad	Estradiol release Testosterone release	±15 ±15	±25 ±25	95 95	<1 pg/1 mg <1pg/1 mgl	B,C,M,S B,C,M,S	S ± 25%, RPD of D ≤ 20%; B < 1 pg/1 mg M (see caption)	B, C, M, S Recalibrate and/or reanalyze
Egg suspension	Fertilization success Germinal vesicle breakdown Embryological success Egg diameter	±5 ±5 ±5 ±5	±10 ±20 ±15 ±5	95 95 95 95	n/a –	D,V @ 5% for all samples D,V @ 5% for all samples D,V @ 5% for all samples D,V @ 5% for all samples	D, V ≤ DQO –	and/or reanalyze
Larval	% abnormal larvae	±5	±10	95	n/a	D,V @ 5% for all samples	D,V ≤ DQO	D, V Recalibrate and/or reanalyze
Various tissues	Tissue lesions	±25	n/a	95	n/a	D,V @ 5-20% for all samples	concurrence of analysts	D, V Reanalyze
Water (T= tank) (I = influent)	Temperature Ph Dissolve oxygen Ammonia (NH-3) Conductivity	±0.1°C ±0.1 units ±0.1 mg/1 ±°0.1 mg/1 ±10µMho	±0.1°C ±0.1 units ±0.1 mg/1 ±°0.1 mg/1 ±10µMho	95 95 95 95 95	n/a –	R @ daily R @ daily (I), R @weekly(T) R @ daily (I), R @weekly(T) R @ daily (I), R @weekly(T) R @ daily (I), R @weekly(T)	R = certified value –	instrument and reanalyze

B=blank, C=unstimulated control, D=duplicate, M=multiple dilutions, R=calibrate by SOP with standard reagents, S=spike, ES=extraction spike, V=verification by alternate method (or individual), E=extract, RPD=relative percent difference, SD=serial dilution. For M, two dilutions are measured, the result from the lower dilution extrapolated to higher dilution, and RPD of extrapolated value and measured value ≤ 20%

Laboratory: For analytical chemistry, one of the most useful measurements of accuracy and precision is the repeated analysis of certified reference materials (CRMs) and Standard Reference Materials (SRMs), which are samples in which chemical concentrations have been determined accurately using a variety of technically valid procedures. These samples are issued by a certifying body (e.g. agencies such as the National Research Council of Canada (NRCC), USEPA, U.S. Geological Survey, National Institute of Standards and Technology (NIST)). A useful catalogue of marine science reference materials has been compiled by UNESCO (1993).

Completeness refers to the number of data points that meet the data quality objectives, i.e. those that are acceptable with no data qualifier. In the above field example, if one or more of the counts did not meet the precision objective, they were marked with a qualifier. Qualification does not mean that these data cannot be used, but that the qualified data should be used with caution as they may or may not be adequate for the project needs.

Sampling Procedures and Sample Handling: SOPs describing sample collection or data generation procedures, including the labeling, handling, and preservation of the samples, should be written in detailed, clear and simple language. Personnel must be knowledgeable and experienced in the sampling techniques described and must adhere to the SOPs.

Samples should be labeled at the earliest possible opportunity to minimize the chance of confusing one sample with another. The minimum information to be included on the tag or label identifying the sample are the sample identification number, the location of the collection site, the date of collection, the name/signature of the collector, and sample description (who, what, where, and when). This information and any other pertinent data such as the common and scientific names of the organism collected, the tissue collected, and any remarks also are recorded in the logbook.

All information pertinent to sample generation and collection techniques, including descriptive notes on each situation, must be recorded in indelible marker in a bound logbook. The information must be accurate, objective, up-to-date, and legible. It should be detailed enough to allow anyone reading the entries to reconstruct the sampling situation. Additional information may be provided by data sheets, sample tags, photographs, or videos.

Sample Custody, Transportation and Storage: Samples and log books must be kept in such a manner that they cannot be altered either deliberately or accidentally. Any indication that a sample has been subjected to tampering or physical alteration could disqualify it as evidence. The sampler is personally responsible for the care and custody of the samples collected until they are transferred under chain of custody procedures. A sample is considered in *custody* if: it is in your actual physical possession or view, it is retained in a secured place (under lock) with restricted access; or it is placed in a container and secured with an official seal(s) such that the sample cannot be reached without breaking the seal(s).

When samples are transferred from one individual to another, even within the same facility, they must be accompanied by a chain of custody record. Exhibit 3.3 provides an example of a chain of custody record. The individuals relinquishing and receiving the samples must sign and date the chain of custody record in indelible ink at the time that the samples are transferred. The completed original form accompanies the samples. The person who relinquished the samples should keep a copy of the form.

Because the NRDA process may be lengthy, trustees should archive all samples, raw data, and data documentation under chain of custody and in a manner to preserve their integrity until the case has been resolved.

Calibration Procedures and Frequency: These procedures apply to instruments as diverse as balance scales, thermometers, pH meters, current meters, and gas chromatographs. In all cases, the procedures must be performed and the results recorded in logbooks. At a minimum, all similar instruments should be calibrated against the same standard. Calibration to standards developed by the NIST provides consistency with a national dataset and strengthens the credibility of the developed data.

The remaining topics on Exhibit 3.1 should be addressed in SOPs covering all field and laboratory procedures, instruments, and analyses.

Exhibit 3.3
CHAIN OF CUSTODY FORM

NOAA DAMAGE ASSESSMENT CENTER
CHAIN OF CUSTODY FORM

1305 East-West Hgwy, Rm 10229, Silver Spring, MD 20910
For more information contact Douglas Helton
301-713-3038 or fax 301-731-4387

Project ________________________________
Sampler______________________________

Sample I.D.	**Date Collected**	**Location**	**Sample Type** (Tissue, oil, water, Include species name and tissue type)	**Comments**

Collected by: (signature)	**Received by: (signature)**	**Condition:**	**Date/Time**
Relinquished by: (signature)	**Received by: (signature)**	**Condition:**	**Date/Time**
Relinquished by: (signature	**Received by: (signature)**	**Condition:**	**Date/Time**

3.5.3 Quality Assessment

All data generating activities should be audited by independent external personnel. These audits should include:

- System audits conducted to qualitatively evaluate operational details; and

- Performance audits conducted to evaluate data quality, adequacy of documentation, and technical performance characteristics.

The audits should use comparisons to the quality assurance documentation developed for that activity, that is, these audits should confirm the quality of the data. If there are discrepancies between the documentation and actual operations, the quality assurance program manager should determine if the discrepancy will significantly affect the ability of the trustees to successfully conduct the injury assessment. This may require reanalysis of existing samples or collection of new samples. For this reason, quality assessment should be conducted in a timely fashion so that any necessary changes can be made before the project concludes.

3.6 Assessment Methods

There are a number of injury assessment methods available to trustees, including literature reviews, field studies, laboratory studies, and modeling studies:

Literature reviews are an important first step in planning any injury assessment study and is an important method, either alone or in combination with field, laboratory, and/or modeling studies. The systematic compilation of data from previously completed studies may suggest that injury to one or more natural resources has occurred. This approach also may provide information about gaps in knowledge that may be filled by proposed assessment studies.

Field studies are the most direct means to evaluate injury. In general, these studies require the careful collection and analysis of data to determine spatial and temporal relationships.

Laboratory studies offer a less direct, but often equally effective, means to determine that a natural resource may be injured due to exposure conditions similar to those in the field. The results of laboratory studies may provide additional evidence to support observations made in the field, although laboratory studies sometimes stand alone in determining that an adverse effect is possible.

Modeling provides a means to simulate the interactions between oil and the environment (e.g., flow and dispersion models) and predict the environmental consequences of an incident. Models may be used as a complete assessment tool for small incidents or to address specific components of an injury assessment for a larger incident. Models may also be useful for screening, to focus an assessment on the most probable injuries, or to integrate other assessment techniques.

These methods may be used alone or in combination. For example, during the design of the injury assessment, trustees should include studies that will demonstrate pathway and exposure. These studies may include:

- Field data (e.g., aerial photos, water and sediment samples) along the pathway the oil is thought to have followed;
- Published literature on the uptake of oil by the natural resource of interest;
- Laboratory studies that demonstrate bioavailability and uptake; and
- Modeling studies that simulate both physical movement from source and biological uptake.

These general methods are described in more detail in the following sections.

3.6.1 Review of Existing Literature

Many of the injuries resulting from oil are well documented. By collecting and reviewing the literature from case histories and field and laboratory studies, trustees can focus their efforts both on the natural resources most likely affected and the types of data needed to evaluate and quantify the injuries to those natural resources.

To be most useful, the literature studies should match the incident in the following parameters:

- *Oil type and amount*: Is the oil type in the incident similar to that in the literature study?

- *Resources of interest*: Are the natural resources affected by the incident the same or similar to those studied in the literature?

- *Fate of the oil*: Is the behavior of oil during the incident similar to the behavior of the oil in the literature study? Are exposure pathways to affected natural resources the same?

- *Acute or chronic discharge*: Is the duration of exposure in the literature study similar to that observed in the incident?

Case histories are important sources of information on oil behavior and fate, and can be used to develop conceptual models for pathways of exposure. Although each incident is a unique combination of events, there are consistent patterns in oil behavior and effects. However, much of the case history literature considers medium to large marine oil discharges, with little published information on freshwater or terrestrial discharges.[3]

Case studies may also be important sources of data on the degree and duration of injuries. For example, the recovery rate for an oiled marsh could be established from studies conducted at previous incidents similar in type and degree of oil contamination, vegetation type, and physical setting to the present discharge (e.g., Alexander and Webb, 1983, 1985, 1987; Bender et al., 1980; Delaune et al., 1984; Holt et al., 1978).

Data from previously conducted laboratory and field studies may be used to predict the type and extent of injuries. For example, projections of the number of birds in a nesting colony that will not produce fledglings after being exposed to oil can be estimated from published studies (Eppley and Rubega, 1990; Fry et al., 1986; Peakall et al., 1982; Trivelpiece et al., 1984).

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3 Refer to the American Petroleum Institute, which published two reports on fresh water oil spills.

A range of options is available for literature review. At a minimum, trustees can conduct a preliminary review of major data sources and relevant published literature. The next level of effort would be more appropriate in situations where there is a considerable amount of data of sufficient quality that could be validly applied to a specific injury study. In some cases, this approach might take the place of original field or laboratory studies. In others, it would allow trustees to identify important areas to focus new assessment efforts. For example, if a discharge of crude oil has impacted a shellfish bed, the trustees may search the published literature to determine the range of possible adverse biological effects to this natural resource that could result from the oil. If the trustees determine that there are numerous studies that document the effects of this type of oil on the specific shellfish in question, they then may determine that additional injury studies are not needed and focus their attention on pathway determination and injury quantification.

Alternatively, if the trustees determine that there are a number of studies that demonstrate effects of crude oil on other types of shellfish, then the trustees may wish to expand their search to determine whether these species are good indicators of likely effects for the species of shellfish in question. If not, the trustees can consider conducting field studies and/or laboratory-based exposure studies to determine the adverse effects.

3.6.2 Field Studies

Field studies may provide the most relevant and direct evidence for injury determination and quantification. Data developed by direct observation, photographs, videos, and samples of biota, sediments, and water may be used to evaluate:

- Whether there is a pathway from the point of discharge to the natural resource of concern;
- Whether the natural resource was exposed and injury has occurred (injury determination); and
- The degree and extent of the injury (injury quantification).

However, field studies may be hampered by the lack of true reference sites and a clear assessment of within treatment variation may be difficult. This problem may confound conclusions about the cause of any observed differences between stations. For example, differences between stations could be due to difference in habitat (e.g., fresh water input, wave energy, etc.), rather than exposure to oil. This is one reason that the most convincing evaluations of the effect of discharged oil on natural resources include three types of information:

- Assessment of effects in the field;
- Chemical data; and
- Toxicity data.

The ultimate selection of field assessment strategies and sampling designs will depend on the unique nature of the discharge, and goals of the trustees. In all cases, the design and implementation of the field studies requires a thoughtful consideration of the sampling design and strategy.

Spatial and Temporal Design of Field Studies[4]

Field study designs include:

- Pre- and post-incident comparisons within the impact area;
- Post-incident comparisons between impact and reference areas;[5]
- Pre- and post-incident comparisons between impact and reference areas; and
- Gradient comparisons.

A brief description of each type appears below. Trustees may not have a choice among these comparison types, as some depend on the availability of data collected before the incident.

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4 The text in this section and the next has been taken, with slight modification, from text originally drafted by Lyman McDonald, WEST, Inc., Cheyenne, WY.

5 The terms *reference*, *control*, and *baseline* are often used interchangeably to identify sample locations that have not been subjected to the effects of the particular incident being studies.

Pre- and post-incident comparisons within the impact area allow determination and quantification of injury when characteristics of the impact area or affected population(s) have been measured prior to the incident and can be measured again (ideally using comparable protocols and procedures) following the incident. This type of comparison may be particularly useful in areas that are more susceptible to accidental discharges or are subject to repeated threats of discharge, since ongoing monitoring efforts may have been established with the express purpose of providing comprehensive baseline data. However, ecological systems are not static and environmental conditions will vary over time, so any change observed in the impact area during the pre- and post-incident periods could conceivably be unrelated to the incident. During an extended study period, significant natural changes might be expected.

Post-incident comparisons between impact and reference areas are more common because pre-incident data is usually lacking in the reference areas. Simply observing a difference between impact and reference areas following a discharge does not necessarily mean that the incident was the cause of the difference. Similarly, the absence of any differences may not be an indication that there were no impacts from the incident.

A common problem for the design of field studies is the difficulty in finding suitable reference areas. Exact replicas of impact areas do not exist. Trustees should find reference areas that are as similar as possible to the impact area while recognizing the inherent differences between them. One approach is the stratification or classification of the impact area according to a set of specific, objective criteria (e.g., climate, geology, substrate, hydrology/hydrodynamics, biota) followed by the identification of potential reference areas that are closely matched on the basis of these characteristics. The spatial and temporal variability of these environmental parameters also are important considerations when comparing impact areas with potential reference areas. Trustees should select reference areas based on the use of a predetermined set of criteria. Trustees should consider the use of two or more reference areas.

Pre- and post-incident comparisons between impact and reference areas (commonly referred to as before-after/control-impact, or BACI, comparisons) are intended to address the two potential difficulties associated with the comparison types described above through a combined comparison. Natural variability in an impact area can be assessed through the analysis and comparison to data from reference areas. At the same time, variability over time can be accounted for through the use of pre- and post-incident data.

Gradient comparisons between impact and non-impact areas or within an impact area are useful for the determination and quantification of injury in a relatively small impact area within a homogeneous environment. The gradient comparison is based on the assumption of a dose-response relationship in which varying levels of biological response are correlated to decreasing contaminant levels extending out from the point of discharge. If a gradient of biological response is identified along the contamination gradient, the magnitude of differences can be translated into a minimum estimate of the amount of injury. Careful consideration should be given to natural gradients that could be confounded with effects from the incident. Gradient comparisons are analogous to laboratory toxicity tests conducted along gradients of toxicant concentrations.

Field Sampling Strategies

Census is the most direct type of sampling. Examples where it may be effectively used include counting all dead birds killed by a discharge of oil. Difficulties with this method include the potential for undercounting. Bodies may drift off, sink, be buried or scavenged, and adjustments may be necessary to account for this undercounting. Costs associated with conducting census studies over large areas also limit the usefulness of this approach for many natural resources. For example, even in a small study area it may be impossible to conduct a census of all dead bivalves. Sub-sampling within impact and/or reference areas is one way to overcome the limitations of total census studies.

Sub-sampling will allow the trustees to cost-effectively sample a large area. The design of sub-sampling plans will, in large part, determine the trustees' ability to make comparisons between impact and reference areas. In general, there are four types of sub-sampling plans - haphazard sampling, judgment sampling, probability sampling, and search sampling (Gilbert, 1987).

- ***Haphazard sampling*** is collection based on convenience, which may introduce bias into the results and reduce the chances of generating statistically meaningful conclusions.

- ***Judgment sampling*** is based on the investigator's knowledge of the study area and ability to subjectively select appropriate sample locations. While this method reduces the potential for bias compared to haphazard sampling, it does not eliminate it entirely.

- ***Probability sampling*** provides a means for making statistical inferences through the random selection of sites within impact and reference areas. There are several types of probability sampling:

  In ***true random sampling***, each sample site is selected independently of all other sites. This method provides a representative set of samples within impact and reference areas, but in practice random locations tend to be less evenly distributed than would be expected.

  Stratified random sampling guarantees that sampling will occur over previously defined sub-areas, or strata. Strata can be defined on the basis of factors such as habitat type, depth (of soil, sediment, water, etc.), oil concentration, and physiography. Sub-areas can be stratified further depending on the needs of the assessment. Within each stratum, sample sites can be selected randomly or with one of the other techniques described below.

  Random start systematic sampling begins with a random starting point rule and distributes the locations of sample sites uniformly (using lines or grids) over the impact or reference areas. Systematic sampling has been proposed as a suitable alternative in cases where stratified sampling may not be appropriate (e.g. long duration, potential misclassification of sample sites or changes in site classification).

  Sequential random sampling may be useful if the cost of laboratory analyses is a primary consideration during the assessment and only as many samples as are necessary are submitted for analysis. The ability to use rapid-turnaround field analysis instruments may warrant sequential sampling, since the results from the analyses of one set of samples can help determine the need for additional samples.

- ***Search sampling*** involves the identification of local "hot spots" where the measure for injury responses is relatively high. This can be accomplished through systematic sampling on a grid of points arranged in a certain pattern. If no measured response values exceed a pre-determined standard, trustees could conclude that hot spots do not exist. The detection of hot spots would lead to a decision regarding the need for additional sampling to quantify injury more accurately.

3.6.3 Laboratory Studies

Laboratory studies may serve multiple purposes including injury, pathway, and exposure determination. Properly designed and implemented laboratory studies may provide substantiation or confirmation of conclusions suggested by field studies. Conversely, the results of laboratory studies also may suggest the types of field studies that will be necessary to evaluate injury. In general, short-term studies that measure acute mortality are easier to design and conduct than long-term, multi-generational studies that attempt to measure on-going sublethal effects.

Toxicity Tests

Toxicity tests determine whether the discharged oil can have a measurable effect on the exposed biota. When combined with field surveys documenting a pathway and adverse effects in the field, toxicity test data may establish the causal link between the discharge and injury. The objectives of toxicity tests are to correlate an adverse effect with exposure to the discharged oil and determine the concentrations at which the effect occurs. An adverse effect may be determined directly by exposing the organisms to the oil discharged or inferred by measuring the concentration of oil either in the organism or its environment and comparing this value to literature values associated with adverse effects. While mortality is the most common effect measured in toxicity tests, these tests are also commonly used to measure developmental abnormalities, behavioral changes, changes in reproductive success, and alteration of growth.

Bioavailability Studies

Bioavailability studies may be either the measurement of tissue residues in indigenous organisms or tests of surrogates exposed to contaminated environmental media (water or sediment) for a specific length of time. Bioavailability studies are complicated by the rapid metabolism of petroleum hydrocarbons by almost all organisms except bivalve mollusks. In practice this means that analyzing any vertebrate animal and the majority of invertebrate animals for the presence of petroleum hydrocarbons will yield non-detectable results. For this reason, bivalve mollusks, such as oysters and mussels, are often transplanted to the discharge site to determine the availability of oil to biota. An alternative is the use of surrogate organisms, such as lipid bags, which provide passive bioavailability data.

A second alternative is the analysis of bile for the metabolites of the petroleum hydrocarbons. Many vertebrates excrete petroleum hydrocarbon metabolites in their bile. This tissue can be quickly and easily screened for the presence of these compounds in a semi-quantitative manner (Krahn et al., 1988).

Biomarkers

Biomarkers are ". . . biochemical, physiological, or histological indicators of either exposure to, or effects of, xenobiotic chemicals at the suborganismal or organismal level" (Hugget et al., 1992). Exposure indicators establish that organisms were subjected to a potentially deleterious stressor and quantify the extent of that exposure. However, exposure indicators cannot be used to detect adverse effects. In contrast, response indicators demonstrate that adverse effects are occurring, although often it is difficult to link the cause of the effect to exposure to the discharged oil. Thus, in most instances both response and exposure indicators are needed to establish that effects are occurring and to link the causes of those effects to oil exposure.

Exposure and response indicators include, but are not limited to, the appearance of metabolites in bile, the production of detoxification enzymes, genetic disorders, histopathological disorders, pathological deformities, and impaired reproductive abilities.

3.6.4 Modeling Studies[6]

Scientists frequently use models to describe or quantify physical, chemical, and biological processes and systems. In general, models consist of mathematical equations that require the user to specify the value of input variables, boundary conditions, and other parameters (e.g., rate constraints) in order to apply the model to a particular situation. Scientists can then use the model to study how a specific process or system will respond to changes in input variables and other parameters and may predict how a process or system might change in the future.

Models are abstractions of real processes and systems and are useful because complex phenomena can be studied in a structured, controlled way. By necessity, models are simplifications of real processes. It is not possible to build all of the complex interactions that occur in a real system into a system of mathematical equations. It is important, however, that the model successfully simulate the important processes occurring in any system. Model validation is a technique used to make this determination. For injuries to natural resources resulting from a discharge of oil, models must be able to simulate the processes occurring without the presence of oil, as well as simulate the movement of oil throughout the system after it is discharged. This requires an understanding of how the oil interacts physically, chemically, and biologically with the environment.

[6] The text in this section was drafted by Deborah P. French, Applied Science Associates, Narragansett, RI.

The sensitivity of model results to changes in inputs or parameters can be studied and uncertainty quantified. If a model's output is extremely sensitive to small changes in a given input or parameter, the trustees can consider allocating resources to studies that will increase confidence in the value of that particular input or parameter to be used in subsequent model analyses.

Strategies for the Use of Models

Models may be used as a predictive or screening tool. In the Preassessment Phase, for example, the trustees could use a model to approximate potential injuries. Model results would be used to develop an injury assessment plan, such that the focus of further studies would be on those resources expected to be injured.

Trustees may also use models as stand alone assessment procedures. For example, the type A models developed by the U.S. Department of the Interior (USDOI), including the Natural Resources Damage Assessment Model for Coastal and Marine Environments (NRDAM/CME) and for Great Lakes Environments (NRDAM/GLE), are valid assessment tools for small spills (French et al., 1994 a, b,c; Reed et al., 1994). Trustees may combine limited studies with these models. For example, field observations and surveys may be used to improve input parameters or to help validate the model predictions. More comprehensive studies may be conducted to address injuries not included in the model, or to replace sections of the model with site-specific injury information.

Alternatively, models may be used in support of specific injury determination and quantification elements. For example, fate and exposure models may be used in support of pathway and exposure determination studies.

Several types of models may be useful for injury assessment studies. Physical models, such as oil trajectory models, sediment transport models, hydrodynamic flow models, and, more generally, physical and chemical fate and transport models may be used to demonstrate physical pathways. Results from physical and chemical models may be used in biological effects models to estimate the effects of oil discharges on biological resources. Concurrent use of laboratory and/or *in situ* toxicity and bioaccumulation studies may provide calibration or validation data. Population models may be used to estimate future changes in populations as a result of acute toxicity and/or reproductive impairment effects caused by oil discharges. A biochemical, or toxicokinetic, model may also be useful in determining the mechanisms by which contaminants cause natural resource injuries.

Oil Spill Modeling for NRDA

There is a large body of literature available on oil spill modeling, including reviews by Stolzenbach et al (1977), Huang and Monastero (1982), Murray (1982), Huang (1983), Spaulding (1988), Reed (1992), French (1992), ASCE (1994), and Spaulding (1995). The reader is referred to these reviews for details. Only a brief summary is presented below.

Fates Models

Fates models may be used to predict the behavior, transport, and weathering of oil in the NRDA context. This information may be used to predict the temporal and geographic extent of exposure and the potential for injury to natural resources. Models vary in complexity and design. Fates models are available to predict weathering the process of evaporation, dispersion, dissolution, emulsification, photolysis, biodegradation and sinking/sedimentation, and transportation (spreading, drifting, entrainment, and stranding).

Two primary methodologies for representing the physical distribution of oil have evolved. The first describes surface oil as one or more uniform circular (or elliptical or rectangular) spillets, with radius, thickness, and other variables computed dynamically. This allows easy calculation of surface area and facilitates the inclusion of fates processes that depend on surface area and thickness. A second approach describes the oil as a large number of individual particles. On the surface, the particles may take on the characteristics of spillets. In the water column, a particle takes on the characteristics of a droplet. The buoyant behavior of different sized droplets, combined with vertical shear in the velocity profile, allows a realistic representation of slick evolution. The approach can also follow hydrocarbons entrained or dissolved in the water column.

Biological Effects Models

Fate models provide a mass balance and chemical characterization of oil in two phases, as surface slicks and as subsurface concentrations in water and sediments. The output of a fate model is a three-dimensional description of oil components as a function of time. This information may be used as input to a biological effects model. Typically, surface slicks are assumed to be lethal to wildlife (mammals, birds). Smothering of intertidal plants, invertebrates, and vertebrate eggs and larvae is potentially lethal depending on oil type and thickness. Subtidal biota have not been shown to be affected by slicks on the surface. Water and sediment concentrations of petroleum hydrocarbons may be lethal to fish, invertebrates, and plants, but have not been shown to cause wildlife mortality directly. Indirect and sublethal effects may also be induced by water and sediment concentrations of petroleum components. These may impact all biota.

Biological effects models consider one or more of these exposure pathways for mortality and sublethal effects. Some models also include population-level responses to these effects. The literature on oil effects modeling is much smaller than that for fates modeling. Only one review (French 1992) appears available. Below are summaries of some of the methods used in oil spill biological effects models.

The greatest uncertainty in modeling mortality appears to be in the estimation of the probability of being oiled and dying from it. Estimation of the number of animals oiled has been performed at three levels of sophistication:

- The animals are assumed stationary and the area swept by the slick determines the number oiled (Trudel, 1984; Trudel and Ross, 1987; Trudel et al., 1987, 1989; French and French, 1989; French et al., 1994a; Reed et al., 1994);

- The average slick area over a time step may be calculated and animal movements over that time calculated. Animals moving through the slick area are oiled (Ford, 1985; Ford et al., 1987; Samuels and Lanfear, 1982; Samuels and Ladino, 1984; Brody, 1988); and

- Both oil slicks and animals are treated as Lagrangian particles, with intersections of oil and animals calculated dynamically (Reed et al., 1987a,b; French and Reed, 1989; French et al., 1989; Jayko et al., 1990).

The third method using Lagrangian particles is most realistic in that active, directed, and individualized behaviors, as well as exposure histories, may be simulated. However, hundreds or thousands of particles may be needed to achieve necessary resolution. Detailed migrational simulations are only possible if behavior is known. For some populations, the assumption of random movements may be more appropriate. Also, for general applications and where computer run time is a consideration, the simpler approaches may be appropriate.

Population modeling of wildlife impacts once mortality is estimated is well developed in the oil spill modeling literature and the general ecological literature. The primary limitation on population modeling is the availability of data for estimating population parameters.

Estimation of exposure and mortality of fish and invertebrates has been modeled at four levels of sophistication:

- Laevastu and others at the National Marine Fisheries Service (NMFS-NWAFC) developed a subsurface oil fishery mortality model. (Laevastu and Fukuhara, 1984; Laevastu et al., 1985; Fukuhara and Natural Resources Consultants, 1985). This model provides three-dimensional quantification of the water soluble fraction over time. Fish and eggs migrating or advected through the oil are assumed killed in those areas where the water soluble concentration exceeds a threshold value. A full fisheries population and catch model is then used to evaluate impacts. (Fukahara and Natural Resources Consultants (1985.)

- Reed, Spaulding and others at Applied Science Associates developed a fisheries impact model based on oil-induced egg and larval mortality. (Reed and Spaulding, 1979, 1984; Reed 1980; Reed et al., 1985; Spaulding et al., 1983, 1985.) This model uses Lagrangian particles to trace the movements of eggs and larvae as they are dispersed by currents and random mixing. Those particles exposed to oil concentrations exceeding a threshold are assumed killed. The model includes a fisheries population and catch model.

- The biological effects model developed for the CERCLA Type A NRDAM/CME and NRDAM/GLE (French 1991; French et al., 1994 a,b,c; Reed et al., 1994) includes a dynamic assessment of the exposure history of individual organisms to oil in three-dimensional space and time. The type A models use Lagrangian particles to trace the time history and concentration of exposure of individuals. This exposure history is functionally related to mortality. Standard fisheries models are used to estimate population effects and lost catch.

- French et al., (1989) developed a single-species model similar to the type A models described above. The model simulates detailed spatial distributions of adults as well as Lagrangian-particle-traced eggs and larvae. Impacts to particular beds, as well as the whole population, are assessed. The population model includes age-specific density-independent and density-dependent mortality.

3.7 References

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CONCLUSIONS CHAPTER 4

This document provides an introduction and general guidance in designing injury assessments within the NRDA context, and in selecting procedures for ensuring that the information produced meets the needs of trustees and other users as required under the Oil Pollution Act of 1990.

The overriding theme in this document is that ***the design and implementation of injury studies is but one of the elements that trustees should consider when making NRDA decisions***. When developing an injury assessment, it is important that the trustees evaluate the potential for and significance of the injuries, the strength of that information, and whether actions can be taken to restore the injured natural resources and make the environment and public whole. However, it is equally important to assess other considerations (i.e., regulatory requirements, public policies, economic factors, etc.) that may affect decisionmaking. In Chapter 2 (section 2.4.2), there were a number of questions that trustees should ask when evaluating whether and how an NRDA should be conducted. It is instructive to reiterate them here:

- What are the natural resources and services of concern?
- What are the procedures available to evaluate and quantify injury, and the associated cost and time requirements?
- What is the evidence indicating exposure?
- What is the pathway from the incident to the natural resource and/or service of concern?
- What is the adverse change or impairment that constitutes injury?
- What is the evidence indicating injury?
- What is the mechanism by which injury occurred?
- What is the potential degree and spatial and temporal extent of the injury?

- What is the potential natural recovery period?

- What are the kinds of primary and/or compensatory restoration actions that are feasible?

Lessons learned from prior NRDAs also suggest that the role of injury assessment in NRDA decisionmaking can be strengthened by addressing the following areas:

- Injury assessment efforts should include mechanisms for periodic review and redirection of efforts when information justifies a change.

- Prior to implementing injury assessment, it must be clear how data are to be used, and what type of decisions will be based upon the data.

- The objectives established for any injury assessment should be achievable scientifically, technologically, logistically, and cost-effectively.

- Injury assessment efforts should be integrated and coordinated among all involved parties in order to optimize use of available staff and financial resources. Fiscal controls should be compatible with program controls and objectives.

- The results of the injury assessment should be clearly communicated to decisionmakers and the public.

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Subpart A—Introduction

§ 990.10 Purpose.

The goal of the Oil Pollution Act of 1990 (OPA), 33 U.S.C. 2701 *et seq*., is to make the environment and public whole for injuries to natural resources and services resulting from an incident involving a discharge or substantial threat of a discharge of oil (incident). This goal is achieved through the return of the injured natural resources and services to baseline and compensation for interim losses of such natural resources and services from the date of the incident until recovery. The purpose of this part is to promote expeditious and cost-effective restoration of natural resources and services injured as a result of an incident. To fulfill this purpose, this part provides a natural resource damage assessment process for developing a plan for restoration of the injured natural resources and services and pursuing implementation or funding of the plan by responsible parties. This part also provides an administrative process for involving interested parties in the assessment, a range of assessment procedures for identifying and evaluating injuries to natural resources and services, and a means for selecting restoration actions from a reasonable range of alternatives.

§ 990.11 Scope.

The Oil Pollution Act of 1990 (OPA), 33 U.S.C. 2701 *et seq*., provides for the designation of Federal, state, and, if designated by the Governor of the state, local officials to act on behalf of the public as trustees for natural resources and for the designation of Indian tribe and foreign officials to act as trustees for natural resources on behalf of, respectively, the tribe or its members and the foreign government. This part may be used by these officials in conducting natural resource damage assessments when natural resources and/or services are injured as a result of an incident involving an actual or substantial threat of a discharge of oil. This part is not intended to affect the recoverability of natural resource damages when recoveries are sought other than in accordance with this part.

§ 990.12 Overview.

This part describes three phases of a natural resource damage assessment. The Preassessment Phase, during which trustees determine whether to pursue restoration, is described in subpart D of this part. The Restoration Planning Phase, during which trustees evaluate information on potential injuries and use that information to determine the need for, type of, and scale of restoration, is described in subpart E of this part. The Restoration Implementation Phase, during which trustees ensure implementation of restoration, is described in subpart F of this part.

§ 990.13 Rebuttable presumption.

Any determination or assessment of damages to natural resources made by a Federal, State, or Indian trustee in accordance with this part shall have the force and effect of a rebuttable presumption on behalf of the trustee in any administrative or judicial proceeding under OPA.

§ 990.14 Coordination.

(a) *Trustees*. (1) If an incident affects the interests of multiple trustees, the trustees should act jointly under this part to ensure that full restoration is achieved without double recovery of damages. For joint assessments, trustees must designate one or more Lead Administrative Trustee(s) to act as coordinators.

(2) If there is a reasonable basis for dividing the natural resource damage assessment, trustees may act independently under this part, so long as there is no double recovery of damages.

(b) *Response agencies*. Trustees must coordinate their activities conducted concurrently with response operations with response agencies consistent with the NCP and any pre-incident plans developed under § 990.15(a) of this part. Trustees may develop pre-incident memoranda of understanding to coordinate their activities with response agencies.

(c) *Responsible parties*. (1) *Invitation*. Trustees must invite the responsible parties to participate in the natural resource damage assessment described in this part. The invitation to participate should be in writing, and a written response by the responsible parties is required to confirm the desire to participate.

(2) *Timing*. The invitation to participate should be extended to known responsible parties as soon as practicable, but not later than the delivery of the "Notice of Intent to Conduct Restoration Planning," under § 990.44 of this part, to the responsible party.

(3) *Agreements*. Trustees and responsible parties should consider entering into binding agreements to facilitate their interactions and resolve any disputes during the assessment. To maximize cost-effectiveness and cooperation, trustees and responsible parties should attempt to develop a set of agreed-upon facts concerning the incident and/or assessment.

(4) *Nature and extent of participation*. If the responsible parties accept the invitation to participate, the scope of that participation must be determined by the trustees, in light of the considerations in paragraph (c)(5) of this section. At a minimum, participation will include notice of trustee determinations required under this part, and notice and opportunity to comment on documents or plans that significantly affect the nature and extent of the assessment. Increased levels of participation by responsible parties may be developed at the mutual agreement of the trustees and the responsible parties. Trustees will objectively consider all written comments provided by the responsible parties, as well as any other recommendations or proposals that the responsible parties submit in writing to the Lead Administrative Trustee. Submissions by the responsible parties will be included in the administrative record. Final authority to make determinations regarding injury and restoration rest solely with the trustees. Trustees may end participation by responsible parties who, during the conduct of the assessment, in the sole judgment of the trustees, cause interference with the trustees' ability to fulfill their responsibilities under OPA and this part.

(5) *Considerations*. In determining the nature and extent of participation by the responsible parties or their representatives, trustees may consider such factors as:

(i) Whether the responsible parties have been identified;

(ii) The willingness of responsible parties to participate in the assessment;

(iii) The willingness of responsible parties to fund assessment activities;

(iv) The willingness and ability of responsible parties to conduct assessment activities in a technically sound and timely manner and to be bound by the results of jointly agreed upon studies;

(v) The degree of cooperation of the responsible parties in the response to the incident; and

(vi) The actions of the responsible parties in prior assessments.

(6) Request for alternative assessment procedures.

(i) The participating responsible parties may request that trustees use assessment procedures other than those selected by the trustees if the responsible parties:

(A) Identify the proposed procedures to be used that meet the requirements of § 990.27 of this part, and provide reasons supporting the technical adequacy and appropriateness of such procedures for the incident and associated injuries;

(B) Advance to the trustees the trustees' reasonable estimate of the cost of using the proposed procedures; and

(C) Agree not to challenge the results of the proposed procedures. The request from the responsible parties may be made at any time, but no later than, fourteen (14) days of being notified of the trustees' proposed assessment procedures for the incident or the injury.

(ii) Trustees may reject the responsible parties' proposed assessment procedures if, in the sole judgment of the trustees, the proposed assessment procedures:

(A) Are not technically feasible;

(B) Are not scientifically or technically sound;

(C) Would inadequately address the natural resources and services of concern;

(D) Could not be completed within a reasonable time frame; or

(E) Do not meet the requirements of § 990.27 of this part.

(7) *Disclosure*. Trustees must document in the administrative record and Restoration Plan the invitation to the responsible parties to participate, and briefly describe the nature and extent of the responsible parties' participation. If the responsible parties' participation is terminated during the assessment, trustees must provide a brief explanation of this decision in the administrative record and Restoration Plan.

(d) *Public*. Trustees must provide opportunities for public involvement after the trustees' decision to develop restoration plans or issuance of any notices to that effect, as provided in § 990.55 of this part. Trustees may also provide opportunities for public involvement at any time prior to this decision if such involvement may enhance trustees' decisionmaking or avoid delays in restoration.

§ 990.15 Considerations to facilitate restoration.

In addition to the procedures provided in subparts D through F of this part, trustees may take other actions to further the goal of expediting restoration of injured natural resources and services, including:

(a) *Pre-incident planning*. Trustees may engage in pre-incident planning activities. Pre-incident plans may identify natural resource damage assessment teams, establish trustee notification systems, identify support services, identify natural resources and services at risk, identify area and regional response agencies and officials, identify available baseline information, establish data management systems, and identify assessment funding issues and options. Potentially responsible parties, as well as all other members of the public interested in and capable of participating in assessments, should be included in pre-incident planning to the fullest extent practicable.

(b) *Regional Restoration Plans*. Where practicable, incident- specific restoration plan development is preferred, however, trustees may develop Regional Restoration Plans. These plans may be used to support a claim under § 990.56 of this part. Regional restoration planning may consist of compiling databases that identify, on a regional or watershed basis, or otherwise as appropriate, existing, planned, or proposed restoration projects that may provide appropriate restoration alternatives for consideration in the context of specific incidents.

Subpart B—Authorities

§ 990.20 Relationship to the CERCLA natural resource damage assessment regulations.

(a) *General*. Regulations for assessing natural resource damages resulting from hazardous substance releases under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended (CERCLA), 42 U.S.C. 9601 *et seq*., and the Federal Water Pollution Control Act (Clean Water Act), 33 U.S.C. 1321 *et seq*., are codified at 43 CFR part 11. The CERCLA regulations originally applied to natural resource damages resulting from oil discharges as well as hazardous substance releases. This part supersedes 43 CFR part 11 with regard to oil discharges covered by OPA.

(b) *Assessments commenced before February 5, 1996*. If trustees commenced a natural resource damage assessment for an oil discharge under 43 CFR part 11 prior to February 5, 1996 they may complete the assessment in compliance with 43 CFR part 11, or they may elect to use this part, and obtain a rebuttable presumption.

(c) *Oil and hazardous substance mixtures*. For natural resource damages resulting from a discharge or release of a mixture of oil and hazardous substances, trustees must use 43 CFR part 11 in order to obtain a rebuttable presumption.

§ 990.21 Relationship to the NCP.

This part provides procedures by which trustees may determine appropriate restoration of injured natural resources and services, where such injuries are not fully addressed by response actions. Response actions and the coordination with damage assessment activities are conducted pursuant to the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), 40 CFR part 300.

§ 990.22 Prohibition on double recovery.

When taking actions under this part, trustees are subject to the prohibition on double recovery, as provided in 33 U.S.C. 2706(d)(3) of OPA.

§ 990.23 Compliance with NEPA and the CEQ regulations.

(a) *General*. The National Environmental Policy Act (NEPA), 42 U.S.C. 4321 *et seq*. and Council on Environmental Quality (CEQ) regulations implementing NEPA, 40 CFR chapter V, apply to restoration actions by federal trustees, except where a categorical exclusion or other exception to NEPA applies. Thus, when a federal trustee proposes to take restoration actions under this part, it must integrate this part with NEPA, the CEQ regulations, and NEPA regulations promulgated by that federal trustee agency. Where state NEPA-equivalent laws may apply to state trustees, state trustees must consider the extent to which they must integrate this part with their NEPA-equivalent laws. The requirements and process described in this section relate only to NEPA and federal trustees.

(b) *NEPA requirements for federal trustees*. NEPA becomes applicable when federal trustees propose to take restoration actions, which begins with the development of a Draft Restoration Plan under § 990.55 of this part. Depending upon the circumstances of the incident, federal trustees may need to consider early involvement of the public in restoration planning in order to meet their NEPA compliance requirements.

(c) *NEPA process for federal trustees*. Although the steps in the NEPA process may vary among different federal trustees, the process will generally involve the need to develop restoration plans in the form of an Environmental Assessment or Environmental Impact Statement, depending upon the trustee agency's own NEPA regulations.

(1) *Environmental Assessment*. (i) *Purpose*. The purpose of an Environmental Assessment (EA) is to determine whether a proposed restoration action will have a significant (as defined under NEPA and § 1508.27 of the CEQ regulations) impact on the quality of the human environment, in which case an Environmental Impact Statement (EIS) evaluating the impact is required. In the alternative, where the impact will not be significant, federal trustees must issue a Finding of No Significant Impact (FONSI) as part of the restoration plans developed under this part. If significant impacts to the human environment are anticipated, the determination to proceed with an EIS may be made as a result, or in lieu, of the development of the EA.

(ii) *General steps*. (A) If the trustees decide to pursue an EA, the trustees may issue a Notice of Intent to Prepare a Draft Restoration Plan/EA, or proceed directly to developing a Draft Restoration Plan/EA.

(B) The Draft Restoration Plan/EA must be made available for public review before concluding a FONSI or proceeding with an EIS.

(C) If a FONSI is concluded, the restoration planning process should be no different than under § 990.55 of this part, except that the Draft Restoration Plan/EA will include the FONSI analysis.

(D) The time period for public review on the Draft Restoration Plan/EA must be consistent with the federal trustee agency's NEPA requirements, but should generally be no less than thirty (30) calendar days.

(E) The Final Restoration Plan/EA must consider all public comments on the Draft Restoration Plan/EA and FONSI.

(F) The means by which a federal trustee requests, considers, and responds to public comments on the Draft Restoration Plan/EA and FONSI must also be consistent with the federal agency's NEPA requirements.

(2) *Environmental Impact Statement*. (i) *Purpose*. The purpose of an Environmental Impact Statement (EIS) is to involve the public and facilitate the decisionmaking process in the federal trustees' analysis of alternative approaches to restoring injured natural resources and services, where the impacts of such restoration are expected to have significant impacts on the quality of the human environment.

(ii) *General steps*. (A) If trustees determine that restoration actions are likely to have a significant (as defined under NEPA and § 1508.27 of the CEQ regulations) impact on the environment, they must issue a Notice of Intent to Prepare a Draft Restoration Plan/EIS. The notice must be published in the Federal Register.

(B) The notice must be followed by formal public involvement in the development of the Draft Restoration Plan/EIS.

(C) The Draft Restoration Plan/EIS must be made available for public review for a minimum of forty-five (45) calendar days. The Draft Restoration Plan/EIS, or a notice of its availability, must be published in the Federal Register.

(D) The Final Restoration Plan/EIS must consider all public comments on the Draft Restoration Plan/EIS, and incorporate any changes made to the Draft Restoration Plan/EIS in response to public comments.

(E) The Final Restoration Plan/EIS must be made publicly available for a minimum of thirty (30) calendar days before a decision is made on the federal trustees' proposed restoration actions (Record of Decision). The Final Restoration Plan/EIS, or a notice of its availability, must be published in the Federal Register.

(F) The means by which a federal trustee agency requests, considers, and responds to public comments on the Final Restoration Plan/EIS must also be consistent with the federal agency's NEPA requirements.

(G) After appropriate public review on the Final Restoration Plan/EIS is completed, a Record of Decision (ROD) is issued. The ROD summarizes the trustees' decisionmaking process after consideration of any public comments relative to the proposed restoration actions, identifies all restoration alternatives (including the preferred alternative(s)), and their environmental consequences, and states whether all practicable means to avoid or minimize environmental harm were adopted (e.g., monitoring and corrective actions). The ROD may be incorporated with other decision documents prepared by the trustees. The means by which the ROD is made publicly

(d) *Relationship to Regional Restoration Plans or an existing restoration project*. If a available must be consistent with the federal trustee agency's NEPA requirements. (Regional Restoration Plan or existing restoration project is proposed for use, federal trustees may be able to tier their NEPA analysis to an existing EIS, as described in §§ 1502.20 and 1508.28 of the CEQ regulations.

§ 990.24 Compliance with other applicable laws and regulations.

(a) *Worker health and safety*. When taking actions under this part, trustees must comply with applicable worker health and safety considerations specified in the NCP for response actions.

(b) *Natural Resources protection*. When acting under this part, trustees must ensure compliance with any applicable consultation, permitting, or review requirements, including but not limited to: the Endangered Species Act of 1973, 16 U.S.C. 1531 *et seq*.; the Coastal Zone Management Act of 1972, 16 U.S.C. 1451 *et seq*.; the Migratory Bird Treaty Act, 16 U.S.C. 703 *et seq*.; the National Marine Sanctuaries Act, 16 U.S.C. 1431 *et seq*.; the National Historic Preservation Act, 12 U.S.C. 470 *et seq*.; the Marine Mammal Protection Act, 16 U.S.C. 1361 *et seq*.; and the Archaeological Resources Protection Act, 16 U.S.C. 470 *et seq*.

§ 990.25 Settlement.

Trustees may settle claims for natural resource damages under this part at any time, provided that the settlement is adequate in the judgment of the trustees to satisfy the goal of OPA and is fair, reasonable, and in the public interest, with particular consideration of the adequacy of the settlement to restore, replace, rehabilitate, or acquire the equivalent of the injured natural resources and services. Sums recovered in settlement of such claims, other than reimbursement of trustee costs, may only be expended in accordance with a restoration plan, which may be set forth in whole or in part in a consent decree or other settlement agreement, which is made available for public review.

§ 990.26 Emergency restoration.

(a) Trustees may take emergency restoration action before completing the process established under this part, provided that:

(1) The action is needed to minimize continuing or prevent additional injury;

(2) The action is feasible and likely to minimize continuing or prevent additional injury; and

(3) The costs of the action are not unreasonable.

(b) If response actions are still underway, trustees, through their Regional Response Team member or designee, must coordinate with the On-Scene Coordinator (OSC) before taking any emergency restoration actions. Any emergency restoration actions proposed by trustees should not interfere with on-going response actions. Trustees must explain to response agencies through the OSC prior to implementation of emergency restoration actions their reasons for believing that proposed emergency restoration actions will not interfere with on-going response actions.

(c) Trustees must provide notice to identified responsible parties of any emergency restoration actions and, to the extent time permits, invite their participation in the conduct of those actions as provided in § 990.14(c) of this part.

(d) Trustees must provide notice to the public, to the extent practicable, of these planned emergency restoration actions. Trustees must also provide public notice of the justification for, nature and extent of, and results of emergency restoration actions within a reasonable time frame after completion of such actions. The means by which this notice is provided is left to the discretion of the trustee.

§ 990.27 Use of assessment procedures.

(a) *Standards for assessment procedures*. Any procedures used pursuant to this part must comply with all of the following standards if they are to be in accordance with this part:

(1) The procedure must be capable of providing assessment information of use in determining the type and scale of restoration appropriate for a particular injury;

(2) The additional cost of a more complex procedure must be reasonably related to the expected increase in the quantity and/or quality of relevant information provided by the more complex procedure; and

(3) The procedure must be reliable and valid for the particular incident.

(b) *Assessment procedures available*. (1) The range of assessment procedures available to trustees includes, but is not limited to:

(i) Procedures conducted in the field;

(ii) Procedures conducted in the laboratory;

(iii) Model-based procedures, including type A procedures identified in 43 CFR part 11, subpart D, and compensation formulas/schedules; and

(iv) Literature-based procedures.

(2) Trustees may use the assessment procedures in paragraph (b)(1) of this section alone, or in any combination, provided that the standards in paragraph (a) of this section are met, and there is no double recovery.

(c) *Selecting assessment procedures*. (1) When selecting assessment procedures, trustees must consider, at a minimum:

(i) The range of procedures available under paragraph (b) of this section;

(ii) The time and cost necessary to implement the procedures;

(iii) The potential nature, degree, and spatial and temporal extent of the injury;

(iv) The potential restoration actions for the injury; and

(v) The relevance and adequacy of information generated by the procedures to meet information requirements of restoration planning.

(2) If a range of assessment procedures providing the same type and quality of information is available, the most cost-effective procedure must be used.

Subpart C—Definitions

§ 990.30 Definitions.

For the purpose of this rule, the term:

Baseline means the condition of the natural resources and services that would have existed had the incident not occurred. Baseline data may be estimated using historical data, reference data, control data, or data on incremental changes (e.g., number of dead animals), alone or in combination, as appropriate.

Cost-effective means the least costly activity among two or more activities that provide the same or a comparable level of benefits, in the judgment of the trustees.

CEQ regulations means the Council on Environmental Quality regulations implementing NEPA, 40 CFR chapter V.

Damages means damages specified in section 1002(b) of OPA (33 U.S.C. 1002(b)), and includes the costs of assessing these damages, as defined in section 1001(5) of OPA (33 U.S.C. 2701(5)).

Discharge means any emission (other than natural seepage), Intentional or unintentional, and includes, but is not limited to, spilling, leaking, pumping, pouring, emitting, emptying, or dumping, as defined in section 1001(7) of OPA (33 U.S.C. 2701(7)).

Exclusive Economic Zone means the zone established by Presidential Proclamation 5030 of March 10, 1983 (3 CFR, 1984 Comp., p. 22), including the ocean waters of the areas referred to as “eastern special areas” in Article 3(1) of the Agreement between the United States of America and the Union of Soviet Socialist Republics on the Maritime Boundary, signed June 1, 1990, as defined in section 1001(8) of OPA (33 U.S.C. 2701(8)).

Exposure means direct or indirect contact with the discharged oil.

Facility means any structure, group of structures, equipment, or device (other than a vessel) which is used for one or more of the following purposes: exploring for, drilling for, producing, storing, handling, transferring, processing, or transporting oil. This term includes any motor vehicle, rolling stock, or pipeline used for one or more of these purposes, as defined in section 1001(9) of OPA (33 U.S.C. 2701(9)).

Fund means the *Oil Spill Liability Trust Fund*, established by section 9509 of the Internal Revenue Code of 1986 (26 U.S.C. 9509), as defined in section 1001(11) of OPA (33 U.S.C. 2701(11)).

Incident means any occurrence or series of occurrences having the same origin, involving one or more vessels, facilities, or any combination thereof, resulting in the discharge or substantial threat of discharge of oil into or upon navigable waters or adjoining shorelines or the Exclusive Economic Zone, as defined in section 1001(14) of OPA (33 U.S.C. 2701(14)).

Indian tribe (or *tribal*) means any Indian tribe, band, nation, or other organized group or community, but not including any Alaska Native regional or village corporation, which is recognized as eligible for the special programs and services provided by the United States to Indians because of their status as Indians and has governmental authority over lands belonging to or controlled by the tribe, as defined in section 1001(15) of OPA (33 U.S.C. 2701(15)).

Injury means an observable or measurable adverse change in a natural resource or impairment of a natural resource service. Injury may occur directly or indirectly to a natural resource and/or service. Injury incorporates the terms "destruction," "loss," and "loss of use" as provided in OPA.

Lead Administrative Trustee(s) (or *LAT*) means the trustee(s) who is selected by all participating trustees whose natural resources or services are injured by an incident, for the purpose of coordinating natural resource damage assessment activities. The LAT(s) should also facilitate communication between the OSC and other natural resource trustees regarding their activities during the response phase.

NCP means the National Oil and Hazardous Substances Pollution Contingency Plan (National Contingency Plan) codified at 40 CFR part 300, which addresses the identification, investigation, study, and response to incidents, as defined in section 1001(19) of OPA (33 U.S.C. 2701(19)).

Natural resource damage assessment (or *assessment*) means the process of collecting and analyzing information to evaluate the nature and extent of injuries resulting from an incident, and determine the restoration actions needed to bring injured natural resources and services back to baseline and make the environment and public whole for interim losses.

Natural resources means land, fish, wildlife, biota, air, water, ground water, drinking water supplies, and other such resources belonging to, managed by, held in trust by, appertaining to, or otherwise controlled by the United States (including the resources of the Exclusive Economic Zone), any state or local government or Indian tribe, or any foreign government, as defined in section 1001(20) of OPA (33 U.S.C. 2701(20)).

Navigable waters means the waters of the United States, including the territorial sea, as defined in section 1001(21) of OPA (33 U.S.C. 2701(21)).

NEPA means the National Environmental Policy Act, 42 U.S.C. 4321 et seq.

Oil means oil of any kind or in any form, including, but not limited to, petroleum, fuel oil, sludge, oil refuse, and oil mixed with wastes other than dredged spoil. However, the term does not include petroleum, including crude oil or any fraction thereof, that is specifically listed or designated as a hazardous substance under 42 U.S.C. 9601(14)(A) through (F), as defined in section 1001(23) of OPA (33 U.S.C. 2701(23)).

On-Scene Coordinator (or *OSC*) means the official designated by the U.S. Environmental Protection Agency or the U.S. Coast Guard to coordinate and direct response actions under the NCP, or the government official designated by the lead response agency to coordinate and direct response actions under the NCP.

OPA means the Oil Pollution Act of 1990, 33 U.S.C. 2701 *et seq*.

Pathway means any link that connects the incident to a natural resource and/or service, and is associated with an actual discharge of oil.

Person means an individual, corporation, partnership, association, state, municipality, commission, or political subdivision of a state, or any interstate body, as defined in section 1001(27) of OPA (33 U.S.C. 2701(27)).

Public vessel means a vessel owned or bareboat chartered and operated by the United States, or by a state or political subdivision thereof, or by a foreign nation, except when the vessel is engaged in commerce, as defined in section 1001(29) of OPA (33 U.S.C. 2701(29)).

Reasonable assessment costs means, for assessments conducted under this part, assessment costs that are incurred by trustees in accordance with this part. In cases where assessment costs are incurred but trustees do not pursue restoration, trustees may recover their reasonable assessment costs provided that they have determined that assessment actions undertaken were premised on the likelihood of injury and need for restoration. Reasonable assessment costs also include: administrative, legal, and enforcement costs necessary to carry out this part; monitoring and oversight costs; and costs associated with public participation.

Recovery means the return of injured natural resources and services to baseline.

Response (or *remove* or *removal*) means containment and removal of oil or a hazardous substance from water and shorelines or the taking of other actions as may be necessary to minimize or mitigate damage to the public health or welfare, including, but not limited to, fish, shellfish, wildlife, and public and private property, shorelines, and beaches, as defined in section 1001(30) of OPA (33 U.S.C. 2701(30)).

Responsible party means:

(a) *Vessels*. In the case of a vessel, any person owning, operating, or demise chartering the vessel.

(b) *Onshore facilities*. In the case of an onshore facility (other than a pipeline), any person owning or operating the facility, except a federal agency, state, municipality, commission, or political subdivision of a state, or any interstate body, that as the owner transfers possession and right to use the property to another person by lease, assignment, or permit.

(c) *Offshore facilities*. In the case of an offshore facility (other than a pipeline or a deepwater port licensed under the Deepwater Port Act of 1974 (33 U.S.C. 1501 *et seq*.)), the lessee or permittee of the area in which the facility is located or the holder of a right of use and easement granted under applicable state law or the Outer Continental Shelf Lands Act (43 U.S.C. 1301-1356) for the area in which the facility is located (if the holder is a different person than the lessee or permittee), except a federal agency, state, municipality, commission, or political subdivision of a state, or any interstate body, that as owner transfers possession and right to use the property to another person by lease, assignment, or permit.

(d) *Deepwater ports*. In the case of a deepwater port licensed under the Deepwater Port Act of 1974 (33 U.S.C. 1501-1524), the licensee.

(e) *Pipelines*. In the case of a pipeline, any person owning or operating the pipeline.

(f) *Abandonment*. In the case of an abandoned vessel, onshore facility, deepwater port, pipeline, or offshore facility, the persons who would have been responsible parties immediately prior to the abandonment of the vessel or facility, as defined in section 1001(32) of OPA (33 U.S.C. 2701(32)).

Restoration means any action (or alternative), or combination of actions (or alternatives), to restore, rehabilitate, replace, or acquire the equivalent of injured natural resources and services. Restoration includes:

(a) *Primary restoration*, which is any action, including natural recovery, that returns injured natural resources and services to baseline; and

(b) *Compensatory restoration*, which is any action taken to compensate for interim losses of natural resources and services that occur from the date of the incident until recovery.

Services (or *natural resource services*) means the functions performed by a natural resource for the benefit of another natural resource and/or the public.

Trustees (or *natural resource trustees*) means those officials of the federal and state governments, of Indian tribes, and of foreign governments, designated under 33 U.S.C. 2706(b) of OPA.

United States and *State* means the several States of the United States, the District of Columbia, the Commonwealth of Puerto Rico, Guam, American Samoa, the United States Virgin Islands, the Commonwealth of the Northern Marianas, and any other territory or possession of the United States, as defined in section 1001(36) of OPA (33 U.S.C. 2701(36)).

Value means the maximum amount of goods, services, or money an individual is willing to give up to obtain a specific good or service, or the minimum amount of goods, services, or money an individual is willing to accept to forgo a specific good or service. The total value of a natural resource or service includes the value individuals derive from direct use of the natural resource, for example, swimming, boating, hunting, or birdwatching, as well as the value individuals derive from knowing a natural resource will be available for future generations.

Vessel means every description of watercraft or other artificial contrivance used, or capable of being used, as a means of transportation on water, other than a public vessel, as defined in section 1001(37) of OPA (33 U.S.C. 2701(37)).

Subpart D—Preassessment Phase

§ 990.40 Purpose.

The purpose of this subpart is to provide a process by which trustees determine if they have jurisdiction to pursue restoration under OPA and, if so, whether it is appropriate to do so.

§ 990.41 Determination of jurisdiction.

(a) *Determination of jurisdiction*. Upon learning of an incident, trustees must determine whether there is jurisdiction to pursue restoration under OPA. To make this determination, trustees must decide if:

(1) An incident has occurred, as defined in § 990.30 of this part;

(2) The incident is not:

(i) Permitted under a permit issued under federal, state, or local law; or

(ii) From a public vessel; or

(iii) From an onshore facility subject to the Trans-Alaska Pipeline Authority Act, 43 U.S.C. 1651, *et seq*.; and

(3) Natural resources under the trusteeship of the trustee may have been, or may be, injured as a result of the incident.

(b) *Proceeding with preassessment*. If the conditions listed in paragraph (a) of this section are met, trustees may proceed under this part. If one of the conditions is not met, trustees may not take additional action under this part, except action to finalize this determination. Trustees may recover all reasonable assessment costs incurred up to this point provided that conditions in paragraphs (a)(1) and (a)(2) of this section were met and actions were taken with the reasonable belief that natural resources or services under their trusteeship might have been injured as a result of the incident.

§ 990.42 Determination to conduct restoration planning.

(a) *Determination on restoration planning*. If trustees determine that there is jurisdiction to pursue restoration under OPA, trustees must determine whether:

(1) Injuries have resulted, or are likely to result, from the incident;

(2) Response actions have not adequately addressed, or are not expected to address, the injuries resulting from the incident; and

(3) Feasible primary and/or compensatory restoration actions exist to address the potential injuries.

(b) *Proceeding with preassessment*. If the conditions listed in paragraph (a) of this section are met, trustees may proceed under § 990.44 of this part. If one of these conditions is not met, trustees may not take additional action under this part, except action to finalize this determination. However, trustees may recover all reasonable assessment costs incurred up to this point.

§ 990.43 Data collection.

Trustees may conduct data collection and analyses that are reasonably related to Preassessment Phase activities. Data collection and analysis during the Preassessment Phase must be coordinated with response actions such that collection and analysis does not interfere with response actions. Trustees may collect and analyze the following types of data during the Preassessment Phase:

(a) Data reasonably expected to be necessary to make a determination of jurisdiction under § 990.41 of this part, or a determination to conduct restoration planning under § 990.42 of this part;

(b) Ephemeral data; and

(c) Information needed to design or implement anticipated assessment procedures under subpart E of this part.

§ 990.44 Notice of Intent to Conduct Restoration Planning.

(a) *General*. If trustees determine that all the conditions under § 990.42(a) of this part are met and trustees decide to proceed with the natural resource damage assessment, they must prepare a Notice of Intent to Conduct Restoration Planning.

(b) *Contents of the notice*. The Notice of Intent to Conduct Restoration Planning must include a discussion of the trustees' analyses under §§ 990.41 and 990.42 of this part. Depending on information available at this point, the notice may include the trustees' proposed strategy to assess injury and determine the type and scale of restoration. The contents of a notice may vary, but will typically discuss:

(1) The facts of the incident;

(2) Trustee authority to proceed with the assessment;

(3) Natural resources and services that are, or are likely to be, injured as a result of the incident;

(4) Potential restoration actions relevant to the expected injuries; and

(5) If determined at the time, potential assessment procedures to evaluate the injuries and define the appropriate type and scale of restoration for the injured natural resources and services.

(c) *Public availability of the notice*. Trustees must make a copy of the Notice of Intent to Conduct Restoration Planning publicly available. The means by which the notice is made publicly available and whether public comments are solicited on the notice will depend on the nature and extent of the incident and various information requirements, and is left to the discretion of the trustees.

(d) *Delivery of the notice to the responsible parties*. Trustees must send a copy of the notice to the responsible parties, to the extent known, in such a way as will establish the date of receipt, and invite responsible parties' participation in the conduct of restoration planning. Consistent with § 990.14(c) of this part, the determination of the timing, nature, and extent of responsible party participation will be determined by the trustees on an incident-specific basis.

§ 990.45 Administrative record.

(a) If trustees decide to proceed with restoration planning, they must open a publicly available administrative record to document the basis for their decisions pertaining to restoration. The administrative record should be opened concurrently with the publication of the Notice of Intent to Conduct Restoration Planning. Depending on the nature and extent of the incident and assessment, the administrative record should include documents relied upon during the assessment, such as:

(1) Any notice, draft and final restoration plans, and public comments;

(2) Any relevant data, investigation reports, scientific studies, work plans, quality assurance plans, and literature; and

(3) Any agreements, not otherwise privileged, among the participating trustees or with the responsible parties.

(b) Federal trustees should maintain the administrative record in a manner consistent with the Administrative Procedure Act, 5 U.S.C. 551-59, 701-06.

Subpart E—Restoration Planning Phase

§ 990.50 Purpose.

The purpose of this subpart is to provide a process by which trustees evaluate and quantify potential injuries (injury assessment), and use that information to determine the need for and scale of restoration actions (restoration selection).

§ 990.51 Injury assessment—injury determination.

(a) *General*. After issuing a Notice of Intent to Conduct Restoration Planning under § 990.44 of this part, trustees must determine if injuries to natural resources and/or services have resulted from the incident.

(b) *Determining injury*. To make the determination of injury, trustees must evaluate if:

(1) The definition of injury has been met, as defined in § 990.30 of this part; and

(2)(i) An injured natural resource has been exposed to the discharged oil, and a pathway can be established from the discharge to the exposed natural resource; or

(ii) An injury to a natural resource or impairment of a natural resource service has occurred as a result of response actions or a substantial threat of a discharge of oil.

(c) *Identifying injury*. Trustees must determine whether an injury has occurred and, if so, identify the nature of the injury. Potential categories of injury include, but are not limited to, adverse changes in: survival, growth, and reproduction; health, physiology and biological condition; behavior; community composition; ecological processes and functions; physical and chemical habitat quality or structure; and public services.

(d) Establishing exposure and pathway. Except for injuries resulting from response actions or incidents involving a substantial threat of a discharge of oil, trustees must establish whether natural resources were exposed, either directly or indirectly, to the discharged oil from the incident, and estimate the amount or concentration and spatial and temporal extent of the exposure. Trustees must also determine whether there is a pathway linking the incident to the injuries. Pathways may include, but are not limited to, the sequence of events by which the discharged oil was transported from the incident and either came into direct physical contact with a natural resource, or caused an indirect injury.

(e) *Injuries resulting from response actions or incidents involving a substantial threat of a discharge*. For injuries resulting from response actions or incidents involving a substantial threat of a discharge of oil, trustees must determine whether an injury or an impairment of a natural resource service has occurred as a result of the incident.

(f) *Selection of injuries to include in the assessment*. When selecting potential injuries to assess, trustees should consider factors such as:

(1) The natural resources and services of concern;

(2) The procedures available to evaluate and quantify injury and associated time and cost requirements;

(3) The evidence indicating exposure;

(4) The pathway from the incident to the natural resource and/or service of concern;

(5) The adverse change or impairment that constitutes injury;

(6) The evidence indicating injury;

(7) The mechanism by which injury occurred;

(8) The potential degree, and spatial and temporal extent of the injury;

(9) The potential natural recovery period; and

(10) The kinds of primary and/or compensatory restoration actions that are feasible.

§ 990.52 Injury assessment—quantification.

(a) *General*. In addition to determining whether injuries have resulted from the incident, trustees must quantify the degree, and spatial and temporal extent of such injuries relative to baseline.

(b) *Quantification approaches*. Trustees may quantify injuries in terms of:

(1) The degree, and spatial and temporal extent of the injury to a natural resource;

(2) The degree, and spatial and temporal extent of injury to a natural resource, with subsequent translation of that adverse change to a reduction in services provided by the natural resource; or

(3) The amount of services lost as a result of the incident.

(c) *Natural recovery*. To quantify injury, trustees must estimate, quantitatively or qualitatively, the time for natural recovery without restoration, but including any response actions. The analysis of natural recovery may consider such factors as:

(1) The nature, degree, and spatial and temporal extent of injury;

(2) The sensitivity and vulnerability of the injured natural resource and/or service;

(3) The reproductive and recruitment potential;

(4(The resistance and resilience (stability) of the affected environment;

(5) The natural variability; and

(6) The physical/chemical processes of the affected environment.

§ 990.53 Restoration selection—developing restoration alternatives.

(a) *General*. (1) If the information on injury determination and quantification under §§ 990.51 and 990.52 of this part and its relevance to restoration justify restoration, trustees may proceed with the Restoration Planning Phase. Otherwise, trustees may not take additional action under this part. However, trustees may recover all reasonable assessment costs incurred up to this point.

(2) Trustees must consider a reasonable range of restoration alternatives before selecting their preferred alternative(s). Each restoration alternative is comprised of primary and/or compensatory restoration components that address one or more specific injury(ies) associated with the incident. Each alternative must be designed so that, as a package of one or more actions, the alternative would make the environment and public whole. Only those alternatives considered technically feasible and in accordance with applicable laws, regulations, or permits may be considered further under this part.

(b) *Primary restoration*. (1) *General*. For each alternative, trustees must consider primary restoration actions, including a natural recovery alternative.

(2) *Natural recovery*. Trustees must consider a natural recovery alternative in which no human intervention would be taken to directly restore injured natural resources and services to baseline.

(3) *Active primary restoration actions*. Trustees must consider an alternative comprised of actions to directly restore the natural resources and services to baseline on an accelerated time frame. When identifying such active primary restoration actions, trustees may consider actions that:

(i) Remove conditions that would prevent or limit the effectiveness of any restoration action (e.g., residual sources of contamination);

(ii) May be necessary to return the physical, chemical, and/or biological conditions necessary to allow recovery or restoration of the injured natural resources (e.g., replacing substrate or vegetation, or modifying hydrologic conditions); or

(iii) Return key natural resources and services, and would be an effective approach to achieving or accelerating a return to baseline (e.g., replacing essential species, habitats, or public services that would facilitate the replacement of other, dependent natural resource or service components).

(c) *Compensatory restoration*. (1) *General*. For each alternative, trustees must also consider compensatory restoration actions to compensate for the interim loss of natural resources and services pending recovery.

(2) *Compensatory restoration actions*. To the extent practicable, when evaluating compensatory restoration actions, trustees must consider compensatory restoration actions that provide services of the same type and quality, and of comparable value as those injured. If, in the judgment of the trustees, compensatory actions of the same type and quality and comparable value cannot provide a reasonable range of alternatives, trustees should identify actions that provide natural resources and services of comparable type and quality as those provided by the injured natural resources. Where the injured and replacement natural resources and services are not of comparable value, the scaling process will involve valuation of lost and replacement services.

(d) *Scaling restoration actions*. (1) *General*. After trustees have identified the types of restoration actions that will be considered, they must determine the scale of those actions that will make the environment and public whole. For primary restoration actions, scaling generally applies to actions involving replacement and/or acquisition of equivalent of natural resources and/or services.

(2) *Resource-to-resource and service-to-service scaling approaches*. When determining the scale of restoration actions that provide natural resources and/or services of the same type and quality, and of comparable value as those lost, trustees must consider the use of a resource-to-resource or service-to-service scaling approach. Under this approach, trustees determine the scale of restoration actions that will provide natural resources and/or services equal in quantity to those lost.

(3) *Valuation scaling approach*. (i) Where trustees have determined that neither resource-to-resource nor service-to-service scaling is appropriate, trustees may use the valuation scaling approach. Under the valuation scaling approach, trustees determine the amount of natural resources and/or services that must be provided to produce the same value lost to the public. Trustees must explicitly measure the value of injured natural resources and/or services, and then determine the scale of the restoration action necessary to produce natural resources and/or services of equivalent value to the public.

(ii) If, in the judgment of the trustees, valuation of the lost services is practicable, but valuation of the replacement natural resources and/or services cannot be performed within a reasonable time frame or at a reasonable cost, as determined by § 990.27(a)(2) of this part, trustees may estimate the dollar value of the lost services and select the scale of the restoration action that has a cost equivalent to the lost value. The responsible parties may request that trustees value the natural resources and services provided by the restoration action following the process described in § 990.14(c) of this part.

(4) *Discounting and uncertainty*. When scaling a restoration action, trustees must evaluate the uncertainties associated with the projected consequences of the restoration action, and must discount all service quantities and/or values to the date the demand is presented to the responsible parties. Where feasible, trustees should use risk-adjusted measures of losses due to injury and of gains from the restoration action, in conjunction with a riskless discount rate representing the consumer rate of time preference. If the streams of losses and gains cannot be adequately adjusted for risks, then trustees may use a discount rate that incorporates a suitable risk adjustment to the riskless rate.

§ 990.54 Restoration selection—evaluation of alternatives.

(a) *Evaluation standards*. Once trustees have developed a reasonable range of restoration alternatives under § 990.53 of this part, they must evaluate the proposed alternatives based on, at a minimum:

(1) The cost to carry out the alternative;

(2) The extent to which each alternative is expected to meet the trustees' goals and objectives in returning the injured natural resources and services to baseline and/or compensating for interim losses;

(3) The likelihood of success of each alternative;

(4) The extent to which each alternative will prevent future injury as a result of the incident, and avoid collateral injury as a result of implementing the alternative;

(5) The extent to which each alternative benefits more than one natural resource and/or service; and

(6) The effect of each alternative on public health and safety.

(b) *Preferred restoration alternatives*. Based on an evaluation of the factors under paragraph (a) of this section, trustees must select a preferred restoration alternative(s). If the trustees conclude that two or more alternatives are equally preferable based on these factors, the trustees must select the most cost-effective alternative.

(c) *Pilot projects*. Where additional information is needed to identify and evaluate the feasibility and likelihood of success of restoration alternatives, trustees may implement restoration pilot projects. Pilot projects should only be undertaken when, in the judgment of the trustees, these projects are likely to provide the information, described in paragraph (a) of this section, at a reasonable cost and in a reasonable time frame.

§ 990.55 Restoration selection—developing restoration plans.

(a) *General*. OPA requires that damages be based upon a plan developed with opportunity for public review and comment. To meet this requirement, trustees must, at a minimum, develop a Draft and Final Restoration Plan, with an opportunity for public review of and comment on the draft plan.

(b) *Draft Restoration Plan*. (1) The Draft Restoration Plan should include:

(i) A summary of injury assessment procedures used;

(ii) A description of the nature, degree, and spatial and temporal extent of injuries resulting from the incident;

(iii) The goals and objectives of restoration;

(iv) The range of restoration alternatives considered, and a discussion of how such alternatives were developed under Sec. 990.53 of this part, and evaluated under § 990.54 of this part;

(v) Identification of the trustees' tentative preferred alternative(s);

(vi) A description of past and proposed involvement of the responsible parties in the assessment; and

(vii) A description of monitoring for documenting restoration effectiveness, including performance criteria that will be used to determine the success of restoration or need for interim corrective action.

(2) When developing the Draft Restoration Plan, trustees must establish restoration objectives that are specific to the injuries. These objectives should clearly specify the desired outcome, and the performance criteria by which successful restoration will be judged. Performance criteria may include structural, functional, temporal, and/or other demonstrable factors. Trustees must, at a minimum, determine what criteria will:

(i) Constitute success, such that responsible parties are relieved of responsibility for further restoration actions; or

(ii) Necessitate corrective actions in order to comply with the terms of a restoration plan or settlement agreement.

(3) The monitoring component to the Draft Restoration Plan should address such factors as duration and frequency of monitoring needed to gauge progress and success, level of sampling needed to detect success or the need for corrective action, and whether monitoring of a reference or control site is needed to determine progress and success. Reasonable monitoring and oversight costs cover those activities necessary to gauge the progress, performance, and success of the restoration actions developed under the plan.

(c) *Public review and comment*. The nature of public review and comment on the Draft and Final Restoration Plans will depend on the nature of the incident and any applicable federal trustee NEPA requirements, as described in §§ 990.14(d) and 990.23 of this part.

(d) *Final Restoration Plan*. Trustees must develop a Final Restoration Plan that includes the information specified in paragraph (a) of this section, responses to public comments, if applicable, and an indication of any changes made to the Draft Restoration Plan.

Sec. 990.56 Restoration selection—use of a Regional Restoration Plan or existing restoration project.

(a) *General*. Trustees may consider using a Regional Restoration Plan or existing restoration project where such a plan or project is determined to be the preferred alternative among a range of feasible restoration alternatives for an incident, as determined under § 990.54 of this part. Such plans or projects must be capable of fulfilling OPA's intent for the trustees to restore, rehabilitate, replace, or acquire the equivalent of the injured natural resources and services and compensate for interim losses.

(b) *Existing plans or projects*. (1) *Considerations*. Trustees may select a component of a Regional Restoration Plan or an existing restoration project as the preferred alternative, provided that the plan or project:

(i) Was developed with public review and comment or is subject to public review and comment under this part;

(ii) Will adequately compensate the environment and public for injuries resulting from the incident;

(iii) Addresses, and is currently relevant to, the same or comparable natural resources and services as those identified as having been injured; and

(iv) Allows for reasonable scaling relative to the incident.

(2) *Demand*. (i) If the conditions of paragraph (b)(1) of this section are met, the trustees must invite the responsible parties to implement that component of the Regional Restoration Plan or existing restoration project, or advance to the trustees the trustees' reasonable estimate of the cost of implementing that component of the Regional Restoration Plan or existing restoration project.

(ii) If the conditions of paragraph (b)(1) of this section are met, but the trustees determine that the scale of the existing plan or project is greater than the scale of compensation required by the incident, trustees may only request funding from the responsible parties equivalent to the scale of the restoration determined to be appropriate for the incident of concern. Trustees may pool such partial recoveries until adequate funding is available to successfully implement the existing plan or project.

(3) *Notice of Intent To Use a Regional Restoration Plan or Existing Restoration Project*. If trustees intend to use an appropriate component of a Regional Restoration Plan or existing restoration project, they must prepare a Notice of Intent to Use a Regional Restoration Plan or Existing Restoration Project. Trustees must make a copy of the notice publicly available. The notice must include, at a minimum:

(i) A description of the nature, degree, and spatial and temporal extent of injuries; and

(ii) A description of the relevant component of the Regional Restoration Plan or existing restoration project; and

(iii) An explanation of how the conditions set forth in paragraph (b)(1) of this section are met.

Subpart F—Restoration Implementation Phase

Sec. 990.60 Purpose.

The purpose of this subpart is to provide a process for implementing restoration.

§ 990.61 Administrative record.

(a) *Closing the administrative record for restoration planning*. Within a reasonable time after the trustees have completed restoration planning, as provided in §§ 990.55 and 990.56 of this part, they must close the administrative record. Trustees may not add documents to the administrative record once it is closed, except where such documents:

(1) Are offered by interested parties that did not receive actual or constructive notice of the Draft Restoration Plan and the opportunity to comment on the plan;

(2) Do not duplicate information already contained in the administrative record; and

(3) Raise significant issues regarding the Final Restoration Plan.

(b) *Opening an administrative record for restoration implementation*. Trustees may open an administrative record for implementation of restoration, as provided in Sec. 990.45 of this part. The costs associated with the administrative record are part of the costs of restoration. Ordinarily, the administrative record for implementation of restoration should document, at a minimum, all Restoration Implementation Phase decisions, actions, and expenditures, including any modifications made to the Final Restoration Plan.

§ 990.62 Presenting a demand.

(a) *General*. After closing the administrative record for restoration planning, trustees must present a written demand to the responsible parties. Delivery of the demand should be made in a manner that establishes the date of receipt by the responsible parties.

(b) *When a Final Restoration Plan has been developed*. Except as provided in paragraph (c) of this section and in Sec. 990.14(c) of this part, the demand must invite the responsible parties to either:

(1) Implement the Final Restoration Plan subject to trustee oversight and reimburse the trustees for their assessment and oversight costs; or

(2) Advance to the trustees a specified sum representing trustee assessment costs and all trustee costs associated with implementing the Final Restoration Plan, discounted as provided in § 990.63(a) of this part.

(c) *Regional Restoration Plan or existing restoration project*. When the trustees use a Regional Restoration Plan or an existing restoration project under Sec. 990.56 of this part, the demand will invite the responsible parties to implement a component of a Regional Restoration Plan or existing restoration project, or advance the trustees' estimate of damages based on the scale of the restoration determined to be appropriate for the incident of concern, which may be the entire project or a portion thereof.

(d) *Response to demand*. The responsible parties must respond within ninety (90) calendar days in writing by paying or providing binding assurance they will reimburse trustees' assessment costs and implement the plan or pay assessment costs and the trustees' estimate of the costs of implementation.

(e) *Additional contents of demand*. The demand must also include:

(1) Identification of the incident from which the claim arises;

(2) Identification of the trustee(s) asserting the claim and a statement of the statutory basis for trusteeship;

(3) A brief description of the injuries for which the claim is being brought;

(4) An index to the administrative record;

(5) The Final Restoration Plan or Notice of Intent to Use a Regional Restoration Plan or Existing Restoration Project; and

(6) A request for reimbursement of:

(i) Reasonable assessment costs, as defined in § 990.30 of this part and discounted as provided in Sec. 990.63(b) of this part;

(ii) The cost, if any, of conducting emergency restoration under § 990.26 of this part, discounted as provided in Sec. 990.63(b) of this part; and

(iii) Interest on the amounts recoverable, as provided in section 1005 of OPA (33 U.S.C. 2705), which allows for prejudgment and post-judgment interest to be paid at a commercial paper rate, starting from thirty (30) calendar days from the date a demand is presented until the date the claim is paid.

§ 990.63 Discounting and compounding.

(a) *Estimated future restoration costs*. When determining estimated future costs of implementing a Final Restoration Plan, trustees must discount such future costs back to the date the demand is presented. Trustees may use a discount rate that represents the yield on recoveries available to trustees. The price indices used to project future inflation should reflect the major components of the restoration costs.

(b) *Past assessment and emergency restoration costs*. When calculating the present value of assessment and emergency restoration costs already incurred, trustees must compound the costs forward to the date the demand is presented. To perform the compounding, trustees may use the actual U.S. Treasury borrowing rate on marketable securities of comparable maturity to the period of analysis. For costs incurred by state or tribal trustees, trustees may compound using parallel state or tribal borrowing rates.

(c) Trustees are referred to Appendices B and C of OMB Circular A-94 for information about U.S. Treasury rates of various maturities and guidance in calculation procedures. Copies of Appendix C, which is regularly updated, and of the Circular are available from the OMB Publications Office (202-395-7332).

§ 990.64 Unsatisfied demands.

(a) If the responsible parties do not agree to the demand within ninety (90) calendar days after trustees present the demand, the trustees may either file a judicial action for damages or seek an appropriation from the Oil Spill Liability Trust Fund, as provided in section 1012(a)(2) of OPA (33 U.S.C. 2712(a)(2)).

(b) Judicial actions and claims must be filed within three (3) years after the Final Restoration Plan or Notice of Intent to Use a Regional Restoration Plan or Existing Restoration Project is made publicly available, in accordance with 33 U.S.C. 2717(f)(1)(B) and 2712(h)(2).

§ 990.65 Opening an account for recovered damages.

(a) *General*. Sums recovered by trustees in satisfaction of a natural resource damage claim must be placed in a revolving trust account. Sums recovered for past assessment costs and emergency restoration costs may be used to reimburse the trustees. All other sums must be used to implement the Final Restoration Plan or all or an appropriate component of a Regional Restoration Plan or an existing restoration project.

(b) *Joint trustee recoveries*. (1) *General*. Trustees may establish a joint account for damages recovered pursuant to joint assessment activities, such as an account under the registry of the applicable federal court.

(2) *Management*. Trustees may develop enforceable agreements to govern management of joint accounts, including agreed-upon criteria and procedures, and personnel for authorizing expenditures out of such joint accounts.

(c) *Interest-bearing accounts*. Trustees may place recoveries in interest-bearing revolving trust accounts, as provided by section 1006(f) of OPA (33 U.S.C. 2706(f)). Interest earned on such accounts may only be used for restoration.

(d) *Escrow accounts*. Trustees may establish escrow accounts or other investment accounts.

(e) *Records*. Trustees must maintain appropriate accounting and reporting procedures to document expenditures from accounts established under this section.

(f) *Oil Spill Liability Trust Fund*. Any sums remaining in an account established under this section that are not used either to reimburse trustees for past assessment and emergency restoration costs or to implement restoration must be deposited in the Oil Spill Liability Trust Fund, as provided by section 1006(f) of OPA (33 U.S.C. 2706(f)).

§ 990.66 Additional considerations.

(a) Upon settlement of a claim, trustees should consider the following actions to facilitate implementation of restoration:

(1) Establish a trustee committee and/or memorandum of understanding or other agreement to coordinate among affected trustees, as provided in § 990.14(a)(3) of this part;

(2) Develop more detailed workplans to implement restoration;

(3) Monitor and oversee restoration; and

(4) Evaluate restoration success and the need for corrective action.

(b) The reasonable costs of such actions are included as restoration costs.

RELATED GUIDANCE DOCUMENTS APPENDIX B

In support of the NRDA regulations under OPA and for the purpose of facilitating the NRDA process under OPA, NOAA has produced a number of related guidance documents, in addition to the Injury Assessment Guidance Document, that are relevant to injury assessment activities. All of these documents are currently available in final form.

NOAA. 1996. Preassessment Phase, Guidance Document for Natural Resource Damage Assessment under the Oil Pollution Act of 1990. National Oceanic and Atmospheric Administration, Damage Assessment and Restoration Program, Silver Spring, MD.

NOAA. 1996. Specifications for Use of the NRDAM/CME Version 2.4 to Generate Compensation Formulas, Guidance Document for Natural Resource Damage Assessment under the Oil Pollution Act of 1990. National Oceanic and Atmospheric Administration, Damage Assessment and Restoration Program, Silver Spring, MD.

NOAA. 1996. Primary Restoration, Guidance Document for Natural Resource Damage Assessment under the Oil Pollution Act of 1990. National Oceanic and Atmospheric Administration, Damage Assessment and Restoration Program, Silver Spring, MD.

NOAA. 1996. Restoration Planning, Guidance Document for Natural Resource Damage Assessment under the Oil Pollution Act of 1990. National Oceanic and Atmospheric Administration, Damage Assessment and Restoration Program, Silver Spring, MD.

Table of Contents

C.1 Introduction[1]

The purpose of this appendix is to provide a general discussion of oil chemistry and the behavior of oil following an incident, including exposure and pathway information. Trustees may use this material when developing an inventory of possible injuries and evaluating the strength of evidence for these injuries, as described in Chapter 2. Trustees should recognize that the literature is extensive and growing rapidly and the information contained herein is subject to change. The information in this appendix is intended only to provide an overview.

In order to conclude that natural resource injuries resulted from the incident in the event of an actual discharge, trustees need to consider:

- The pathway(s) of the oil from the point of discharge to the injured natural resources;
- Whether injured natural resources were exposed, either directly or indirectly, to the same oil that was discharged;
- The geographical and temporal nature of the exposure; and
- Whether exposure to the discharged oil caused the injury.

Pathway and exposure information is important regardless of which NRDA procedure is selected. If a model-based assessment is conducted, pathway and exposure data may be the only incident- specific information collected.

As with other elements of the NRDA process, selection of appropriate strategies for evaluating oil pathways and exposure will depend upon the type and volume of spilled oil, natural resources at risk, and nature of the receiving environment. Early consideration of exposure and pathway issues (ideally during the Preassessment Phase) should help to focus the assessment on those natural resources that are most likely to be affected by a discharge. The following sections of this appendix provide a basic overview of oil chemistry and oil types, oil fates and weathering, mass balance estimates, pathways, and exposure considerations.

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[1] The text in this appendix was drafted by Douglas Helton, Damage Assessment Center, Seattle, WA.

C.2 Oil Chemistry and Oil Types

The characteristics of discharged oil can provide the trustees with an initial screening of the potential pathways, exposure, and injuries resulting from the incident. However, the number and variability of crude and refined oils, each with different physical and chemical characteristics, makes such characterization daunting. For instance, fuel oils often are blended and the relative proportions of the component oils frequently change. Further, crude oils from different wells in the same region can have markedly different properties, and even the properties of oil taken from an individual well can vary with the depth of the well and the year of production (Bobra and Callaghan, 1990). Variability also exists within types or grades of oil. Therefore, the trustees need to access specific sources (i.e., databases) to simplify their task of characterizing oil in an adequate fashion. One such source is NOAA's Automated Data Inquiry for Oil Spills (ADIOS) database, which lists approximately one thousand different oils (NOAA, 1994a).

C.2.a Oil Chemistry

Oils are complex mixtures of organic compounds and trace elements. Carbon (82-87%) and hydrogen (11-15%) are the most common elements of petroleum, with sulfur (0-8%), nitrogen (0-1%) and oxygen (0-0.5%) as important minor constituents (Duckworth and Perry, 1986). Trace elements vary widely and may include vanadium, nickel, iron, aluminum, sodium, calcium, copper, and others (National Research Council, 1985).

Oils typically are described in terms of their physical properties (e.g., density, pour point) and chemical composition (i.e., percent composition of various petroleum hydrocarbons, asphaltenes, and sulfur). Although very complex in makeup, these oils can be broken down into four basic classes of petroleum hydrocarbons: alkanes, naphthenes, aromatics and alkenes. Each class is distinguished on the basis of molecular composition, as described below.[2]

Alkanes (Also called normal paraffins): Alkanes are characterized by branched or unbranched chains of carbon atoms with attached hydrogen atoms and contain only singly carbon-carbon bonds (i.e., they are saturated, since they contain no double or triple bonds). Common alkanes include methane, propane, and isobutane.

Naphthenes (Also called cycloalkanes or cycloparaffins): Naphthenes typically comprise about 50% of the average crude oil. Naphthenes are similar to alkanes, but are characterized by the presence of simple closed rings of carbon atoms. Naphthenes are generally stable and relatively insoluble in water. Common naphthenes include cyclopropane and cyclopentane.

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[2] The following discussion is based on Fingas et al., 1979; Duckworth and Perry, 1986; Clarke and Brown, 1977; and National Research Council, 1985. The reader should refer to these documents for further information.

Aromatics: Aromatics are a class of hydrocarbons characterized by rings with six carbon atoms. Aromatics are considered to be the most acutely toxic component of crude oil, and are also associated with chronic and carcinogenic effects. Many low-weight aromatics also are soluble in water, increasing the potential for exposure to aquatic resources. Aromatics are often further distinguished by the number of rings, which may range from one to six. Aromatics with two or more rings are referred to as polycyclic aromatic hydrocarbons. Common aromatics include benzene, naphthalene, and benzo(a)pyrene.

Alkenes (Also called olefins or isoparaffins): Alkenes are characterized by branched or unbranched chains of carbon atoms, similar to alkanes except for the presence of double bonded carbon atoms. Alkenes are not generally found in crude oils, but are common in refined products, such as gasoline. Common alkenes include ethene and propene.

Other Components: In addition to these four major classes of hydrocarbons, oils also are characterized by other components. Asphaltenes and resins can comprise a large fraction of crude oils and heavy fuel oils, making those oils very dense and viscous. Other non-hydrocarbons that incorporate nitrogen, sulfur, and oxygen (also referred to as NSO) are also common. Crude oils that are high in sulfur are referred to as "sour."

- **20-200 ^{o}C:** 4-12 carbons: Straight-run gasoline (e.g., not produced through catalytic decomposition).

- **185-345 ^{o}C**: 10-20 carbons: Middle distillates, including kerosene, jet fuels, heating oil, diesel fuel.

- **345-540 ^{o}C:** 18-45 carbons: Wide cut gas oils, including light lube oils, heavy lube oils, waxes, and catalytic feed stock for production of gasoline.

- **>540 ^{o}C:** >40 carbons: Residual oils, which may be cut with lighter oils to produce bunker oils.

Refined oils also may have a number of additives (e.g., gelling inhibitors) that are added to diesel fuels during cold weather. Certain additives may be of special concern in an injury assessment, either because they are toxic themselves or because they significantly change the behavior of the oil.

C.2.b Oil Types and Behavior

An understanding of the likely physical and chemical behavior of the discharged oil will help to focus the assessment on the most important injuries. For example, one of the most important factors in minimizing the shoreline impacts of the 1993 *Braer* incident in the Shetland Islands was the type of discharged oil (Harris, 1995). Norwegian Gullfaks crude oil has a low viscosity and relatively high degree of natural dispersion and, when combined with high wave energy, tends to disperse. Most of the oil from the *Braer* dispersed into the water column or broke into thin sheens within the first two days of the discharge and shoreline injuries were minimal. If the *Braer*'s cargo had been a heavier crude, shoreline injuries would have been significantly greater.

There are a number of oil properties that should be considered when developing hypotheses about the potential for injury, including:

- Density;
- Viscosity;
- Pour point;
- Solubility;
- Chemical composition (especially percent aromatics); and
- Potential for emulsification.

These properties, combined with environmental information (e.g., water density, wave height, wind speed, currents, temperature, suspended sediment load, and cloud cover) and response efforts (i.e., use of chemical dispersants, and other countermeasures) can help to determine the fate of the discharged oil and natural resources that may be at risk.

Despite the variability noted by Bobra and Callaghan (1990), oils can be divided into six broad classes based on the predicted short-term behavior and likely injuries to natural resources. Pertinent properties of each oil class are summarized in Exhibit C-1 (RPI, 1994; NOAA, 1994b; Duckworth and Perry, 1986).

C. 3 Oil Fates and Weathering

After oil is discharged into the environment, a wide variety of physical, chemical, and biological processes begin to transform the discharged oil. These processes are illustrated schematically in Exhibit C.2. Collectively, these processes are referred to as weathering and act to change the composition, behavior, routes of exposure, and toxicity of the discharged oil. For example, penetration into marsh vegetation may depend on oil viscosity. Weathered oils penetrate less than fresh oil (NOAA, 1992a). Weathered oil is composed of relatively insoluble compounds and often coalesces into mats or tarballs. As a result, the potential for exposure to fish through water column toxicity is lessened, as is the potential for birds or mammals to encounter the oil. Alternatively, certain species are known to ingest tarballs and the potential for exposure of those species may increase as the oil weathers (Lutz and Lutcavage, 1989, Gitschlag, 1992). Also, the loss of the lighter fractions through dissolution and/or evaporation during the weathering process can cause normally buoyant oil to sink, thereby contaminating subtidal sediment and contributing to water column toxicity (Burns et al., 1995; Michel and Galt, 1995).

Understanding the weathering process is important in interpreting oil samples. Constituents of the oil provide a chemical "fingerprint" that can be used to help identify or distinguish oil from a specific incident from other discharges, biogenic and pyrogenic sources, or background contamination. These constituents will vary depending on the geologic source of the oil and refinery process. In fingerprinting, the presence and relative concentration of specific constituents of the oil are compared with known source samples. Although fingerprinting focuses on constituents that are dominant constituents of the oil or that may be persistent, these constituents may change in concentration as the oil weathers, making it more difficult to identify the oil. Even in highly weathered oil, however, fingerprinting may still be useful in excluding other potential sources.

The primary weathering processes include spreading, evaporation, dissolution, dispersion, emulsification, and sedimentation. These processes occur for all discharges, but the rate and relative importance of each process depends on the specific oil and ambient environmental conditions. Exhibit C.3 illustrates the relative importance of these primary processes over time.

Exhibit C.1

GENERAL OIL PROPERTIES

Type 1 Very Light Oils (Gasoline)
- Highly volatile and soluble..
- Evaporates quickly, often completely within 1 to 2 days.
- High acute toxicity.

Type 2 Light Oils (Jet Fuels, Diesel, No. 2 Fuel Oil, Light Crudes)
- Moderately volatile.
- Will leave residue (up to one-third of spill amount) after a few days.
- Moderately soluble, especially distilled products.
- Moderate to high acute toxicity; product-specific toxicity related to type and concentration of aromatic compounds

Type 3 Medium Oils (Most Crude Oils)
- About one-third will evaporate within 24 hours.
- Typical water-soluble fraction 10-100 ppm.
- May penetrate substrate and persist.
- May be significant clean-up related impacts.
- Variable acute toxicity, depending on the amount of light fraction.

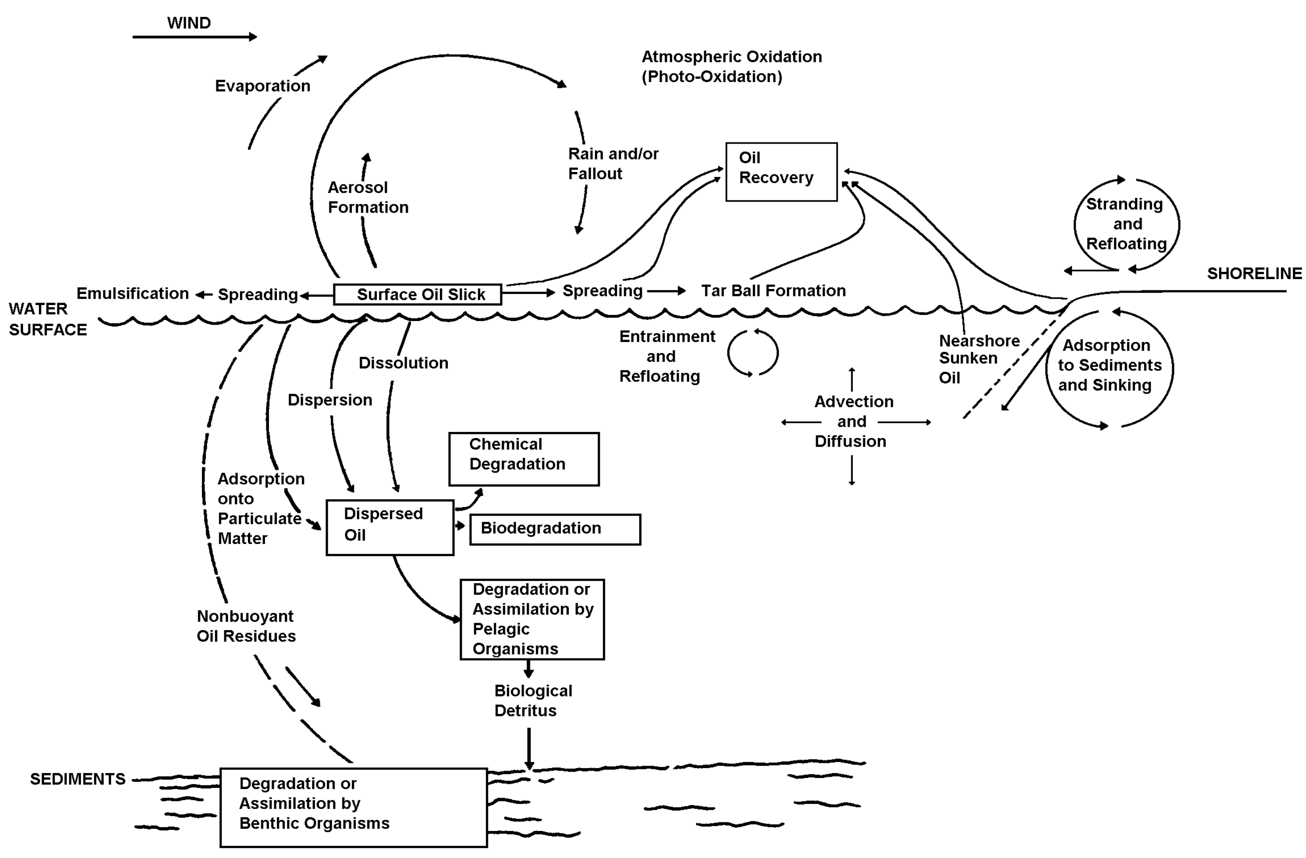
Type 4 Heavy Oil (Heavy Crudes, No. 6 Fuel Oil, Bunker C)
- Heavy oils with little/no evaporation or dissolution.
- Water-soluble fraction typically less than 10 ppm.
- Heavy surface contamination likely.
- Highly persistent, long-term contamination possible.
- Weathers very slowly; may form tarballs.
- May sink depending on product density and water density.
- May be significant clean-up related impacts.
- Low acute toxicity relative to other oil types.

Type 5 Low API Fuel Oils (Heavy Industrial fuel oils)
- Neutrally buoyant or may sink depending on water density.
- Weathers slowly; sunken oil has little potential for evaporation.
- May accumulate on bottom under calm conditions and smother subtidal resources.
- Sunken oil may be resuspended during storms, providing a chronic source of shoreline oiling.
- Highly variable and often blended with oils.
- Blends may be unstable and the oil may separate when spilled.
- Low acute toxicity relative to other oil types.

Type 6 Animal and Plant Oils (Fish oil, vegetable oil)
- Shipped in smaller quantities than petroleum oils, but may be stored in large quantities.
- Physical properties are highly variable.
- High biological oxygen demand (BOD), which could result in oxygen deprivation in confined water bodies.
- Low acute toxicity relative to petroleum oils.

Exhibit C.2

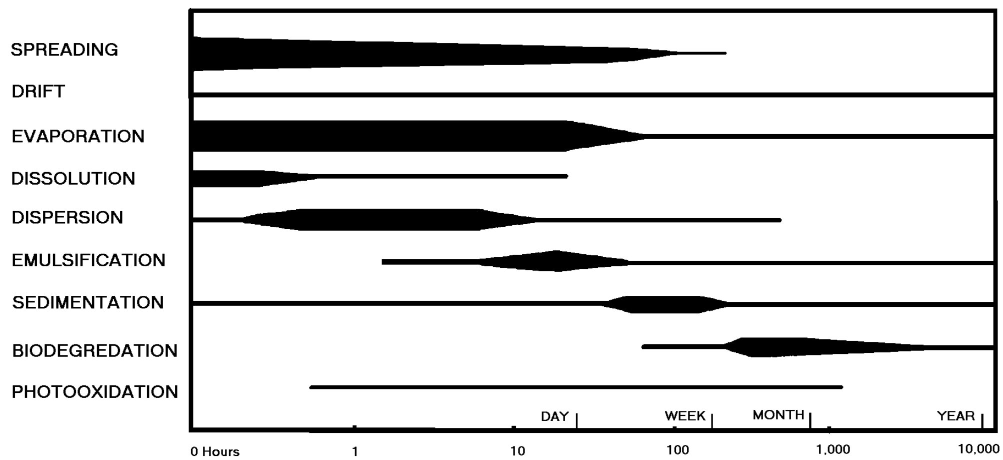
SCHEMATIC OF OIL FATES AND WEATHERING



Modified from National Research Council (1985)

Exhibit C.3

RELATIVE IMPORTANCE OF WEATHERING PROCESSES



From NOAA, 1992a

Spreading: As oil enters the environment, it begins to spread immediately. The viscosity of the oil, its pour point, and the ambient temperature will determine how rapidly the oil will spread, but light oils typically spread more rapidly than heavy oils. The rate of spreading and ultimate thickness of the oil slick will affect the rates of the other weathering processes. For example, discharges that occur in geographically contained areas (e.g., a pond or slow moving stream) will evaporate more slowly than if the oil were allowed to spread.

Evaporation: Evaporative processes begin immediately after oil is discharged into the environment. Some light products may evaporate entirely. A significant fraction of heavy refined oils also may evaporate. For crude oils, the amount lost to evaporation can typically range from approximately 20 to 60 percent (NOAA, 1992a). The primary factors that control evaporation are the composition of the oil, slick thickness, temperature and solar radiation, windspeed, and wave height. While evaporation rates increase with temperature, this process is not restricted to warm climates. For the *Exxon Valdez* incident, which occurred in cold conditions (March 1989), Wolfe et al. (1994) estimated that appreciable evaporation occurred even before all the oil escaped from the ship and that evaporation ultimately accounted for 20 percent of the oil.

Dissolution: Dissolution is the loss of individual oil compounds into the water. Many of the acutely toxic components of oils such as benzene, toluene, and xylene will readily dissolve into water. This process also occurs quickly after a discharge, but tends to be less important than evaporation. In a typical marine discharge, generally less than 5 percent of the benzene is lost to dissolution while greater than 95 percent is lost to evaporation (NOAA, 1992b). The dissolution process is thought to be much more important in rivers because natural containment may prevent spreading, reducing the surface area of the slick and thus retarding evaporation. At the same time, river turbulence increases the potential for mixing and dissolution.

Dispersion: The physical transport of oil droplets into the water column is referred to as dispersion. This is often a result of water surface turbulence, but also may result from the application of chemical agents (dispersants). These droplets may remain in the water column or coalesce with other droplets and gain enough buoyancy to resurface. Dispersed oil tends to biodegrade and dissolve more rapidly than floating slicks because of high surface area relative to volume.

Emulsification: Certain oils tend to form water-in-oil emulsions or "mousse" as weathering occurs. This process is significant because, for example, the apparent volume of the oil may increase dramatically and the emulsification will slow the other weathering processes, especially evaporation. Under certain conditions, these emulsions may separate and release relatively fresh oil.

Sedimentation or adsorption: As mentioned above, most oils are buoyant in water. However, in areas with high suspended sediment levels, oils may be transported to the river, lake, or ocean floor through the process of sedimentation. Oil may adsorb to sediments and sink or be ingested by zooplankton and excreted in fecal pellets, which may settle to the bottom. Oil stranded on shorelines also may pick up sediments, refloat with the tide, and then sink.

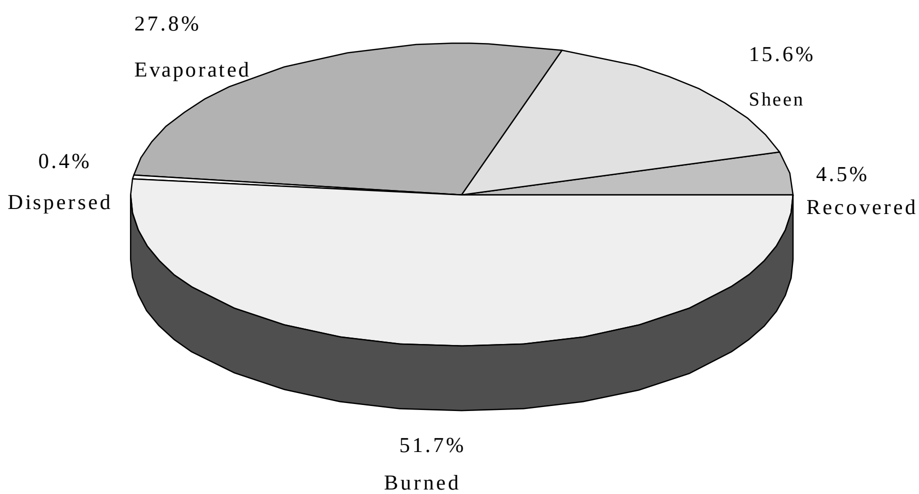
Other processes: In addition to the primary weathering processes described above, there are several other processes that may be important to understanding the fate and potential for exposure. These include aeolian (wind) transport, photochemical degradation, and microbial degradation

C.4 Mass Balance

One way to synthesize the overall fate of a discharge, including cleanup and weathering, is through the development of a mass balance. Although a detailed mass balance such as the one developed by Wolfe et al., (1994) for the *Exxon Valdez* incident may take several years to construct, a preliminary mass balance may be feasible during the Preassessment Phase. Consideration of the potential fates of the oil will assist trustees in estimating the loading of oil into certain habitats, which may be useful in identifying and scaling injury studies in certain areas. For example, Scholz and Michel (1992) conducted a mass balance on the *T/V Mega Borg* incident in Texas to determine the fate of the oil, including the fraction of the oil burned in the fire. This mass balance is illustrated in Exhibit C-4. This information was used in determining the potential for oil exposure to shrimp (Nance, 1992).

Exhibit C.4

ESTIMATED MASS BALANCE FOR THE *MEGA BORG* INCIDENT



Source: Scholz and Michel, 1992.

A mass balance also may be useful in evaluating the success of the response operations and provide a check on the total amount of oil discharged. A mass balance approach was used to check divergent estimates of a fuel oil discharge into the Cape Fear River, North Carolina (Baca et al., 1983). Mass balance estimates may be necessary if the trustees decide to use a model or compensation formulas, because these methods generally require an estimate of both the amount discharged and the amount recovered.

C. 5 Pathways

To conclude that a specific injury resulted from a discharge, an exposure pathway linking the incident to the injury must be identified. Understanding the potential pathways will help to narrow the scope of the NRDA investigation, but also may be important in deciding which assessment methodology to use. For example, the Type A model does not address injuries that occur via air or terrestrial pathways. Note that injury determination does not require that natural resources be directly exposed to oil. An injury or loss of services can occur without the presence of oil. Therefore, an exposure pathway can be either:

- *Direct*: A sequence of events by which the oil traveled through the environment and physically came into contact with the natural resource. For example, direct oiling of a shellfish bed may result in mortality and decreased growth.

- *Indirect*: A sequence of events by which the effect of exposure to oil was transferred to the natural resource of concern, without the oil directly contacting the natural resource. For example, a decreased bait fish population caused by a spill may result in the starvation of a piscivorous bird, or a fishery may be closed to prevent potentially tainted fish from being marketed.

There are a number of potential exposure pathways. In some cases, these pathways may have multiple steps. For example, a common exposure pathway for birds is a surface water pathway, leading to physical exposure, leading to ingestion from preening. Although it is difficult to list all of the potential direct and indirect exposure pathways, several of the predominant pathways for discharges of oil are discussed below.

Surface Waters: Because most oils float, surface waters are often the exposure pathway of greatest concern. Surface waters may provide a pathway for exposure of open-water natural resources such as birds, mammals, and plankton in the surface microlayer; or a pathway to shoreline and intertidal natural resources. The surface waters themselves are a natural resource and floating oil may disrupt a number of natural resource services including recreation, transportation, and aesthetic values. This pathway is relatively straightforward to document using aerial overflights, surface vessel observations, and computer models designed to simulate the behavior and transport of surface oil slicks.

Ingestion: Ingestion is a common exposure pathway. Oiled birds will ingest oil during preening. Turtles feed on objects floating at the water surface, therefore they are susceptible to ingestion of tar balls, which can block the oral cavity and digestive tract (Van Vleet and Pauly, 1987). Injuries to river otters have been related to ingestion pathways, both from preening and from contaminated food (Bowyer et al., 1993). Ingestion pathways also have been observed for invertebrates. Christini (1992) noted that blue crabs were attracted to and ingested tarballs. Because many organisms can metabolize petroleum, biomagnification via trophic pathways is not considered an important pathway (McElroy et al., 1989; National Research Council, 1985), however, organisms may be exposed by ingesting contaminated prey (e.g., bioavailability). For example, bivalve mollusks such as mussels may accumulate petroleum hydrocarbons in their tissues and pass contamination on to higher trophic level predators such as birds or marine mammals. This pathway has been linked to the persistent reproductive failure of Harlequin Ducks in Western Prince William Sound following the *Exxon Valdez* incident (Patten, 1993). Approaches to studying ingestion and food web pathways include direct observation of feeding, preening behavior, and oiling of mouth parts; analysis of gut contents; tissue analysis of prey species; and feces analysis.

Inhalation: The potential for inhalation pathways depends on the volatility of the oil and degree of weathering. Inhalation pathways have been hypothesized to be important, especially to marine mammals. For example, following the *Exxon Valdez* incident, Frost and Lowry (1993) found central nervous system injuries and edema in harbor seals that was similar to that present in humans that die from inhaling solvents. Researchers postulate that killer whales were killed by exposure to volatile hydrocarbons after the *Exxon Valdez* incident (Dalheim and Matkin, 1993).

Physical (Dermal) Exposure: Surface water and other pathways may lead to direct physical exposure of a natural resource to oil. This contact may directly cause injury (e.g., smothering), may impair the physiology of the organism resulting in injury (e.g., hypothermia in birds and mammals from impaired thermoregulation), or may cause a service loss (e.g., dermal exposure in fish resulting in tainting). Direct contact through a dermal absorption pathway also may lead to contamination of organs, fluids, and tissues.

Atmospheric: The atmosphere may provide a pathway to natural resources or affect the service flows from these natural resources. The 1993 *Braer* incident in the Shetland Islands provides an example of an aeolian pathway. High winds carried the oil as a mist inland and contaminated approximately 20 square miles of crop lands, as well as oiling houses, cars, and a lake used for drinking water (Harris, 1995). Other less dramatic examples include the 1993 Colonial Pipeline incident in Virginia (Koob, 1995), where a break in a pipeline sprayed oil into the air and oiled a number of natural resources, including an upland forest area. The burning of oil (either deliberately or by chance) could increase atmospheric impacts. Atmospheric pathways may be especially important in determining the potential for lost use. For example, oil from the Colonial incident eventually flowed into the Potomac River, where odors resulted in the closure of Great Falls National Park and impairment of air quality along the Capital Mall area.

Sediments: Subtidal and intertidal sediments are an important pathway in most discharges, affecting biological resources, habitats, and service flows. In most instances, intertidal sediments are the primary pathway of concern, but extensive subtidal sediment contamination has been observed in a number of large incidents, such as the *Amoco Cadiz*, *Exxon Valdez*, *Braer*, and *Morris J. Berman*. Chronic exposure to oiled sediments has been correlated with reduced feeding, growth, and reproduction, and with histopathological changes in benthic fish. Sediment pathways also are important in recreational lost use. Beaches, for example, may be closed because of oiled sediments. Subtidal sediments may provide a pathway for chronic beach oiling (Burns et al., 1995).

Groundwater: Groundwater petroleum contamination can involve large amounts of oil and affect huge areas. One tank farm facility alone has been estimated to have released between 84 and 252 million gallons of petroleum into groundwater (Mould et al., 1995). Chronic groundwater contamination may result from leaking underground storage tanks or from chronic surface discharges (e.g., refineries, tank farms), while acute contamination may result from the sudden failure of storage tanks or other terrestrial incidents. Groundwater may provide a pathway for exposure to terrestrial and aquatic resources. In fact, many groundwater problems are first discovered when oil begins leaching into surface waters. Studying groundwater pathways generally involves the use of monitoring wells or sampling of existing drinking water wells in the aquifer.

Water Column: The potential for a significant water column exposure pathway depends on the dispersion and dissolution characteristics of the oil, response countermeasures, and ambient environmental conditions. Because of the ephemeral nature of water column exposure, studying water column pathways in-situ must be done quickly after a discharge and can be very costly. Alternatively, this pathway may be demonstrated based on literature information, laboratory studies on the physical behavior of the oil, or through the use of models

C.6 Exposure

Demonstrating exposure is an important step in determining injury, but evidence of exposure alone is not sufficient to conclude that injury to a natural resource has occurred (e.g., the presence of petroleum hydrocarbons in oyster tissues is not in itself an injury). The purpose of the exposure portion of an injury assessment is to determine whether natural resources came into contact, either directly or indirectly, with the oil and to estimate the amount or concentration of the oil and the geographic extent of the oil. This information is necessary to design, interpret, and extrapolate the results of the injury studies.

A number of factors should be considered when formulating hypotheses regarding the potential for and significance of exposure.

Oil Type: The physical and chemical characteristics of the oil will strongly influence the potential for and nature of exposure.

Spill Volume: The size of the discharge will affect the nature of the exposure. During small discharges, for example, oil may concentrate in a band along the high tide line. The greatest potential for exposure may therefore occur at the high tide line and in detrital material. Under heavy accumulations, however, oil may cover the entire intertidal zone.

Cleanup effects: If oil is removed from the environment quickly before it comes in contact with sensitive natural resources, the potential for exposure will be greatly minimized. Response actions also may change the nature of oil exposure. For example, use of chemical dispersants will increase exposure to the water column. Increased sediment exposure may occur where machinery and foot traffic force oil into the substrate and equipment staging areas may also be severely impacted.

Shoreline Type and Exposure: The potential for exposure to oil varies with shoreline geomorphology and degree of exposure. In high energy areas, oil may be rapidly dispersed, generally reducing the potential for exposure. However, these same forces may result in oil being deposited above the high-water swash or buried by clean sand. Stranded or buried oil may be highly persistent. Oil exposure to rocky headlands may be minimal, but a sheltered beach a few meters away, where wave energy is less, may be heavily oiled.

In support of the NRDA regulations under OPA and for the purpose of facilitating the NRDA process under OPA, NOAA has produced a number of related guidance documents, in addition to the Preassessment Phase Guidance Document, that are relevant to preassessment activities. All of these documents are currently available in final form.

Sediment Grain Size: Oil holding capacity and the depth of penetration depends on sediment grain size. Oil will penetrate coarse-grained sediments much more rapidly and more deeply than fine sediments.

Tide Stage: For certain natural resources, the potential for exposure will depend on tidal height. Subtidal seagrass beds are generally less sensitive to oil discharges than intertidal plants, since they usually do not come into direct contact with the floating oil. Similarly, supratidal vegetation may be exposed to floating oil only on the highest spring tides.

Weather Conditions: Flood conditions or storm driven tides may strand oil in areas that would otherwise be immune from oiling. In freshwater systems, oil may be carried over stream or river banks and stranded in the flood plain. In open water, high winds and waves may break up some oils and minimize shoreline contamination. Weather conditions also can accelerate or retard oil weathering. Temperature can affect species presence and behavior and thus the potential for exposure to oil and injury.

Behavior and Life History Considerations: Animal behavior is a significant factor in the potential for exposure. For example, the feeding and roosting behavior of birds is a major factor in their potential for exposure to oil (King and Sanger, 1979). Certain life stages may be more vulnerable than others. Planktonic fish larvae have a greater potential for exposure because they tend to drift at the same rate as the oil, while adult fish may be able to avoid contaminants. Depending on the season, migratory birds and wildlife may be present and therefore at risk for exposure. Animals that aggregate during reproduction, such as certain marine mammals, birds, and fish, may be highly vulnerable.

Duration of Exposure: Time of exposure is a critical consideration in evaluating the potential for injury. A pelagic fish that is briefly exposed to oil while passing through a plume will be less likely to be injured than a fish that remains or is confined in the discharge area.

C.7 Approaches to Exposure Assessment

Exposure is generally evaluated with a combination of quantitative and qualitative methods. As with other elements of the NRDA process, selection of appropriate strategies for determination of oil exposure will depend on the type and volume of discharged oil, natural resources at risk, nature of the receiving environment, and availability of personnel, funds, and equipment. A few of the potential approaches to evaluating exposure are described below.

Computer Models: Trajectory and weathering models may provide the first quantitative information on the fates of oil and the likelihood for exposure to specific natural resources and habitats. The NOAA On-Scene Spill Model (OSSM) is used to predict the short-term trajectory of the oil for response purposes, but also provides useful information for injury assessment (NOAA 1992b). Trajectory models are especially important if the trustees want to sample unoiled areas that are likely to be oiled later. The U.S. Department of the Interior's Type A models, Natural Resource Damage Assessment Model for Coastal and Marine Environments (NRDAM/CME) and Great Lakes Environments (NRDAM/GLE), also simulate the physical fates of spilled oils (USDOI, 1994). The SAIC oil weathering model (Payne et al., 1983), and the NOAA ADIOS model (NOAA, 1994a) also predict the pathways and fates of specific oils. Models also may be useful in evaluating the potential for exposure in locations that are difficult or costly to sample, such as estimating subsurface hydrocarbon concentrations.

Visual Observation: Aerial and ground surveys provide a rapid tool for exposure assessment of large areas. This approach is especially useful in documenting the overall distribution of oil-induced injuries by habitat or region, as well as identification of potential reference and impact areas. The qualitative and semi-quantitative information collected in this manner is generally combined with more detailed ground surveys and oil sampling to confirm exposure. Observations generally include estimates of the width, length, area, and degree of contamination in each affected habitat. General guidance on conducting and interpreting aerial and shoreline surveys can be found in NOAA (1992a,b); NOAA (1994c); Owens (1991); Environment Canada (1992); and Michel et al., (1994). Visual observation also may be used to determine the presence of oil on vegetation and individual organisms.

Presence of Oily Odor: Exposure to oil may also be evaluated qualitatively through organoleptic testing, the sensory evaluation of tainting using taste and smell (Ackman and Heras, 1992; Tidmarsh and Ackman, 1986; NOAA, 1994d). This was one of the approaches used in the *Exxon Valdez* incident to determine if commercially caught fish had been exposed to oil (Walker and Field, 1991). The ability to detect oils by smell will vary with the chemical composition of the oil, degree of weathering, and sensitivity of the individual. Low molecular weight oil components tend to be the easiest to smell, while the high molecular weight oil components, which may be of the greatest concern for possible long-term effects, are less volatile and thus harder to detect. The high variability of crude and fuel oils makes it difficult to characterize individual products by their odor threshold, but the USCG Chemical Hazards Response Information System (CHRIS) database lists the odor threshold for several petroleum products, including gasoline at 0.25 ppm, kerosene at 1 ppm, and Jet fuel (JP-5) at 1 ppm (Weiss, 1980).

Body Burden: Exposure to oil can be evaluated with a suite of analytical chemistry techniques ranging in cost, selectivity, and sensitivity. The choice of the method(s), analytes, and detection limits should be made by the NRDA team, in concert with their analytical laboratory, and should depend on the circumstances of the discharge, the type of sample, the required sensitivity, the degree of sample degradation, metabolism, and weathering, and whether quantitative or qualitative information is necessary. Chemical analyses for fingerprinting, for example, may provide information on the type and degree of weathering of the oil, but generally will not provide an estimate of the concentration of the contaminant in the sample matrix. However, both fingerprinting and determination of contaminant concentrations can be accomplished simultaneously, depending upon how the sample is collected. A detailed discussion of the various analytical methods used in petroleum chemistry is beyond the scope of this document, but the basic approaches are outlined below. For more information on oil chemistry and analysis, the reader should refer to Burns (1993); Sauer et al. (1993); Duckworth and Perry (1986); Boehm et al. (1995); Sauer and Boehm (1991); and McAullife et al., (1988). Trustees also may review PTI (1992) for general guidance on selecting chemical analyses.

There are three major objectives for the chemical analysis of oil, and different analytical methods may be necessary to accomplish these objectives. The three objectives are:

- *Physical and chemical characterization* of the oil, including major constituents, to provide information on how that oil will behave in the environment, its potential fates, persistence, toxicity, and carcinogencity, and to identify target analytes for fingerprinting;

- *Fingerprinting* to determine whether the oil in an environmental sample is from the specific incident, or from another source of oil pollution; and

- *Concentration* to determine the quantity of the oil or important constituents of the oil in environmental samples.

Presence of Oil in Transplanted Bivalves: Bivalves such as clams, mussels, and oysters can be used as indicators of exposure and bioeffects. They provide integrated information about the bioavailability and effects of oil that cannot be determined solely through the chemical analysis of discrete water samples. This capability is particularly important in monitoring oil discharges where exposure can be highly variable. The uptake of the discharged oil by bivalves is evidence of exposure to the bivalves themselves as well as an indication of exposure for other injured natural resources. Bivalve collection and procedures for chemical analysis of tissues have been standardized as part of the National Status and Trends Program (NOAA, 1989) and guidelines for using transplanted mussels in NRDA studies are summarized in Salazar (1992) and Michel et al. (1994). Mehl and Kocan (1993) have developed methods to estimate the exposure concentration of the seawater soluble fraction of crude oil from the tissue concentrations in caged mussels deployed after discharges.

Surrogate Samplers: Water column and sediment exposure may be integrated over time through the use of surrogate samplers, such as semi-permeable membrane devices (SPMDs) or lipid bags (Lebo et al., 1992; Crecelius and Lefkovitz, 1992; Crecelius et al., 1994).

PAH Metabolites: Many oil components including benzene and polycyclic aromatic hydrocarbons (PAHs) are rapidly metabolized by aquatic organisms and do not tend to accumulate in tissues. For vertebrates, documentation of exposure to petroleum hydrocarbons may be complicated. However, the metabolites of PAH compounds can be detected, especially in bile, even though the parent compound may no longer be detectable (Varanasi et al., 1989). Presence of these metabolites is an indication that the organism has been exposed to PAHs, but it may be difficult to determine the exact source of that exposure.

Mixed Function Oxygenase (MFO) Enzymes: Certain organisms possess enzyme systems that can detoxify contaminants. The most important enzymes in the detoxification process are known as MFO enzymes. The activity of these enzymes is evidence that the organism has been exposed to contaminants (Payne et al., 1986; Collier and Varanasi, 1991). However, interpretation of enzyme activity level is complicated because other stresses can lead to elevated levels, so other exposure data may be necessary to confirm that the elevated levels are associated with the contaminant of concern (McDonald, 1992).

Hemolytic Anemia: The decreased concentration of red blood cells and/or hemoglobin has been used as an indicator of oil exposure in certain vertebrates. Birds that have been exposed to oil may develop anemia within days (Leighton, 1982). Sea otters exposed to oil from the *Exxon Valdez* incident also developed anemia (Williams, 1990).

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Table of Contents

[1] The text in this appendix was drafted by Jacqueline Michel, Research Planning Inc., Columbia, S.C.

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D.1 Introduction

The purpose of this appendix is to provide examples of the types of injuries that have been documented for a number of natural resources and habitats in association with incidents involving oil. Although such injuries may result from the actual discharge of oil as well as from response-related actions, this appendix only addresses the former. The natural resources discussed include:

- **Physical Natural Resources** (surface water, ground water, sediments/soils, and air)

- **Biological Natural Resources - Species Groups**

  - Birds
  - Marine Mammals
  - Freshwater and Terrestrial Mammals
  - Reptiles and Amphibians
  - Fish
  - Shellfish

- **Biological Natural Resources - Habitats**

  - Emergent Wetlands
  - Submerged Aquatic Vegetation
  - Coral Reef Ecosystems
  - Shoreline Communities
  - Benthic Ecosystems
  - Terrestrial Ecosystems

Each section includes a brief summary of the sensitivity of the natural resource or habitat to oil, a listing of indicators of exposure and examples of the types of measurement methods used to document exposure, a description of the methods commonly used for injury determination, and a list of references where trustees can find additional information. The natural resources and habitats discussed in this appendix are not meant to be all inclusive. On-going research continues to expand our knowledge of how oil affects these and other natural resources and habitats. The literature cited in this appendix will continue to expand as new information is generated.

D.2 Physical Natural Resources

D.2.a Sensitivity to Oil Impacts

Physical natural resources include surface water, ground water, sediments and soils, and air. These resources often are the primary pathway of exposure to oil. This section addresses direct injuries that affect these resources, usually in the form of contamination at levels that impair services provided to other natural resources and/or humans.

Surface water is the physical resource most often affected by oil because spilled oil frequently reaches a water body. Most crude oils and refined products have a low water solubility, less than 100 mg/L and usually less than 50 mg/L (Sutton and Caulder, 1975; McAuliffe, 1987). The most water-soluble components in oil are also the most volatile, so evaporation as well as dilution rapidly reduce the amount of oil dissolved in water. Incidents on land seldom contaminate ground water, primarily because the high viscosity of most oils limits penetration into surface sediments. Underground discharges from buried tanks and pipelines can affect ground water, with the largest spread of contamination most often resulting from discharges of light refined products such as gasoline. For NRDAs involving oil spills, contamination of ground water is treated as a pathway to other natural resources and habitats, rather than a natural resource in and of itself.

Sediments and soils often are contaminated during incidents, primarily as a result of direct contact with the oil such as at the water/shoreline interface for floating oil. Subaqueous sediments are at risk under specific conditions (see discussion in section on Benthic Ecosystems). Response efforts are seldom effective at removing all sediment contamination, particularly where removal activities pose a high risk of further injury, such as on mud flats.

Non-petroleum compounds in crude oils, such as metals, are seldom of environmental concern for sediment contamination. For example, after the discharge of an estimated 160 to 340 million gallons of crude oil during the 1991 Gulf War, trace metal concentrations in oiled intertidal and subtidal sediments were not above background levels (Fowler et al., 1993). Spills from crude oil pipelines, however, can contain high salinity water, which can adversely affect freshwater and terrestrial resources. Refined products may contain toxic, non-petroleum additives.

Injury to air during incidents involving oil is rarely addressed. Evaporation of oil is considered to be a desirable weathering process removing the lighter, more toxic fractions from the water and soils. Recently there has been concern about benzene exposures to response personnel early during an incident, because of the chemical's classification as a human carcinogen. Overexposure is possible under the right conditions (Eley et al., 1989) namely volatile oil, low wind, restricted spreading, and sheltered areas where the vapors can pocket. A large incident near a populated area could raise health concerns for the general public, from either volatilization or combustion by-products. Particulates from the combustion of oil, those less than 10 microns (PM-10), pose the greatest risk to the respiratory tract (Wright, 1978).

D.2.b Indicators of Exposure

Indicator of Exposure	Measurement Methods
Petroleum hydrocarbon content	Sampling and laboratory analysis of air, water, and/or sediments/soils to quantify the amount of oil contamination, fingerprint the oil, and characterize oil weathering.
Petroleum hydrocarbon by-product content	Sampling of air, water, and/or sediments/soils to quantify the amount of oil by-products. For air, combustion by-products would be of greatest concern. For water, intermediate oxidation by-products would be of concern because they are highly water soluble and have acute toxicity.

Total Petroleum Hydrocarbons, PAH, and Oxidation by-Products in Water. Petroleum hydrocarbons in water can be measured using ultraviolet fluorescence (UV/F), infrared spectrometry (IR), and gas chromatography using USEPA Methods 418.1 and 8015, or American Society for Testing and Materials (ASTM) Methods D 3414, 3415, and 3650. Individual and total PAHs in water can be quantified by Gas Chromatography/Mass Spectroscopy (GC/MS) (IOC, 1991). Ehrhardt and Burns (1993) and Burns (1993) describe new methods for quantification of oxidation by-products, but few laboratories have experience with these methods.

Total Petroleum Hydrocarbons and PAH in Sediments. Total extractable hydrocarbons in sediments and soils can be measured gravimetrically after extraction (USEPA Method 503) or by UV/F (USEPA Method 418.1). Samples with high biogenic hydrocarbon content need additional cleanup steps during the extraction process or they may have high detection levels. Individual and total PAHs in sediments can be quantified by GC/MS (IOC, 1991).

Fingerprinting of oil involves a complex series of chemical and interpretative techniques that increase the confidence with which the source of oil in the sample can be inferred (McAuliffe et al., 1988; Sauer and Boehm, 1991). The confidence in the ability to fingerprint the discharged oil decreases with time (due to weathering) and distance (due to the potential for contamination from other sources of petroleum hydrocarbons). Both aliphatic and aromatic hydrocarbons are used to confirm the presence of petroleum and for fingerprinting.

D.2.c Injury

Injuries to physical natural resources are primarily determined by measurement of toxicity or violation of established standards. Use of established standards is limited because there are very few standards for specific petroleum hydrocarbon compounds in the various media, and those that do exist are mainly for pyrogenic hydrocarbon compounds that comprise only small amounts of typical oils.

Water and Sediment Toxicity Measures. There are two approaches used to characterize the toxicity of water and sediments:

- Direct measurement of the biological response of a test organism placed in water or sediment from the discharge site; and
- Comparison of the level of the contaminants in the sample, as determined by chemical analysis, with levels of contamination known to cause adverse effects (e.g., acute and chronic toxicity testing).

Direct measurement can be in-situ, for example, transplanting of infauna to contaminated sediments. Measurement may also involve the collection of sediments or water for controlled toxicity tests in the laboratory. In-situ methods can be complicated by the presence of other sources of toxicity not related to the discharge in the media being tested. Laboratory tests are designed for testing of a specific contaminant, but may not be realistic in terms of the level, pathway, and duration of actual exposures. Standard tests have been published for water and sediment for many different fish and invertebrates (ASTM, 1992; PSEP, 1991; USEPA, 1985), echinoderm sperm cell fertilization (Dinnel *et al.*, 1987), and bacteria (PSEP, 1991). The advantages and disadvantages of toxicity testing are summarized in Chapter 3.

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D.3 Biological Natural Resources - Species Groups

D.3.a Birds

D.3.a.1 Sensitivity to Oil Impacts

Many field and laboratory studies have demonstrated the differences in the effects of oil on various groups of birds. The three most important factors affecting sensitivity are behavior, distribution, and reproductive rate. Two indices have been developed to quantify the factors influencing the vulnerability of each species, the Oil Vulnerability Index of King and Sanger (1979), and the Bird Oil Index of Wahl et al. (1981). These indices and other literature were used to generate the following relative sensitivity rankings for each group of species, with emphasis on marine birds. This information is less relevant for terrestrial species, however the same principles can be used to assess the sensitivity of birds to terrestrial conditions. Note that these rankings are general guidelines. Actual conditions will likely dictate how birds are affected by a specific incident.

<u>Highly Sensitive Bird Groups</u>

Diving Pelagic Seabirds (Alcids)

- Alcids are considered to be the most vulnerable of all bird groups to oil. They form large flocks and spend most of the time floating on cold, offshore waters. For incidents in their habitats, alcids usually comprise the largest fraction of birds directly killed by oil.

- Large-scale mortality of eggs is likely because alcids form large breeding colonies in open marine settings.

- There can be long-term impacts on reproduction because of irregular cycles in breeding success, nesting abandonment and mate switching by oiled adults (Fry et al., 1987), various effects on eggs and chicks ultimately leading to lower survival rates, lower prey availability, and social disruptions at colonies that affects timing and success of egg-laying (Nysewander et al., 1993).

Waterfowl (Diving ducks, dabbling ducks, brant)

- Direct mortality from exposure to floating slicks can be high, especially during incidents involving persistent oils and when large numbers of birds are concentrated in migration and overwintering areas. For most coastal incidents, diving ducks are at greatest risk because of their preference for nearshore marine waters. In comparison, dabbling ducks prefer shallow, freshwater habitats with a reduced risk of an incident (RPI, 1988).

- Direct mortality of oiled eggs can occur but is less frequent because adults and nests are dispersed during the breeding season.

- Oiled but surviving birds often experience behavioral and physiological problems that leads to reduced reproduction from abandoned nesting activities (Hartung, 1965), reduced courtship behavior (Holmes et al., 1978), and disrupted egg-laying and incubation cycles (Holmes, 1984). These responses can result from oil ingestion during preening of oiled plumage.

- Reproductive failure can also result from ingestion of oil-contaminated prey, especially for those species (e.g., harlequin ducks) that feed primarily on intertidal invertebrates (Patten, 1993).

Diving Coastal Birds (Pelicans, loons, grebes, cormorants, boobies)

- Direct mortality from contact with floating slicks can be high because these birds regularly roost in moderate-sized flocks on nearshore coastal waters and they dive into the water to feed.

- Colonial nesting species (pelicans, cormorants, boobies) are more vulnerable than non-colonial nesters because they concentrate in breeding colonies.

Moderately Sensitive Bird Groups

Diving Pelagic Seabirds (Albatrosses, petrels, fulmars, shearwaters, skuas, jaegers)

- These birds are extremely reliant on open-water marine habitats for feeding and roosting, making them susceptible to incidents in these settings. They scatter over large areas, however, they may congregate in large rafts.

- There have been numerous studies documenting many reproductive effects for seabirds from external oiling and oil ingestion, including colony abandonment and mate switching (Fry et al., 1987), reduced laying and incubation of eggs (Fry et al., 1986), egg and chick rejection and desertion (Butler et al., 1988), and low chick growth rates (Trivelpiece et al., 1984).

Shorebirds (Sandpipers, plovers, turnstones, phalaropes)

- Direct mortality rates are generally low for shorebirds because they spend very little time in the water. Phalaropes are the exception because they winter on the open ocean where they behave more like diving pelagic seabirds.

- Sublethal effects from either reduced or contaminated prey are more likely for shorebirds because they feed in intertidal habitats where oil strands and persists. For species which form very large migrating flocks, loss of critical forage areas during migration could cause high mortalities.

Raptors (Bald eagles, osprey, peregrine falcons)

- Raptors become oiled primarily via consumption of oiled prey, particularly eagles and falcons that may take oiled, disabled birds.

- Reproductive failures can be caused by oiling of eggs as well as disturbance from shoreline cleanup operations (Bowman and Schempf, 1993).

Less Sensitive Bird Groups

Wading Birds (Herons, egrets, rails)

- Direct mortality of wading birds is usually low because they wade in shallow, sheltered waters to feed. However, their plumage can become contaminated by walking through oiled vegetation.

- Indirect effects on reproduction can occur from loss of prey, causing hatchling starvation, particularly for species unable to shift to alternative foraging sites (Parsons, 1990; 1991).

Gull and Terns

- These species are usually oiled in low proportion to the exposed populations because they are readily able to avoid oil. Gulls in particular are highly adaptable, opportunistic feeders, and prolific breeders.

D.3.a.2 Indicators of Exposure

Birds may be directly exposed to oil through oiling of plumage and eggs, ingestion of oil during preening, ingestion of oiled prey, absorption, and inhalation of oil through the skin or egg. The following methods can be used to document exposure:

Indicator of Exposure	**Measurement Methods**
Direct oiling of plumage/skin	Visual estimates of number of individuals or percent of flock/study group by degree of oil coverage on plumage; photographic or video documentation; sampling of oiled feathers to fingerprint and characterize oil weathering.
Direct oiling of eggs	Counts of percent of eggs oiled; samples to fingerprint and characterize oil weathering.
Oil ingestion	Discharged oil in stomach contents and/or feces to document actual oil ingestion, even months or years post-spill. Oil and/or metabolites in bird tissues to document the degree and duration of exposure. Oil in preferred prey items can be used to confirm the source and estimate duration of oil exposure.
Tissue damage	Post-mortem examination of lung tissue for hemorrhagic lesions from inhalation of oil vapors, and of other internal organs for lesions from inhalation of oil vapors.

D.3.a.3 Injury

In addition to the direct pathways of exposure listed above, birds may be indirectly affected by oil through habitat loss (e.g., vegetation mortality), habitat degradation, and diminished food populations. Commonly used methods for injury determination are discussed below.

Acute Mortality. Rehabilitation centers keep records on numbers of recovered dead and surviving birds, by species, sex, and age. These data, corrected for the background number of dead birds, provide the minimum count of birds affected by the incident. To expand the count, trained observers can survey shorelines to conduct carcass counts. Survey methods are provided in Ford et al. (1987) for marine species and Fite et al. (1988) for terrestrial species. Following these guidelines can improve the accuracy of these mortality estimates. Otherwise, problems such as insufficient or incomparable data for beach carcasses throughout the study area or over time can increase the uncertainty in the mortality estimate. Only persons with a Federal permit are allowed to collect or conduct experiments on migratory or endangered birds.

Simple extrapolations can be used to estimate total mortality from the carcass counts. There are also computer models that use currents, wind, bird distributions, beached bird counts, and other factors during the incident to estimate total number of dead birds (Ford et al., 1991). High natural variability in bird distributions, both spatially and seasonally, makes it difficult to estimate the total and exposed population actually present during an incident.

Recovered birds can be examined to determine cause of death and document exposure to the oil. Methods include collection of samples of oiled plumage and gut contents to fingerprint oil, blood and tissue analysis for oil residues, and histological analysis of tissues to determine cause of death and to rule out other non-incident related causes of death (Leighton, 1995).

Reduced Reproduction. There are many measures of reproductive success that can be used to assess injury such as number of nests built, clutch size, egg-laying dates, hatching success/growth rates, and fledgling success. Field studies usually compare rates for exposed and reference nesting colonies. This approach works best when there is extensive knowledge of the normal rates or behavior for the study population or species, such as in Parsons (1990, 1991) where oil-affected colonies were part of a five-year study on nesting and foraging ecology prior to the incident.

Laboratory studies may be used to document reduced reproduction for the oil type or degree of weathering (e.g., Stubblefield et al., 1993), particularly when direct observation of reproductive behavior is not possible (such as oiled waterfowl that dispersed to remote nesting sites).

There can be many causes of reduced reproductive success including loss of nesting habitat, disruption of courtship, incubation, attention, and feeding patterns and social structures, loss of prey, and toxicity from oil coating or ingestion of contaminated food. It is important to understand the cause of an observed reduction in reproduction in order to link the incident and the observed effect. Birds can experience total nesting failure on a regular basis, making it difficult to determine oil-related injury.

Reduced Survival. Sublethal impacts associated with exposure to oil or indirect effects can reduce the overall survival rates of birds. Banding of oiled birds released after rehabilitation can be used to document survival and reproductive rates. Studies of feeding behavior patterns can show longer time spent feeding or longer distances traveled because of loss of prey and degradation of foraging habitat (Parsons, 1990).

These studies often include chemical and histopathological analysis of tissues from exposed birds, such as PAH levels in tissues and elevated mixed function oxygenase (MFO) activity in the liver (Gorsline and Holmes, 1982) to document on-going exposures, and liver, kidney, and intestinal necrosis to document physiological responses to exposure that could lead to reduced survival (Fry and Lowenstine, 1985).

Habitat Loss or Degradation. Because birds rely heavily on wetlands and aquatic prey, habitat loss and degradation are extremely important to local populations. Methods to quantify habitat loss or degradation are discussed in section B.4.

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D.3.b Marine Mammals

D.3.b.1 Sensitivity to Oil Impacts

Most marine mammals have special management status as threatened or endangered species. A brief summary of their sensitivity to oil by groups is provided below.

Baleen Whales. These whales have a series of elongated, bristled structures (baleen) in the mouth acting as filters to separate food items (mostly small crustaceans and fish) from seawater. Laboratory studies have not found any evidence that oil or tarballs significantly foul the feeding apparatus of baleen whales, and whale skin is nearly impermeable, even to the most volatile oil fractions (Geraci, 1990). Baleen whales, however, are considered to be the most vulnerable to oil discharges, based on their generally low numbers, feeding strategies (skimming the surface and scouring of the bottom) that increase the risk of oil ingestion, and dependence on specific sites for feeding and reproduction (Würsig, 1990).

Toothed Whales and Dolphins. These cetaceans capture individual prey items using toothed jaws. Most prey is captured below the water surface so there is little risk of direct ingestion of floating oil during feeding. Most species are highly mobile and wide-ranging, except for belugas and narwhals. Following the *Exxon Valdez* incident, fourteen killer whales were lost from a very stable pod from 1989 through 1991. The seven deaths that occurred immediately may have resulted from inhalation of volatile gases or oil ingestion, six more deaths that occurred within one year after the incident may have resulted from residual effects or consumption of contaminated prey (Dahlheim and Matkin, 1993). Dolphins can see oil on the surface and can avoid it (Geraci, 1990; Sumltea and Würsig, 1992), thus they are not considered to be particularly sensitive to oil discharges.

Fur Seals. These seals rely on dense fur as the primary means of insulation and thermoregulation. Fouling of one-third of the body surface resulted in a 50 percent increase in heat loss in fur seals (Kooyman et al., 1976). Thus, they are susceptible to death by hypothermia and stress. Other known effects of oil include ingestion-related mortalities, interference with swimming ability, lethargic behavior, irritation of the respiratory system from inhalation of fumes, and inflammation of mucous membranes (St. Aubin, 1990).

Other Seals and Sea Lions. These animals rely on a thick layer of blubber for insulation. Pinnipeds other than fur seals are less threatened by thermal effects of fouling (St. Aubin, 1990). Young animals with fur would be at greatest risk. Direct oiling of animals and their haulouts can cause mortality, as well as internal damage. Frost and Lowry (1993) reported debilitating lesions in the brains of harbor seals taken from oiled areas following the *Exxon Valdez* incident. Conditions that would lead to the highest mortality include exposure of animals early and close to the discharge, heavy contamination around haulouts, and sub-populations already stressed by disease or limiting environmental conditions (St. Aubin, 1990).

Walruses and Polar Bears. These two very different species are grouped together because both are associated with pack ice, and little is known about how oil affects them. Walruses are highly gregarious and form large non-breeding haulouts. They have sparsely distributed hair, so thermal stress is not likely to be important (St. Aubin, 1990). In contrast, polar bears occur in low densities as solitary animals or family groups. However, they must maintain a clean pelt for thermoregulation, and would likely undergo thermal stress if oiled. Polar bears have been shown to ingest oil during grooming (Stirling, 1990).

Manatees. Little information is available regarding the effects of oil exposure on manatees. Manatees are considered able to detect and avoid oil (St. Aubin and Lounsbury, 1990). They tend to concentrate in shallow water, increasing the risk of direct contact with oil. Their non-selective feeding habits may allow them to consume floating tarballs along with their normal foods. If a discharge were to occur in their preferred habitat during winter, manatees may be forced into colder waters inducing thermal stress. Displacement during summer months would not be as disturbing (St. Aubin and Lounsbury, 1990).

Suspected injury to manatees could include irritation to mucous membranes and lungs, dermal membrane irritation, interference with gastric gland secretions, and loss of intestinal flora (Geraci and St. Aubin, 1980). Increased boat activity during response efforts could also result in manatee injury or death.

Sea Otters. Sea otters are highly sensitive to oil because they have dense fur for thermoregulation, groom excessively (ingesting oil); have a metabolism rate so high that they must consume 23 to 33 percent of their body weight per day, consume benthic organisms that tend to accumulate petroleum hydrocarbons, form large concentrations in coastal areas, with high site fidelity, and spend much time in kelp beds that tend to trap and hold oil (Ralls and Siniff, 1990).

D.3.b.2 Indicators of Exposure

Marine mammals may be directly affected by uptake of oil via the water surface, while grooming and from ingestion of food. Indicators of exposure and measurement methods are listed below:

Indicator of Exposure	Measurement Methods
Direct oiling of skin/fur	Visual estimates of number of individuals or percent of study group by degree of oil coverage on body surface; photographic or video documentation. Sampling of oiled materials to fingerprint and characterize oil weathering.
Oiling of habitat	Maps of oil distribution on the water surface and in preferred habitats using standardized methods and descriptors (Owens and Sergy, 1994). Sampling of oiled materials to fingerprint and characterize oil weathering.
Oil ingestion	Discharged oil in stomach contents and/or feces to document actual oil ingestion. Oil in tissues to document the degree and duration of exposure. Visual observations of animals consuming oiled prey.
Tissue damage	Post-mortem examination of lung tissue for hemorrhagic lesions from inhalation of oil vapors and of other internal organs for lesions from inhalation of oil vapors.
Increased mixed function oxygenase (MFO) activity	Tissue samples collected from fresh specimens and analyzed for hepatic cytochrome P4501A (Payne et al., 1986). Marine mammals appear to have the liver enzymes needed to metabolize and excrete petroleum hydrocarbons. Although there is no systematic dose-response relationship, laboratory and field studies have found an increase in MFO following oil exposure (Geraci and St. Aubin, 1990).

D.3.b.3 Injury

In addition to direct effects from contact with discharged oil, marine mammals may be indirectly affected by oil through habitat degradation (particularly contaminated haulout areas) and diminished prey populations. Injury determination methods for marine mammals are summarized below. Only a limited number of laboratory studies on a very small number of individuals have been conducted to confirm cause and effects of petroleum exposures. Many sublethal injuries have been suspected based on knowledge of life history and ecology of marine mammals. The size and behavior of most marine mammals precludes capture-based study methods, thus most studies have to be conducted using visual observation and census techniques.

Mortality. Mortality investigations are conducted by aerial, boat, and foot surveys to identify and count dead organisms, usually shortly after the discharge. Because of their large size, most stranded marine mammals (except sea otters) are readily sighted, so mortality estimates may be lower due to carcasses sinking. Only persons with a Federal permit are allowed to conduct work on marine mammals, thus all sightings should be reported to the Marine Mammal Stranding Network. Trained mammalogists can collect the necessary data, photographs, and samples for necropsy to confirm cause of death and chemical samples for fingerprinting. Early reporting of carcasses is very important because tissues break down rapidly.

A second approach is to compare post-discharge counts with pre-discharge data, using the same or similar survey methods to increase the validity of the comparisons. High seasonal variations and incomplete pre-discharge coverage for the affected area/populations can be serious limitations. This approach is best used for stable, well-studied populations.

A third approach is to develop computer models to simulate oil movement, the distribution and abundance of animals, and the likelihood of intersection between the two. Such an intersection model was developed to estimate sea otter mortality following the *Exxon Valdez* incident (Bodkin and Udevitz, 1993).

Reduced Reproduction. Reproductive impacts are determined by monitoring for the number and survival of young. Marine mammals nurture their young for periods ranging from one month to two years, thus it is possible to observe and count parents and young over time to determine survival rates. Photo-identification techniques have been used to identify and track individual whales in stable pods according to their unique markings (Bigg et al., 1986). However, there is often a lack of baseline data on life history (birth rates, survival rates for juveniles and adults, etc.) for many species and sub-populations.

Reduced Survival. Sublethal effects of exposure can eventually lead to reduced survival. Behavioral effects (e.g., lethargy, reduction in feeding effort, increased vulnerability to predation) can be noted during observations of oiled and unoiled populations, so that oil-related responses can be differentiated from normal behavior. Reduced growth rates can be measured, but sample sizes are usually small, making data interpretation more difficult.

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D.3.c Freshwater and Terrestrial Mammals

D.3.c.1 Sensitivity to Oil Impacts

Freshwater mammals at risk from oil-related injuries include river otter, beaver, mink, nutria, and muskrat. Like sea otters, these animals spend much of the time in water, have high site fidelity, and rely on fur to maintain thermoregulation. They are highly susceptible to direct mortality. Terrestrial mammals of concern include species associated with water bodies and riparian habitats, such as bear, panther, moose, fox, deer, and raccoon. These species are likely to be affected by the consumption of oiled food items as well as by direct contact and habitat degradation.

Little is known about the impacts of oil on freshwater and terrestrial mammals. Acute effects from contamination of fur and ingestion of oil during preening and chronic effects from ingestion of contaminated food are most likely. In oiled/reference area comparisons of river otters in *Exxon Valdez* studies, researchers found a less diverse diet, lower body mass, larger home ranges, avoidance of preferred habitat, and abnormal blood characteristics in animals from oiled areas one year after the incident (Bowyer et al., 1993). Efforts were made to determine differences in populations for oiled/control study areas, but the confidence limits for the population estimates overlapped for most surveys. A laboratory study to determine the influence of hydrocarbons on reproduction in ranched mink was planned, but never conducted. Thus, there are little data on whether sublethal doses of oil will influence reproduction in terrestrial mammals.

Field studies also were conducted to determine effects of the *Exxon Valdez* incident on Sitka black-tailed deer, which concentrate on beaches during late winter and early spring to forage on intertidal marine vegetation. Study plans included comparisons of the number of dead deer on oiled versus reference islands and the hydrocarbon levels in tissues and rumen contents, however, the study results have not been published.

D.3.c.2 Indicators of Exposure

Freshwater and terrestrial mammals may be directly affected by contact with oil on the water surface and oiled vegetation while grooming and from contaminated food. Indicators of exposure and measurement methods are listed below:

Indicator of Exposure	**Measurement Methods**
Direct oiling of fur	Visual estimates of number of individuals or percent of study group by degree of oil coverage on body surface; photographic or video documentation; sampling of oiled fur to fingerprint and characterize oil weathering.
Oiling of habitat	Maps of the distribution of oil on the water surface and in preferred habitats using standardized methods and descriptors (Owens and Sergy, 1994); sampling of oiled materials to fingerprint and characterize oil weathering.
Oil ingestion	Discharged oil in stomach contents and/or feces to document actual oil ingestion. Oil in tissues to document the degree and duration of exposure.
Tissue damage	Post-mortem examination of lung tissue for hemorrhagic lesions from inhalation of oil vapors, and of other internal organs for lesions from inhalation of oil vapors.

D.3.c.3 Injury

In addition to direct effects from contact with or ingestion of discharged oil, freshwater and terrestrial mammals may be indirectly affected by oil through habitat degradation and diminished food availability. Injury determination methods are summarized below.

Mortality. Surveys of the affected areas to count the number of animals killed (body count) by the incident typically include systematic methods using transects or quadrats to count/collect dead or oiled animals (Anderson et al., 1976). The total number of animals killed are extrapolated from the sampled data, using actual mortality rates for the known survey area modified with correction factors to account for differences between the surveyed area and the entire impact zone. Small mammals, such as oiled beach mice, are likely to be quickly scavenged by predators or return to their burrows thereby avoiding discovery by survey teams. Thus, these counts may underestimate the actual number of animals killed. However, field surveys are important in documenting that exposure and mortality have occurred to each species of concern.

If there are other likely causes of mortality for the species of concern, it may be important to determine the cause of death in a representative number of animals. Other possible causes could include a large winter kill or high incidence of disease. Dead animals from the oiled area can be collected for necropsy and histopathological analysis for comparison with animals collected from outside the oiled areas.

For species with very limited populations, it may be possible to estimate changes in population based on the estimated mortality. Otherwise, studies of population densities between oiled and control areas may be used. The actual field methods for detecting population density changes would be selected based on the behavioral characteristics of each species and availability of historical population distribution data. Measurement of significant differences between impacted and reference sub-populations, particularly for larger animals with low densities and long lifetimes, is extremely difficult, although there are standard methods in use for data collection and analysis (e.g., Davis and Winstead, 1980; Seber, 1982; Shirley et al., 1988; Chao, 1989; Pollock et al., 1989).

Reduced Reproduction. For most incidents, it may be difficult to directly measure reproductive success in wild populations of small mammals. There is a general lack of baseline data on life history (birth rates, survival rates for juveniles and adults, etc.) for many species and sub-populations. Reproductive injury can be assessed by investigation of the reproductive potential through study of physiological effects on the reproductive organs. Such studies could include comparisons of the histology of the gonads of males and females in the oiled and control populations; or the size, development, and contents of the uterus of mature females can be used to determine if gonadal failure is evident.

Alternatively, it may be preferable to conduct laboratory studies to assess the influence of oil on reproduction. If sublethal effects on reproduction are thought to be significant for a species, laboratory experiments may be used to demonstrate a direct cause and effect relationship between exposure and changes in reproduction, in support of field observations of such changes. Otherwise, because of the limited data on the effects of oil on reproductive performance in freshwater and terrestrial mammals, it may be difficult to prove that the oil exposure was the cause of the observed changes. In developing laboratory experiments, it is important to ensure that the oil used in the experiments is the same product that was discharged and has weathered to the same degree as the oil to which wild animals have been exposed.

Reduced Survival. Sublethal impacts associated with exposure to oil or indirect effects can reduce the overall survival rates of exposed animals and/or populations. Tagging of oiled animals released after rehabilitation can be used to document survival and reproductive rates of oiled/cleaned individuals, usually the smaller species such as river otters or beaver. In the field, behavioral effects (e.g., lethargy, reduction in feeding effort, increased vulnerability to predation) are recorded during observations of oiled and unoiled populations, so that oil-related effects can be quantified. Reduced growth rates or body mass can be measured, but usually sample sizes are small, making data interpretation more difficult.

Indirect effects can be caused by reductions in available food or having to shift to less-productive habitats. Studies of food habits, movements, and habitat selection can show longer time spent feeding or longer distances traveled because of degradation of foraging habitat. Study of feces can document differences in the diet in oiled versus unoiled areas, supporting other observations of reduced viability.

These studies can include chemical and histopathological analysis of tissues from exposed animals to document on-going exposures, and liver, kidney, and intestinal necrosis to document injury. Bowyer et al. (1993) monitored specific blood parameters in oiled and unoiled populations of river otters, using the results to indicate exposure and some degree of physiological injury. These measurements support the weight of evidence by documenting pathways, exposures, and biological responses that can be used to estimate a reduction in the overall viability of the exposed population.

Habitat Degradation. There are various biological indicators of habitat degradation appropriate to assessment of injuries to freshwater and terrestrial mammals. Two possible indicators include changes in food habits and habitat use. Changes in food habits can result from both contamination or localized reductions in preferred food items. Food habits can be described from prey remains in feces or examination of the stomach contents of collected animals. Habitat-use studies are more complex, consisting of descriptions of activity patterns (e.g., percent time spent foraging and resting), distances traveled to foraging areas or home range size, and other factors appropriate to the species. Methods to assess these indicators include time and area-constrained observations during which records of the percent time spent on various activities are recorded.

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D.3.d Reptiles and Amphibians

D.3.d.1 Sensitivity to Oil Impacts

Reptiles and amphibians are a complex group of organisms, with highly diverse life histories, physiologies, survival strategies, and habitat requirements. The species at greatest risk from an incident are those associated with open marine, estuarine, and riverine habitats such as sea turtles, crocodiles, and alligators. Other wetland-associated species are at moderate risk and terrestrial species are at lowest risk. There are many threatened and endangered species of reptiles and amphibians in freshwater habitats that could be at risk from an incident in these areas.

Because of their diversity, it is not possible to predict the relative sensitivity among species groups. There are little data on effects of petroleum hydrocarbons on reptiles and amphibians, with the exception of sea turtles. Hall and Henry (1992) found that it was not possible to extrapolate study results from other vertebrate classes (mostly fish) for even general conclusions on the relative toxicity of chemicals. Because of these limitations, most assessment studies of oil impacts to reptiles and amphibians have focused on counting the number of dead animals.

The effects of oil are best known for sea turtles, because of their status as threatened/ endangered and because of their higher risk of exposure from marine incidents. The direct and indirect effects of oil on sea turtles can be divided into three general categories based on the life stage and habitat affected by the oil:

- Direct effects on eggs and hatchlings on nesting beaches;
- Direct effects on hatchlings, juvenile, and adult turtles at sea; and
- Indirect effects resulting from impacts to turtle habitats both in the water and on the beach.

Direct Effects on Eggs and Hatchlings by Stranded Oil. Various researchers have studied the physiological and behavioral effects of oil on each life stage in laboratory experiments (Fritts and McGehee, 1982; Vargo et al., 1986; Lutz et al., 1986). The major conclusions on the effects of oil on eggs and hatchlings from these studies are summarized below.

- The number of unhatched eggs in a nest was much higher when fresh crude oil was on the surface of the sand during the last half or quarter of incubation, due to displacement of oxygen by the lighter oil fractions when the rate of oxygen consumption in the nest is at its peak.

- Weathered crude oil was less toxic to turtle eggs than fresh crude oil.

- Hatchling morphology was affected by the amount and time of oiling.

Studies by Mahaney (1994) on frogs found no effect of crankcase oil on hatching success, but no successful metamorphosis of highly exposed tadpoles.

Direct Effects of Oil on Juvenile/Adult Turtles at Sea. Juvenile and adult turtles are likely to contact oil slicks during the early stages of an incident and tarballs as the oil weathers. From laboratory studies on the physiological effects of oil on subadult loggerhead turtles (Lutz et al., 1986; Bossart et al., 1993), the direct effects of oil exposure include coating of sensory organs, reddening and sloughing off of the skin, dysfunction of the salt gland, uptake of oil in the gastrointestinal system, and disturbed diving and respiration patterns. Although there have been many incidents in areas populated by turtles, it is unusual to have large numbers of turtles directly affected by an incident of oil. Reports of adverse effects of oil on adult and juvenile turtles are mostly anecdotal and poorly documented as to the cause of death (Rytzler and Sterrer, 1970; Delikat, 1980; Hooper, 1981; Gitschlag, 1992). It is difficult to document the number of turtles affected by an incident and it is likely that many of the affected turtles may never be seen by rescue workers. High-risk areas include migratory routes, foraging areas, and areas offshore of heavily utilized nesting beaches.

The effects of pelagic tar on sea turtles have been well documented (Witham, 1978, 1983; Vargo et al., 1986; Van Vleet and Pauly, 1987; Gramentz, 1988). Turtles feed on objects floating at the water surface, therefore they are susceptible to ingestion of tar balls, which can block the oral cavity and digestive tract. Floating tar can coat the flippers, the mouth can become coated as the turtle attempts to clean its flippers. Large quantities of tar have been known to immobilize smaller turtles. Southeastern Florida has high concentrations of pelagic tar and Van Vleet and Pauly (1987) concluded that tarballs from tanker incidents were having a significant effect on turtle populations.

Indirect Effects as a Result of Impacts to Habitats. Degradation of nesting, foraging, resting, or critical habitats may have long-term effects on reptile and amphibian populations. These concerns are important in developed areas where these critical habitats are subject to many other sources of contamination, particularly for threatened and endangered species.

D.3.d.2 Indicators of Exposure

Reptiles and amphibians may be directly affected by oil through oiling of skin and eggs, ingestion of oil and oiled food, and inhalation of oil fumes. Indicators of exposure and measurement methods are listed below:

Indicator of Exposure	**Measurement Methods**
Direct oiling of skin and eggs	Visual estimates of number of individuals or percent of study population by degree of oil coverage on skin; photographic or video documentation; counts of percent of eggs oiled; samples of oiled eggs or oil from dead animals to fingerprint and characterize oil weathering.
Extent and degree of oil contamination of habitats	Aerial and ground surveys to make systematic, visual estimates of the areal extent and degree of oil of habitats using standardized methods and terminology (Owens and Sergy, 1994); photographic or video documentation of visual observations; sampling of oiled water and sediments to fingerprint the oil and characterize oil weathering.
Oil ingestion	Discharged oil around mouth parts, in stomach contents and/or feces to document actual oil ingestion. Oil in tissues to document the degree and duration of exposure. Oil in preferred food items to confirm the source, degree, and duration of oil ingestion.
Tissue damage	Post-mortem examination of lung tissue for hemorrhagic lesions from inhalation of oil vapors and of other internal organs for lesions from inhalation of oil vapors.

D.3.d.3 Injury

Reptiles and amphibians may be indirectly affected by oil through habitat loss (e.g., vegetation mortality), habitat degradation, and diminished prey populations. Injury determination methods for reptiles and amphibians are summarized below. Methods for assessment of sea turtles are better established than methods for other species. Survey methods for counting the number of dead animals on land and in wetlands would be similar to those listed for freshwater and terrestrial mammals (See B.3.3). Little is known about the effects of oil on most species of reptiles and amphibians; therefore, research would be needed to document the link between exposure and sublethal injuries.

Mortality. Surveys can be conducted to document dead or moribund animals on land and in the water. All oiled turtles should be reported to the Marine Mammal Stranding Network, which include sea turtles found dead in the water or onshore or alive but in a weakened condition. Under Federal law, only permitted individuals are allowed to handle sea turtles or other endangered and threatened animals.

Quantification of the number of oiled turtles at sea is more difficult. It is likely that oiled animals will be difficult to observe from aircraft. As demonstrated during at-sea capture efforts for turtles at the *Mega Borg* incident in the Gulf of Mexico, it is very difficult to capture healthy adult turtles at sea (Gitschlag, 1992). Therefore, only seriously injured or trapped turtles are likely to be captured.

It may be important to determine the cause of death through histopathological analysis (Van Vleet et al., 1986) although this can difficult in old specimens.

Reduced Reproduction. Except for sea turtles, there is little information on the likely effects of oil exposure on reproductive potential of reptiles and amphibians. Site-specific studies of exposed populations would be needed to document reproductive effects on these animals. The high genetic variability in amphibians needs to be considered in any study design.

For sea turtles, monitoring of oiled and reference nests can be conducted to compare hatching success, emergence success, etc. with degree and nature of oil contamination. If all nests cannot be monitored, a stratified-random sampling strategy can be used to select nests for monitoring. Maps of oiled nesting beaches and nest counts can be used to extrapolate the total impact on nesting success. Selected samples of addled eggs and dead hatchlings can be examined to determine cause of mortality. Lights used for night cleanup activities could cause disorientation and reduced survival of hatchlings.

Reduced Survival. Sublethal impacts resulting from exposure to oil or indirect effects could reduce the overall survival rates of exposed animals, but there are few existing studies that predict these effects. Documentation of reduced survival might have to be accomplished through detailed studies of exposed populations, even for sea turtles.

Habitat Degradation. When incidents have occurred in habitats known to be highly utilized by the species of concern for foraging or resting, studies can be conducted to determine the extent and degree of habitat degradation. Conditions when such impacts might occur include heavy oil that eventually sinks, contaminating benthic habitats, light, refined products that result in mortality to preferred food items that are sensitive to oil or high-wave energy conditions that naturally disperse a light crude oil or refined product in shallow waters, causing mortality and oil accumulation in benthic invertebrates and sediment contamination. Oil residues and cleanup activities can degrade important habitats for threatened and endangered reptiles and amphibians, particularly in wetlands.

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D.3.e Fish

D.3.e.1 Sensitivity to Oil Impacts

The probability of adverse changes to fish from oil is influenced by the inherent sensitivity and susceptibility of each species, duration of exposure, and temperature. Sensitivity and susceptibility are functions of life history stage and habitat preference, behavior, diet, and other factors. Each life stage has characteristics that directly control the likelihood and degree of impact from an incident (RPI, 1987) as summarized below.

The sensitivity of fish eggs is high, but lower than the larval stage due to the presence of protective membranes that may reduce exposure of the developing embryo to oil. Susceptibility of eggs is highly variable. Benthic eggs released in deep water are unlikely to be exposed to floating oil during an incident. Benthic eggs released in shallow waters are vulnerable to exposure to light oils having a significant water-soluble fraction, non-floating oils, and dispersed oil. Benthic eggs spawned on intertidal or very shallow subtidal substrates are highly vulnerable to direct mortality from contact with floating slicks, the water-accommodated oil fraction, and contaminated sediments.

The larval stages of most marine fish are planktonic, their large-scale movements are controlled by water currents. Within the first few days or weeks, planktonic larvae start feeding on phytoplankton and zooplankton, which are concentrated in the upper water column. Larval life stages are the most sensitive to acutely toxic effects of oil because of their preference for the upper water column and shallow, estuarine habitats.

Adult fish are considered to be the least sensitive life stage to oil impacts because they are highly motile and better able to detect and avoid discharges, have fully developed dermal protection, and have a metabolic capability to degrade oil. Acute toxicity is most likely to occur when light, refined products are spilled in shallow, confined waterbodies or in creeks and small rivers where the entire waterbody can be contaminated (Vandermeulen, 1987). Territorial fish also are highly susceptible. At the *Morris J. Berman* incident in Puerto Rico, for example, the heavy oil sank in nearshore lagoons and territorial fish in the lagoons experienced high mortality and sublethal effects (Vicente, 1994). Chronic impacts are of greater concern for species that use shallow, nearshore habitats because these habitats are most likely to be contaminated by oil. After chronic exposure to oiled sediments, benthic fish have been shown to exhibit reduced feeding, growth, and reproduction, as well as histopathological changes (Haensly et al., 1982; McCain et al., 1978; Collier et al., 1993). There could be long-term, sublethal injuries where subtidal sediments in nursery areas have been contaminated. Historically, extensive subtidal sediment contamination with measurable fishery injuries have been documented for very few incidents, with the *Amoco Cadiz*, *Exxon Valdez*, and *Braer* as notable exceptions.

Recent laboratory research on the toxicity of the degradation by-products of petroleum hydrocarbons has shown that these by-products have high acute toxicities to fish and that the toxicity is increased when microbes and nutrients are used to speed degradation (Doug Middaugh, USEPA, pers. comm.). Studies by Burns (1993) of bivalve tissue from beaches heavily oiled by the *Exxon Valdez* incident showed that a complex assemblage of intermediate hydrocarbon oxidation by-products were bioavailable for uptake in marine organisms several years post-spill. Thus, oxidation by-products may be an additional source of chronic exposure and effects on fish populations.

D.3.e.2 Indicators of Exposure

Direct measurement of petroleum hydrocarbons in fish tissue may not always be an appropriate indicator of exposure because of the high rate of metabolism of petroleum by most fish species (Varanasi et al., 1989). Methods have been developed, however, to detect exposure by measurements of petroleum metabolites, which are rapidly excreted through the bile, or by measuring increases in mixed function oxygenase (MFO) enzymes. The presence of fluorescent aromatic carbon (FAC) in the bile, for example, is evidence of a relatively recent exposure to oil. Although there is no systematic dose-response relationship, there are many laboratory and field studies showing an increase in MFO activity following oil exposure (Collier et al., 1993). Petroleum metabolites in bile, however, cannot be used to identify the source of the oil exposure. Indications of exposure are listed below:

Indicator of Exposure	Measurement Methods
Petroleum hydrocarbon metabolites in bile	Bile collected from freshly caught fish to measure the fluorescent aromatic carbon (FAC) content by fluorescence spectroscopy (Krahn et al., 1992).
Increased MFO activity	Tissue samples collected from live fish and analyzed for hepatic cytochrome P450 (Payne et al., 1986).
Tissue damage	Fish (moribund or from affected habitats) preserved for histological examination (Meyer and Barclay, 1990; Huggett et al., 1992).

D.3.e.3 Injury

Fish may be directly affected by uptake of oil via water, contaminated sediments, and food. They may be indirectly affected by oil through habitat loss (e.g., dieback of seagrass beds in nursery areas), habitat degradation, and diminished prey populations. Injury assessment methods for fish are summarized below.

Mortality. Fish-kill surveys estimate the number of adult fish killed immediately after an incident. Although the American Fisheries Society (AFS, 1992) and U.S. Fish and Wildlife Service/USFWS (Meyer and Barclay, 1990) have recently updated their publications on fish-kill methods, these approaches often greatly underestimate the total injuries from an incident because they only estimate the number of dead adult fish. Fish-kill investigations are more appropriate in streams and small rivers where the entire water surface along the sampling transect can be surveyed and the dead fish tend to accumulate within a reasonable distance from their original habitat. The method can be augmented with snorkeling surveys to detect and count dead fish that sink.

Reduced Abundance and Diversity. Changes in the number of fish or species resulting from an incident can be measured by comparing pre- and post-incident abundances at the same sites, or paired oiled and unoiled sites where pre-incident data are not available and the paired sites are comparable (Hilborn, 1993). The value of pre- versus post-incident surveys in quantifying oil-related injuries to fish will depend on natural variability in the measured parameters, reliability of the data-collection methods, and degree of injury caused by the incident. For many species, the year-to-year variability is so large that only severe impacts could be measured at statistically significant levels. Prior to developing study plans for quantification of population-level injuries using this method, the degree of change that would have to occur from pre- to post-incident in order to be statistically different should be estimated and the reasonableness of that level of change should be evaluated. Also, recent natural events (e.g., cold weather, droughts, hurricanes) should be evaluated with respect to their potential for confounding changes for a particular incident.

Oiled versus unoiled comparisons have similar limitations, with the added difficulty of finding truly representative reference sites. Sampling plans should include analyses of the likely variability in the data and the number of replicates needed to increase the statistical power of the comparisons to a level needed to detect a minimum change.

Abundances can be measured using standard fisheries survey techniques, including diver counts along transects, trawls and tows, counting of anadromous fish at weirs in streams, and tagging and marking of fish. Rapid bioassessment techniques such as those USEPA developed for rapid fish surveys in streams and rivers (Plafkin et al., 1989) are useful as quick screening tools to determine if there is a need for more detailed, quantitative surveys.

Where population-level changes are difficult to measure directly, a biological-effects model in conjunction with a population model can be used. Biological effects are derived from exposure levels estimated from a physical fates or water quality model for the incident conditions and toxicity test data (either from the literature or using local communities and the discharged material). Exposure concentrations and conditions are used to calculate mortality rates and sublethal effects. These effects are then applied to data on species abundance and structure to quantify impacts. The DOI Type A models (NRDAM/CME and NRDAM/GLE) uses this approach to calculate the mortality and lost weight of both adult and larval fish resulting from exposure to toxic fractions of the oil during a discharge, as well as reduced recruitment and lost productivity (French and Reed, 1993).

Reduced Reproduction. Study methods to measure reduced reproduction under both laboratory and field conditions include reduced egg viability and hatchability (Rice et al., 1983; McGurk and Biggs, 1993) and larval malformations (Hose et al., 1993).

Reduced Survival. Sublethal impacts associated with exposure to oil or indirect effects can reduce the overall survival rates of fish. A wide range of behavioral responses to oil exposure have been investigated in laboratory studies, including avoidance/preference (Rice, 1985), reduced locomotor activity and predator avoidance (Berge et al., 1983), changes in feeding activity (Williams and Kiceniuk, 1987), disruption of chemoreception and homing signals (Nakatani and Nevissi, 1991), and reduced growth and altered respiration rates (Rice et al., 1983). Histopathological analysis of tissues (Huggett et al., 1992) from exposed fish can be used to document physiological responses to exposure that could lead to reduced survival, including fin rot, lesions on the liver, kidney, spleen, gills, and olfactory nares, and tumors. These measurements support a weight of evidence approach by documenting pathways, exposures, and biological responses that can be used to estimate a reduction in the overall viability of the exposed population.

Fish Tainting. Although fish usually metabolize petroleum hydrocarbons, tissue concentrations can reach levels where consumption poses a health risk or tainting affects taste and/or smell. Although there are no food safety standards specifying a maximum contaminant level for oil or petroleum hydrocarbons in seafood, guidelines followed in the past state that if the seafood tastes or smells oily, it is not safe to eat. Tainting is as much a perception problem as a real risk. Fear of tainting can result in a loss of a natural resource service as serious as actual tainting.

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D.3.f Shellfish

D.3.f.1 Sensitivity to Oil Impacts

Shellfish are grouped into crustaceans (e.g., shrimp, lobster, and crab), molluscs (e.g., abalone, oyster, clam, mussel, scallop, gastropod, and chiton), and cephalopods (e.g., squid and octopus). There have been numerous studies on the toxicity, uptake, and depuration of petroleum hydrocarbons for shellfish (compiled in Scott et al., 1984). The effects of exposure to oil are influenced by the inherent sensitivity and susceptibility of the species and are a function of their life-history stage, habitat preference, behavior, and diet. Each stage has characteristics that directly control the likelihood and degree of impact during an incident (RPI, 1989).

In general, life stage sensitivity to oil impacts decreases from the egg to the adult life stages (Scott et al., 1984). However, life cycle circumstances make larvae more likely (i.e., more vulnerable) than eggs to be injured by oil. For many shellfish species, the eggs are either benthic or nektonic, reducing their vulnerability to floating slicks. There are notable exceptions, such as white shrimp that can spawn in shallow water and near the surface. However, the larvae of most species are found near the water surface in shallow, estuarine water bodies, making them highly vulnerable to oil. Juveniles and adults occupy similar habitats and have similar vulnerabilities to oil.

Bivalve molluscs and shrimp lack the ability to metabolize petroleum hydrocarbons, thus they readily accumulate these compounds in their tissues. Once the source of exposure is removed, however, depuration can occur within a few days to months. For example, following dispersion of No. 6 fuel oil in shallow, nearshore waters, oysters attached to rocky substrate in 4-6 m water depth were sampled one and four weeks post-incident, and targeted PAHs dropped by 94-98 percent over the three-week period (Michel and Henry, 1994). Bioaccumulation is influenced by the lipid content of the organism, which can change according to its reproductive status. Contaminated molluscs can provide a pathway for exposure of other natural resources that feed heavily on them.

Observations of discharges of heavy oil have shown that crabs can be directly exposed when the oil sinks. Their mouth parts typically become heavily oiled from feeding on tarballs. Laboratory studies have shown that hydrocarbon uptake with food by crabs does not accumulate but is eliminated in the feces (Lee et al., 1976).

D.3.f.2 Indicators of Exposure

Because shellfish are filter feeders or grazers and generally do not metabolize petroleum hydrocarbons, measurement of body burdens is very appropriate for documentation of oil exposure.

Indicator of Exposure	Measurement Methods
Direct oiling of external parts	Visual observations of oil on beds or individual animals; photographic or video documentation; oil samples for fingerprinting.
Petroleum hydrocarbons in tissue	Analysis of tissues from live organisms for petroleum hydrocarbon content and fingerprinting the oil to identify its source.
Tissue damage	Specimens from affected habitats preserved for histological examination (Huggett et al., 1992).

D.3.f.3 Injury

The physiological indicators of stress in shellfish, especially molluscs, have been well documented (Scott et al., 1984). Sublethal effects of oil exposure include depressed feeding, changes in respiration rates (both decreases and increases), reduced growth, decreased gonadal condition, tissue necrosis, and behavioral changes such as decreased burrowing and slower tactile response (Scott et al., 1984). Injury assessment methods for shellfish are summarized below.

Mortality. Shellfish may be directly and acutely killed by coming into contact with toxic levels of oil in the water column or being smothered by oil stranded on intertidal shellfish beds. Quantification of the number of individuals or percent of a specific population killed is accomplished in a variety of approaches, depending upon the species type, habitat, and life stage affected. Concentrations of juvenile and adult animals in the water column are usually too patchy for trawling to be of value. Quantification of impacts to planktonic life stages are often difficult to detect, but plankton tows can be used to observe whether post-larvae are generally normal or moribund. Pots can be used for benthic species (lobsters, crabs, large shrimp) to detect differences in abundance in comparable oiled and unoiled areas. Viability of eggs on gravid females can be measured on captured animals.

Where affected animals are stranded onshore (e.g., the *North Cape* oil spill in Rhode Island where large numbers of moribund lobsters and surf clams were washed ashore), systematic counts of the number of stranded animals using quadrats and/or transacts can provide the basis for calculating the minimum mortality.

For infaunal species such as clams and scallops, changes in density and abundance can be estimated from sediment cores, though large numbers of cores may be needed to provide statistically significant results. Mortality to epifaunal species, such as oysters and mussels, can be assessed through direct count, using quadrats or transects.

Reduced Abundance and Diversity. Changes in the number of species resulting from an incident can be measured by comparing pre- and post-incident abundance at the same sites, or paired oiled and unoiled sites where pre-incident data are not available and the paired sites are comparable (Hilborn, 1993). Abundance is measured using standard shellfish survey techniques such as trawls and tows for shrimp, capture in pots for crabs and lobsters, benthic cores for clams and scallops, and surface quadrat/transect counts for abalone, oysters, mussels, gastropods, and chitons.

Where population-level changes are difficult to measure directly, a biological-effects model in conjunction with a population model may be used. Biological effects are derived from exposures estimated from a physical fates or water quality model for the incident conditions and toxicity test data (either from the literature or using local communities and the discharged material). Exposure concentrations and conditions are used to calculate mortality rates and sublethal effects. These effects are then applied to data on species abundance and structure to quantify impacts. The DOI Type A model uses this approach to calculate the mortality and lost weight for shellfish resulting from exposure to toxic fractions of the oil, as well as reduced recruitment and lost productivity (French and Reed, 1993).

Reduced Reproduction. Study methods to measure reduced reproduction under both laboratory and field conditions include reduced egg viability and hatchability (Rice et al., 1983), reduced spawn settlement rates, and changes in spawning patterns (Houghton et al., 1992).

Shellfish Tainting. Because many types of shellfish bioaccumulate petroleum hydrocarbons, tissue contaminations can reach levels where consumption poses a health risk or tainting affects taste and/or smell. Although there are no food safety standards specifying a maximum contaminant level for oil or petroleum hydrocarbons in seafood, guidelines followed in the past state that if the seafood tastes or smells oily, it is not safe to eat. Tainting is as much a perception problem as a real risk. Fear of tainting can result in loss of natural resource services as serious as actual tainting.

D.3.f.4 References

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D.4 Biological Natural Resources - Habitats

D.4.a Wetlands

D.4.a.1 Sensitivity to Oil Impacts

The wetlands habitat includes salt and fresh water wetlands of all types, namely mangroves and marshes, forested swamps, floating vegetation, and wet tundra. Most information regarding the impact of oil on wetlands comes from studies of oil impacts on the vegetation of coastal tidal estuaries. Most of the studies have been of marshes dominated by *Spartina alterniflora* and mangroves dominated by *Rhizophora mangle*. Based on the available data, there are significant differences in the degree of impact of oil among species assemblages. Although every incident is unique, there are several factors that affect the behavior and impact of oil on wetlands.

Impacts by Oil Type. Light refined products (e.g., No. 2 fuel oil) have the greatest acute toxicity to all types of vegetation, but have shorter persistence and a lower likelihood of sediment contamination. For herbaceous vegetation, crude oils and intermediate refined products show mostly medium-term impacts, a higher tendency for sediment contamination, and recovery within 1 to 5 years (Alexander and Webb, 1983; Baca et al., 1983; Bender et al., 1980; Michel, 1989). In contrast, heavy crude and refined oils can severely affect mangroves, where toxicity results from coating of the roots which prevents gas exchange (Getter et al., 1984). Impacts can last up to 20 years, until the mangrove returns to a mature forest habitat.

Extent of Vegetation Contamination. Many plants can survive partial oiling. Few survive when all or most of the above-ground vegetation is coated (Alexander and Webb, 1983; 1985; Baker, 1971).

Degree of Sediment Contamination. The degree of contamination of sediments can prolong impacts to marsh ecosystems for many years, compared with the initial loss of oiled vegetation. Slower recolonization rates are frequently related to hydrocarbon levels in the sediments, though the composition of the oil is as important as the total petroleum content (Alexander and Webb, 1987). Studies of a large incident in Panama showed that chronic oiling from oil slowly released from sediments had significantly reduced recolonization by mangrove prop root communities for five years (Burns et al., 1993).

Physical Setting. The relative degree of exposure to waves and currents is one of the most important factors controlling the persistence of oiled vegetation and overall rate of recovery. Exposure to waves and currents usually works to enhance recovery, but in some cases it can also work to increase erosion after plant roots die and before new growth can occur. Many isolated freshwater wetlands have little or no exposure to physical removal processes and are thus susceptible to long-term oil persistence and effects.

Seasonal Effects. The timing of an incident relative to the growing season can affect the nature and duration of the impact. In general, oiling during the dormant season has the lowest impact, whereas oiling of vegetation during the growing season will likely have longer effects (Baker, 1971). Mechanisms responsible for the slower recoveries during the growing season have not been extensively studied, but probably are related to plant stress and food reserves at a time when the plant's resources are being fully expended (Mendelssohn, 1993, personal communication).

Species Sensitivity. Although there are limited data, annuals may be more sensitive than perennials because annuals have small root systems and low food reserves, whereas perennials are able to regenerate from underground rhizomes (Baker, 1979). However, annuals tend to be the first recolonizers (Getter et al., 1984).

Effects of Cleanup. During response activities, the vegetation and substrate can be trampled and the oil can get mixed deeper into the substrate, extending the injuries both in degree and duration. Trustees also need to protect vegetation from trampling during injury assessment studies.

D.4.a.2 Indicators of Exposure

Exposure can be documented through both visual and chemical measures. The extent and degree of oiling on vegetation and in the substrate are important variables in quantification of the injury. Indicators of exposure are listed below:

Indicator of Exposure	Measurement Methods
Extent and degree of oil contamination on vegetation and substrate, and disturbance by trampling	Aerial and ground surveys for systematic, visual estimates of the areal extent and degree of oil adhering to vegetation and substrate; photographic/video documentation, using standardized terminology (Owens and Sergy, 1994); summary statistics on the total acreage of injured wetland habitat by degree of oiling and trampling categories.
Contamination of biotic and abiotic components	Collection of samples for chemical analysis to measure petroleum hydrocarbons levels; to identify the source of the contamination; and to characterize the degree of weathering.

D.4.a.3 Injury

Injury assessment studies of past incidents have concentrated primarily on injury to vegetation. An injury assessment should generate data on severity of injury, total acreage of injured wetland, and duration of the injury. It is important that field study designs consider the effect that other environmental factors may have on plant recovery including changes in salinity (Winfield and Mendelssohn, 1994), water level, or temperature. Detailed field methods for assessing oiled marshes are provided in Mendelssohn et al. (1990) and Michel et al. (1994). Field methods for study of oiled mangroves are provided in Getter et al. (1981), Getter and Ballou (1985), Garrity et al. (1994), and Levings and Garrity (1995). Injury assessment methods for wetlands are summarized below.

Percent Live and Dead Cover. To quantify injury to vegetation, estimates of the percent live and dead cover or trees can be made along transects or in randomly located quadrats in each category of oiling (as determined from aerial mapping). Transects can be used where it is important to consider topographic controls. Using fixed transects and quadrats allows better control for long-term monitoring of changes in cover. Ground stations can be used to verify estimates of vegetation die-back or stress measured from aerial photography.

Species Abundance and Diversity. Abundance may be recorded at the species level so that temporal changes in species composition can be monitored. Such studies are important when there is a potential for re-colonization of oiled areas by pioneering species, which might not be detected by simple live/dead cover or biomass assessment methods.

Reproductive Status or Potential. At selected sampling sites along transects or in quadrats, quantitative measurements of the reproductive status of the plants can be recorded for comparison of oiled versus reference sites. For mangroves, seedling density and condition are sensitive indicators.

Above-ground Biomass. Net above-ground effect on production is determined by counting the number and height of all stems within quadrats (Morris and Haskins, 1990). Estimates of individual stem biomass can be accomplished by harvesting the vegetation from selected quadrats within the marsh.

Observations of Effects on Marsh Fauna. It is important to make systematic observations on obvious effects on dominant marsh fauna. Observations include the presence/absence of organisms, qualitative estimates on relative abundance, visual extent of oil contamination, and behavioral observations. If a more rigorous assessment of impacts to marsh fauna is appropriate, methods to use can be found in the section on shoreline communities (B.4.4).

Net Erosion. Along exposed shorelines, there is a risk of shoreline erosion after the oiled vegetation dies back. Stakes can be placed landward of the shoreline and the distance to the shoreline measured at regular intervals (Michel et al., 1994). Only under extreme erosion conditions can shoreline changes in wetlands be detected using sequential aerial photography.

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D.4.b Submerged Aquatic Vegetation

D.4.b.1 Sensitivity to Oil Impacts

Submerged aquatic vegetation (SAV) includes rooted vascular plant species that grow primarily below the water surface in both fresh and salt water (e.g., water lilies, eel grass, surf grass, manatee grass, kelp). SAV is considered to be highly sensitive to oil impacts because of its high productivity, key role in nutrient cycling, and value as nursery, foraging, and sheltering habitats for many endangered and commercially and recreationally important species. However, SAV is not as vulnerable as intertidal vegetation because it is mostly subtidal and less likely to be in direct contact with floating oil slicks. Oil effects on SAV habitats as discussed in Zieman et al. (1984) are summarized below:

- Greatest impacts occur on SAV that is on the water surface or in the intertidal zone, where the oil comes in direct contact with exposed blades.

- Oil readily adheres to exposed blades, particularly when the oil is heavy or weathered.

- Oiled SAV quickly defoliates but the plants have the capacity to grow new leaves (the leaves grow from a relatively protected meristem) in a relatively short period of time unless the sediments also are oiled. Recovery can occur with 6-12 months.

- Plant mortality has been observed during incidents when the sediments were contaminated by oil although such incidents have been rare.

- The most sensitive component of the SAV ecosystem is the epiphytic community and juvenile organisms that utilize the grass beds as a nursery. These species and life stages can be highly sensitive to both the water-soluble and insoluble fractions of oil.

- The plants can uptake hydrocarbons from the water column and sediments, potentially lowering their tolerances to other stresses.

D.4.b.2 Indicators of Exposure

Exposure can be documented through both visual and chemical measures. Degree of oiling on vegetation and in the substrate is an important variable in quantification of the injury. Oiled seagrass blades are quickly sloughed off, so early surveys are needed to document exposure. Indicators of exposure are listed below:

Indicator of Exposure	Measurement Methods
Direct oiling of vegetation	Visual estimates of the areal extent and degree of oil on blades/leaves; photographic or video documentation; sampling of oiled vegetation to fingerprint the oil and characterize oil weathering. For kelp, maps of distribution of oil slicks in kelp beds over time.
Oil contamination in sediments and water	Collection and analysis of sediment from below and water samples from above the SAV beds. Oil stranded on adjacent shorelines may be a chronic source of exposure.

D.4.b.3 Injury

Most injury assessments focus on injury to the SAV bed itself because it is the basis for a highly productive ecosystem. An injury assessment should generate data on severity of injury, total acreage of injured SAV, and duration of the injury. Careful site selection for oiled and reference sites is particularly important for seagrass beds, to make sure that they have similar physical settings in terms of current and wave energy, substrate type, water depth, and so forth. In some cases, it may be important to demonstrate similarity of oiled and reference sites by continuing the evaluation of injury over time until natural recovery has progressed and the measured parameters converge. An excellent source for seagrass assessment methods is Phillips and McRoy (1990). Injury assessment methods for SAV are summarized below.

Biomass. Measurements of biomass can have extremely high variability, thus many replicates per site may be needed to support statistical analysis. Although the standing crop of leaves is significant, the majority of the biomass is in the rhizomes and roots, thus both above- and below-ground biomass measurements are important. Above-ground biomass can be measured by repeated clipping of the leaves (Kenworthy et al., 1993). Below-ground biomass can be measured from cores.

Species Abundance and Density. Many SAV beds follow standard successional sequences (Zieman, 1982) that result in beds dominated by a single plant species. Frequently the successional steps are reset by perturbations or environmental conditions such that the climax is not reached. Thus, relative species abundance is generally not useful in detecting oil effects. Instead, it is used to characterize the seagrass habitat in general. Relative abundance and density most frequently are measured using standard quadrat counting methods at randomly located sites. The high natural variability in SAV cover will likely require many replicates to determine differences among sites.

Growth Rates. Sublethal effects of oil exposure can result in reduced productivity and growth rates. Short-term growth of leaves can be measured by perforation with a needle at the base of shoots in quadrats and measuring growth over a time period usually of days to weeks (Thom, 1990). Eventually the leaves can be harvested to measure growth in terms of leaf area and dry weight. Long-term growth can be measured by tagging rhizomes at the base of the most recent shoot, then returning months later to collect the tagged segments and any new growth (Houghton et al., 1992). Reduction in flowering shoot density has been reported for several incidents and may be a sensitive indicator of exposure (Houghton et al., 1992; Dean et al., 1994).

Morphological Measures. Leaf area index, the ratio of leaf area to substrate surface area, provides an estimate of secondary surface area available for epibiota, habitat complexity, and photosynthetic potential (Evans, 1972). Short-shoot and leaf-pair densities may be a better indicator of biomass where there are large seasonal fluctuations in standard biomass measurements (Kenworthy, 1992).

Physiological Measures. Sub-lethal effects of oil on seagrasses can be measured by changes in the photosynthesis and respiration rates of exposed plants. Durako et al. (1993) used photosynthesis versus irradiance (i.e., radiant flux density) responses of leaf tissues exposed to oil to assess oil toxicity to seagrasses. Such laboratory experiments may be needed to link the injury to exposure for the specific oil type and seagrass species.

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D.4.c Tropical Reef Ecosystems

D.4.c.1 Sensitivity to Oil Impacts

Tropical reefs are highly productive ecosystems that experience long-term natural fluctuations as well as a wide range of responses to man-made disturbances. There have been relatively few studies of reefs following exposure to incidents involving oil. Loya and Rinkevich (1980), Ray (1980), and Tetra Tech (1982) compiled data on the effects of oil on coral reef communities for fifteen incidents. These studies looked only at acute impacts. Some sublethal work on coral reefs is documented in Fucik et al. (1984).

Long-term studies by Cubit et al. (1987), Guzman et al. (1991), and Guzman and Holst (1993) of the 1986 Texaco incident in Panama reported delayed and extensive patterns of injury to shallow coral reefs 2.5 to 5 years after the incident. The extent and degree of injury to coral reefs were related to chronic exposure as oil leached out of adjacent mangroves for years. A recent consolidation and overview of oil impacts on coral reefs was published by IPIECA (1992).

The sensitivity of coral reef ecosystems to episodic incidents can be divided into three categories:

<u>Highly Sensitive</u>

- Intertidal reefs and reef flats, where direct contact with the oil is likely.
- Sheltered, shallow water settings where high concentrations of dissolved and particulate oil are likely to persist.
- Areas where oil leaching from adjacent areas creates chronic oil exposures.
- Areas where coral reefs already are stressed by pollution, sedimentation, thermal problems, etc.

<u>Moderately Sensitive</u>

- Reefs located in water depths of 1-5 m below low water, where high levels of dissolved or particulate oil are possible, especially when the oil is fresh.
- Partially-sheltered locations where oil mixed into the water column can cause exposure for up to a few days.

Less Sensitive

- Reefs located at greater than 5 m water depth at low tide; dilution can reduce oil levels in the water column to below acute toxicity levels.

- Highly flushed settings where fresh oil could mix into the water column, but exposure is more likely to be short (hours to days).

- Healthy subtidal reefs that are likely to recover from short-term exposures within days or weeks after oil exposure.

D.4.c.2 Indicators of Exposure

Exposure can be documented through both visual and chemical measures. Oil stranded on adjacent shorelines may be a chronic source of exposure with greater long-term impacts than acute exposures during the incident event. Indicators of exposure are listed below:

Indicator of Exposure	Measurement Methods
Direct contact of reef with whole oil during low tide	Visual estimates of the areal extent and degree of oil adhering to or in direct contact with reef structure; photographic or video documentation; sampling of oiled material to fingerprint the oil and characterize oil weathering.
Direct contact with the water-accommodated fraction (both dissolved and dispersed oil)	Observations, maps, and photographs showing the presence of oil slicks in the vicinity of reefs; water samples to measure the amount of oil in the water column; computer models that calculate the water-column concentrations of oil expected in the vicinity of the reef.
Physical destruction of the reef (e.g., ship grounding)	Observations, maps, and photographs showing the extent of damage to the reef.

D.4.c.3 Injury

The focus of the injury assessment is often on the reef-building community, which is the structural basis for the reef ecosystem. It is important to note, however, that corals are not always the primary components of the tropical reef ecosystem. Calcareous red and green algae are often the dominant cover. In addition some organisms, such as sponges, may be better indicators of oil effects.

Brown and Howard (1985) review methods for assessing the effects of stress on coral reefs, many of which are applicable to injury assessment. For oil, short-term mortality is expected from physical destruction or direct exposure. Thus, the emphasis is on measures of sublethal effects that can be used to estimate the degree, areal extent, and duration of injury. It is important to document the degree and frequency of oil exposure and to stratify sampling sites according to degree and type of exposure. Injury assessment methods for coral reefs are summarized below.

Percent Cover. Quantitative methods for assessing cover can be conducted using the line-transect (point) method or the quadrat method (Weinburg, 1981). If pre-incident data are available, using the same methods as those in the previous surveys improves the strength of before-after comparisons. Fixed transects often are recommended over random ones, so that repeat surveys can confidently identify shifts in zonation. When using the point method, it is important to record what is directly under (and over, for branching corals) the point. There is a wide range in oil sensitivity among coral species that is not well known or understood.

Within the reef ecosystem, some organisms may be more abundant and at greater risk to oil impacts, such as sponges. Cover and abundance measures for these organisms should be included along the transects.

Tissue Injury Rates. Measurements of tissue injury for all sessile organisms on the reef can include lesions, necrosis, and morbidity. In general, there is a high background injury rate on reefs which should be defined. Injury categories should be objective and standardized among observers.

Growth Rate. Changes in growth rates result from a variety of physiological processes, thus growth rate can be a good indicator of oil-induced stress. However, growth rates are inherently variable among species and within a single species, requiring a large number of samples. Gladfelter et al. (1978) describe methods for measuring growth rates in the field using x-radiography for massive corals or stain markings on branching corals, as well as radioisotope dating and weighing of specimens. For sparse reefs, collecting samples for analysis can cause extensive injury to the reef. To link reduction in growth rates to health of the reef, it may be necessary to monitor direct physiological measures of injury, such as reduced reproduction.

Expulsion of Zooxanthellae. Expulsion of zooxanthellae (or bleaching) following exposure to oil has been found both in the laboratory and following spills (Birkelund et al., 1976; Neff and Anderson, 1981). Documentation of bleaching following a discharge may be evidence of short-term exposure and response.

Reproduction Rates. Guzman and Holst (1993) were able to detect reductions in gonad size of reef corals at oiled versus unoiled reefs five years after the Panama (1986) incident. They suggest that female gonads (eggs) can be the easiest method to measure changes in reproduction rates for gonochoric coral species. However, because reef sampling is destructive and sample preparation and analysis is very time-consuming and expensive, this technique is only applicable to those species for which the reproductive cycle has been previously studied. Another approach is to measure recruitment on settling plates or natural surfaces in oiled and non-oiled areas in similar habitats and time periods.

Other physiological and histopathological parameters, including mucous production, algal invasions, bacterial infections, other diseases, and reductions in metabolism, could be used to assess injury. There is little baseline information by species, however, and in general there is high natural variability in these parameters (Brown and Howard, 1985). In addition, corals exhibit these responses for a wide range of stresses that are not well understood.

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D.4.d Shoreline and Riparian Communities

D.4.d.1 Sensitivity to Oil Impacts

This grouping of shoreline communities includes all biological communities associated with shoreline and riparian habitats, including estuarine and marine intertidal zones and riverine and lacustrine shorelines, from arctic to tropical settings. Habitats include rocky shores, sand beaches, gravel beaches, tidal flats, vegetated banks, wetlands, and man-made structures. These habitats are often severely injured when oil strands on the shoreline. There have been numerous studies on the effects of oil on these habitats. Some events such as the *Torrey Canyon* incident in 1967 have been studied for over 20 years (Hawkins and Southward, 1992). Ganning et al. (1984) summarized the literature on the effects, recovery, and restoration of oiled shoreline ecosystems, mostly marine. They summarized numerous studies on acute and sublethal effects, but none on coating or habitat alterations. They concluded that it was difficult to generalize the impacts of an oil discharge because of the wide range in environmental factors controlling both the fate of the oil and community behavior. In particular, there is not a great deal of information on which to predict oil impacts to riparian habitats.

D.4.d.2 Indicators of Exposure

Exposure can be documented through both visual and chemical methods. Visual observations of the presence of oil are most important during the early phases of an incident, whereas chemical measures are valuable for documenting chronic and low-level exposures. Indicators of exposure are listed below:

Indicator of Exposure	Measurement Methods
Extent and degree of oil contamination on the substrate	Aerial and ground surveys to make systematic, visual estimates of the areal extent and degree of oil adhering to the shoreline substrate, using standardized terminology and methods (Owens and Sergy, 1994;); photographic or video documentation of visual observations; sampling of oiled substrate to fingerprint the oil and characterize oil weathering; summary statistics on the total distance of oiled shoreline by degree of oiling categories.
Sediment contamination	Collection of sediment samples for chemical analysis to measure the level and type of petroleum hydrocarbons present.
Levels of petroleum hydrocarbons in tissue	Collection of tissue samples, usually from organisms that are known to uptake and concentrate petroleum hydrocarbons, such as bivalves and gastropods.

D.4.d.3 Injury

Assessment of injury to shoreline communities is most often conducted through field measurement of population parameters and statistical analysis of the data. The primary goal is to document the community response to oiling over time by establishing enough permanent plots within the study area to quantify the changes in the measurement parameters. Study design is extremely important to being able to detect oil-related changes. It may be important to classify stations according to the degree of contamination, exposure to wave and tidal energy, habitat, elevation, and type of clean up conducted at the station. Most communities undergo complex successional stages that need to be considered in sampling design and data interpretation. Repetitive surveys should be scheduled consistently, coinciding with reproductive events or maximum development, if possible.

Another alternative is to use previously established stations (Mussel Watch, State or University long-term monitoring sites, etc.) located in the area of impacts. These sites can provide historical data on population compositions and natural variations. In addition, the Minerals Management Service is currently (1995) funding a research program to develop detailed guidelines for injury assessment studies of rocky intertidal coasts. These guidelines should have broad applicability to all shoreline habitats. Injury assessment methods for shoreline and riparian communities are summarized below.

Percent Cover and Species Abundance and Diversity Indices. Methods for measuring these community parameters are described in Littler and Littler (1985) for algae, Baker and Wolff (1987) for many different communities, Cubit and Conner (1993) for reef-flat communities, Zeh et al. (1981) and Moore and McLaughlin (1978) for intertidal communities, and Holme and McIntyre (1979) for coring of benthic fauna. Depending on the site conditions, transects are set up either parallel or perpendicular to the shoreline. Along the transects, quadrats are located either randomly or at fixed distances. Estimates of percent cover and other parameters within quadrats can be made visually or by using systematic or random point contact methods. Dethier et al. (1992) indicated that visual estimation of percent cover by experienced biologists was more accurate and precise, especially for rare species, than 50 or 100 point contact methods.

Growth Rates. Growth can be a very sensitive indicator of on-going sublethal effects on shoreline communities, either directly from contamination or indirectly from reductions in the food base. Growth is studied by collecting animals from classified sites and measuring length and/or weight at selected intervals. To improve the precision of the data, individual specimens can be tagged for re-collection and measurement. Specimens with shells can be evaluated by measuring increments between growth rings in the shell, tagging the shell chemically with a fluorescent dye (calcein) that binds with calcium, or taking repetitive measurements of shell length of individual organisms (Houghton et al., 1992). Transplanting experiments can be used to document injury and potential recovery at oiled sites (Houghton et al., 1994). For plants, growth rates can be determined by marking or tagging individual plants for repetitive length measurements over time.

Reproductive Condition. There are several methods for measuring reproduction, depending upon the species and reproductive mechanism. For species that broadcast eggs or seeds, plates can be set out to compare the settling rate in oiled versus unoiled sites. For attached plants or sedentary animals, visual estimates or counts can be made of the percent or number of the species that are in a reproductive stage.

Biomass. Nearly all methods of measuring biomass require destructive sampling, that is, all biota in a specific area are removed for analysis in the laboratory (Littler and Littler, 1985). Epifauna are scraped from the surface. Infauna can be field-sieved and preserved (Holme and McIntyre, 1979). Larger organisms can be hand-sorted, identified, and measured or weighed in the field. In the laboratory, the samples are sorted, identified to the lowest practical taxonomic level, and counted.

Species Behavior. Field observations can be made of behavior including response to tactile stimuli, gapping shells, re-attachment rates, righting ability, reactor muscle function, and so forth.

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D.4.e Benthic Ecosystems

D.4.e.1 Sensitivity to Oil Impacts

Benthic ecosystems include underwater habitats not addressed elsewhere:

- Subtidal rocky reefs and sand/mud bottoms; and
- Lake and river unvegetated bottoms.

For most incidents benthic ecosystems are usually at much less risk of significant exposure to oil. Benthic ecosystems are at risk when oil sinks, either because it is heavier than water initially, or because the oil picks up enough sediment to cause it to sink (Michel and Galt, 1995; Michel et al., 1995). Under these conditions, benthic resources can come in direct contact with heavy amounts of oil, with significant injuries.

Oil also can contaminate benthic habitats through the deposition of oil-contaminated sediments, mostly sand and mud. Extensive contamination of subtidal sediments has been documented for only the *Florida* barge in Buzzards Bay (Sanders, 1978; Sanders et al., 1980), the *Amoco Cadiz* off the coast of Brittany, France (Cabioch et al., 1982), the *Exxon Valdez* in Prince William Sound (O'Clair et al., 1993; Jewett and Dean, 1993), and the *Braer* off the Shetland Islands (Ecological Steering Group, 1993). With the exception of the *Exxon Valdez*, these incidents occurred during extremely high wave energy conditions in shallow water, where both oil and fine-grained sediments were mixed into the water column in the nearshore zone. During the *Exxon Valdez*, high-pressure washing of oil from the shoreline during the summer months probably mobilized oil and fine-grained sediment for mixing and deposition in shallow offshore areas. It appears that somewhat unique conditions are required before large-scale contamination of benthic habitats by oil is likely to occur. Muddy sediments are more likely to be contaminated than rocky reefs or even sandy bottoms where the substrate undergoes some reworking by currents and/or waves.

D.4.e.2 Indicators of Exposure

Exposure can be documented through both visual and chemical methods. Visual observations of the presence of oil in benthic habitats are difficult and feasible only under heavy oiling conditions. More commonly, samples are taken for chemical analysis or toxicity testing to document the presence of oil in these habitats. Indicators of exposure are listed below:

Indicator of Exposure	**Measurement Methods**
Extent and degree of oil contamination of the substrate	Sampling of sediments to quantify the amount of oil contamination, fingerprint the oil, and characterize oil weathering. Sampling methods include the use of sediment coring devices (USEPA, 1984; PSEP, 1991) or hand-held diver-collected cores.
Sediment toxicity	Collection of sediment samples for bioassays to demonstrate the presence of toxicity (Chapman, 1988). These tests provide information that is independent of chemical characterization and ecological surveys.
Levels of petroleum hydrocarbons in biota tissue	Collection of tissue samples, usually from organisms that are known to uptake and concentrate petroleum hydrocarbons, such as bivalves.

D.4.e.3 Injury

Assessment of injury to benthic ecosystems is conducted with field measurements of population parameters and statistical analysis of the data (Zeh et al., 1981). The primary goal is to document the community response to oiling over time by collecting enough samples within the study area to quantify the changes in abundance, density, diversity, and so forth. It is important to classify stations according to substrate type and degree of exposure to wave and current energy. Injury assessment methods for benthic communities are summarized below.

Mortality. Where large-scale mortality of benthic organisms is expected, divers can make observations on the extent and relative abundance of dead organisms along transects using video cameras to document these observations.

Benthic Species Abundance and Diversity Indices. Coring methods for measuring community parameters for benthic fauna are described in Holme and McIntrye (1979). Divers can census epibiota along transects using methods similar to those described for shoreline ecosystems. Rapid bioassessment techniques are useful as quick screening tools to determine if there is a need for more detailed, quantitative surveys. For example, the USEPA has published rapid bioassessment protocols for use in streams and rivers for benthic macroinvertebrates and fish (Plafkin et al., 1989).

Biomass. Infauna samples are collected from sediment grabs or dredges, field-sieved, and preserved (Holme and McIntrye, 1979). Larger organisms can be hand-sorted, identified, and measured or weighed in the field. In the laboratory, the samples are sorted, identified to the lowest practical taxonomic level, and counted.

Growth Rates. Growth is studied by collecting animals from specific locations and measuring length and/or weight at selected intervals. Specimens with shells can be evaluated by measuring increments between growth rings in the shell, tagging the shell chemically with a fluorescent dye (calcein) that binds with calcium, or taking repetitive measurements of shell length of individual organisms (Houghton et al., 1992). Transplanting experiments can be used to document injury and potential recovery at oiled sites (Houghton et al., 1994). For shoreline communities, growth rates can be determined by marking or tagging individual plants for repeat length measurements over time. For macroalgae, stipe diameter may be a good indicator of length and weight of each plant (Dean et al., 1993).

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D.4.f Terrestrial Ecosystems

D.4.f.1 Sensitivity to Oil Impacts

This category includes all terrestrial ecosystems, with emphasis on the most sensitive types including dry tundra, taiga, temperate grasslands, and tropical rain forests. Because of extensive development of Arctic and subarctic oil fields, there have been more studies of the effects of oil on tundra and taiga environments compared to the other types (McCown and Simpson, 1973).

Tundra and taiga soils are highly sensitive to both the physical and chemical effects of oil and to response activities (Linkins et al., 1984). Studies of experimental and accidental incidents have found extremely slow weathering rates for oil that had penetrated below the surface in arctic and subarctic soils. Slightly weathered oil was still present fifteen years after an experimental incident in taiga soils in interior Alaska (Collins et al., 1993). Three factors contribute to the long-term effects of oil in these habitats:

- Very low plant productivity and recycling of nutrients because of the short growing season, limited nutrients, and acid, organic soils;
- Slow weathering rates of stranded oil; and
- Severe access limitations, particularly in summer when physical destruction from access is unavoidable and extensive.

In general, oil impacts to terrestrial ecosystems are a function of the following factors.

Depth of Penetration. In terrestrial environments incidents usually occur as point discharges on the surface and subsurface, where penetration is a function of soil permeability; and as aerial spray, which usually causes low soil penetration. Deep penetration into soils (particularly tundra, peat and gravel soils) will likely slow the rate of weathering, and increase the duration of acute and chronic toxicity.

Potential for Temperature Change. Oil can significantly affect the soil temperature, especially in arctic and tropical settings. In arctic settings, the ground surface heat flux can be modified because albedo is decreased, leading to surface heating, solar radiation flux is increased by death of the canopy, thermal diffusivity changes because of the oil, and the organic layer is less insulative where the vegetation has died (Mackay et al., 1975). Elevated soil temperatures in arctic settings can melt permafrost, which can lead to permanent soil compaction and subsidence of the surface (Collins et al., 1993). In tropical settings, decreased albedo and die-back of the canopy can cause soil heating, dehydration, and reduced viability (Kinako, 1984).

Changes in Water-holding Capacity. One of the more important effects of oil on soils is a reduction in their water-wettability, making the soil hydrophobic (Schwendinger, 1968). Contaminated soils often resist wetting, reducing the amount of water available for uptake by plant roots.

Potential for Anaerobic Conditions. Oiled soils can have an increased oxygen demand, which leads to anaerobic conditions in soils with low oxygen permeability. Microbial degradation rates are extremely slow under anaerobic conditions, leading to longer oil persistence and effects.

D.4.f.2 Indicators of Exposure

Exposure can be documented through both visual and chemical methods. Visual observations of the presence of oil are most important during the early phases of the discharge, whereas chemical measures are valuable for documenting chronic and low-level exposures. Indicators of exposure are listed below:

Indicator of Exposure	**Measurement Methods**
Extent and degree of oil contamination and trampling on vegetation and soils	Aerial and ground surveys to make systematic, visual estimates of the areal extent and degree of oil adhering to vegetation and on/penetrated into soils using standardized terminology (Owens and Sergy, 1994); photographic or video documentation of visual observations; sampling of oiled soils and vegetation to fingerprint the oil and characterize oil weathering; summary statistics on the total acreage of each habitat by degree of oiling and trampling categories.
Soil contamination and toxicity	Collection of soil samples for chemical analysis to measure the levels of petroleum hydrocarbons present and toxicity.

D.4.f.3 Injury

Injury assessment studies of past incidents have concentrated on injury to vegetation. The objective is to quantify the injury in terms of reductions in the key measures of vegetation productivity and function and the areal extent and duration of the injury. These reductions can be translated into lost services and functions for valuable and sentinel species. Standard field methods for plant ecology studies can be used (e.g., Barbour et al., 1980). There have been many field studies of the effects of air pollution on vegetation that can be modified for oil pollution studies (e.g., Heck and Brandt, 1977).

Percent Live, Dead, and Stressed Vegetation. To quantify vegetation injury, estimates of the percent live, dead, and stressed vegetation can be made along transects utilizing a line-intercept sampling method. Transects are preferred because they provide topographic control. Using fixed transects allows better control for long-term monitoring of changes in cover. Alternately, study plots can be located in areas defined by degree of oiling and randomly located quadrats within each plot can then be used for making observations. Depending on the habitat, plant cover may need to be measured in three layers: canopy, understory, and herbaceous cover. Photography is important for documenting and supporting visual estimates or observations. Hemispheric photography and automated scanning of photographs can be used to determine percent canopy coverage (Anderson, 1964). Types of vegetation stress to be recorded include chlorosis, bronzing, marginal necrosis, leaf wilt, and leaf death. Ground stations can be used to verify estimates of vegetation die-back or stress measured from time-series aerial photography, using false-color infrared film (Murtha, 1978).

Above-ground Biomass. Net above-ground effects on production of herbaceous vegetation can be conducted by harvesting the vegetation from selected quadrats (subdivided into sections by degree of oiling) within the affected areas.

Growth. These measures may be valuable when particular species known to have high sensitivity to oil are present in the plant community. Under conditions of severe injury, each age class for key species can be studied using standard tree boring techniques, the diameter at breast height (dbh), and height measurements. These data can be used to calculate the time required for recovery to the pre-incident age structure in the affected area.

Seed Germination Success. For many species, stress is manifest as a reduction in reproduction. Comparisons between comparable oiled and unoiled study areas can be made of the percent of plants flowering and producing seeds, and seed viability. Seed germination studies can be conducted to determine the continued toxicity of soils and reduction in reproductive capability.

Net Erosion. Loss of vegetation could result in increased erosion, by wind or water. Sequential ground photography can be used to document sediment erosion following vegetation die-back. Seldom is erosion severe enough to detect using standard aerial photography. Erosion of stream banks can be monitored using standard topographic survey methods.

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