A Regional Multiple-Stressor Ecological Risk Assessment for Port Valdez, Alaska

Prepared by:

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The following organizations, located in Valdez, provided much of the local information for this report: Alaska Department of Environmental Conservation; City of Valdez Public Works; Nautilus Marine Inc.; Peter Pan Seafoods; Petro Star Refinery; Sea Hawk Seafoods; Solomon Gulch Hatchery; North Star Terminal and Stevedore Co.; Valdez Marine Terminal; Valdez Small Boat Harbor; and the U.S. Coast Guard.

The following organizations were contacted for both local and general information: Alyeska Pipeline Service Co.; Alaska Department of Environmental Conservation; Alaska Department of Fish and Game; Bureau of Land Management; Institute of Marine Science, University of Alaska; Oil Spill Public Information Center; U.S. Army Corps of Engineers; U.S. Coast Guard; U.S. Environmental Protection Agency; U.S. Fish and Wildlife Service; and the Yukon Pacific Co.

Contract Managers: Joe Bridgman, Prince William Sound Regional Citizens' Advisory Council
Carl Rutz, Alyeska Pipeline Service Company

List of Acronyms

ADEC	Alaska Department of Environmental Conservation
ADF&G	Alaska Department of Fish and Game
ADNR	Alaska Department of Natural Resources
APSC	Alyeska Pipeline Service Company
BLM	Bureau of Land Management
BWTP	Ballast Water Treatment Plant (Alyeska)
EcoRA	Ecological Risk Assessment
ET	Ecotox Threshold
LOAEL	Lowest Observed Adverse Effects Level
LTEMP	Long Term Monitoring Program
NAWQC	National Ambient Water Quality Criteria
NMFS	National Marine Fisheries Service
NOAA	National Oceanic Atmospheric Administration
NOAEL	No Observed Adverse Effects Level
NPDES	National Pollutant Discharge Elimination System
PWS	Prince William Sound
RCAC	Regional Citizens' Advisory Council
SERVS	Ship Escort and Response Vessel Service
U.S. ACE	U.S. Army Corps of Engineers
U.S. EPA	U.S. Environmental Protection Agency
U.S. FWS	U.S. Fish and Wildlife Service
USCG	U.S. Coast Guard
VFDA	Valdez Fisheries Development Association (Solomon Gulch Hatchery)
VMT	Valdez Marine Terminal
WWTP	Wastewater Treatment Plant (City of Valdez)

Risk Terminology

The following risk assessment terminology used in the report is consistent with the U.S. EPA's framework for ecological risk assessment (U.S. EPA, 1992) and the work of Suter (1993).

Stressor: Anything that is physical, chemical, or biological in nature which causes an effect to an organism or system. Initial stressors may result in secondary stressors, as in the case of excess nutrient input (initial stressor) causing mortality due to microbial activity and a decrease in oxygen (secondary stressors).

Source: An anthropogenic input or activity that releases or creates a stressor in the environment. The characteristics of a stressor may be influenced by the type of source.

Receptor: The organism or group of organisms that have the potential to be affected by a stressor.

Habitat: The type of environment in which the receptors are found. Receptors may live exclusively within a single habitat or may move between and use several habitats.

Exposure: The interaction of a receptor with a stressor. Exposure will result in a chemical dose, a physical disturbance, or a biological displacement of the receptor.

Effect: A change in the state or dynamics of an organism or other components of the ecological system resulting from exposure to a stressor. An indirect effect occurs when the initial effect results in additional stressors or effects to any component of the system.

Response: The effect of exposure to a stressor on a single organism.

Assessment Endpoint: An aspect of the natural system that is of value to society or the local community as well as important to the ecology of the system.

Measurement Endpoint: An effect that is measurable through a tool (*e.g.*, toxicity test or field survey) and can be used to link the effects of a stressor to the assessment endpoints.

Conceptual Model: Description of the effects that stressors have on the ecological components in the environment and the relationship with assessment endpoints.

Executive Summary

We have conducted an ecological risk assessment of the marine environment of Port Valdez, Alaska. Concerns about the environmental consequences of present and proposed activities in Port Valdez and about potential conflicts and incompatibilities among those activities have grown with development of the Port. These concerns led to an awareness that environmental management of Port Valdez is a complex task which can best be approached in a unified way. The Prince William Sound Regional Citizens' Advisory Council (RCAC) and the Alyeska Pipeline Service Company (APSC) have sponsored this regional ecological risk assessment to provide a factual basis for comparing the various environmental risks which must be managed in the Port.

This risk assessment was not performed in response to any specific regulatory action or policy decision. Rather it was intended to improve environmental management of Port Valdez by analyzing and ranking the various kinds of ecological risks from human activity in the Port. The resulting assessment was broad in scope and required the extension of the risk analysis paradigm to allow comparative risk assessment on a regional basis. The assessment relied on input from stakeholders through public meetings in Valdez, comments on preliminary drafts of this report, meetings with the principal stakeholders (RCAC, APSC, and state and federal regulatory agencies), and individual conversations with stakeholders, environmental scientists, and other knowledgeable individuals.

Following an introduction and description of methods, this report contains a detailed description of the Port Valdez marine environment (Sec. 3) based on data and technical information available in 1996. Section 4 describes the chosen assessment endpoints, those environmental features to which the assessment estimates risk. The report presents a conceptual model and its results in Sec. 5 and 6. The conceptual model depicts the set of relationships and procedures by which relative risk has been ranked in Port Valdez. In Sec. 7 we present information about widely accepted measures of environmental risk for some chemicals in the Port. This information serves to associate some of the relative risks ranked by the conceptual model with "acceptable" levels of environmental risk. Sections 8 and 9 present possible scenarios for potential risks to Port Valdez. The final section of the body of the report discusses the types and degree of uncertainty thought to be associated with this risk assessment. The report also includes a set of appendices which give detailed data, methods, and other background material.

In assessing ecological risk to this area, we developed a conceptual model that can help with prioritization of future studies, interpretation, or decision making in the Port environment. This model involves the division of the Port into sub-areas that contain specific ecological and anthropogenic structures and activities. The sub-areas used in this assessment can be thought of as units which are compared and analyzed to form a Port-wide perspective of ecological risk. Within each sub-area the sources of stressors are analyzed to estimate the extent to which they result in exposure of receptors within habitats which may lead to effects relevant to the chosen assessment endpoints. To evaluate these risks we developed a numerical analysis of the conceptual model: the Relative Risk Model. This analysis leads to a ranking of individual risks which are then summed to estimate relative risks within each sub-area, from each source, and to each habitat.

Our application of the model indicates that the highest relative environmental risk is found in the sub-area containing the Duck Flats and Old Valdez. Other shoreline areas in the eastern Port including both the City of Valdez and the Alyeska Marine Terminal are at moderate relative risk while the relatively undeveloped western shoreline and deep water environments are at low relative risk. Using the model to rank risk from various sources present in the Port indicated that contaminated runoff, accidental spills, construction and development, and shoreline activity present high relative risk. Vessel traffic and treated discharges pose moderate relative risk; and seafood processing and fish wastes, and salmon released from the hatchery present low relative risk to Port Valdez.

In order to confirm our ranking of chemical risks by more conventional analyses, chemical concentrations were compared to reference values generally considered to be low risk. This comparison could only be made in areas with sufficient chemical data. In sediments collected from 1992 to 1995 near the Valdez Marine Terminal, polyaromatic hydrocarbon (PAH) concentrations exceeded these values in 4 of 819 measurements. For samples collected in 1995 at the Small Boat Harbor, PAH concentrations exceeded the reference values on 11 of 36 measurements. Benzo[a]pyrene concentrations in mussels collected from 1992 to 1995 at Shoup Bay, Gold Creek, Sawmill Creek, and the Alyeska marine terminal were all below the reference value. A model used to estimate the risk of PAHs to marine invertebrates indicated low risk, with the boat harbor having the highest estimate. Biomonitoring tests using sediment organisms also have failed to detect effects due to chemical contamination. These studies confirm our predictions based on the ranking techniques.

Some possible risks to Port Valdez could not be adequately treated using the conceptual model. These risks include rare but potentially catastrophic events such as large oil spills and introduction of non-native species. Risks in Port Valdez about which data are totally absent, such as the risk posed by organotins from anti-fouling paints, cannot be addressed until data become available. Such risks are discussed in general terms emphasizing the key information needed for adequate risk assessment.

Substantial uncertainty is associated with this ecological risk assessment. The sources of this uncertainty include missing information, ambiguities in the available information, errors in the conceptual model, and errors in the estimate of relative risk. Uncertainty is lower at well studied locations like Alyeska's Valdez Marine Terminal and higher at less studied areas.

This risk assessment should serve as a working document such that any further data collected can be applied according to the conceptual model and ranked by the Relative Risk Model. To encourage use of this model for the evaluation of comparative risks in the future, we have enclosed a diskette with this report that contains the model in Microsoft Excel® format.

1.0 Introduction

The city of Valdez is a developing center of human activity in a largely undeveloped area of great natural value. Valdez is situated near the head of Port Valdez, a fjord in northeastern Prince William Sound (PWS) (**Figure 1-1**). With a population of about 9,000 Valdez is home to a major crude oil shipping terminal. Valdez also accommodates a commercial fishing fleet, serves as a base for recreation and tourism, and is home to many individuals with a deep interest in the quality of their environment.

Concerns about the environmental consequences of present and proposed activities, and about potential conflicts and incompatibilities among those activities, have grown with increasing development of the Port. These concerns have led to an awareness that environmental management of Port Valdez is a complex task which can best be approached in a unified way. In order to provide a factual basis for comparing the various environmental risks which must be managed in the Port, the Prince William Sound Regional Citizens' Advisory Council (RCAC) and the Alyeska Pipeline Service Company (APSC) jointly sponsored preparation of this ecological risk assessment (EcoRA). The regional scope of the project requires public involvement as well as cooperation with the private and commercial concerns in the community.

The goals identified for the Port Valdez risk assessment include the following:

1. Identify anthropogenic stressors and sources of stressors in the environment.
2. Identify effects that may result from the identified stressors.
3. Compare the identified risks to the environment.
4. Describe estimates of risk and uncertainty associated with these estimates.
5. Identify gaps in the level of understanding associated with impacts to the environment.
6. Provide a framework in which to address future concerns, management, and monitoring issues.

The basic principles of EcoRA were applied to the Port Valdez environment in order to accomplish these goals and address concerns about the Port. The resulting assessment provides a framework for understanding the anthropogenic role in environmental impacts in the area, as well as a format for integrating data collected for monitoring purposes. EcoRA is a relatively new technique in the environmental field which has evolved from damage and hazard assessment. This process seeks not only to identify anthropogenic effects and describe their

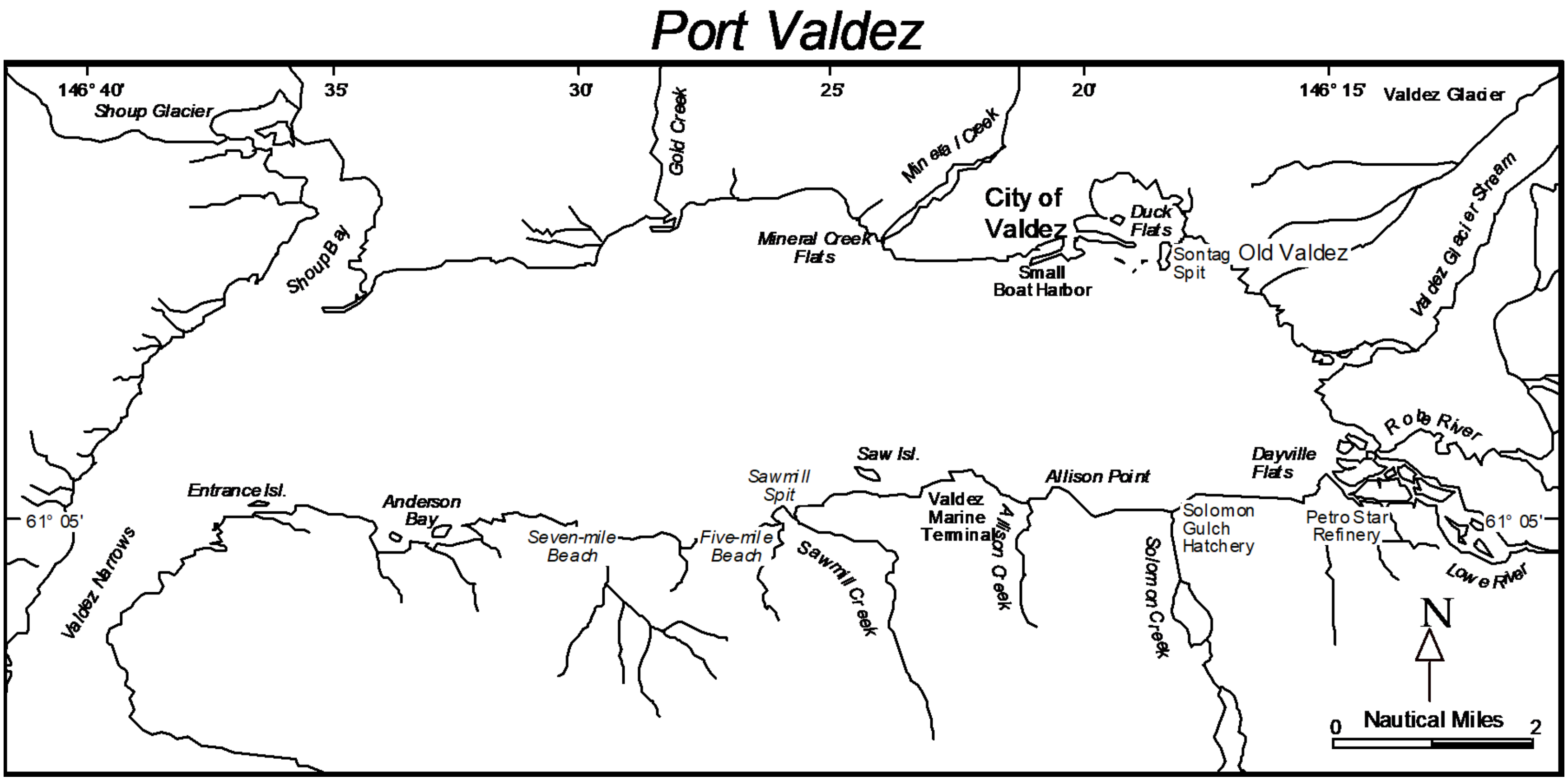


Figure 1-1. Map of Port Valdez study area.

impacts to the environment, but also to analyze the probability of an impact occurring and clearly define the uncertainty associated with this prediction. The EcoRA of Port Valdez, presented in this document, is based on guidance developed by the U.S. Environmental Protection Agency (U.S. EPA, 1992) and principles described in Suter (1993). In an area such as Port Valdez where potential exists for industrial growth and continued land development, risk assessment provides a basic tool for management. This risk assessment was structured to address public comments about environmental threats to the Port. As such it is a stakeholder-driven risk assessment and is not based on any current regulatory need or requirement.

The field of EcoRA is directed primarily at site-specific problems. The Port Valdez assessment applies to a region instead of a specific site. The regional approach requires modification of the guidances mentioned above to meet this larger scale. Our approach is to consider not only the direct stressors and the organisms affected by these stressors, but also the sources producing these stressors and the habitats on which the organisms depend. We have assessed the potential for adverse impacts to the marine environment of Port Valdez through comparison and ranking of various risks. This assessment is based on the types of habitat and the types of anthropogenic or man-made sources of stressors in the environment.

1.1 Basics of Risk Assessment

Perhaps the most basic definition of an EcoRA is “determining the probability of an adverse impact occurring to an ecological structure”. To assign a "probability" of risk, the assessment process incorporates estimations of the exposure and effects that result from a stressor or series of stressors coming into contact with organisms or the physical environment. These estimations are a measure of the chance of an adverse impact occurring.

Assessing risk depends on a number of factors that include the type of anthropogenic stressors and receptors found in the environment, the exposure of the receptor to a stressor, and its effect on that receptor. Risk is a combination of the exposure and the effect expressed as a probability.

A **stressor** can be a natural or anthropogenic substance, event, or energy field that causes positive or negative impacts on a biological system. Although many risk assessments apply specifically to the effects of chemicals, a wide range of stressors is possible. Rapid changes in temperature, earthquakes, introductions of non-native invasive species, or hatchery fish that spawn with natural fish stocks are all examples of stressors capable of causing environmental impacts. Once the stressor is released into the environment, a potential exists for receptors to encounter it. **Receptors** are organisms affected by the stressor. This effect may produce a negative impact (*e.g.*, a population reduction) or apparently positive impact to (*e.g.*, enhanced growth of an organism). It is important to note that effects having positive impacts on one species often have negative impacts on another.

A stressor poses no risk to an environment unless it interacts with a biological system. This interaction is called **exposure**. The size (*e.g.*, concentration, magnitude, abundance), frequency, and persistence of a stressor within the defined system all contribute to exposure. Exposure can be measured as the amount of the stressor in the environment or available to a receptor. Chemical exposure is best expressed as a dose, or the actual amount in an organism. The chemical concentration in plant or animal tissues is an estimate of the chemical dose. Changes in physiology or behavior can also provide an indication of dose. Often it is only possible to measure the concentration of the stressor in the environment. The dose to the receptor must then be extrapolated from this information. Different types of measurements are necessary for stressors that are of a physical or biological nature.

Hazard refers to the potential for a stressor to cause an undesirable change in an organism or a biological system. The **effect** caused by the stressor, or the **response** of a receptor, are measurable components of hazard. Toxicity, mutagenicity, and the displacement of native species are examples of hazards posed by stressors. The extent and severity of a hazard depends directly on the rate and amount of exposure to the stressor and the significance of the effect to the receptor.

Theoretically, effects are associated with a threshold, below which the stressor has no effect on the biological receptor (**Figure 1-2**). The existence of an effects threshold has been

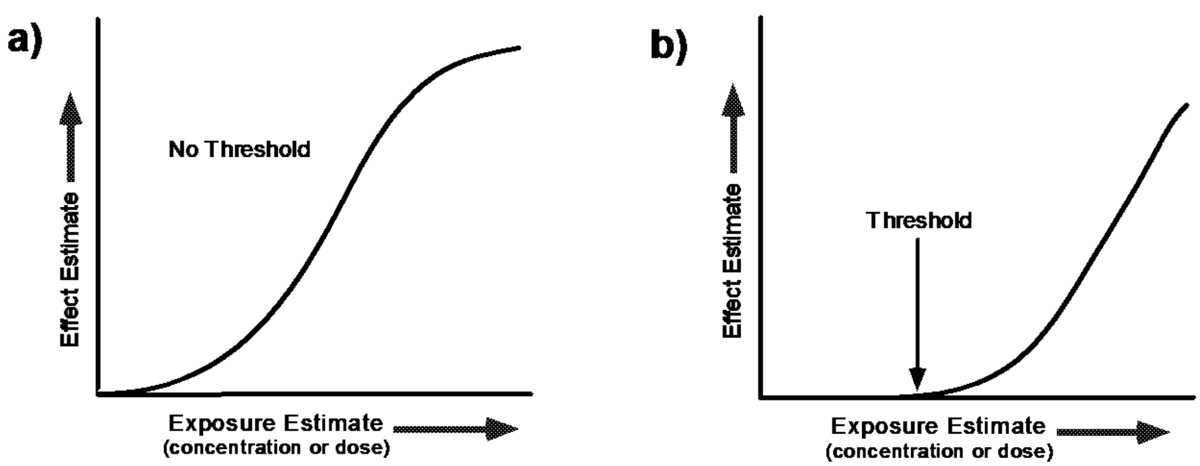


Figure 1-2. Effects Threshold. In a) an effect is assumed to occur at all levels of exposure. In b) a certain amount of a stressor has no apparent effect, due to the organism's ability to compensate for the stressor.

controversial and is an ongoing point of discussion in the literature (Chapman *et al.*, 1996). Threshold values are often used to determine if a chemical concentration in the environment creates a risk to that environment (see Section 7.1).

Chemical effects thresholds are often confused with calculated values such as the no observed effect concentration (NOEL). Calculated values are derived from toxicity tests and are usually determined with statistical methods. The quality of a statistical result depends greatly on the number of organisms used in the toxicity test, the number of replicates for each concentration, and the concentration levels tested. Higher numbers of organisms and replicates increase the statistical power of the test. In tests with fewer organisms and replicates, the statistical power decreases and the NOEL appears to be higher. In addition, the NOEL for one toxicological endpoint such as mortality, may be much higher than for another endpoint, such as reproduction.

Permits and other environmental quality limits are often set by an exposure level, such as the concentration or dose of the stressor. A concentration or dose is chosen, above which the effects are deemed unacceptable, and below which the effects are considered acceptable. Ultimately these values are set by consensus and can vary with the level of conservatism and protection. Often these values are used as rapid screens for environmental risks and are termed **benchmarks**.

1.2 Approach - Ecological Risk Assessment Applied Regionally

The traditional approach to EcoRA is derived from the U.S. EPA framework (1992) (**Appendix A**). The framework is applicable at any landscape scale or to any ecological stressor, but is typically used on a small scale for single sites or for single chemicals. We extended this approach to provide a broad, yet comprehensive, screening assessment of impacts from all known sources in Port Valdez. Unfortunately, data and resource limitations, prevents a detailed assessment of all interactions between all stressors and receptors in a given site. However, detailed and quantitative determinations of risk posed by specific exposures and effects can be further evaluated within the framework of this regional assessment (see Section 7). An example of an EcoRA for a specific organism in Port Valdez is provided in Section 9.

EcoRA methods traditionally evaluate the interaction of three environmental components: **stressors** released into the environment, **receptors** living in and using that environment, and the receptor **response** to the stressors. Measurements of **exposure** and **effects** quantify the degree of interaction between these components (**Figure 1-3a**). At a single contaminated site, especially where only one stressor is involved, the connection of the exposure and effects measurements to the assessment endpoints may be relatively simple. However, in a regional, multiple stressor assessment, the number of possible interactions increases dramatically. Stressors arise from diverse sources, receptors are often associated with a variety of habitats, and one impact may lead to additional impacts. Such a complex background of natural stressors and effects further clouds the picture.

Expanding an assessment to cover a region requires consideration of larger scale, regional components: sources that release stressors, habitats where the receptors live, and impacts to the assessment endpoints (**Figure 1-3b**). The three regional components are analogous to the three traditional components.

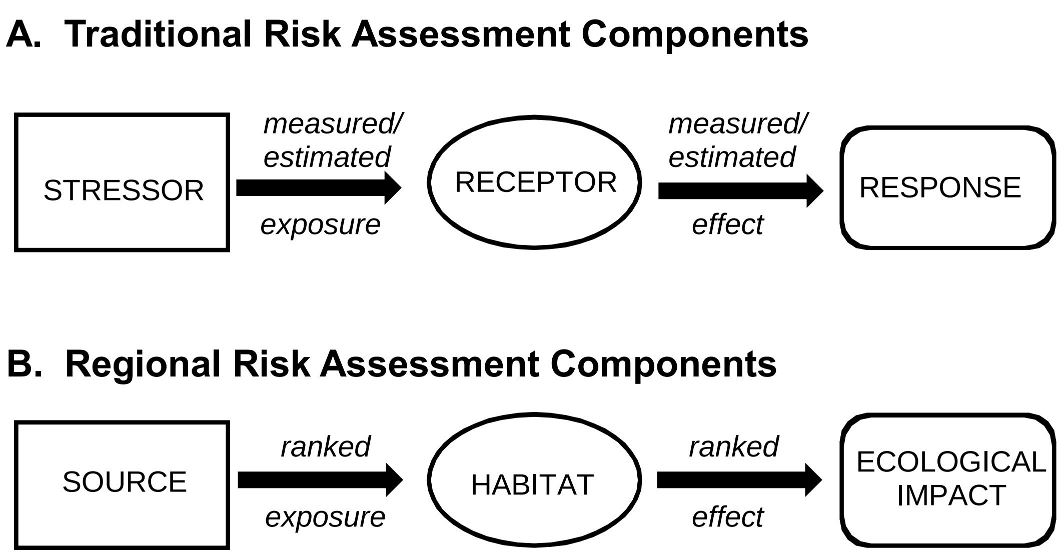


Figure 1-3. Comparison of risk components at a) the traditional small scale, and b) the regional large scale.

Traditional risk assessment determines the level of exposure and effects in order to calculate risk. However, exposure and effects cannot be directly measured unless a specific stressor and a specific receptor is identified. At a regional level stressors and receptors can be represented as groups: a source as a group of stressors, a habitat as a group of receptors, and an ecological impact as a group of receptor responses. These groupings are usually too indistinct to obtain overall measurements of exposure and effects. However, comparisons are possible. For instance, exposure from a continuous source is greater than exposure from a similar, but infrequent source. Likewise, effects to a salmonid population are different in intertidal areas where they spawn than in the open water where they feed and travel. At the regional scale, exposures and effects are ranked instead of measured (**Figure 1-3**).

The approach of this regional assessment is to identify the sources and habitats in different locations of the Port, rank their importance in each location, and combine this information to predict relative levels of risk. The number of possible risk combinations that can result from this approach depends on the number of categories that are identified for each regional component. For example, if two source types (*e.g.*, point discharges and fish wastes) and two habitat types (*e.g.*, the benthic environment and the water column) are identified, then there are four possible combinations of these components that can lead to an impact. If we are concerned about two different impacts (*e.g.*, a decline in the sportfish population and a decline in sediment quality) eight possible combinations exist (**Figure 1-4**).

Each identified combination establishes a possible pathway to a risk in the environment. If a particular combination of components affect each other, then they can be thought of as overlapping (**Figure 1-5**). When a source generates stressors that affect habitats important to the assessment endpoints the ecological risk is high (**Figure 1-5a**). A minimal interaction between components results in a low risk (**Figure 1-5b**). If one component does not interact with one of the other two components, there is no risk (**Figure 1-5c**). For example a discharge piped into a deep water body is not likely to impact salmon eggs, which are found in streams and intertidal areas. In such a case the source component (an effluent discharge) does not interact with the habitat (streams and intertidal areas), and no impact would be expected (*i.e.*, harm to the salmon eggs).

In **Figure 1-4,** *impact 1* appears in four different combinations. Each combination overlaps to varying degrees as explained in **Figure 1-5**. Integrating these combinations demonstrates that *impact 1* is actually the result of several combinations of sources and habitats (**Figure 1-6**). In order to fully describe the risk of a single impact occurring, each possible route to the impact needs to be investigated. However, integration of these routes is not always a simple matter. Often, measurements of various exposure and effects levels cannot be added together to determine the overall impact to the assessment endpoint. For example, a decline in wild salmon populations can result from a combination of eggs in the spawning grounds being exposed to chemicals, and increased predation when the juveniles migrate out of the Port. However, chemical exposure to the eggs may also influence growth of the juvenile fish. Smaller fish are less able to avoid predation; therefore, mortality from predation may increase beyond what would be expected if the effect to the eggs was not considered.

Our regional approach develops a system of numerical ranks and weighting factors to address the difficulties encountered when attempting to combine different kinds of risks (**Figure 1-7**). Ranks and weighting factors are unitless measures that operate under different limitations

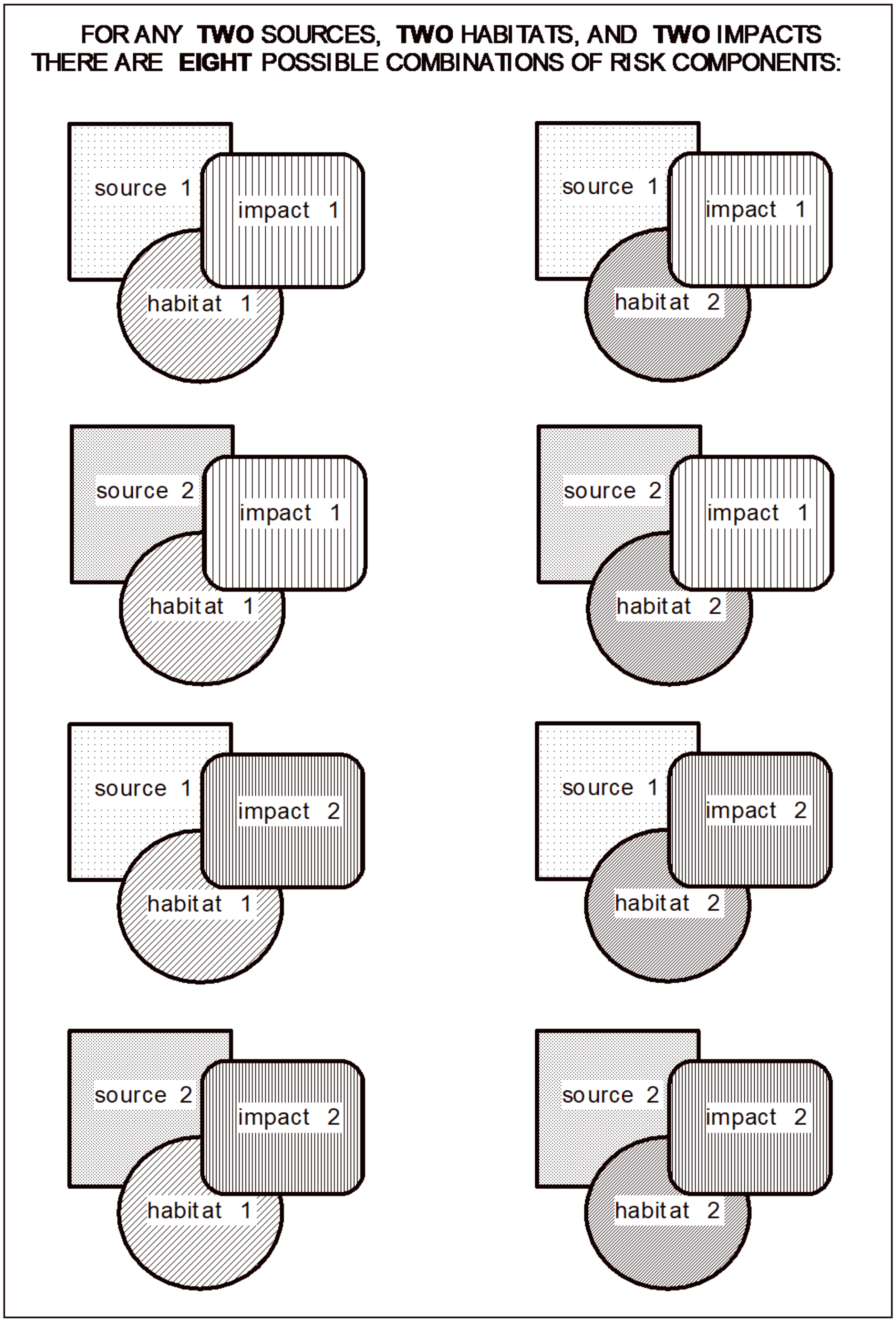


Figure 1-4. Combinations possible in a system with two sources, two habitats, and two impacts of concern. Refer to text and Figures 1-5 and 1-6 for further explanation.

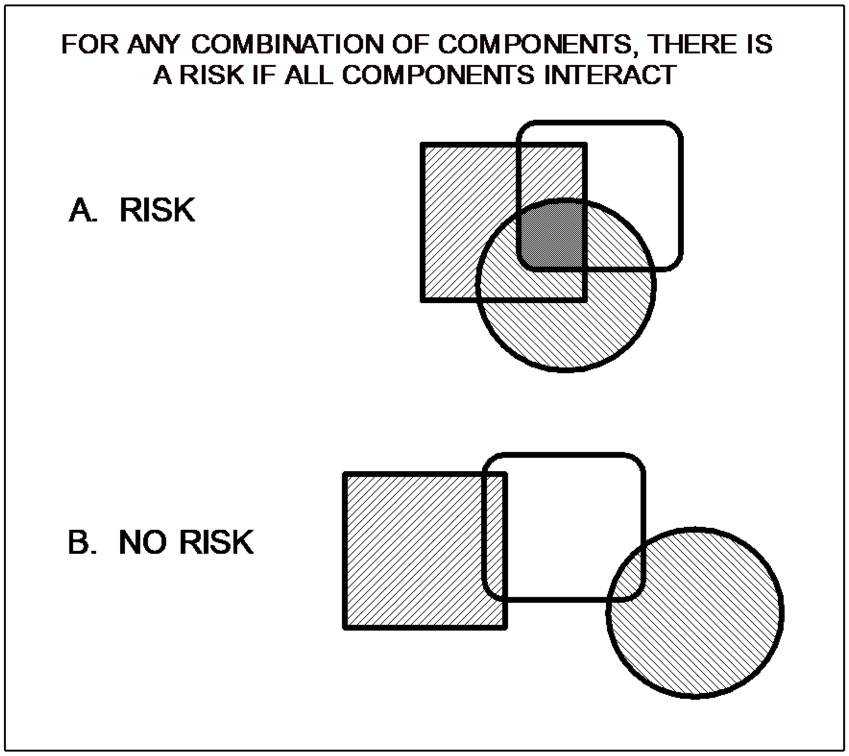


Figure 1-5. Ecological risks resulting from the interactions between sources, habitats, and ecological impacts.

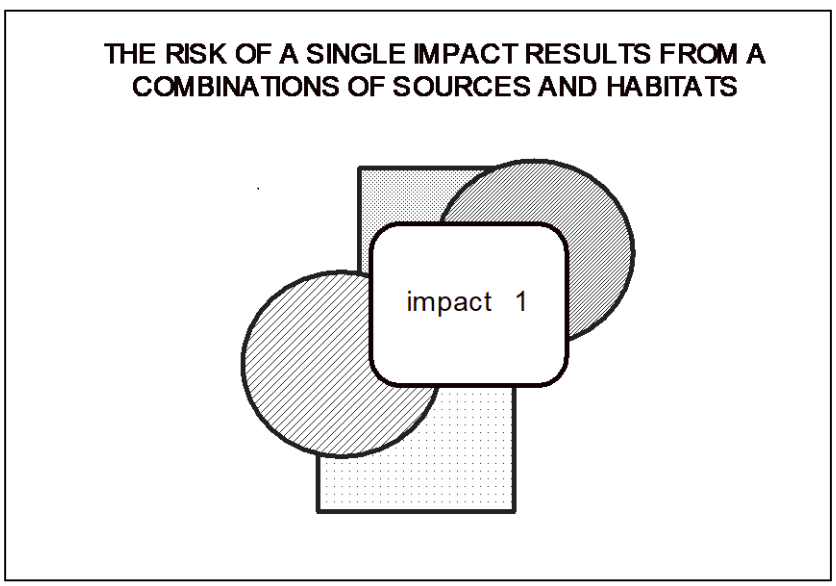


Figure 1-6. Integration (through overlap) of the possible combinations of two sources and two habitat types that can influence the risk of an impact to an assessment endpoint.

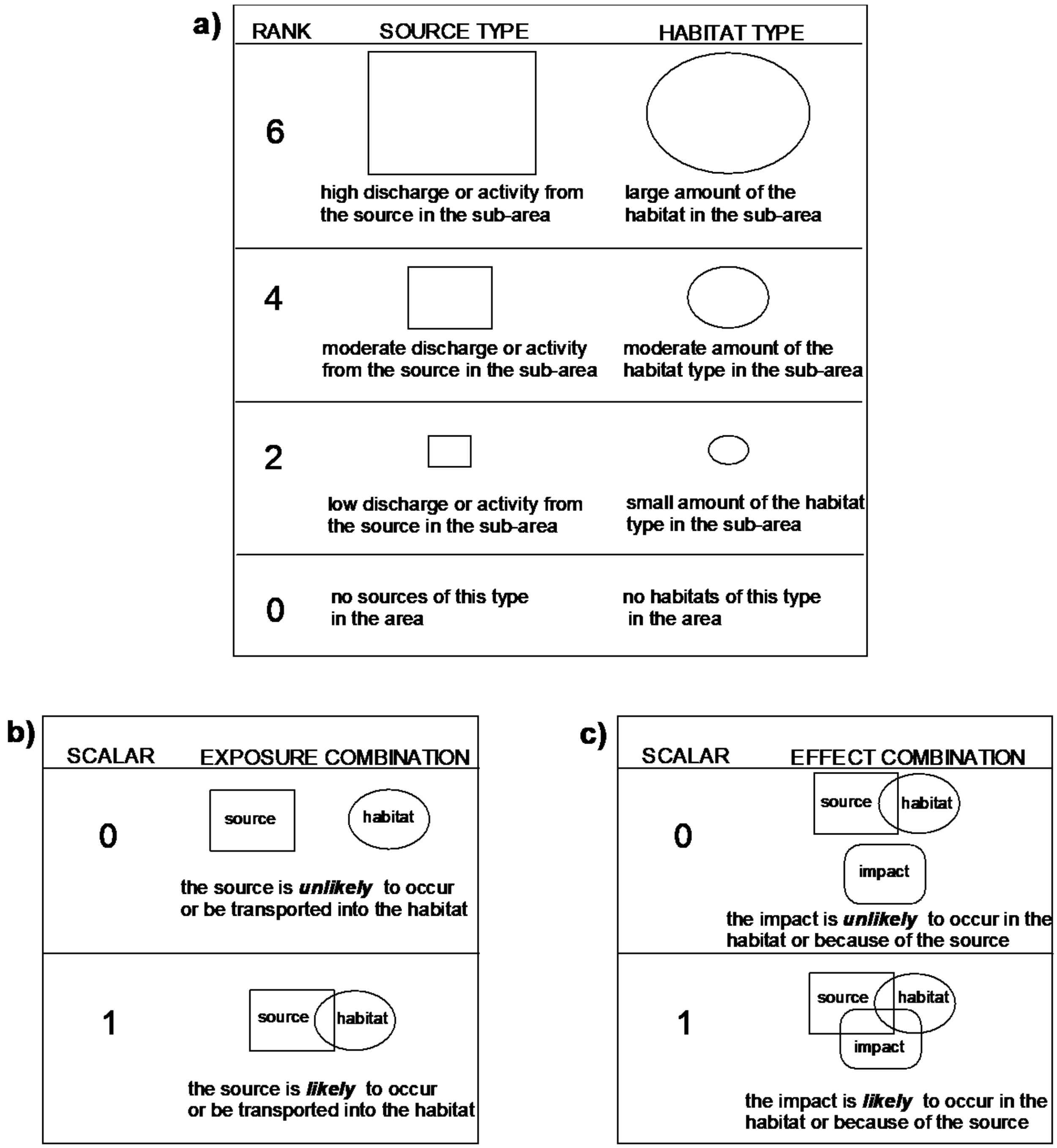


Figure 1-7. Method of comparing and combining risk components in sub-areas of Port Valdez through a) ranking, and weights based on the likelihood of b) exposures and c) effects.

than measurements with units (*e.g.*, mg/L, individuals/cm^2). In a complex system with a wide range of dissimilar stressors and effects, there are few measurements that are additive. For example, there is little meaning in adding toxicant concentrations to counts of introduced predators to determine the total risk in a system. However, it is useful to know that a particular region has both the highest concentrations of a contaminant and the most introduced predators.

1.3 Scope of the Port Valdez Assessment

The scope of an EcoRA depends on the stressors involved, the understanding of the local ecology, and the policy goals of the system managers (Suter, 1993). In Port Valdez a variety of anthropogenic stressors, as well as a variety of natural stressors, is possible. Natural environments are inherently variable. For example, fish stocks fluctuate in size and precipitation differs from year to year. This variability is compounded in Port Valdez by the extreme seasonal patterns of light and temperature found at high latitudes, and by frequent natural disturbances such as earthquakes and winter storms. In a system with high variability, detection of effects due to human disturbances is more difficult against the background of natural disturbance.

Ecological knowledge of an area determines the degree to which environmental impacts can be defined, understood, and differentiated from natural events within the system. In Port Valdez, much of the scientific work reflects baseline data collection and environmental monitoring performed in the late 1960s and the 1970s prior to and during the construction of the trans-Alaska Pipeline and the Valdez Marine Terminal. Available data include physical and chemical characteristics of the Port waters and sediment, as well as information about the pelagic, intertidal, and benthic subtidal organisms of the Port. Ongoing monitoring studies since that time have focused on the intertidal and subtidal organisms, and the hydrocarbon levels in the sediments of the Port. Other studies were conducted to assess the potential for environmental impacts of proposed petroleum refineries in the 1970s, to study hatchery fish released by the Solomon Gulch fish hatchery built in the late 1980s, and to evaluate the Duck Flats (Mineral Island Flats) as an important ecological area in the 1990s. The research focused on wild salmon, hatchery salmon, migratory and nonmigratory waterfowl, and sea otters. Bears and eagles were also addressed in studies of the terrestrial components of the Port Valdez ecology. The following items are reports or papers that we used for background information concerning risks in the Port.

Environmental Monitoring and Management Programs

- Monitoring of hydrocarbons in sediments and mussels, and benthic community structure in relation to the BWTP discharge from 1976 to 1996 (Shaw *et al*., 1985; Shaw and Hameedi, 1988; Karinen *et al*., 1993; Feder and Shaw, 1996; Feder and Blanchard, 1996b; previous reports cited in these references).

- Monitoring of hydrocarbons in sediments and mussels in relation to oil transport and spills in Prince William Sound (Kinnetics Laboratories, 1995, 1996).
- Monitoring reports on the toxicity of the BWTP effluent and Port Valdez sediments (CAS 1995a; Karle *et al*., 1994; Gardiner, 1993a; APSC, 1995; similar reports referred to in these references).
- Monitoring of intertidal invertebrate populations, including life cycle studies of limpets and mussels (Feder, McCumby and Jewett, 1992; previous reports cited in this reference).
- Coastal management plan (City of Valdez, 1992).

Environmental Impact Assessments

- Impact assessment for a proposed petrochemical refinery near the Valdez Glacier Stream (U.S. EPA, 1980).
- Human health risk assessment associated with air emissions of petroleum hydrocarbons (Goldstein *et al.*, 1992; Cohen, 1992).
- Impact assessments associated with port expansion (the Container Dock) and reports on the Valdez Duck Flats (Jones, 1979; Morsell *et al.*, 1979; Jon Isaacs and Associates, 1992).
- Comparison of sediments and benthic community at a dredge spoil disposal adjacent to the SERVS dock (Feder and Shaw, 1994a; Feder and Blanchard, 1995a, 1996a)
- Impact assessment for a proposed liquid natural gas terminal in Anderson Bay (FERC, 1995).

Environmental Studies of Effects in Port Valdez

- Studies of the effects of a simulated oil spill (Feder *et al*., 1976; Shaw *et al*., 1977; Shaw *et al*., 1977; Clement *et al.*, 1980; Stekoll *et al*., 1980; Feder *et al*., 1990).
- Investigations of the clam (*Macoma balthica*) population at Dayville Flats during and after construction of the Dayville Road (Myren and Pella, 1977; Naidu and Feder, 1992).
- Sea otter population in Port Valdez and effects of boat traffic (Anthony *et al*., 1992; Anthony, 1995).

Ecological and Baseline Studies

- Baseline studies associated with planning and construction of the Valdez Marine Terminal and subsequent wastewater disposal (Hood, 1969; Hood *et al*., 1973; Colonell, 1980).
- Baseline studies associated with a refinery proposed by the Alaska Petrochemical Company (Dames and Moore, 1979a, 1979b, 1979c; Hemming and Erikson, 1979).
- Studies of intertidal and subtidal organisms on Port Valdez (Nauman and Kernodle, 1976; Feder and Paul, 1977; Jewett and Feder, 1977; Lees *et al.*, 1979; Calvin and Lindstrom, 1980; Feder and Paul, 1980).
- Studies of birds and salmon in the Port Valdez vicinity of birds and salmon fry (Pirtle, 1979; Hogan and Colgate, 1980; Jewett and Stark, 1990; Jewett and Stark, 1994).
- Physical studies of nutrient and sediment flux (Naidu, 1987).

The potential for contamination and the social values placed on this environment result in public concern for the Port Valdez ecosystem. This concern, rather than any impending regulatory decision, has led to the present assessment of ecological risk in Port Valdez.

Resources of Port Valdez are managed by several agencies organized at the local, state, and federal levels, each with its own perspective and concerns regarding impacts to the environment. A summary of these agencies and the resource areas that they manage are listed in **Table 1-1**.

Table 1-1. Management agencies and programs with interests in the Port Valdez area.

Agency	***Management Area***
U.S. Environmental Protection Agency	Wastewater and regulated stormwater discharges Non-regulated runoff Water and sediment quality Spill response Wetlands and wetland communities Landfills and RCRA Air Quality Endangered species
Alaska Department of Environmental Conservation (ADEC)	Wastewater and regulated stormwater discharges Non-regulated runoff Water and sediment quality Spill Response Wetlands and wetland communities Landfills Air Quality Chemical Applications
Bureau of Land Management (BLM)	Mining Federal lands
Alaska Department of Natural Resources (ADNR)	Mines Wetlands State Parks and Outdoor Recreation
Alaska Department of Fish and Game (ADF&G)	Shellfish and finfish populations Anadromous streams Non-regulated runoff Fish hatcheries Bird populations Habitat Wetlands
U.S. Army Corps of Engineers (U.S. ACE)	Dredging and fill Wetlands
U.S. Fish and Wildlife Service (U.S. FWS)	Sensitive habitats Fish populations
National Marine Fisheries Service (NMFS)	Marine Mammals
U.S. Coast Guard (USCG)	Vessel traffic Spill Response Boat sewage
Valdez Coastal Management Program	Development Resource management Alaska Coastal Clean Water Plan

2.0 Methods

The methods used here conform to the three-phase approach of traditional ecological risk assessments: *problem formulation, analysis,* and *risk characterization* (see Appendix A). Problem formulation is the information gathering phase. Information is then processed into an estimate of risk during the analysis phase and described in a probabilistic context in the risk characterization phase. This section describes resources, decision points, and the means used to complete each phase of the assessment.

The methods described here are for a regional assessment. More traditional analyses of site-specific data were also included to compare and confirm this regional approach. Traditional risk assessment requires enough quantitative data to generate an accurate risk estimate. Because of this requirement, the traditional analyses were only conducted for chemical stressors, such as hydrocarbons and heavy metals. There are fewer methods for assessing risk from physical and biological stressors. These stressors were not included in the analyses.

2.1 Problem Formulation

To frame the assessment within the ecological and sociological context of Port Valdez, we asked some general questions based on our research of scientific papers, monitoring and technical reports, and discussions with stakeholders in the area. Stakeholders were identified as members of the community, state and federal agencies with jurisdiction in the Port, and the private and commercial enterprises operating in the vicinity. Mr. Joe Bridgman of the RCAC was our liaison to these risk managers, suggesting contacts and providing local information. The problem formulation phase culminated with the selection of assessment endpoints and formation of a conceptual model, on which was based the second phase of the assessment. We intentionally chose general assessment endpoints relevant to the entire region. Likewise, the conceptual model was broad in scope. The selection of endpoints and the formation of the model was an iterative process that evolved throughout the assessment process, and could easily be modified to reflect new data or changes in the environment. These two parameters in the problem formulation, general assessment endpoints and a flexible conceptual model, provided the structure for this regional assessment.

2.1.1 Background Investigation

We initiated this investigation by asking the following:

1. What are the physical and biological characteristics of the Port? Baseline studies of the oceanographic and biological resources in Port Valdez provided information about seasonal fluctuations, circulation patterns, habitat types, and plant and animal populations.
2. How do people interact with this environment? We identified activities and substances that could impact physical or biological characteristics of the environment. Investigation of the sources involved gaining access to permits, determining if data regarding stressors were available, requesting data, and examining the literature to determine the range of stressors that could result from each source. The level of characterization was not equal for all sources. Regulated activities that were regularly monitored were the most easily characterized, while other sources were only suspected to exist.
3. What impacts are known to have occurred in the environment? Research efforts in the Port Valdez area and anecdotal information provided guidance for determining the type of effects likely to occur in the Port. The information acquired during the background investigation is summarized in Sections 3.1 to 3.4.

We then met with members of the Port Valdez community. Our objectives were to gain further insight into the study site, determine community values, and move toward the selection of assessment endpoints. Three public meetings were held in the city of Valdez on October 19th and 20th, 1995. After a brief introduction to the EcoRA process, the public was asked:

4. What are you concerned about in the Port Valdez environment? Responses were sorted into two general categories: identification of stressors and sources of concern in the Port, and identification of populations or attributes of the Port that people would like to protect. We used this information to develop assessment endpoints, which are primarily socially driven, i.e., based on social values, in the risk assessment process. We also scheduled interviews with agencies to supplement the information obtained in the public meetings, and to ask specific questions that had arisen during the information gathering phase. Participants included the city planning department, the ADEC, and the U.S. Coast Guard (USCG), as well as local industry managers. Results of these meetings and interviews can be found in Section 3.5.

2.1.2 Assessment Endpoint Selection

The discussions with risk managers, community interviews, and public meetings resulted in the selection of assessment endpoints. Factors considered in the selection process included public interest, susceptibility to suspected stressors, and degree of interaction with the environment. We chose an assortment of endpoints designed to cover a variety of ecological risks in the Port. These endpoints included aspects of water and sediment quality, sport and commercial fisheries, and wildlife populations of fishes, birds, and mammals. The assessment endpoints reorganized the questions asked during the problem formulation into new questions relevant to the risk managers' needs.

1. What are the risks to water and sediment quality in Port Valdez?
2. What are the risks to finfish and shellfish populations harvested by sport or commercial fishermen?
3. What are the risks to fish and wildlife populations that use the Port?

2.1.3 Conceptual Model Formation

Information gathered during the problem formulation provided a base for constructing the conceptual model. First, we divided the Port into eleven separate sub-areas (**Table 2-1, Figure 2-1**). Analysis of smaller areas within a region maximizes the chance of detecting effects from an anthropogenic input. We then selected categories for each of the regional risk components: sources, habitats, and impacts (**Tables 2-2, 2-3,** and **2-4)**. Source and habitat categories described anthropogenic and ecological components of the Port (**Figure 2-2** and **2-3**) whereas impact categories incorporated the assessment endpoints. Other categories can be nested into these primary categories. In this way all potential stressors, receptors, and receptor responses in the Port are included in the assessment. For instance, accidental spills are a source category that releases hydrocarbons and other stressors. Hydrocarbons include both alkanes and aromatic compounds. Aromatics can be further broken down into the monoaromatics and the polyaromatics, which in turn are made up of a numerous individual chemicals (*e.g.*, benzo[a]pyrene, fluorene, and phenanthrene). Likewise, hydrocarbons represent a number of mixtures released into the environment. Crude oil, gasoline, diesel, kerosene, and jet fuel are all materials that contain an individual array of hydrocarbons, along with many other non-hydrocarbon constituents. Receptors in the environment are also numerous as demonstrated by the number of species found in the Port (Appendix B). For the model we placed receptors into general groups and identified the predominant habitat types in which they are found.

Once these component categories were established, we explored links between the components. In traditional risk assessment, where one or only a few stressors, are involved the exposure pathway links the stressor to receptors. However, in a regional multiple stressor assessment the stressors can also be linked to sources, and the receptors to habitats (described in Section 1.2).

Table 2-1. Location of each sub-area chosen for the conceptual model.

Sub-Areas Defined

A. Shoup Bay
Shoup Bay, including the bay entrance, the entrance spit, and a portion of the shoreline to the east of the bay.

B. Mineral and Gold Creeks
Shoreline area and the shallow shelf of the Mineral Creek embayment, including Gold Creek.

C. City of Valdez
The city and the shoreline and shallow shelf areas from just east of Mineral Creek to the eastern end of the Small Boat Harbor.

D. Duck Flats (or Mineral Island Flats) and Old Valdez
The Duck Flats, including the islands and shallow shelf south of the flats, and the shoreline area including the Richardson Highway extending east to the Valdez Glacier Stream.

E. Robe and Lowe Rivers
Shoreline, river deltas, and shallow subtidal areas of the Valdez Glacier Stream, Robe River and Lowe River, including the Petro Star Refinery.

F. Dayville Flats and Solomon Gulch
Shoreline along Dayville Road and shallow subtidal areas from the southern edge of the Lowe River to just east of Allison Point, including the Solomon Gulch Hatchery.

G. Valdez Marine Terminal
Shoreline and shallow subtidal areas from Allison Point to just west of Saw Island, including the Valdez Marine Terminal.

H. Sawmill to Seven-Mile Creeks
Shoreline and shallow subtidal areas from west of Saw Island to a point east of Anderson Bay, including Sawmill Creek, five-mile beach, and seven-mile beach.

I. Anderson Bay
Shoreline and shallow subtidal areas from just east of Anderson Bay to west of Entrance Island.

J. Western Port
The western, flat-bottomed basin from the Valdez Narrows to a middle boundary between the Mineral Creek embayment to the eastern edge of the Valdez Marine Terminal.

K. Eastern Port
The eastern, upward sloping basin from the middle boundary to the edge of the shallow offshore area of the eastern shoreline.

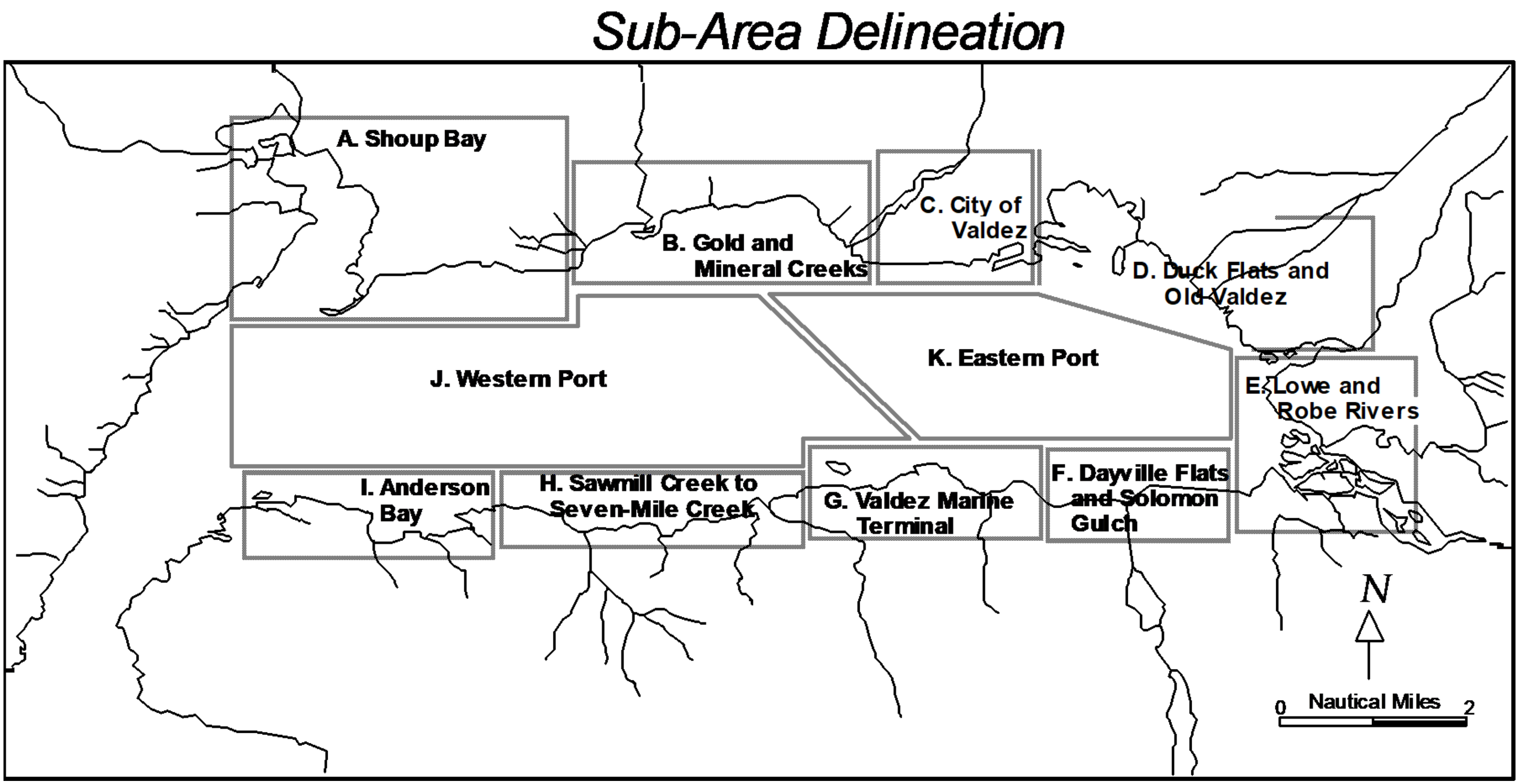


Figure 2-1. Map of sub-area delineations chosen for the risk assessment of Port Valdez.

Table 2-2. Definitions of sources of stressors categories chosen for the conceptual model.

Sources Defined

Treated Discharges

Effluents from point sources (released from a pipe) that are treated to reduce chemical and physical contaminants before release.

Contaminated Runoff

Runoff from land that has been contaminated through air pollution, groundwater contamination, spills on land, pesticide and other chemical applications, or another process.

Accidental Spills

Spills of oil, lubricants, solvents, antifreeze, fluids, or other chemicals on the water.

Fish and Seafood Processing Wastes

Wastes composed of solid or settling organic matter, including seafood processing, sport fish wastes, and food or fecal matter resulting from aquatic culturing.

Vessel Traffic

Small or large vessels that may cause injury through contact or propeller wash, disturbance from noise or movement, release of fuels and other chemicals from normal operation, release of sewage wastes, or release of ballast water.

Construction and Development

Activities such as land clearing, building, and road and dock construction that directly alter habitat, release debris or sediment, or change physical conditions such as water flow.

Hatchery Fish

Salmon returning to the hatchery that stray into other spawning streams, and hatchery fry migrating out of the port.

Shoreline Activity

Recreational or residential activity resulting in disturbance or injury.

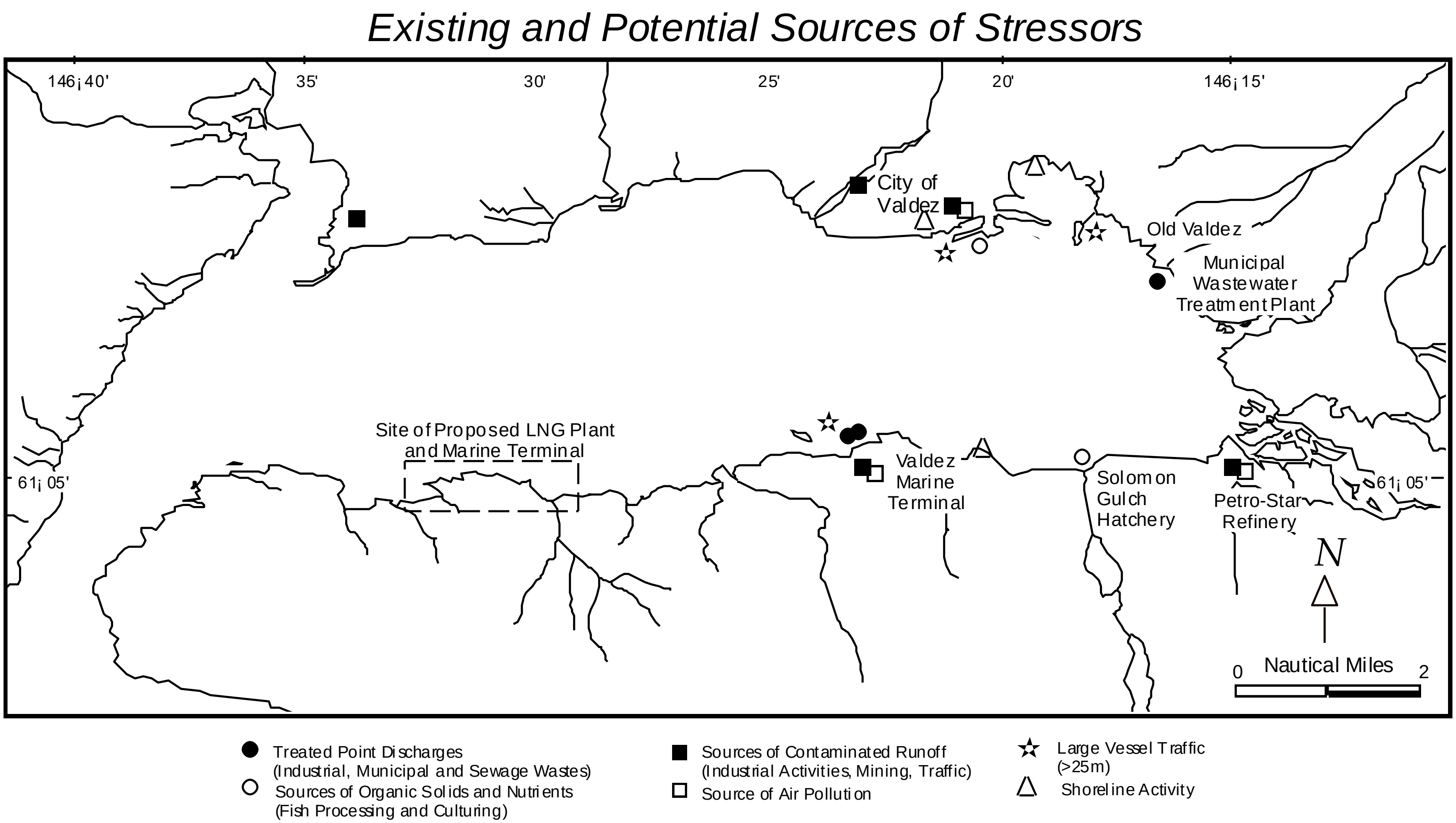


Figure 2-2. Map of potential sources of stressors identified in Port Valdez, Alaska.

Table 2-3. Definitions of habitat categories chosen for the conceptual model.

Habitats Defined

Saltmarsh

Shoreline areas characterized by marsh grasses and sedges.

Mudflats

Shoreline areas with an extensive tidal flat consisting of mostly silt and clay sediments.

Spits and Low-Profile Beaches

Flat shoreline areas or spits extending out from the shoreline that consist of broken rock, cobble beaches, or coarse sediment and gravel.

Rocky Shoreline

Sloped to steep shorelines consisting of large rocks, boulders, or seacliffs.

Shallow Subtidal

Water column and benthic areas less than 50 meters deep with either sediment or rocky bottoms.

Deep Benthic

Underwater areas greater than 50 meters deep consisting of mostly a sediment bottom.

Open Water

Water column or pelagic zone in deep water areas where influences from land are lessened.

Stream Mouths

Intertidal mud, sandy gravel, and gravel entrances to streams and rivers and upstream areas influenced by tidal flows.

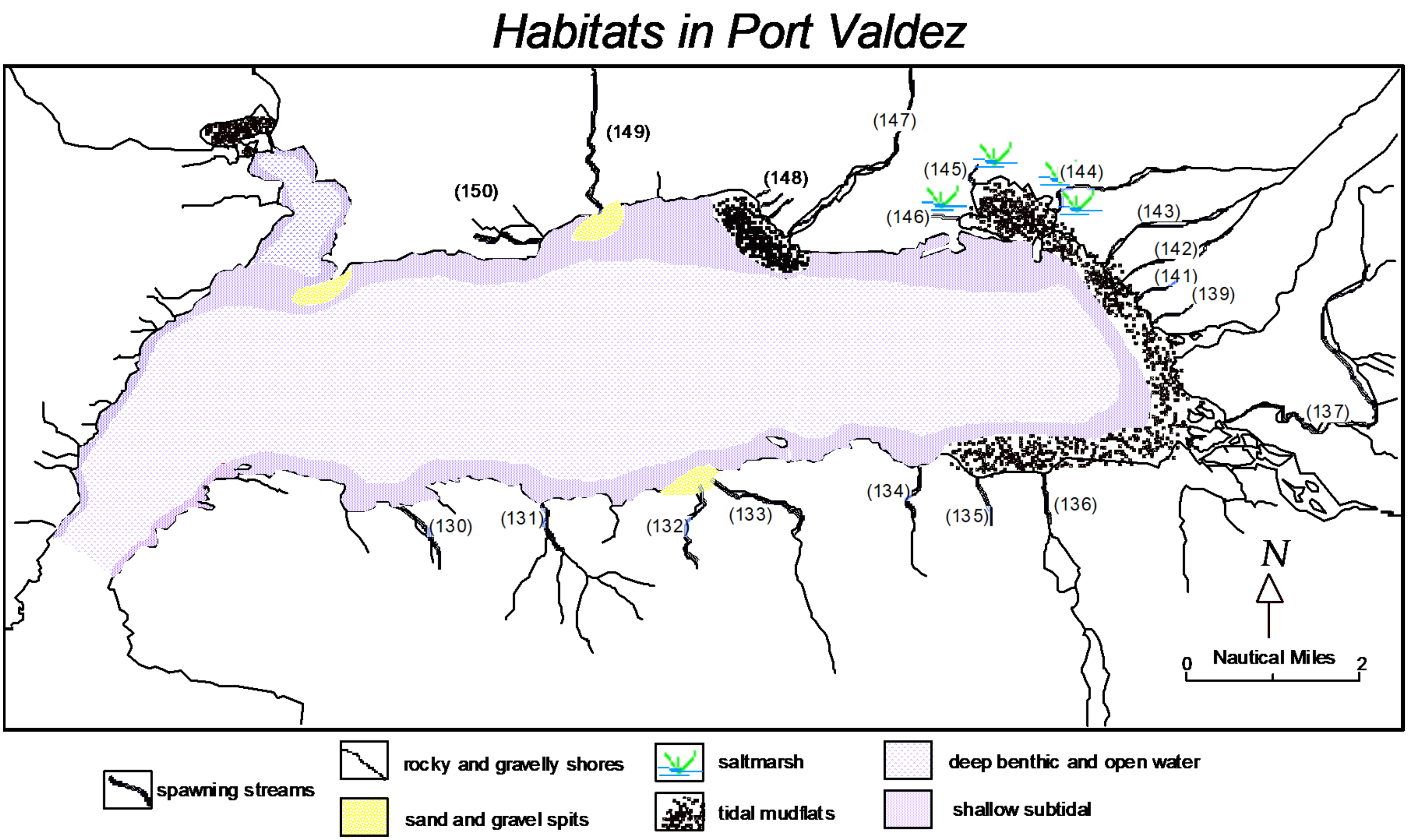


Figure 2-3. Map of habitats identified in Port Valdez, Alaska.

Table 2-4. Definitions of impact categories chosen for the conceptual model.

Impacts to Assessment Endpoints

Water Quality Impairment

A change in normal water condition that affects some ecological function. For example, increases in toxicity caused decreased survival, increased nutrients cause increased biological production, and decreased water clarity causes decreased biological production.

Sediment Quality Impairment

A change in normal sediment condition that results in toxicity or a loss of function.

Decreases in Hatchery Salmon Returns

Reductions in survival or growth of pink salmon fry during their spring migration, and decreased survival or growth of juvenile silver salmon during rearing in net pens or migrations out of the Port.

Population Declines Associated with Bottom Fisheries

Reductions in the number of crustaceans and bottom fishes that live, feed, or reproduce in the Port.

Declines in Wild Populations of Anadromous Fishes

Reductions in the number of pink, silver, red, and king salmon and Dolly Varden that spawn in the Port.

Decreased Reproduction of Bird Populations

Decrease in nesting and hatching success, and survival of young.

Decreased Food Availability for Wild Fishes, Birds and Mammals

Decline in abundance, nutritional quality, or availability of invertebrate populations commonly used as a food resource by the fishes, birds, and mammals of the Port.

Decisions made while developing the model were based on information specific to Port Valdez. We developed two sets of tables to characterize stressors and receptors in the Port (Appendix C). The tables represent a working document used to record and process information regarding the various sub-areas.

Stressors and receptors, which were both present or expected in an area and likely to overlap in the environment provide the basis for developing risk scenarios (*e.g.*, sea otters feeding in high traffic areas are exposed to disturbance from vessel traffic and may suffer nutritional deficiencies). The characterizations (found in Appendix C) describe factors that drive exposures and the effects that are likely to occur with each combination of stressor and receptor. This can lead to the formation of a generalized risk scenario as demonstrated in Section 9. Generalized risk scenarios provide a format from which to develop hypotheses for future quantitative assessments of selected concerns.

Together, all of the risk components (sources, stressors, habitats, receptors, ecological impacts, and receptor responses) and links form the basis of the conceptual model. In a large area, risks vary by location. Applying the model between sub-areas of the Port led to a comparative analysis of risk.

2.2 Analysis

The conceptual model is a framework for comparing risks from anthropogenic stressors throughout the Port, and for considering more than one stressor and one receptor at a time. The analysis phase of the assessment includes two parts: comparative analysis of risks from a regional approach, and quantitative analyses from a traditional approach. For the regional approach, a model was developed to estimate relative risks between the 11 sub-areas described in the conceptual model. Traditional analyses estimated site-specific risks from quantitative data collected in the Port. These data consisted of chemical concentrations in effluent, sediment, and mussel tissue samples. Risk estimates resulting from the traditional analyses have two functions: they determine the severity of risk from chemical exposures in the Port and provide site-specific risk estimates that can be compared to results from the regional analysis.

2.2.1 Relative Risk Model

The Relative Risk Model compares sources and habitats in sub-areas of the Port and determines if the chance of an impact is greater in one sub-area than another. Comparisons are based on ranking criteria that use information specific to each sub-area. By not using external reference sites for comparison, the analysis remains specific to the Port Valdez environment. Assessing risk in this manner establishes a relative scale that weighs the likelihood of receptors in a particular habitat being exposed to, and possibly affected by, human activities in the Port. Comparative risk estimates are useful in setting priorities and integrating the range of possible exposures and impacts region-wide. Comparative risk estimates are based on the following assumptions

1. The greater the size or frequency of a source in a sub-area, the greater the potential for exposure to stressors in that sub-area;
2. The type and density of receptors present in a sub-area is related to the available habitat;
3. The sensitivity of receptors to stressors varies in different habitats; and the severity of effects between different sub-areas of the Port depends on relative exposures and the characteristics of the receptors present.

The Relative Risk Model is a system of ranking risk components established in the conceptual model and filtering each possible combination. This system involves the three steps described below.

1) *Ranking.*

Each source and habitat is ranked between sub-areas to indicate whether risk is high, moderate, or low within the context of the Port. Ranks are assigned using criteria specific to Port Valdez. The criteria are based on the size and frequency of the source, and the amount of available habitat (**Tables 2-5** and **2-6**). Ranks are assigned for each source and habitat type on a 2 point scale from 0 to 6 where 0 indicates little potential for exposure and 6 indicates the highest potential for exposure.

2) *Filter Design*.

Filters determine the relationship between the risk components (sources, habitats, and impacts to assessment endpoints). A filter consists of the weighting factors, 0 or 1, which indicate either a low or a high probability. We have incorporated two types of filters: an *exposure filter* and an *effects filter*. The exposure filter screens the source and habitat types for the combinations which are more likely to result in exposures *(i.e.,* receptors in the habitat will come into contact with stressors generated by the source). The effects filter screens the source and habitat combinations for those that are more likely to affect a specific assessment endpoint. An example describes the design of both an exposure and an effects filter (see **Example 1**).

The first step in designing an exposure filter is to determine which stressors are produced by the sources. Professional knowledge is then used to answer two sequential questions about each stressor in relation to specific source-habitat combinations

- Will the source release or cause the stressor?
- Will the stressor then occur and persist in the habitat?

If the answer to both questions is yes, then a 1 is assigned to the source-habitat combination. If the answer to either question is no, then a 0 is assigned.

The design of an effects filter is similar, but a separate filter is made for each assessment endpoint. The first step in this process is to determine what type of effects are important to the specific endpoint. For instance, if maintaining crab populations is an assessment endpoint, some of the important effects to consider are toxicity, predation, and food availability. The questions asked to develop the effects filters are

- Will the source release stressors that are known to cause this particular effect to the endpoint?
- Are receptors associated with the endpoint sensitive to the stressor in this habitat?

If the answer to both questions is yes, then a 1 is assigned to the source-habitat combination. If the answer to either question is no, then a 0 is assigned.

3) *Integrating Ranks and Filters.*

Ranks and weighting factors are combined through multiplication. The results are a relative estimate of risk in each sub-area (see **Example 2**). Final risk scores (RS) are calculated for each sub-area by multiplying ranks by the appropriate weighting factor (W_{ij}) as indicated below.

$$RS = S_{ij} \times H_{ik} \times W_{jk} \qquad (1)$$

where: i = the sub-area series (A. Shoup Bay ... K. Eastern Port)

j = the source series (discharges ... shoreline activity)

k = the habitat series (mudflats ... stream mouths)

and: S_{ij} = rank chosen for the sources between sub-areas

H_{ik} = rank chosen for the habitats between sub-areas

W_{jk} = weighting factor established by the exposure or effects filter

The results form a matrix of risk scores related to the relative exposure or effects associated with a source and habitat in each sub-area. The potential risk resulting from a specific source (2) and occurring within a specific habitat (3) can be summarized for each sub-area by adding the related scores,

$$RS_{source} = \sum(S_{ij} \times H_{ik} \times W_{jk}) \text{ for } j = 1 \text{ to } 8, \text{ and} \quad (2)$$

$$RS_{habitat} = \sum(S_{ij} \times H_{ik} \times W_{jk}) \text{ for } k = 1 \text{ to } 8. \quad (3)$$

Each sub-area matrix calculated by the above method is included in Appendix D.

Table 2-5. Criteria used to establish ranks for each source of stressor(s). The ranks indicate the potential for exposure to anthropogenic stressors in each sub-area.

Source	***Criteria***	***Uncertainty in the Criteria***
Treated Discharges	6 - flow greater than 10 mgd 4 - flow between 5 and 10 mgd 2 - flow less than 5 mgd 0 - no flow	• treatment effectiveness • undetected sporadic discharge of contaminants at high levels • continuous discharge of contaminants below detection levels, especially for contaminants that can accumulate in the environment
Contaminated Runoff	6 - large industrial, commercial, or dense residential areas 4 - light industrial areas, landfills, or subdivisions with septic tanks 2 - sparse residential areas or possible mining 0 - no known or suspected sources of contamination	• some sites have stormwater containment and treatment (*e.g.*, Valdez Marine Terminal) • contamination in stormwater from storm drains or sites without treatment or monitoring are uncertain (*e.g.*, the city, most industrial or commercial sites) • contaminated runoff from active and inactive mines uncertain
Accidental Spills	6 - loading or unloading facilities for fuels or oil 4 - other docks or commercial boating activity 2 - recreational boating activity 0 - no sources of spills	• spills at sites that are highly monitored (*e.g.*, the Valdez Marine Terminal and other fuel transfer docks) are more likely to be reported and cleaned-up
Fish and Seafood Processing Wastes	6 - seasonal seafood processing waste streams 4 - seasonal use of net pens 2 - sporadic fish wastes 0 - no known or suspected sources	• dispersal on the bottom depends on water depth and current strengths • some organic solids may contain other wastes (*e.g.*, cleaners, antibiotics)
Vessel Traffic	6 - year round daily traffic present 4 - year round monthly traffic present 2 - seasonal traffic 0 - little boat traffic expected	• commercial shipping, especially for crude oil, is frequent, although long-term trends may change • recreational, charter and tour services, and fishing traffic are seasonal and may be sporadic
Construction and Development	6 - large-scale development expected 4 - frequent construction or small-scale development expected 2 - developed 0 - no current or expected development	• construction activities are mostly seasonal and short-term, although a specific project may last over years • areas where future development projects are planned have high uncertainty.
Hatchery Fish	6 - near hatchery 4 - expected adult and fry migration route 2 - possible locations of adult and fry 0 - no hatchery fish expected	• the number of hatchery fish that stray into other streams is not known • the criteria assume straying is more likely on the southern shore near the hatchery
Shoreline Activity	6 - daily activity, year round 4 - recreational, road access 2 - recreational, no road access 0 - little shoreline activity expected	• exposure depends on type of activity, proximity to receptors, and sensitivity of the receptors • some receptors occur or are more sensitive on a seasonal basis (*e.g.*, migratory birds, spawning salmon)

Table 2-6. Criteria used to rank the amount of each type of habitat within the Port. The ranks indicate the potential for exposure and effects to receptors in each sub-area.

Habitat	*Criteria*	*Uncertainty in the Criteria*
Mudflats	6 - extensive mudflats 4 - moderate or extensive mudflats with low population densities 2 - limited mudflat areas 0 - no mudflats	• population density and community types vary depending on sediment grain size, nutrient and organic carbon levels, sedimentation, and salinity
Saltmarsh	6 - extensive saltmarsh 4 - moderate area of saltmarsh 2 - limited saltmarsh areas 0 - no saltmarsh	• high productivity of saltmarshes and infrequent occurrence of this habitat type in Prince William Sound (PWS) may increase its regional importance • disturbance would affect some populations more than others (*e.g.*, high-use habitat for migratory birds)
Spits and Low-Profile Beaches	6 - spits, spit-like formations, or extensive low-profile beaches 4 - some low-profile beaches 2 - limited areas with low-profile beaches 0 - no spits or low-profile beaches	• generally low productivity may limit the importance of this habitat type • importance of these areas may depend on their proximity to other habitats
Rocky Shoreline	6 - extensive rocky shoreline 4 - some rocky shoreline 2 - limited rocky shoreline 0 - no rocky shoreline areas	• population density and community types vary depending on the availability of nutrients and organic carbon, sedimentation, salinity, and wave action
Shallow Subtidal (<50 m deep)	6 - extensive shallow subtidal shelf 4 - moderate shallow subtidal area 2 - narrow shallow subtidal area 0 - no shallow subtidal areas	• limited or narrow areas of shallow subtidal in the Port • this habitat group does not differentiate between hard and soft bottomed subtidal areas, which will affect the biological activity in the habitat
Deep Benthic (>50 m deep)	6 - extensive deep subtidal areas 4 - moderate deep subtidal areas 2 - limited deep subtidal areas 0 - no deep subtidal areas	• population density and community types are affected by the amount of settling sediment and occasional seismic slumping • sediment grain size, which varies slightly in the eastern and western Port, also influences animal assemblages
Open Water	6 - large areas with deep water column 4 - moderate areas with deep water column 2 - small areas with deep water column 0 - no deep water	• flushing in the Port is tied to seasonal events, variability in the tides and currents, and stratification of the water column • nutrient cycling in the Port is related to stratification of the water column and to yearly variation in phytoplankton and zooplankton communities
Stream Mouths	6 - large river or creek systems with many freshwater tributaries 4 - streams with few tributaries, moderate flows 2 - few streams with low flows 0 - no streams	• steep terrestrial slopes of Port Valdez limit stream habitat areas • stream mouths are exposed to large variations in salinity and turbidity • substrate found at stream mouths is coarser than most sediments in the Port

Example 1 *Exposure Filter Design*

This example designs an exposure filter for three sources *(i.e.,* effluent discharges, road runoff, and seafood processing gurry) and three habitats *(i.e.,* mudflats, rocky intertidal, and deep benthic). The stressors examined include hydrocarbons and solids. Hydrocarbons are more likely to result from effluents and runoff than from seafood, while solids are more likely to result from seafood wastes and runoff than effluents. Combinations where the stressor is likely to be related to the source are assigned a value of 1.

Hydrocarbons

effluents	1
runoff	1
seafood	0

Solids

effluents	0
runoff	1
seafood	1

Not all of these sources will release stressors into the same habitats. The baseline established in the former tables is expanded to include different habitat types.

Hydrocarbons

	mudflats	benthic	rocky
effluents	1	1	1
runoff	1	1	1
seafood	0	0	0

Solids

	mudflats	benthic	rocky
effluents	0	0	0
runoff	0	0	0
seafood	1	1	1

The assigned values of 1 are then re-evaluated and changed to 0 if the habitat is not likely to be exposed by that source. For instance hydrocarbons from liquid effluents discharged year-round could conceivably occur in any habitat. However, hydrocarbons from runoff are more likely to affect shoreline habitats than deep benthic habitats. Likewise, seafood processing plants are allowed to release solids offshore, but not to mudflats or rocky intertidal areas.

Hydrocarbons

	mudflats	benthic	rocky
effluents	1	1	1
runoff	1	0	1
seafood	0	0	0

Solids

	mudflats	benthic	rocky
effluents	0	0	0
runoff	0	0	0
seafood	0	1	0

The completed exposure filter is made by merging each individual filter. During merging, a 1 over-rides a 0 so that all stressors are represented in the final filter.

Exposure Filter

	mudflats	benthic	rocky
effluents	1	1	1
runoff	1	0	1
seafood	0	1	0

Example 1, cont'd *Effects Filter Design for Fisheries*

This example designs an effects filter associated with an impact to the commercial fishery: decreased survival of the hatchery pink salmon fry released by the Solomon Gulch Hatchery. Effects that could influence this endpoint include: (1) acute toxicity to fry causing death during their migration out of the Port, and (2) increased predation on the migrating fry. Sources that can directly or indirectly cause these effects are assigned a 1. For instance, effluents and runoff can carry contaminants into the Port and directly cause toxicity. Seafood accumulations can result in anoxia and production of hydrogen sulfide by benthic bacteria, which indirectly results in toxicity. Seafood can also attract more scavengers and predators to an area.

Acute Toxicity

effluents	1
runoff	1
seafood	1

Predation

effluents	0
runoff	0
seafood	1

The baseline is expanded to include three habitat types: shallow subtidal, deep subtidal, and rocky intertidal.

Acute Toxicity

	shallow	deep	rocky
effluents	1	1	1
runoff	1	1	1
seafood	1	1	1

Predation

	shallow	deep	rocky
effluents	0	0	0
runoff	0	0	0
seafood	1	1	1

During their outward migration, pink salmon fry travel through and feed in intertidal and shoreline areas. The salmon fry are not expected to travel in the deep benthic habitat, so all values assigned to the deep habitat are changed to 0.

Acute Toxicity

	shallow	deep	rocky
effluents	1	0	1
runoff	1	0	1
seafood	1	0	1

Predation

	shallow	deep	rocky
effluents	0	0	0
runoff	0	0	0
seafood	1	0	1

The final effects filter is a combination of the acute toxicity and the predation filter.

Effects Filter

	shallow	deep	rocky
effluents	1	0	1
runoff	1	0	1
seafood	1	0	1

Example 2 *Sub-Area C: City of Valdez*

Ranks assigned to sources (S_j) and habitats (H_k) in Sub-Area C are identified below:

Source Ranks (S_j)	Habitat Ranks (H_k)
S_1 (treated discharges) = 0	H_1 (mudflats) = 0
S_2 (contaminated runoff) = 6	H_2 (saltmarsh) = 0
S_3 (accidental spills) = 6	H_3 (spits/beaches) = 4
S_4 (solid organics) = 6	H_4 (rocky shoreline) = 2
S_5 (vessel traffic) = 6	H_5 (shallow subtidal) = 4
S_6 (construction/development) = 4	H_6 (deep benthic) = 0
S_7 (hatchery fish) = 0	H_7 (water column) = 0
S_8 (shoreline activity) = 4	H_8 (stream mouth) = 0

These ranks are combined to form a matrix where all possible combinations of the source and habitat ranks are represented: **(S_j x H_k)**.

Source	Habitat							
	mud-flat	salt-marsh	spits beaches	rocky shoreline	shallow subtidal	deep benthic	open water	stream mouth
discharges	0	0	0	0	0	0	0	0
runoff	0	0	24	12	24	0	0	0
spills	0	0	24	12	24	0	0	0
fish wastes	0	0	24	12	24	0	0	0
vessels	0	0	24	12	24	0	0	0
construction	0	0	16	8	16	0	0	0
hatchery fish	0	0	0	0	0	0	0	0
shoreline	0	0	16	8	16	0	0	0

The exposure filter lists a set of binary (1,0) weights (W_{jk}) for each source and habitat combination (see Example 1). The filter arranges each weight in a matrix corresponding to the habitat-source matrix (shown above). Multiplying the filter matrix with the habitat-source matrix results in an exposure matrix: **(S_j x H_k xW_{jk})**.

Source	Habitat							
	mud-flat	salt-marsh	spits beaches	rocky shoreline	shallow subtidal	deep benthic	open water	stream mouth
discharges	0	0	0	0	0	0	0	0
runoff	0	0	24	0	24	0	0	0
spills	0	0	24	12	24	0	0	0
fish wastes	0	0	0	0	24	0	0	0
vessels	0	0	0	0	24	0	0	0
construction	0	0	16	0	0	0	0	0
hatchery fish	0	0	0	0	0	0	0	0
shoreline	0	0	16	8	0	0	0	0

Example 2, cont'd *Sub-Area C: City of Valdez*
Source: Accidental Spills
Habitat: Shallow Subtidal

The risk associated with spills in each habitat of Sub-Area C is calculated by summing all of the terms associated with spills (shaded row). The risk to shallow subtidal habitat resulting from each source type in Sub-Area C is calculated by summing all of the terms associated with this habitat (shaded column).

Source	**Habitat**							
	mud-flat	**Salt-marsh**	**spits beaches**	**rocky shoreline**	**shallow subtidal**	**deep benthic**	**open water**	**stream mouth**
discharges	0	0	0	0	0	0	0	0
runoff	0	0	24	0	24	0	0	0
spills	0	0	24	12	24	0	0	0
fish wastes	0	0	0	0	24	0	0	0
vessels	0	0	0	0	24	0	0	0
construction	0	0	16	0	0	0	0	0
hatchery fish	0	0	0	0	0	0	0	0
shoreline	0	0	16	8	0	0	0	0

The equation for the risk associated with spills can be written and calculated as:

$$S_3 (H_1W_{3,1}+ H_2W_{3,2} + H_3W_{3,3} + H_4W_{3,4} + H_5W_{3,5} + H_6W_{3,6} + H_7W_{3,7} + H_8W_{3,8})$$

$$= 6 (0x1+ 0x1 + 4x1 + 2x1 + 4x1 + 0x0 + 0x1+ 0x1)$$
$$= 6 (10)$$
$$= 60$$

The equation for the risk to shallow subtidal habitat can be written and calculated as:

$$H_5 (S_1W_{1,5} + S_2W_{2,5} + S_3W_{3,5} + S_4W_{4,5} + S_5W_{5,5} + S_6W_{6,5} + S_7W_{7,5} + S_8W_{8,5})$$

$$= 4 (0x1 + 6x1 + 6x1 + 6x1 + 6x1 + 4x0 + 0x0 + 6x0)$$
$$= 4 (24)$$
$$= 96$$

In summary, the relative risks calculated for *Sub-Area C* are described below.

Relative risk from spills to all habitats received a score of 60

Relative risk to shallow subtidal habitat from all sources received a score of 96.

2.2.2 Confirmatory Risk Analyses

Results from the relative risk analysis convey a regional perspective of risk in Port Valdez. Chemical data from Port Valdez provide an opportunity for more traditional analyses of the risks from specific stressors. Results of these traditional, site-specific analyses can then be used for confirmation of the regional results. Three approaches were used for the confirmatory analyses: (1) comparison of chemical concentrations in effluent, sediment, and mussel tissue samples to benchmark values, (2) modeling of chemical concentrations in sediment samples to determine toxicity to marine amphipods, and (3) examination of toxicity tests conducted on effluent and sediment samples with invertebrates and fishes. Each approach focused on chemical exposure and effects. Physical and biological stressors were not assessed. Using three techniques to estimate chemical risks provided three lines of evidence to compare to the relative risk analysis. These techniques are described in Section 7.

1) *Benchmark Values*

This analysis compared PAH and metal concentrations from Port Valdez samples to threshold levels obtained from the literature. The Port data were compiled from effluent, sediment, and mussel tissue samples collected in conjunction with the Ballast Water Treatment Plant (BWTP) permit (APSC, 1995), the Alyeska Environmental Monitoring Program (Feder and Shaw, 1993, 1994b, 1995, 1996), the LTEMP Monitoring Program (Kinnetics Laboratories Inc., 1995, 1996) and U.S. ACE sampling in the Small Boat Harbor (U.S. ACE, 1995) data. Benchmark values were obtained from the U.S. EPA (1996) program for developing Ecotox Thresholds, benchmark determinations for freshwater (Suter, 1996), sediment effects levels (Long and Morgan, 1995), and wildlife threshold levels (Opresko *et al.*, 1995). The purpose of each study was to synthesize effects-based data into useful criteria for determining at what levels adverse effects occur. We compared benchmark values from the references listed above to PAH and metal concentrations in the BWTP effluent, PAH concentrations in sediments from various locations in the Port, and benzo[a]pyrene concentrations in mussels collected from several beaches. The number of times sample concentrations exceeded benchmark values was tallied and compared between different sub-areas. These results were compared to the ranks from the conceptual model. The results of this analysis can be found in Section 7.1.

2) *Modeling PAH Toxicity in Sediments*

The concentrations of selected PAHs in the sediments of Port Valdez have been identified in samples collected during several monitoring and research studies. Sampling sites included the Small Boat Harbor (U.S. ACE, 1995), offshore of the Valdez Marine Terminal and Gold Creek (Feder and Shaw, 1993, 1994b, 1995, and 1996; Kinnetics Laboratories Inc., 1995), near Solomon Gulch Hatchery (unpublished data., David Shaw, University of Alaska Fairbanks, 1996), and other deep water areas of the Port (Feder and Shaw, 1993, 1994b, 1995, and 1996).

These measured concentrations provided input for the ∑PAH model developed by Swartz *et al*. (1995). The steps of the model are shown in **Figure 2-4**.

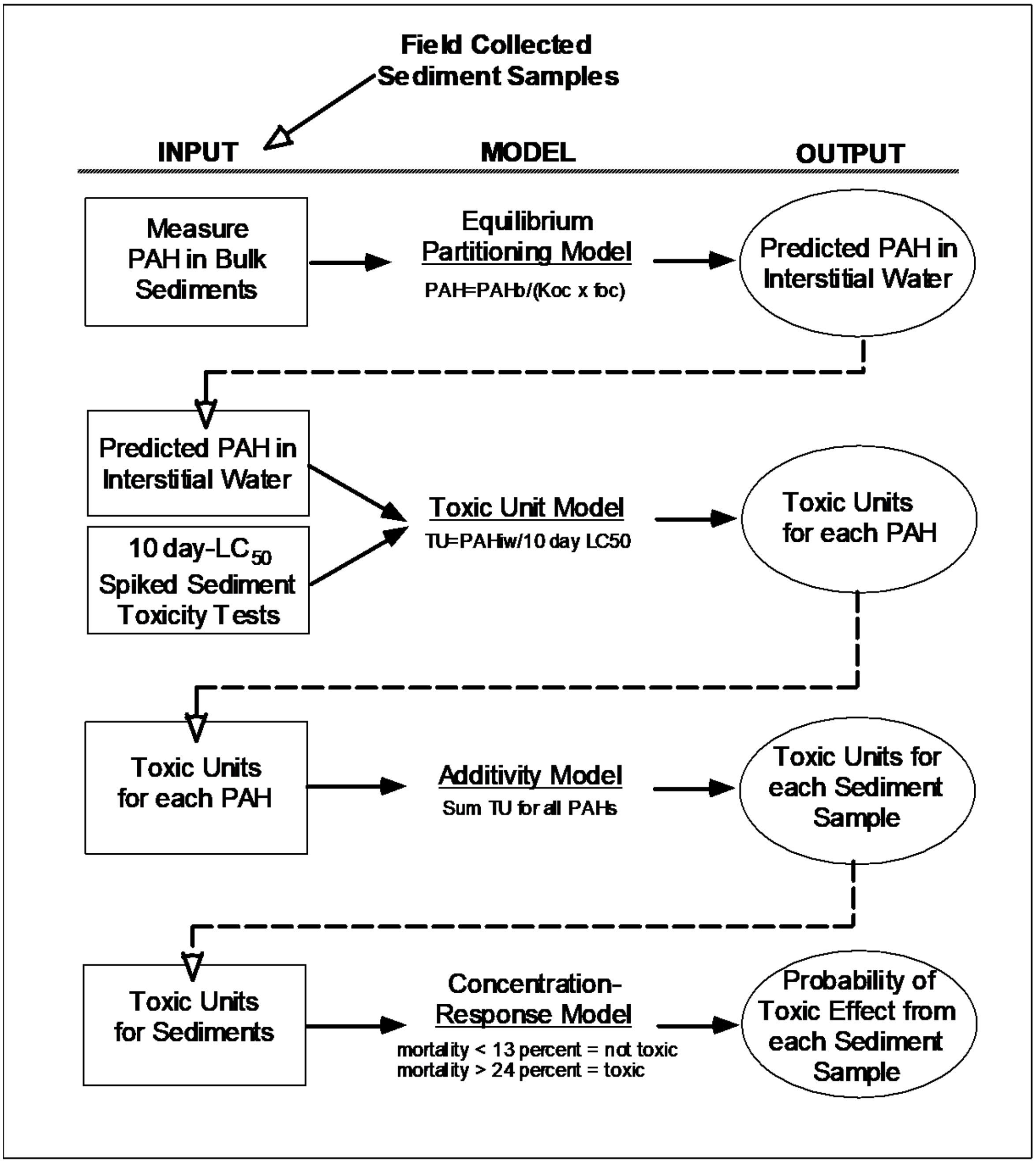


Figure 2-4. Detail of the method used to predict the risk of PAHs in sediments to amphipods.

This model combines five well-known models to assess the risk due to hydrocarbons in the sediments.

1. Equilibrium Partitioning model: describes the partitioning of PAH in the sediment interstitial water based on the total organic carbon content of the sediments
2. QSAR model: determines the acute toxicity of individual PAHs to amphipods in a 10-day test
3. Toxic Unit model: describes the toxicity of the PAHs in the interstitial water
4. Additivity model: determines the total toxicity from 13 selected PAHs
5. Concentration-response model: describes the mortality response of amphipods to spiked field sediments

The model predicts the probability of no toxicity (defined as <13% mortality), uncertain toxicity (defined as 13-24% mortality), and toxicity (defined as >24% toxicity). The model input, output and calculations can be found in Appendix E. The results are described in Section 7.2.

3) *Bioassay Testing in Port Valdez*

Toxicity bioassays are frequently conducted on the BWTP effluent with organisms such as mysids, shrimp larvae, pink salmon juveniles, and echinoderm egg and sperm. The results of these tests were reviewed to determine the risk of toxic effects in the environment. Effluent tests are currently conducted by Columbia Aquatic Sciences (CAS). APSC (1995) reviewed the acute and chronic toxicity associated with the effluent in the past five years. The data reviewed in this report came from tests conducted between 1992 and 1995 for mysids, pandalid shrimp larvae, and pink salmon smolts (CAS, 1995a, 1995b, 1994a, 1994b, 1994c; Gardiner, 1993a, 1993b, 1993c; Gardiner *et al.,* 1993; Antrim and Parkwell, 1992; Antrim *et al*., 1992a, 1992b, 1992c). The most frequent test used for the effluent is the echinoderm sperm fertilization test. The past five years of data from these tests were compiled and reviewed by CAS (1995a). Sediment toxicity tests were also conducted on Port Valdez sediments (Karle *et al.*, 1994). The results from toxicity monitoring of the BWTP and Port Valdez sediments are summarized in Section 7.3.

2.3 Integrated Risk Scenario

The stressor and receptor characterizations described in Appendix C provide information for assessing risk in a particular area or involving specific stressors or receptors. This information can be combined to form a risk scenario. The design of the risk scenario depends on the need. It can apply to a particular habitat type, or be driven by the presence of a particular source in a sub-area. The risk scenario is a valuable tool when developed *before* an assessment because it reminds the assessor of the multiple exposures and effects that are possible. In Section 9 we give an example of how a risk scenario can be developed and how the conceptual model and the relative risk analysis can guide this process.

Unlike the Relative Risk Model, the risk scenarios do not indicate the rank of a risk. To determine the ranked risk of each scenario, steps must be taken to reduce the uncertainty associated with the scenario. The example in Section 9 describes ways to reduce the uncertainty of the presented scenario. This example focuses on clams in the Port, because these organisms are part of the intertidal and subtidal communities and are used as a food resource by crabs, bottom fishes, and mammals.

2.4 Uncertainty Analyses

We addressed three types of uncertainty in this study: uncertainty in the conceptual model, uncertainty in the calculation of relative risk, and uncertainty in the accuracy of the relative risk estimates in Port Valdez. Uncertainty associated with the structure of the conceptual model is mostly of a qualitative nature and is described in the text. The calculation of a relative risk value carries with it a quantifiable level of uncertainty. We designed a sensitivity analysis in order to ascertain the possible variance within this mathematical model. The methods for this analysis are described below. The third type of uncertainty is explored through the confirmatory analyses used to quantify or describe specific risks in the Port. Although these techniques provide evidence to support or contradict the results of the Relative Risk Model, there is additional uncertainty in each of these methods. The results of the uncertainty analyses are described in Section 10.

2.4.1 Sensitivity Analysis for the Relative Risk Model

The results of the sensitivity analysis can be found in Section 10.1. In the following analyses, only the exposure filter was used. The effects filters are expected to affect the model in ways similar to the exposure filter and were not presented here.

The first step in examining the Relative Risk Model was to determine the contribution that each component of the model (source ranks, habitat ranks, and filter values) made to the final result. A component could be removed from the model by changing its values to 1 and then running the model without changing the other components. The model was examined under three conditions:

1. No source ranks,
2. No habitat ranks,
3. No filter.

The sensitivity of the model was examined through a series of tests in which ranks or weighting factors were chosen randomly for input into the model. For instance, in one test the exposure filter was held constant while a random number generator ranked the sources and habitats. We then ran the model twenty times with the ranks randomly generated each time. Plotting the resulting relative risk estimates for each sub-area provided a visual assessment of the variability inherent in the model under these initial conditions. The model was tested in this manner under the following conditions.

1. random input for sub-area ranks, random input for the exposure filter
2. random input for sub-area ranks, fixed input for the exposure filter
3. fixed input for the sub-area ranks, random input for the exposure filter

After each of the 20 trials, the sub-area with the highest relative risk score was identified. These results are summarized in Section 10.1.

We ran an additional test to determine the sensitivity of the model when uncertainty in the ranks was considered. Instead of using a set rank or a randomly chosen rank for the input values, we allowed the model to choose from within a range of ranks that we considered as possible choices. The ranges were our subjective estimates of the chance that the source could cause an impact or that the habitat could be sensitive to an impact in the sub-area.

0	*none* (or very unlikely)
0-2	*unlikely*
0-4	*unlikely* but somewhat uncertain
0-6	*possible* but very uncertain
2-6	*possible* and somewhat uncertain
4-6	*likely*

These ranges represent ambiguity in the ranks chosen as input for the Relative Risk Model and as indicators for the probability of impacts in different areas of the Port. The results from these analyses were plotted to demonstrate the possible variation in the results of the Relative Risk Model when uncertainty is included in the ranking process.

3.0 Characteristics of the Marine Environment

Much of the human and wildlife activity in the Valdez region centers around the Port, a 22 km by 5 km fjord with ecological characteristics typical of a high latitude estuary. The characteristics of the Port, and public concern for protecting its natural resources, define the environment at risk. The Port is affected by stressors originating on land, in streams, in the air and in the marine environment. Therefore, the boundaries of the region to be considered in this risk assessment extend to the watershed of Port Valdez.

Understanding the natural systems, human use patterns and human values connected with a region are important in choosing the format for an EcoRA. Section 3 provides this background information for the Port Valdez EcoRA. Sections 3.1 and 3.2 describe the physical and biological structure and function of the Port, while Section 3.3 examines natural resource use in the area. The environment at risk is the integration of all of these parts: the physical environment, communities of plants and animals, and the social and economic setting. A discussion of the level of disturbance in the environment, a critical concern when evaluating any system, is included in Section 3.4.

3.1 The Physical Environment

Port Valdez is a long and deep fjord surrounded by mountains rising up to 5,000 ft peaks. The shoreline is generally rocky except in areas where sediment outwash from streams and glaciers has created deltas and tidal flats (Hameedi, 1988b). McRoy and Stoker (1969) estimated that more than half of the shoreline in Port Valdez consists of steep rocky beaches and cliffs, while about twenty percent consists of tidal mudflats, found mostly in the eastern Port and at outwashes from glacial streams. The remainder of the coast consists of gravel or broken rock beaches. Like most fjords, Port Valdez has steep walls and a flat bottom with depths of at least 200 m. In the deepest areas, water depths can be as much as 240 m (Sharma, 1979). The mouth of the Port is constricted by the Valdez Narrows and two sills extending across the bottom of the Narrows. The shallower sill is approximately half the depth of the Port basin. Colonell et al. (1988) suggested that the residence time for water in the Port is approximately four weeks, although flushing of the deeper waters may decrease in the summer when stratification limits deep circulation. Modeled simulations of the Port hydrodynamics calculated the residence time of water-borne pollutants in summer to be almost 7 weeks (Hameedi, 1988b). Although dissolved oxygen concentrations in the water column can be depressed during summer stratification, anoxia is not usually observed in Alaskan fjords such as Port Valdez (Hood and Patton, 1973).

3.1.1 Seasonal Cycles

Port Valdez receives large amounts of precipitation, most of which falls as snow during the winter. At northern latitudes, seasonal cycles of light and temperature vary considerably between summer and winter. As air temperature rises in the spring, snow and glacial ice begin to melt. The water column within the Port begins to stratify in late April and May as surface waters warm and freshwater flows increase. Freshwater runoff into the Port reaches a maximum between July and September (Sharma and Burbank, 1973). The water remains vertically stratified in layers defined by differing temperatures and salinities between April and September. While the water is stratified, the top layer of warm, less dense freshwater forms a layer 2 to 20 m thick with salinities approaching 0 $^{o}/_{oo}$ (Hood *et al.*, 1973; Sharma and Burbank, 1973). Surface stratification continues into October. During fall and winter, as surface waters cool and freshwater runoff decreases, the top layer becomes more similar in temperature and salinity to the lower layer of water. By December, winds erode stratification layers and the water column mixes (Cooney and Coyle, 1988; Hood *et al.*, 1973). Mixing circulates nutrients from the depths to the surface and returns oxygen-rich waters to the bottom.

3.1.2 Water and Sediment

The majority of the freshwater entering the Port comes from the drainages of the Lowe River, Valdez Glacier Stream, Mineral Creek, and Shoup Glacier Stream. In summer the low-density freshwater flows along the surface of the Port until it mixes with salt water flowing in through the Valdez Narrows. Most of the freshwater drains into the north and east sections of the Port and then circulates in a counter-clockwise direction, resulting in lower surface water salinities in the northeast than in the southwest.

Summer runoff carries high particulate loads released mostly from melting glaciers (Sharma and Burbank, 1973). An estimated 90% of this suspended material is deposited within the Port as silt and coarse clay. Since the majority of sediment deposited in the Port is brought in by freshwater runoff, the sediment type and accumulation rate differ in the northeastern and southwestern ends of the Port. Coarser particles tend to settle out at a greater rate in the northeastern end while finer materials deposit more in the southwestern end of the Port (Morsell *et al.*, 1979; Naidu and Klein, 1988). Sedimentation rates in Port Valdez are highly seasonal. In winter, stream flow and sedimentation are at a minimum. In summer when snow and glacial melt occur, streams flowing into the Port are loaded with silt and clay particles. Sharma and Burbank (1973) estimated an overall sedimentation rate of 1.67 cm/yr in the Port. The estimates varied from less than 1 cm/yr in the western Port to 13.5 cm/yr at a site in the eastern Port.

The bathymetry of the Port makes it a trap for large quantities of glacial sediments which are chemically unweathered and low in organic carbon (Sharma and Burbank, 1973). These factors are important in determining both the chemical character of the sediments and the biological communities which those sediments support. While nearshore sediments are coarse-grained, those in the deep basin are fine-grained. Although the sediments in a few areas, such as the Duck Flats and the municipal small boat harbor, are enriched organically and may become anoxic at times, most sediments in the Port are low in organic matter (<1% total organic carbon) and well oxygenated. The low organic content and exchange capacity of clay minerals in the sediments results in a low affinity for dissolved hydrocarbons and other organic chemicals (Feder *et al.*, 1990). The combination of low organic carbon and the high deposition rate of fine grained sediments also strongly limits the benthic organisms in the deep basin of the Port (Feder *et al.*, 1973; Feder and Jewett, 1988).

3.2 The Biological Environment

The biological environment of Port Valdez is intricately linked to the physical environment. The combination of a cold northern climate, extreme fluctuations in the physical environment, and normal estuarine gradients creates an ecological system subject to frequent disturbance and continual physical change. In response, the populations of marine plants and animals in the Port must either adapt to this level of disturbance, function under a degree of stress, or fluctuate in population numbers or community structure.

Port Valdez differs from a typical temperate estuary in several important ways. The steep sides and the depth of the central basin (240 m) cause much of the primary production to be recycled in the water column. Little organic matter reaches the deep basin and the benthic community is relatively depauperate and carbon limited (Feder and Jewett, 1988). High deposition rates of fine-grained sediments limit the growth and diversity of intertidal and subtidal invertebrates, especially in the eastern Port (Feder *et al.*, 1973). Intertidal organisms are particularly hardy and survive summers with low surface salinities and long winters with air temperatures often below freezing and little available food in the water column. These recurrent disturbances result in biological communities whose members can accommodate to rapid environmental changes.

There can be marked year-to-year variation in the species composition of phytoplankton and zooplankton because blooms start from small numbers of individuals. This, along with yearly differences in weather, and other factors such as nutrient availability, can result in highly variable phytoplankton densities. Those phytoplankton that are not grazed in the water column settle to the bottom. Consequently, organisms living at the bottom vary in composition and abundance from year to year in response to the quantity and character of organic carbon available.

Because of the latitude (61º N), the growing season is short. Many marine organisms in Port Valdez are at or near the northern end of their range and are susceptible to the stress of harsh winters. Species that are dependent on phytoplankton, such as intertidal organisms, must be able to accommodate the intense pulse of primary production in spring, followed by low to nearly absent production during summer and winter. Intertidal organisms are subject to further stress by the high suspended sediment load in the water column and low salinity during the summer, as well as below freezing air temperatures and occasional ice scour at low tide in winter.

3.2.1 Phytoplankton and Zooplankton

Phytoplankton and zooplankton in the water column are important food resources for intertidal suspension feeders, larval benthic invertebrates and fishes, and adult pelagic fishes. Plankton eventually settles to the bottom where it is also an important food resource for benthic organisms. In Port Valdez, phytoplankton production is closely associated with nutrient levels in the water (nitrates, silicates, phosphates) and summer light intensity. In winter, nutrients are at a maximum concentration, but phytoplankton activity is extremely low due to cold temperatures and reduced light. In spring a large diatom bloom occurs (Horner *et al.*, 1973; Alexander and Chapman, 1980). By late spring, stratification of the water column and nutrient uptake by algae results in a rapid depletion of nutrients in the upper water column. The lack of nutrients and high amounts of suspended sediment from river runoff limit light for photosynthesis and therefore, restrict phytoplankton growth to low levels in the summer (Goering *et al.*, 1973a; Goering *et al*., 1973b). In fall a smaller algal bloom may occur as the water column begins to mix and nutrients are replenished from the lower waters.

Few data exist on zooplankton numbers or species in the Port (Cooney *et al.*, 1973; Cooney and Coyle, 1988). Zooplankton consists primarily of planktonic invertebrates but also includes larvae of benthic invertebrates, larval fishes, and fish eggs. The types of zooplankton in the Port include resident populations as well as some brought in by ocean currents. Oceanic zooplankton are transported into PWS by the Alaska Coastal Current which contributes, in part, to variation in the species composition between years. Cooney *et al.* (1973) found that calanoid copepods were the most diverse and abundant zooplankton group. The abundance and species composition of zooplankton influence the growth and survival of benthic populations in the Port. During years with low numbers of grazing zooplankton, most of the diatoms settle to the bottom and become food for benthic organisms (Feder and Blanchard, 1996b). Alternatively, in years when zooplankton effectively graze the spring diatom bloom (*e.g.*, when the large copepod *Neocalanus* is abundant), much of this organic matter is prevented from reaching the bottom and benthic populations can decline (see review on pelagic-benthic coupling in other areas in Graf, 1992).

3.2.2 Intertidal and Shallow Subtidal Populations

Intertidal regions of Port Valdez are subject to a large degree of natural variability. Organisms living there must be tolerant of extreme seasonal changes in temperature, light, and salinity, although shallow subtidal communities are influenced to a lesser extent. Intertidal and shallow subtidal zones are subject to contaminants transported from the land by runoff and from chemicals or debris that float or are contained in marine surface waters. Organisms in these zones may live in the sediments (*e.g.*, worms and clams), move around at the surface of the sediments (*e.g.*, crabs and small crustaceans), attach to or move over rocky substrates (*e.g.*, algae, mussels, limpets, snails and barnacles), or associate with other plants and animals (*e.g.*, small snails living in beds of intertidal algae). Intertidal and shallow subtidal invertebrates make up a substantial proportion of the diet of sea stars, fishes, birds, and sea otters.

The types of organisms that are found in the intertidal zone depend on the substrate. Although the majority of the coastline in Port Valdez is rocky, large mudflats and gravelly beaches occur in the Port. Mudflats and the adjacent shallow subtidal regions, which are most extensive at the head of the Port, support small invertebrates in the sediment. Polychaete worms, the clam *Macoma balthica*, large numbers of harpacticoid copepods, and cumaceans are common in these areas (Feder *et al.*, 1976; Feder and Keiser, 1980; Feder and Paul, 1980; Lees *et al.*, 1979; Feder and Bryson-Schwafel, 1988; Feder *et al*., 1990; Feder and Blanchard, 1995b). Water held within the silty sediments of mudflats maintains a high salinity throughout the year, which protects sediment-dwelling organisms from exposure to low-salinity water in the summer (Feder *et al.*, 1976; Jewett and Feder, 1977). Diatoms and filamentous green algae grow along the mud surface. This growth increases in the spring and is fed on by harpacticoid copepods and other invertebrates (Feder *et al.*, 1976; Jewett and Feder, 1977). Shallow subtidal sediments contain mostly polychaete worms and clams (*Axinopsida* and *Macoma spp.*) (Lees *et al.*, 1979; Feder and Bryson-Schwafel, 1988; Feder and Blanchard, 1996a).

The rocky shoreline ranges from rock outcroppings and steep rocky beaches to shallow broken rock, cobble, or gravel beaches. A variety of marine plants such as rockweed (*Fucus distichus)* attach to the rocky substrate, providing shelter for a variety of intertidal animals (McRoy and Stoker, 1969; Calvin and Lindstrom, 1980; Feder and Bryson-Schwafel, 1988; Feder *et al.*, 1992). The mussel, *Mytilus trossulus* (formerly named *M. edulis:* Blanchard and Feder (in press) and the barnacles, *Semibalanus balanoides* and *Balanus glandula*, are abundant in the mid and lower intertidal regions (Rucker, 1983; Feder and Bryson-Schwafel, 1988). Periwinkles (*e.g.*, *Littorina sitkana)* and limpets (*e.g.*, *Tectura personce*) are sometimes common in these areas. The whelk (*Nucella lamellosa*) occurs occasionally in the eastern Port but is abundant on rocky shores of the western Port. In summer, many species of seasonal algae are present at the lower edge of the intertidal zone and provide a substrate on which small snails, such as *Lacuna sp.*, deposit eggs. Hermit crabs (*Pagurus hirsutisusculus)* and rock crabs (*Hemigrapsus oregonensis*) are the primary scavengers of the intertidal (Feder and Keiser, 1980; Feder and Bryson-Schwafel, 1988). Common invertebrate predators of the lower rocky intertidal and shallow subtidal regions include whelks and sea stars (*Evasterias* and *Pycnopodia)* (Feder and Bryson-Schwafel, 1988). Like whelks, sea stars are also more common in the western Port where there is less freshwater influence.

Ribbon kelp (*Laminaria saccharina)*, other macroalgae, and seagrass (*Zostera sp.),* grow in shallow subtidal areas near rocky shores (City of Valdez, 1992). The steep sides of the basin tend to limit the amount of shallow subtidal habitat available, although a subtidal reef exists just outside of the Duck Flats (Lees *et al.*, 1979). These areas may provide nursery grounds and protective habitat for crustaceans and fishes. Tanner crabs were commonly found as juveniles in these areas by Lees *et al.* (1979). However, recent studies offshore of the city collected no Tanner crabs (Feder and Shaw, 1994a; Feder and Blanchard, 1995a, 1996a). Herring occasionally deposit eggs on kelp in the spring (Calvin and Lindstrom, 1980).

3.2.3 Deep Subtidal Populations

The benthic invertebrates living in the deep basin of the Port have been the focus of an intensive monitoring study since 1971. Most of the deep subtidal organisms in Port Valdez are deposit-feeding polychaete worms capable of living in and on fine grained soft-bottom sediments. These sediments are easily resuspended and interfere with the success of filter-feeding invertebrates. A greater number of filter-feeding organisms are found in the western Port where sediment deposition is up to 20 times less than that of the eastern Port (Feder and Matheke, 1980). Benthic studies indicate that invertebrates in the deep benthic environment are influenced by depth, sediment grain size, sediment deposition, and food availability (Feder *et al.* 1973; Feder and Jewett, 1988; Feder and Blanchard, 1996b). The abundance of deep benthic invertebrates fluctuates throughout the Port from year to year. Benthic organisms in Port Valdez are stressed seasonally by high sediment loads introduced during spring runoff, and periodically by underwater sediment slumping events triggered by seismic activity. Waste accumulations on the bottom can also change sediment structure or makeup, which in turn may alter the benthic community living there (Parsons *et al.*, 1984; Scott, 1989). Organic loading from waste discharges, yearly variation in zooplankton grazing activities, and changes in water temperature have been suggested as possible factors influencing community structure of the benthic infauna (Feder and Jewett, 1988; Feder and Blanchard, 1996b).

The larger invertebrates that live on subtidal sediments include shrimps, such as pink shrimp (*Pandalus borealis)* and sidestripe shrimp *(Pandalus dispar),* and Tanner crab (*Chionoecetes bairdi)*. Adult Tanner crab are occasionally found although the juvenile crabs are more common (Feder and Paul, 1977; Smith and Stoker, 1969). Dungeness crab (*Cancer magister*) were more common in the Port in the early 70s but are less common now. This decline coincided with increasing numbers of sea otters which feed on crab (Feder and Jewett, 1988; Garshelis, 1983). While juvenile and adult crab are strictly bottom-dwellers, pandalid shrimp feed on the bottom and in the water column.

Bottom fishes occur in low numbers compared to other fjords in PWS. Surveys identified 23 species including sculpins, flounder, cod, skates and rockfish (Smith and Stoker, 1969). Juvenile pollock (*Theragra chalcogramma*) are fairly common and may use the Port as nursery grounds (City of Valdez, 1992).

3.2.4 Anadromous Fish Spawning Habitat

The Alaska Department of Fish and Game has classified more than 20 streams in Port Valdez as anadromous fish streams (Stream Numbers 221-60-11300 to 221-60-11530). These streams provide spawning and rearing habitat for pink, chum, silver, and red salmon, as well as Dolly Varden. Counts of returning adult salmon made during ground surveys of streams are shown in **Figure 3-1**.

The steepness of the surrounding terrain tends to limit the amount of suitable spawning habitat available in many of the streams. Consequently, populations of wild salmon in the Port are relatively small (City of Valdez, 1992). After salmon spawn, the eggs incubate in the gravel of the streambed until hatching in winter. The hatched alevins remain in the gravel until spring when they emerge as fry. During the winter, egg and alevin survival depend on adequate stream flows and proper water temperatures. Spring-fed streams provide a more consistent and warmer stream flow than runoff fed streams and are most often utilized for spawning (Mattson, 1973).

During the spawning season four streams are regularly surveyed from the air for pink or chum salmon (pers. comm., Dan Sharp, Alaska Department of Fish and Game, 1995). Spawning pink and chum salmon are prevalent in streams associated with Mineral Creek and the Duck Flats. Pink salmon are also common in the Robe and Lowe River systems. Both species spawn at the intertidal mouth of the stream as well as further up the stream. Fry emerge from late May through early June. Pink and chum fry spend little time in freshwater. They move quickly into the Port, form schools, and concentrate along the shoreline. Generally, these salmon fry migrate out of the Port within three weeks after emerging, although they may concentrate at the west end of the Port and feed before passing through the Narrows (Jewett and Stark, 1994). Chum salmon fry may feed in the Duck Flats for several weeks before moving out into the Port (Dames & Moore, 1979a).

Silver salmon spawn mostly in the Robe and Lowe River systems. After emerging, the fry remain in freshwater streams for one or two years before migrating out of the Port. Red salmon spawn mostly in the Robe River system where the fry have access to Robe Lake for rearing. Red salmon fry remain in freshwater for two or three years before migrating out of the Port. Before the 1950s, the red salmon run in Port Valdez consisted of approximately 40,000 adults. At that time Corbin Creek, a glacial stream draining into Robe Lake, was diverted into Valdez Glacier Stream to decrease sedimentation in the lake. This stream diversion decreased water flow into the lake, resulting in overgrowth of the aquatic vegetation, other changes in physical conditions, and a possible reduction in suitable rearing habitat for red salmon (City of Valdez, 1992).

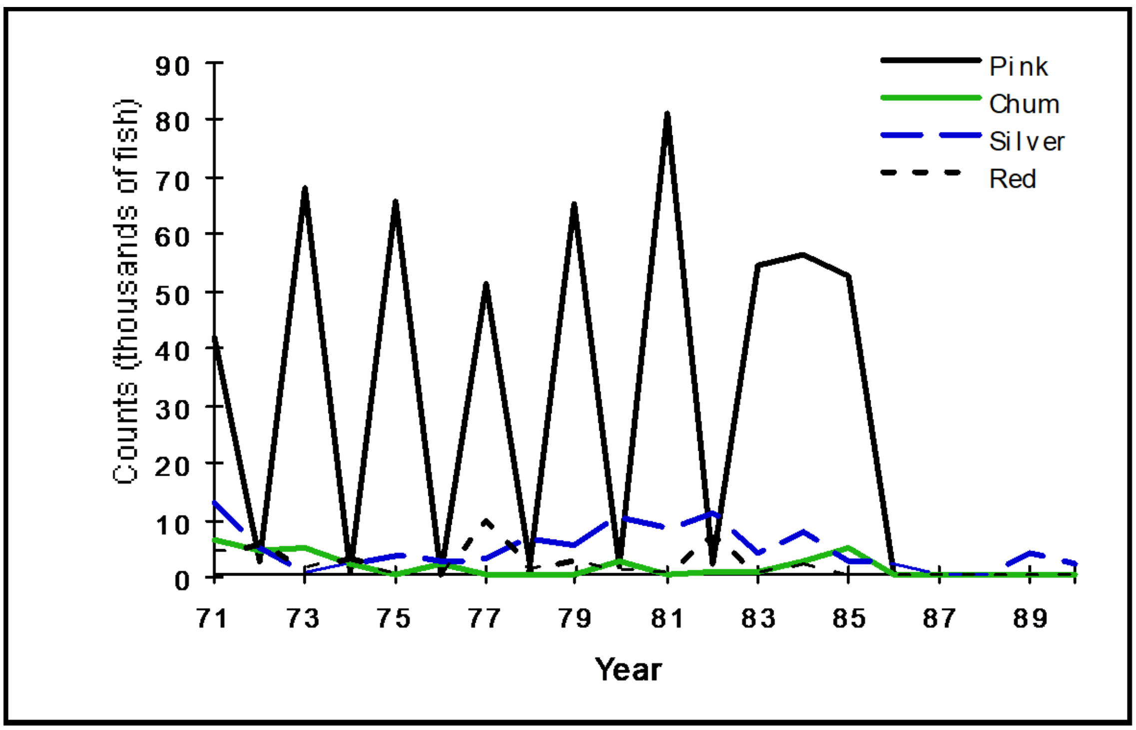


Figure 3-1. Counts of spawning adult salmon in Port Valdez streams. (Data acquired from Andy Hoffman, Alaska Department of Fish and Game, 1995).

3.2.5 Bird Populations

In a 1980 study, the U.S. Fish and Wildlife Service measured the abundance of birds in coastal habitats of Port Valdez (Hogan and Colgate, 1980). Protected bays *(i.e.,* Anderson and Shoup Bays) and tidal mudflats had the highest bird densities. The bays were preferred by murres, scoters, buffleheads, and black-legged kittiwakes. Tidal mudflats were used by feeding sea ducks in winter, and breeding dabblers and feeding gulls in summer. Gravel beaches attracted harlequin ducks and breeding Arctic terns. Although few birds were found on rocky shore and steep cliff habitats, these areas were used by goldeneyes in winter and pigeon guillemots and marbled murrelets in summer.

Species composition varies with season. Sea ducks were the most abundant group in winter, accounting for 38 percent of the birds in the 1980 study (Hogan and Colgate, 1980). Sea ducks included the white-winged scoter, surf scoter, harlequin duck, oldsquaw, Barrow's goldeneye, common goldeneye, bufflehead, common merganser, and red-breasted merganser. Rock sandpipers were the second most abundant species in winter followed by the common murre. In summer, gulls and terns comprised 70 percent of the population while sea ducks represented only 8 percent. Gulls and terns were less than 5 percent of the population in the winter. The peak bird populations were 5,000 to 6,000 in summer and 2,500 to 3,500 in winter (Hogan and Colgate, 1980).

Many bald eagles are present in Port Valdez and along the Lowe and Robe Rivers. Eagles often nest near salmon streams where the adults can feed on spawning salmon in spring and summer. In 1979, six breeding pairs were observed with nests located along Mineral Creek, Siwash Creek/Duck Flats, Gold Creek, and Lowe River (Hogan and Colgate, 1980). Bald eagles are primarily scavengers subsisting mainly on dead or dying fish.

Sea ducks and migrating ducks feed and breed in the Duck Flats, the largest saltmarsh in the Port. Dabbling ducks feed at the northern edge of the mudflats as well as in the northeast corner where they mainly eat the abundant small clam, *Macoma balthica*. Mussel beds in the southern portion of the Duck Flats are fed on by diving ducks, Barrow's goldeneyes, buffleheads and white-winged scoters (Hogan and Colgate, 1980). Gulls, and other fish-eating birds, feed at various salmon streams. Oyster catchers and other shore birds feed intertidally on polychaete worms, limpets, and small snails.

3.2.6 River and Marine Mammal Populations

Sea lions and several species of whales are irregular visitors to the Port. Two marine mammal species are reported on a regular basis in Port Valdez: the harbor seal *(Phoca vitulina*) and the sea otter *(Enhydra lutris*) (Hameedi, 1988b). Harbor seals feed on fishes and are often seen near spawning streams or hauling out to rest on rocky islands and shores

(Dames & Moore, 1979b; Hemming and Erikson, 1979; McRoy and Stoker 1969). Sea otters feed on intertidal and subtidal invertebrates (Anthony, 1995). River otters (*Mustela vison)* and a variety of other terrestrial mammals feed in intertidal areas and could be affected by marine pollution (Hogan and Irons, 1988). Bowyer *et al*. (1994) found that river otters in PWS feed mainly on intertidal invertebrates and bottom-dwelling fishes.

Sea otter populations throughout southern Alaska were greatly depleted in the 1700s and 1800s by over-harvesting. In 1911 the International Fur Seal Treaty was signed, which banned further hunting of sea otters. Since that time, the population in PWS has grown from an estimated 50 otters to 13,000 in 1985 (Garrott *et al.*, 1993). The first modern sighting of a sea otter in Port Valdez occurred in March of 1974 (Hogan and Irons, 1988). Otter sightings in Port Valdez increased to an average of 3 per month by 1978 and 1979 (Hogan and Irons, 1988). By 1991, Anthony (1995) spotted an average of 102 otters per month. Sea otters tend to be the most abundant in Shoup Bay, whereas lower numbers occur in the western and eastern regions of the Port.

Garshelis (1983) determined that male and female otters of PWS differed in resource use and territoriality. Each gender had preferred locations for resting and feeding, which were often shared by several individuals. Anthony (1995) found that most otters in Port Valdez were juvenile or adult males. Sightings of females with pups (21) and without pups (1) were rare and occurred in Shoup Bay and in the vicinity of Mineral Creek. The predominance of juvenile males suggests that Port Valdez is inhabited by a transient population of otters. The sea otter population in the Port is assumed to be at its maximum sustainable size (Anthony, 1995).

Approximately 15 percent of the Port is suitable habitat for foraging sea otters. In Port Valdez most of their diet consists of the mussel, *Mytilus trossulus* and the rock jingle *(Pododesmus macroschisma)*. This diet is supplemented by spoonworms (*Echiurus)* in the western Port (Shoup Bay) and barnacles and clams in the eastern Port (Valdez Marine Terminal) (Anthony, 1995). Sea otters require 20-30% of their body weight in food on a daily basis (Estes and Palmisano, 1974) and have been estimated to feed to depths of 40 m (Anthony, 1995). Even at low densities, sea otters can have a great effect on the local environment (Simenstad *et al.*, 1978). The main effects result from otter excavation causing space restructuring, subordinate benthic species establishment, nutrient circulation to the water column, and local substrate enhancement because of waste deposition (Anthony, 1995). The effect of otters on soft-bottom subtidal communities is estimated to be equal to that of storm waves on rocky intertidal communities and gravel beaches (Anthony, 1995).

3.3 The Human Environment

The community of Valdez formed at the turn of the century as a fishing and mining town and as a gateway to the goldfields of interior Alaska and the Yukon. It continues to be one of the few seaports with access to interior Alaska. Although the population remains low, the number of residents has more than tripled since 1970 to the current level of 4,700 people (**Figure 3-2**). In summer the population increases to around 9,000, primarily due to recreational and sport fishing opportunities (pers. comm., Valdez Chamber of Commerce, 1995). The Port is of economic importance to the people of Valdez for shipping, fishing, and tourism.

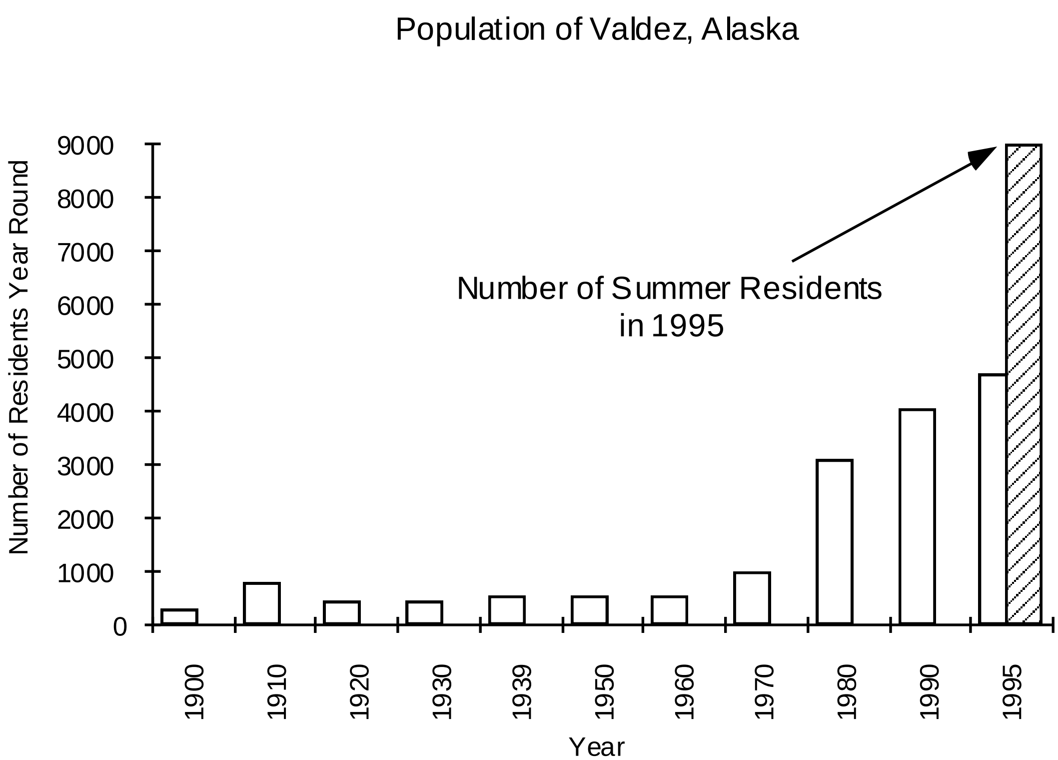


Figure 3-2. Population of Valdez (reported by the U.S. Census Bureau and the Valdez Chamber of Commerce).

3.3.1 Shipping and Transportation

As an ice free deep-water port, Valdez provides a shipping and transportation route to interior Alaska. Shipping is an important source of revenue in Valdez, even though there is competition with Anchorage, Seward, and Whittier as major seaports in south-central Alaska (City of Valdez, 1992; Schmalle, 1978). Valdez is linked to the interior by the Richardson

Highway (the only road entrance to the Port) and to Cordova, Whittier, Kodiak, Seldovia, Port Lions, and Homer by the Alaska State Ferry system.

Crude oil and fuels are the principal cargo in Valdez. Alaska North Slope crude oil is transferred to tankers for transportation to refineries on the U. S. west coast at the Valdez Marine Terminal. Petro Star Refining, a small refinery located just east of the Valdez Marine Terminal, removes crude oil from the pipeline and processes it into marine diesel and jet fuels. The fuel is currently trucked around the head of the Port, stored in tanks, and shipped from the city petroleum dock. The Army Corps of Engineers (U.S. ACE) is reviewing a current proposal to load fuel from the Valdez Container Terminal (pers. comm. Vicki Taylor, U.S. ACE, 1996). The U.S. EPA (1980) reviewed several proposals to build other refineries along the Valdez Glacier Stream at the eastern end of the Port. To date, none of these proposals have been implemented. Other proposed industrial developments in the area include a gas liquefaction plant and marine terminal for a natural gas pipeline from the North Slope, timber export facilities, and agricultural ventures including barley and swine.

3.3.2 Tourism

Valdez received 129,000 visitors during the 1994 summer season. Tourism stimulates the local retail and service businesses. Tourists may pass through the area in a relatively short time, as is common with cruise ship passengers, or spend time camping, boating, and sightseeing in the area. Many people are drawn to the area by the image of Valdez as a pristine wilderness coastline. Three fish derbies (pink salmon, silver salmon, and halibut) and 35 charter services attract sport fishermen. Although tourism is at its peak between May and August, winter recreation and events, such as the World Extreme Skiing Event and the King of the Hill Snowboarding Championship, encourage winter tourism. Maintenance of sport fisheries, wildlife populations, and the region’s scenic values are important to the tourism industry.

3.3.3 Fishing

Commercial fishing is largely limited to PWS and the Valdez Arm, although limited commercial catches of pink and silver salmon occur within the Port (Valdez Fisheries Development Association, 1995). Valdez has a large and popular sport fishery for pink and silver salmon, as well as charter access to salmon and halibut fishing in adjacent waters. Much sport fishing for pink salmon occurs from the shore at Allison Point and from the city docks. Silvers are more often caught from boats (Valdez Fisheries Development Association, 1995). Dolly Varden, rockfish, lingcod, shark, and eulachon, as well as king, red, and chum salmon, are also harvested, making local and charter boat fisheries an important component of the economy in the summer (Merrell 1988; Morsell *et al.*, 1979; Valdez Fisheries Development Association, 1995). Sport and subsistence fishing also occurs in the Port for Dungeness crab, Tanner crab, spot shrimp, coonstripe shrimp, and octopus (pers. comm., Joe Bridgman, RCAC, 1996; Merrel, 1988).

The Valdez Fisheries Development Association, a nonprofit organization formed to enhance the sport and commercial fisheries in the Port, operates a hatchery on the southern shore of the Port at the mouth of Solomon Creek. The Solomon Gulch Hatchery is permitted to raise 230 million pink, 18 million chum, 2 million silver, and 0.3 million king salmon. As of 1994, chum salmon are no longer raised due to the low numbers of returning adults. King salmon release has been postponed until disease free stocks can be obtained. The hatchery uses returning adults as broodstock for acquiring the eggs incubated at the hatchery. The remaining carcasses are either sold, given away, or ground and disposed of in deep water. Adult salmon are also harvested and sold by the hatchery. Commercial harvest of hatchery fish in the Port is allowed when the number of expected returns meets the hatchery's broodstock and harvest needs. Returning pinks arrive in June and July, while silvers arrive in August and September.

3.3.4 Subsistence Hunting

The State of Alaska allows subsistence hunting of sea otters. The U.S. FWS runs a Marking, Tagging, and Reporting Program requiring that all kills be reported. Since 1992, the records indicate a total of 49 sea otters killed for subsistence purposes in Shoup Bay and Anderson Bay. Forty-eight of these were male and 1 was female (pers. comm., David McGillivary, U.S. FWS, 1995).

3.3.5 Mining

Minerals have been mined in the Port Valdez area since the turn of the century. Most mining efforts sought gold, copper, lead, and zinc, although some mining and prospecting for silver, antimony, tungsten, and platinum also occurred. Mines that are currently listed as active in the Port Valdez area include placer mines, lode mines, and tunnel mines (pers. comm. John Pran, Bureau of Land Management, 1995). The active list includes lode mines near Mineral Creek, Shoup Bay, and the Valdez Narrows; and placer mines near Gold Creek and the Valdez Narrows. However, ADNR has no current discharge or stormwater permits for mines in the Port Valdez area. It is possible that some mining claims are being kept minimally active for future use (pers. comm., Alan Wein, ADEC, 1995).

3.4 Disturbance in the Environment

Disturbance in the marine environment results from anthropogenic and natural causes that can occur on a continuous, seasonal, periodic, or catastrophic basis. Many of the natural disturbances in the Port are seasonal (described in Sections 3.1 and 3.2). Seasonal events associated with a cold, northern climate, glacial meltwater and heavy sediment loads are extreme and create a background of yearly disturbance in the Port. To distinguish anthropogenic disturbances from natural disturbance, we must rely on studies conducted in the Port that evaluate effects. Anecdotal information can also provide unconfirmed evidence of anthropogenic disturbance. Anthropogenic effects that are known or suspected to occur in the Port must also be evaluated in relation to large-scale past disturbance events, such as a catastrophic earthquake in 1964, which may continue to have some effect.

3.4.1 Evidence Suggesting Anthropogenic Disturbance in the Port

Anecdotal information and studies suggest some impacts in the Port due to anthropogenic disturbances (**Table 3-1**). The significance of each of these impacts depends on the size of the area affected and the duration of the effect. (An effect is the response of the organism to all of the conditions, both natural and anthropogenic, to which it is exposed.) The effect that a stressor has on the ecology of Port Valdez depends not only on the size and distribution of the stressor, but also on the other stressors (both natural and anthropogenic) that are present in the system, and the interactions between all of these components.

3.4.2 Natural and Background Disturbance

Natural disturbance events function as stressors and can cause marked changes in the physical environment over time, which may be reflected as changes in ecological structure and function. These events may be random and unpredictable, as in the case of earthquakes, or predictable and tied to seasonal events. Seasonal fluctuations in the physical environment include precipitation, temperature, salinity, and sediment loading (see Section 3.1.1). Concurrently, plant and animal population dynamics fluctuate (*e.g.*, algal blooms and salmon migrations) (see Sections 3.2.1-3.2.6) and result in annual changes to environmental conditions in the Port.

Non-seasonal historical disturbances also influence the degree of uncertainty in interpreting environmental conditions (**Table 3-2**). Port Valdez and the surrounding area are within an area of high seismic activity (Shaw and Hameedi, 1988). Earthquakes cause landslides and underwater sediment slumping in the Port that disturb the sediments and create pockets of extreme sediment deposition which can increase turbidity in the water, and disturb or smother benthic organisms (Feder and Jewett, 1988).

Table 3-1. Impacts observed in Port Valdez or the surrounding area. These observations were obtained from scientific study and anecdotal information.

Receptor	***Observed Impact***
Sea Otters	• During surveys of the Port, 28% of otters encountered a moving vessel; otters responded in 33% of these encounters. Otter responses ranged from an alerted pose and visual scanning to diving or swimming (Anthony, 1995). • Berths, docks, and pilings at the Valdez Marine Terminal provide an increased surface area for mussel colonization and increase feeding resources for otters (Anthony, 1995).
Birds	• Seagulls attracted to the landfill, and areas where fish wastes are available. • Nesting terns and oystercatchers thought to have been disturbed by activity at the container dock. • Death or injury of waterfowl noted in the Duck Flats from pets and hikers (Hogan and Colgate, 1980)
Fishes	• Decline in herring populations throughout PWS. • Red salmon populations have been affected by the loss of rearing habitat in Robe Lake (City of Valdez, 1992). • Commercial fishing of hatchery salmon increase the bycatch rate of the protected wild populations. • High levels of hydrocarbons found in some bottom fishes. Unclear if fishes were contaminated in the Port (CAS, 1993).
Dungeness & Tanner Crabs	• Abundance declined in 1980s, probably as a result of the recovering sea otter population after hunting of these animals was banned in 1911 (Anthony, 1995).
Benthic Invertebrates	• Subtidal community show signs of enhancement near the outfall (or diffuser) of the BWTP (Feder and Blanchard, 1996b). • Large number of capitellid worms (indicators of organic enrichment) are found at sites near the fish processing outfalls (Feder and Blanchard, 1995a). • A localized decline in abundance and diversity noted at sites affected by dredge spoils dumping 6 months after construction of the Alyeska ship escort response vessel service dock (Feder and Blanchard, 1996a).
Intertidal Invertebrates	• Clams (*Macoma balthica*) at Dayville Flats decreased during road construction along the shore in the 70s. Abundance measured in 1989-1992 were at or above pre-construction levels (Naidu and Feder, 1992).
Zooplankton	• Hatchery pink salmon fry released in the millions feed on zooplankton populations during their migration from the Port (Jewett and Stark, 1994). The high numbers of fry may reduce zooplankton abundance.

Table 3-2. Historical events and disturbances that may have long-term effects on the Port Valdez ecology. (Adapted in part from Feder and Bryson-Schwafel, 1988, and other sources).

Historical Disturbances in Port Valdez	
1901	City of Valdez incorporates. The town functions as a route to the interior gold fields and a supply center.
1910	Mining of gold-quartz veins starts in the Valdez area which resulted in increases in the leaching of metals and sediments to streams.
1964	Earthquake destroys the old city located at the eastern end of the Port. Large scale sediment slumping and redistribution destroy much of the intertidal and subtidal life. Asphalt and oil storage tanks on the Valdez waterfront spill into the Port.
1965	Extension of the Richardson Highway into the new town of Valdez. The highway crosses through the marshland known as the Duck Flats.
1975	Construction of Dayville Road across the Dayville tideflats along the southern shore of the Port. Construction of the southern terminus of the Alyeska pipeline and the loading facilities begin on the southern end of the Port. Construction activities increase localized sediment inputs at the head of the Port.
1977	New wastewater treatment plant begins discharging near the site of the old city of Valdez. Construction of the oil terminal finished. Tanker loading operations initiated. Alyeska's Ballast Water Treatment Plant begins discharging treated tanker ballast water into the Port.
1981	Solomon Gulch Hatchery begins operation. Millions of pink salmon fry released into the Port to feed on zooplankton populations.
1985	Increased fishing opportunities in the Port begin to draw increasing numbers of sport anglers during the summer.
1989	The *Exxon Valdez* spills 35,000 metric tons of crude oil into PWS. Oil did not enter the Port but cleanup efforts created a population boom and increased boat traffic in Valdez. The *Thompson Pass* spills 250 metric tons into Port Valdez.
1994	The *Eastern Lion* spills 30 metric tons of crude oil into Port Valdez.

A major earthquake occurred on March 27, 1964 and resulted in a series of large waves in Port Valdez. The earthquake measured 8.3-8.6 on the Richter scale and was centered 70 km west of the Port (Hameedi, 1988a). Approximately 75 x 10^6 m^3 of gravel, sand, and silt were deposited in the Port by a massive landslide of the sediments in deltaic fans at the eastern end (Sharma and Burbank, 1973). Observations taken soon after the earthquake confirmed sediment redistribution into the deeper areas of the Port. Some crab pots were buried by several meters of sediments. Most, if not all, of the intertidal plants and animals were destroyed, resulting in only low densities of intertidal animals in 1968, four years after the earthquake (McRoy and Stoker, 1969). Follow-up studies in the late 1970s and early 1980s indicated that substantial intertidal recovery had taken place (Feder and Bryson-Schwafel, 1988). Surviving large invertebrate predators, pelagic and bottom fishes, and a variety of shore birds were indirectly affected by the loss of food resources.

The 1964 earthquake seriously damaged the city of Valdez (currently known as Old Valdez as shown in Figure 1-1). The city waterfront, including asphalt storage facilities, was demolished by the large waves that accompanied the earthquake. Kvenvolden *et al.* (1993) analyzed asphalt residues from the beaches around PWS and attributed these residues to asphalt released into the Port in 1964. Refined hydrocarbon products were also detected in sediments collected along the shore adjacent to the old town of Valdez in 1973 and 1974. This contamination probably resulted from waterfront oil storage tanks that were ruptured during the earthquake (Shaw, 1988).

3.5 Public Concerns

Public meetings and interviews were also used to identify the specific issues in Port Valdez that could pose an ecological risk to the environment. These meetings served a two-fold purpose: (1) validation of the background information gathered as part of the problem formulation, and (2) representation of public knowledge and concerns about the environment. **Tables 3-3** and **3-4** summarize the comments made by members of the community regarding the possible stressors and receptors in the Port. This public involvement is especially vital in a regional assessment not driven by a single contaminated site. Identifying community values leads directly to the formation of relevant assessment endpoints. These values provide the link between the risk assessment process and management of the area that is both effective and plausible.

Table 3-3. Summary of comments about possible stressors in Port Valdez expressed locally at public meetings and in interviews.

Possible Stressors	*Issues Raised by Members of the Community*
Treated Waste Discharges	
Municipal Wastewater Treatment Plant	Effectiveness of treatment, level of monitoring
Alyeska Ballast Water Treatment Plant	Effectiveness of treatment, chemical and hydrocarbon releases
Contaminated Runoff	
Municipal landfills	Proximity to river, high water table, construction wastes
Alyeska Valdez Marine Terminal	Hydrocarbon leaks from underground piping
Petro Star Refinery	Refinery and industrial processes
Small Boat Harbor	Boat maintenance and repair
Septic tanks	Robe River and Alpine Woods subdivisions near river
Mining	Arsenic and other mining contaminants from north shore
Large Oil and Fuel Spills	
Oil tankers	Crude oil spills during transport or loading
Fuel barges	Diesel and jet fuel spills during transport or loading
Small Spills	
Boat maintenance and repair	Small Boat Harbor and Container Dock
Fueling docks	Potential for spills during transfer
Sinking vessels	Accidental, or derelict vessels sunk by weight of snow
Antifouling Paints	
Large vessels	Tributyltin
Small Boat Harbor	Copper and lead based paints
Air Emissions	
Alyeska Valdez Marine Terminal	Volatile organics released from operations
Vessel air emissions	Yellow haze occurs in Port

Table 3-3. (**continued**) Summary of comments about possible stressors in Port Valdez expressed locally at public meetings and in interviews

Possible Stressors	*Issues Raised by Members of the Community*
Vessel Wastes	
Sewage	Illegal dumping in Small Boat Harbor
Fuels and Engine Wastes	Released during engine operation and pumped from bilges
Seafood and Fish Wastes	
Commercial fish tenders	Liquid from fish holds dumped or washed into Small Boat Harbor
Seafood processing plants	Discharge of fish wastes adjacent to the city
Sportfish cleaning	Fish wastes in Small Boat Harbor
Straying of returning hatchery fish	Increase in fish carcasses decaying in streams
Salmon Carcasses	Dumping in the Port after egg harvest by hatchery
Physical Disturbance	
Boating activity	Disturbance of wildlife populations
Shoreline activity	Disturbance of bird presence and nesting
Propeller washes	Sediment disturbance, salinity and temperature changes in water
Straying hatchery fish	Overcrowding of spawning habitat
Logging debris	Wood debris off the container dock in the Duck Flats
Sandblasting debris	Container dock and Valdez Marine Terminal berths
Biological Alteration	
Straying hatchery fish	Loss of genetic diversity in natural salmon runs
Hatchery fish fry	Increased predation on plankton populations and competition for food with wild salmon fry
Introduced species	Imported in ballast water or attached to hulls

Table 3-4. Comments about potential receptors in Port Valdez discussed at public meetings and in interviews.

Possible Receptors	*Issues Raised by Members of the Public*
Wildlife Populations	
Marine Mammals	Tourism pressures
	Population reductions
	Effects of the *Exxon Valdez* Oil Spill on populations that move in and out of the Port
	Sea otter feeding pressure on invertebrates
Terrestrial Predators	Eagles and salmon predation
	Bears , salmon use and human interaction
	Land otter presence and feeding
Birds	Reductions in bird populations
	Resident vs. transient birds
	Specific populations such as Arctic Terns
	Migratory use of tideflats
Quality of the Environment	
Habitat	Duck Flats
	Anderson Bay
	Salmon spawning streams
	Benthic environments
Wild Salmon Runs	Genetic integrity
	Competition for spawning habitat with hatchery salmon
Air, Water, Sediment	Aesthetics
	Perception of pristine water quality
	Sediment quality as a habitat
	Effects of air quality and deposition
	Contaminant leachates from soil
Fisheries	
Commercial Fishes	Pink fry migration
	Salmon harvesting
	Herring survival
Sport Fishes	Shrimp and crab populations
	Hatchery and wild salmon
	Possible depletion of bottom fishes

4.0 Assessment Endpoints

Choosing the assessment endpoints focuses the risk assessment on characteristics that have social and biological importance. The risk to an assessment endpoint will vary within the Port, depending on the habitat in which it is found and the proximity to stressors. For this regional assessment, we chose endpoints that apply Port-wide (water and sediment quality) and to specific locations of the Port (wildlife and fisheries populations).

1. ***Water and Sediment Quality:***
    - prevention of chemical pollution or physical degradation of the water and sediments
2. ***Fisheries:***
    - protection of existing commercial and sport fish populations
    - protection of existing crab and shrimp populations
3. ***Wildlife Populations: (birds, mammals and wild fish)***
    - survival and integrity of wild salmon populations
    - protection of habitat required for feeding, reproduction and survival of young
    - maintenance of intertidal and subtidal populations of invertebrates and fishes

These endpoints reflect human values and uses of the Port. Fisheries, tourism and the community's concern for the quality of their environment influenced the emphasis of the assessment endpoints. Each endpoint is also susceptible to one or more of the stressors that may be in the Port Valdez environment.

Many aspects of the assessment endpoints overlap, which creates an opportunity for understanding and protecting the dynamic and complex relationships within this ecological system. No laboratory or field measurements were taken for this risk assessment. All of the scientific data presented later in this report were collected in other studies and for other purposes. Consequently, the assessment endpoints are primarily a guide for structuring the conceptual model and the risk analysis.

4.1 Water and Sediment Quality

The tourist industry, visitors, and the local population value the ideal of a "pristine environment" in Port Valdez. Protecting air, water, and sediment maintains the quality of this environment. We have included water and sediment quality as assessment endpoints for Port Valdez. Air quality, although not chosen as an endpoint, will affect both the water and sediment endpoints. Particulate air pollutants deposit directly onto the water surface and onto the land where rain and melt-water runoff carry them to the Port. Water and sediments also have critical impacts on the resident microbial, planktonic, and benthic communities, which will in turn affect fish and wildlife populations that depend on these communities for nutrient cycling and food resources. Water and sediment quality include a variety of water and sediment characteristics that are measurable (*e.g.*, turbidity levels, dissolved oxygen content, or toxicity). Possible measurements designed to monitor conditions within the Port that could be affected by anthropogenic activities include:

- Turbidity, suspended solids, or sediment deposition causing changes in intertidal and subtidal community structure;
- Dissolved oxygen levels in sediments or bottom waters capable of supporting benthic communities, habitat for crustaceans or fishes; and
- Survival, growth, and reproduction of organisms sensitive to chemical contaminants.

Poor water and sediment quality are progressive problems and can be difficult or expensive to correct. In areas that are not heavily contaminated, monitoring and attention to potential problems can prevent water and sediment quality declines. In Port Valdez there are large fluctuations in the natural conditions of the water and sediments. These fluctuations include extreme changes in surface water salinity, suspended sediment loads and deposition on the bottom as snow and glacial ice melt in the summer and flow into the Port. Baseline studies in the Port have characterized some of these natural parameters historically and seasonally (Hood, 1969; Hood *et al.*, 1973; Colonell, 1980; Shaw and Hameedi, 1988). Studies of benthic organisms in the subtidal and intertidal environments indicate that the large natural disturbances within the system have discernible effects on community structure and abundance (Feder and Bryson-Schwafel, 1988; Feder and Jewett, 1988; Feder and Shaw, 1995).

Measures of water and sediment quality can be monitored for changes in the environment or in the effluents or wastes that are discharged into the Port. Measurements can be made of physical characteristics, such as temperature, salinity, oxygen, sediment, nutrient and chemical contamination levels, or of biological characteristics such as acute and chronic toxicity, changes in community structure, and accumulation of contaminants in plant and animal tissues. Water and sediment quality measurements are required in the discharge permits held by the Valdez Marine Terminal and the Municipal Wastewater Treatment Plant. We located no other waste or stormwater permits that require measurements other than visual examination.

4.2 Commercial, Sport, and Personal Use Fisheries

Valdez is a popular sport fishing area, particularly for wild and hatchery produced silver salmon. Some sport fishing for bottom fishes and personal-use fishing for crab and shrimp also occurs. There is no commercial fishing for wild salmon in the Port; however, the Solomon Gulch Hatchery provides a stock of pink salmon that is commercially harvested. Incidental takes of wild salmon are expected to occur with this harvest, but management practices attempt to limit the number of wild salmon caught with hatchery salmon. Commercial fishing for herring has also occurred in the Port. Historically, feeding and spawning populations in the Port were small compared to other regions in PWS; however, the severe decline of herring after the 1989 *Exxon Valdez* oil spill increased public sensitivity to this issue. The reduced numbers of herring makes this population more susceptible to other stresses. Measurements associated with risk to the Port Valdez fisheries populations are complicated by commercial or sport harvesting, wild predators, small population sizes, and mobility of the organisms. An effect seen in an individual fish or shellfish may have little connection to the Port Valdez environment. This is particularly true of anadromous fishes that spend almost all of their adult life in the open waters of the Pacific Ocean. Consequently, measurements related to the Port, such as spawning habitat quality, are more relevant to the assessment endpoint than is the health of individual fishes. Risk to fisheries populations in the Port can be monitored by measuring the following:

- Survival and growth of hatchery pink salmon fry during their migration out of the Port;
- Survival and growth of silver salmon fry and smolts during culture in net pens, release, and migration out of the Port;
- Quality of nearshore habitats used for spawning, egg hatch, and embryo survival of herring; and
- Survival and settlement rates of pelagic crab larvae and juvenile crabs.

Possible measurement endpoints related to fish populations are abundance, egg production or spawning success, size or growth of juveniles, food availability, and predation. Impacts to the population from these measurements can be evaluated in field surveys or through population modeling. Laboratory and *in situ* field testing of acute or chronic effects are also useful in obtaining information that can be extrapolated to the populations existing in the Port. Further investigation and study of the population and community dynamics affecting these endpoints are necessary to reduce the uncertainty associated with these methods.

4.3 Wildlife Populations

In the context of this assessment, wildlife includes populations of mammals, birds, and fishes associated with open water, subtidal, and shoreline habitats of the Port. These populations consist of both marine and terrestrial animals which use the marine environment during certain seasons or segments of their life cycle. For example, the marbled murrelet migrates through and feeds in the Port environment, but nests in inland forest stands. Wildlife populations have an aesthetic appeal to tourists, visitors, and residents of Valdez and are a valuable resource to the tourism industry. Wildlife also provides ecological functions associated with community dynamics (*e.g.*, the influence of sea otter predation on intertidal community structure) and nutrient cycling (*e.g.*, nutrient additions from salmon carcasses and migratory bird excrement). Assessment of risk in Port Valdez is complicated by the mobility and transitory nature of many of these populations, natural variability in population size and individual survival, and population pressures imposed by hunting and fishing. Endpoints that are relevant to populations found in the Port include:

- Maintenance of the genetic integrity of individual salmon runs, particularly wild pink salmon which may be affected by fish that stray from the hatchery;
- Successful spawning, egg hatch, and embryo survival for wild salmon populations, particularly in pink and chum intertidal spawning habitat;
- Maintenance of shallow subtidal plant communities, which provide protective habitat and cover for many juvenile organisms;
- Continued and successful nesting, egg hatch, and chick survival of seabirds, waterfowl, and shorebirds nesting near the Port; and
- Maintenance of intertidal and subtidal invertebrate abundance, diversity, and age class structure used by wildlife populations in the Port as food.

Measurements of these endpoints involve field and population studies that are specific to Port Valdez. Assessments can also be designed to describe certain population parameters specific to the Port, through modeling the effects of a stressor on this parameter. For instance, a study of the genetic variability of the wild and hatchery salmon populations, and the straying and cross-strain breeding rate of the hatchery salmon, could be used to model potential genetic dilution in the wild salmon.

5.0 Conceptual Model

The conceptual model simulates general aspects of Port Valdez that can interact and pose a risk to the environment. These aspects covered by the model include:

- **Sub-Areas** - designated subdivisions of the marine environment created for the purpose of comparison
- **Sources** - anthropogenic operations or activities that release stressors
- **Habitats** - environments supporting specific groups of receptor;
- **Impacts** - changes to individuals, populations, or communities related to the assessment endpoints
- **Exposure and Effects-Links** - connections between sources, habitats, and impacts that establish a risk.

The first part of the conceptual model defines the **sub-areas** used for comparison within the Port (Section 5.1). The second part describes components of the model that were compared between the different sub-areas (Section 5.2 to 5.4). In this assessment, these components included sources, habitats, and impacts to assessment endpoints.

Anthropogenic stressors originate from a **source**. Identifying the sources provides information on what types of stressors might be present in the environment. We have identified possible sources of anthropogenic stressors by reviewing scientific and monitoring reports, public comments, use patterns, and regulatory permits. The sources are described in Section 5.2. **Habitats** function as the intermediary between exposures and effects. Stressors are released into, transport through, or accumulate in habitats. Habitat types are defined for Port Valdez based on physical structure. Section 5.3 describes each habitat and some of the organisms that can be found there. The extent of an **impact** to populations or communities depends on the timing and degree of exposure to individual receptors. A receptor responds to the entire array of stressors that exist in its environment. Section 5.4 describes potential responses that can impact the assessment points described in Section 4. These responses were chosen based on the stressors and receptors identified in the conceptual model.

The last part of the conceptual model develops the links between sources, habitats, and possible impacts in the Port. The **exposure-links** connect each source to habitats in which stressors are released or transported. Habitats where an exposure occurs are at risk of an effect. The **effects-links** connect each source and habitat combination to impacts that can result from the exposure.

5.1 Sub-Area Delineation

In order to address the size and diversity of the Port, the conceptual model divides this region into eleven geographic sub-areas (Figure 2-1). Each sub-area contains present or future sources of stressors (*e.g.*, present discharges and areas zoned for future development) as well as specific habitat types. Sub-area boundaries were described previously in Table 2-2. The names refer to the general vicinity or landmarks within each sub-area.

- Shoup Bay
- Mineral and Gold Creek
- City of Valdez
- Duck Flats and Old Valdez
- Lowe and Robe Rivers
- Dayville Flats and Solomon Gulch
- Valdez Marine Terminal
- Sawmill to Seven-Mile Beach
- Anderson Bay
- Western Port
- Eastern Port

Sections 5.1.1 to 5.1.11 describe each sub-area. These divisions allow comparisons to be made between different locations within the Port and result in a Port-wide perspective of risk.

5.1.1 Sub-Area A: Shoup Bay

Shoup Bay is located just inside the Valdez Narrows. The Bay is protected from storms by a shallow underwater ridge and a sandy spit at the entrance. Because this area provides a variety of wildlife habitat, it has been set aside as a marine state park with no road access (City of Valdez, 1992). Shoup Glacier Stream releases heavy loads of glacial silt in the summer. The outwash has formed a small mudflat at the mouth of the stream. The rest of the shoreline is rocky with cliffs near the glacier and along the sides of the Bay.

Shoup Bay supports more sea otters year round and may be more heavily used by migratory birds in the spring and fall than other areas of the Port (Anthony, 1995; Hemming and Erikson, 1979). In summer a colony of Black-legged Kittiwakes nests on the cliffs near Shoup Glacier. Terns and gulls also nest in colonies on the rocky cliffs and the spit at the entrance to the Bay (Hogan and Irons, 1988).

Tour boats and fishing vessels are common in the summer (Anthony, 1995). Mining for gold, copper, lead, and zinc has occurred in the past. A lode mine operates just east of Shoup Bay (pers. comm., John Pran, BLM, 1995).

5.1.2 Sub-Area B: Mineral and Gold Creeks

Mineral and Gold Creeks drain into an unprotected embayment. High sediment loads from the Mineral Creek drainage have formed a mudflat and subtidal shelf in this area. There are extensive mussel beds on the Mineral Creek Flats (Feder and Bryson-Schwafel, 1988). Waterfowl and shorebirds feed at small pools that form on the flats in summer (Hogan and Irons, 1988). Mineral Creek, its tributaries, and nearby streams are one of the main spawning grounds in the Port for pink and chum salmon. The rest of the shoreline ranges from rocky cliffs in the west to gravel beaches in the east.

Some residential development occurs on the east side of Mineral Creek. The Mineral Creek drainage was heavily mined for gold at one time and recent mining has occurred (City of Valdez, 1992). Although no mines are presently listed as active in the Mineral Creek drainage, a placer mine operates on Gold Creek (pers. comm., John Pran, BLM, 1995).

5.1.3 Sub-Area C: City of Valdez

The city waterfront covers approximately a kilometer of the Port Valdez coastline. A small dock for the Alaskan State Ferry, the city dock, and the petroleum dock are found at the western end of this area. Fuel loading and off-loading occur at both the petroleum dock and the city dock. The small boat harbor at the eastern end of the area contains 510 berths, most of which are used by recreational boaters. Local and transient commercial fishing boats also dock in the small boat harbor. There are two seafood processing plants on the boat harbor jetty and one at the city dock. These plants discharge fish wastes into the adjacent waters. The SERVS dock, where the spill response activities are coordinated, is located to the east of the boat harbor jetty.

The shoreline along the city waterfront is mostly gravel or cobble beaches. An area along the south side of the boat harbor jetty supports nesting Arctic Terns (Hemming and Erikson, 1979; Hogan and Irons, 1988; McRoy and Stoker, 1969) Fish wastes in the area are likely to attract crabs, gulls, seals, and other scavengers.

5.1.4 Sub-Area D: Duck Flats and Old Valdez

The Duck Flats supports a number of overwintering waterfowl and migratory birds in the spring and fall. Although the Copper River Delta, east of PWS, is a much larger tidal marsh and the main flyway for migratory birds in Southcentral Alaska, little of this type of habitat exists in PWS. Since the Duck Flats represents some of the largest saltmarsh habitat in the Sound, it has been designated as an area meriting special attention by the U.S. Fish and Wildlife Service. The inland perimeter of the Duck Flats is vegetated saltmarsh which provides waterfowl nesting habitat and feeding grounds for migrant and resident geese. The central region is a mudflat that extends out of the saltmarsh and towards Old Valdez. Polychaete worms, clams, and other invertebrates are abundant in the sediments and are fed on by waterfowl and shorebirds. Rocky islands and a subtidal shelf border the southern edge of the Duck Flats.

The Container Terminal dock and marshaling yard are located on Ammunition Island at the southeastern edge of the Duck Flats. The municipal wastewater treatment plant, municipal landfill, and a construction waste landfill are located in Old Valdez. Industry in the Old Valdez area is limited to storage and stacking of materials because of seismic instability in this area, as demonstrated during the 1964 earthquake (City of Valdez, 1992). Gravel mining occurs on the Valdez Glacier Stream. The upland area above Old Valdez is allotted for industrial growth and is the location of the airport. A petrochemical plant was proposed for a site near the Valdez Glacier Stream, but was not constructed (U.S. EPA, 1980).

5.1.5 Sub-Area E: Lowe and Robe Rivers

These glacial rivers and their freshwater tributaries provide the main spawning and rearing habitat for silver and red salmon and have been designated as Wildlife Habitat in the Public Interest Lands Program (City of Valdez, 1992). The Robe Lake System, a small freshwater lake with its associated tributaries, is important as an upland nesting area for ducks and shorebirds in summer and as rearing habitat for juvenile fishes throughout the year. Both the Lowe and Robe Rivers end in a sediment delta of braided channels and sediment shores in the eastern Port.

A small refinery, Petro Star, operates in this area but has no wastewater discharge. Both the Richardson Highway and the Alyeska Pipeline travel up the Lowe River corridor. Gravel mining along this floodplain also occurs. Residential areas include the Alpine Woods, Nordic, and Robe River subdivisions. A tract of land south of the Lowe River is designated as Forest Land for small scale logging and woodcutting (City of Valdez, 1992).

5.1.6 Sub-Area F: Dayville Flats and Solomon Gulch

Sediment outwash from the Lowe River forms a large mudflat that extends along the southern edge of the Port. The flat is composed of compact muds that support numerous polychaete worms, harpacticoid copepods, cumaceans, and small clams.

The Solomon Gulch Hatchery releases pink salmon fry and juvenile silver salmon each year. The hatchery maintains net pens in the Port to hold juvenile salmon, and sometimes adult salmon, for short periods of time. In the past, chum and king salmon have also been released from the hatchery. The shoreline along Dayville Road up to Allison Point is a popular area for sport fishing and camping in summer.

5.1.7 Sub-Area G: Valdez Marine Terminal

The shoreline in this area is mostly rocky with a small mudflat at the mouth of Allison Creek. The rocky intertidal and shallow subtidal support diverse communities of algae and invertebrates. Allison Creek, a clear water stream that drains from Allison Lake, is the only spawning habitat. Pink salmon fry from the hatchery use the sheltered area between Jackson Point and Saw Island for feeding during their migration out of the Port (Jewett and Stark, 1994). Saw Island at the western end of the marine terminal area supports rich mussel beds that are frequently fed on by sea otters. The islands are also used by harbor seals for hauling out and resting.

This area, which was originally Fort Liscom, is now zoned as industrial land for the Valdez Marine Terminal. Construction of the terminal in 1975 caused major changes to the Jackson Point shoreline (Howard Feder, University of Alaska, pers. comm., 1995). At the terminal, crude oil is loaded into tankers from four berthing docks, located between Jackson Point and Saw Island. Maintenance of these docks requires sandblasting every five years. Oily ballast water is off-loaded from the tankers, treated on site, and discharged at a depth of 60 m. Treated sewage wastes are also discharged by the terminal. The terminal maintains a small boat harbor and tug dock.

5.1.8 Sub-Area H: Sawmill and Seven-Mile Creeks

This area has a rocky shoreline with beaches (five-mile and seven-mile beach) adjacent to the Creeks. A spit has formed at the mouth of Sawmill Creek. At one time there was a large mussel bed in this area, but it has been nearly decimated by the increased population of sea otters (Howard Feder, University of Alaska, pers. comm., 1996). Intertidal plant and animal life is less abundant in this area than in other areas of the Port where the shoreline is steeper. Although the area is currently undeveloped, possible development of the Anderson Bay area would necessitate road construction along the shoreline. Sport fishing from boats along the shore is also popular in the summer.

5.1.9 Sub-Area I: Anderson Bay

Anderson Bay has a mostly rocky coastline with several rocky islands. Its proximity to the more saline waters of the Valdez Narrows increases the richness and diversity of the intertidal and subtidal organisms present (Feder, McCumby and Jewett, 1992). Hatchery reared pink salmon fry also use this area as a nursery grounds during their out-migration.

The bay is currently undeveloped, but is used as a recreational area by boaters and has been considered as a site for a dock and campground (City of Valdez, 1992). The bay is also the site of a proposed liquid natural gas loading terminal (FERC, 1995).

5.1.10 Sub-Area J: Western Deep Port

The deepest areas in the port are in the western end. The bottom consists of fine grained sediments supporting a benthic community with low abundance and biomass (Feder and Jewett, 1988). Less sediment accumulates on the bottom in this area than in the eastern Port. The deep bottom waters probably mix once a year during unpredictable seasonal events which allow influx of more dense water from PWS over the sill at the entrance to the port.

5.1.11 Sub-Area K: Eastern Deep Port

The majority of the sediment flushed out of rivers during the summer runoff period settles in this end of the Port and has formed a large, underwater sediment shelf. Frequent seismic activity causes additional sediment disturbance along the slopes of this sediment shelf. Subsurface currents tend to be weak and nondirectional, increasing the potential for stagnation at the eastern end (City of Valdez, 1992). Currents at the water surface move in a counterclockwise direction. The benthic community living on and within the soft sediments here is similar to that of the western Port. However, the increased sediment deposition results in reduced numbers of suspension feeding organisms.

5.2 Sources

Sources represent potential stressors in the environment. The form, fate, and distribution of stressors depends on the characteristics of their source and their release into the environment. By knowing the source, some assumptions about the distribution of the stressor are possible. For example, metals that are released from bottom paints are likely to end up in harbor sediments or near shipping lanes, while metals that result from mining are likely to end up in sediments near stream mouths. Sections 5.2.1 to 5.2.8 describe eight types of anthropogenic sources in the Port. The source categories, which were previously defined in Table 2-2, include:

- Treated Discharges
- Contaminated Runoff
- Accidental Spills
- Fish and Seafood Processing Wastes
- Marine Vessel Traffic
- Hatchery Salmon Enhancement
- Construction and Development
- Shoreline Activity.

These sources can generate anthropogenic stressors in the environment (**Table 5-1**). Currently in Port Valdez the largest number of potential anthropogenic sources exist for hydrocarbons (treated discharges, contaminated runoff, spills, and vessel traffic) and metals (treated discharges, contaminated runoff, vessel traffic, and spills). Sources of organic matter and nutrients from a variety of sources (treated discharges, contaminated runoff, vessel traffic, sport and commercial fishing, seafood processing, and hatchery wastes) are also common in the Port.

Scientific studies do not always link stressors to their source. The conceptual model assists in forming these links. For instance, hydrocarbon contaminants found in surface water runoff are linked to air emissions, fuel leaks or spills, and leachates from fuel storage tanks and landfills. Natural stressors, such as hydrocarbons released by forest fires, add to these anthropogenic accumulations. Although **Table 5-1** describes both anthropogenic and natural sources, only the risk from anthropogenic stressors are included in the analysis (Section 6).

Table 5-1. Links between potential stressors and natural, as well as anthropogenic sources in Port Valdez.

STRESSORS: CHEMICALS and ORGANIC MATTER

Stressor	*Source*	*Source Link to the Stressor*
Hydrocarbons	**Treated Discharges**	Treated ballast water, municipal wastewater, sewage wastewater from the VMT
	Contaminated Runoff	Deposition on ground from air pollution (emissions from vehicles, vessels, heating or industrial processes), spills on land, leachate from fuel storage and landfills
	Accidental Spills	Fueling, oil and fuel transport, repair and maintenance, sunken vessels
	Vessel Traffic	Discharges of bilge water, fuel and oil leaks, combustion emissions
	Natural	Forest fire emissions of PAHs, biological production of alkanes
Organotins	**Vessel Traffic (>25 m)**	Leaching from bottom paint, paint chips
Metals	**Contaminated Runoff**	Mining activity, roads, industrial activity, landfills, industrial and maintenance spills on land
	Accidental Spills	Crude oil spills, maintenance and repair spills
	Vessel Traffic	Leaching from bottom paint, discharges of bilge water, fuel oil leaks, combustion emissions
	Treated Discharges	Metals not removed during treatment process
	Natural	Leaching from natural rock formations in the area
Other Chemicals (*e.g., Antifreeze, Surfactants, Solvents*)	**Treated Discharges**	Chemicals not removed during treatment process
	Contaminated Runoff	Repair and maintenance spills on land, industrial use spills on land
	Accidental Spills	Repair and maintenance spills, industrial use spills
Organic Matter and Nutrients	**Treated Discharges**	Incomplete decomposition of organic wastes
	Contaminated Runoff	Leachates from landfills, residential areas with septic tanks
	Fish and Seafood Processing Wastes	Seafood processing effluent, sport fish cleaning wastes, cleaning water from commercial fishing boats, hatchery operation and net pen wastes, hatchery fish carcasses
	Vessel Traffic	Sewage wastes from holding tanks
	Natural	Wild salmon carcasses after spawning, fecal wastes from the presence of migratory birds, phytoplankton blooms

Table 5-1. (**continued**) Links between potential stressors and natural, as well as anthropogenic sources in Port Valdez.

STRESSORS: PHYSICAL and BIOLOGICAL

Stressor	*Source*	*Source Link to the Stressor*
Land Use	Construction and Development	Clearing, shoreline construction, log stacking, erosion, dredging
	Natural	Earthquakes, severe storms, ice scour, temperature extremes
Sediment, Solids and Debris	Construction and Development	Sediment in runoff from earth moving activities, construction debris in runoff, sandblasting of nearshore structures, log stacking
	Fish Wastes and Seafood Processing	Seafood processing wastes, sportfish cleaning wastes, hatchery operations
	Natural	Sediment in spring runoff, slumping of sediments
Behavioral and Physical Disturbance	Shoreline Activity	Hiking, hunting, camping, attack by pets, intertidal and subtidal collecting
	Vessel Traffic	Noise and activity of vessels (recreational, charter, commercial fishing, ferries, cruise ships, barges, tankers), sediment or water disturbance by propeller washes, injury from contact
	Natural	Sea otter feeding activities disturb sediments and intertidal community structure, fluctuations in predation or competition
Non-native or Enhanced Species	Treated Discharges	Possible release of disease pathogens brought into the Port and not killed by treatment
	Vessel Traffic	Organisms surviving transport in ballast water of oil tankers, organisms attached to hulls, disease pathogens in untreated sewage wastes released from holding tanks
	Hatchery Fishes	Returning adults (especially pink salmon which may stray from the hatchery and spawn in wild salmon streams), large number of migrating pink salmon fry released in summer, introduction of disease from culturing or introduced with new fish stocks

5.2.1 Treated Discharges

There are currently three treated wastewater discharges into Port Valdez on a continuous or semi-continuous basis. These sources include the Municipal Wastewater Treatment Plant (WWTP), which receives the city's sewage and wastewater, Alyeska's Ballast Water Treatment Plant (BWTP), which receives oily ballast water from tankers, and Alyeska's sewage treatment plant, which receives sewage wastes from the Valdez Marine Terminal. Each of these dischargers has a National Pollutant Discharge Elimination System (NPDES) permit issued by the U.S. EPA. NPDES permits regulate the quantity and quality of effluents released into the environment. The level of monitoring and reporting required for each type of discharge varies (**Table 5-2**). The WWTP, located at the head of the Port, is allowed to discharge a

Table 5-2. NPDES requirements for the three discharges into Port Valdez (described in the city's 1985 permit (#AK-002143-1) and Alyeska's 1990 permit (#AK-002324-8). Italicized parameters are monitored, but no regulatory limits are set.

Treatment Plant	Monitoring Requirement	Frequency
Alyeska's Ballast Water Treatment Plant	Discharge	continuous
	pH	continuous
	Total Suspended Solids	daily
	Total Organic Carbon	daily
	Benzene, Ethylbenzene, Toluene, Xylene	daily, *3 per week
	- Napthalene	4 per year
	- Total Hydrocarbons	twice weekly
	- Total Aromatic Hydrocarbons	4 per year
	+ *Total Aqueous Hydrocarbons*	*monthly*
	- *Temperature*	*daily*
	- *Density*	*daily*
	- *Dissolved Oxygen*	*daily*
	Dissolved Inorganic Phosphorus	*twice weekly, *monthly*
	Ammonia	*twice weekly, *montly*
	Zinc	*4 per year*
Municipal Wastewater Treatment Plant	Discharge	continuous
	pH	twice weekly
	Total Suspended Solids	weekly
	Biochemical Oxygen Demand	weekly
	Fecal Coliform Bacteria	twice weekly
	Total Chlorine Residual	twice weekly
	Dissolved Oxygen	*twice weekly*
Alyeska's Sewage Treatment Plant	Discharge	daily, *continuous
	pH	daily
	Biological Oxygen Demand	monthly
	Total Suspended Solids	monthly
	+ *Fecal Coliform*	*4 per year*

* change proposed in 1996 for the new Alyeska permit
\+ addition proposed in 1996 for the new Alyeska permit
\- removal proposed in 1996 for the new Alyeska permit

discharge a monthly average of 1.25 mgd (1985 NPDES Permit #AK-002143-1). Alyeska, located along the southern shore, is allowed a monthly average discharge of 21 mgd from the BWTP and 0.01 mgd from the sewage treatment plant (1990 NPDES Permit #AK-002324-8). The purpose of treatment is to remove or degrade inorganic and organic contaminants in the waste water through a process of settling, chemical treatment, and biological degradation. Although all of the effluents are treated, there is some concern in the community about the effectiveness of treatment, particularly at the BWTP where incomplete hydrocarbon degradation could release toxic microbial by-products. A variety of chemicals enter each treatment plant and may be discharged if they are not removed by the treatment process. These chemicals may include metals, surfactants and detergents, antifreeze, corrosion inhibitors, solvents, and other chemicals used in domestic, industrial, and commercial settings. Excessive nutrients, suspended solids, and disease vectors can also be released through incomplete treatment.

5.2.2 Contaminated Runoff

Various sites contribute to the contamination of runoff into the Port. Discharge from these sites is continuous or intermittent during warm weather but essentially ceases in winter when the ground is covered with snow. Runoff from residential, commercial, and industrial sites can carry oils and fuels, metals, and a variety of other chemicals into the Port.

Sites where runoff can become contaminated include various large and small-scale petroleum-related industries, storage and fueling facilities, high density residential and commercial areas within the city, municipal and construction waste landfills, the airport, residential sub-divisions where septic tanks are used, active and inactive mines, and roads and highways. The Valdez Small Boat Harbor on the north shore of the Port receives much of the stormwater from the city and from the harbor grounds where boats are repaired and stored on land. Old Valdez and areas to the north and east are zoned for industrial use (City of Valdez, 1992). The airport, which uses de-icing chemicals, is located in this area and a municipal and construction waste landfill operate north of the Valdez Glacier Stream. There was an old landfill in Old Valdez that was closed and covered in the early 80s. Leachates from the landfills are possible, especially when ground water levels are high.

The deposition of air contaminants also increases the potential for surface water contamination. In Valdez, air pollution occurs on a local scale through industrial emissions, fuel and wood burning for home heating, and vehicle and vessel emissions. Industrial emissions include volatilization of hydrocarbons during crude oil loading at the Valdez Marine Terminal and during treatment processes at the BWTP (Cohen, 1992; Goldstein *et al.*, 1992). Hydrocarbons which enter the atmosphere as vapors are rapidly dispersed and photo-oxidized; however, hydrocarbons (especially PAH's) which are adsorbed onto soot particles eventually settle back onto land or water. Regionally, forest fires can release particulates and gases, including PAH's, on an irregular basis. Aerial transport of PAHs and metals over long distances has been shown to contribute to marine pollution (Chester and Bradshaw, 1991; Hites *et al*., 1980).

Pesticide use is probably low, except for insecticides applied by the city and private companies to kill mosquitos and black flies in the summer. In June and July of 1994 the City applied 6 gallons of Multicide in approximately 33 hours of spraying. Multicide contains a synthetic pyrethroid chemical that targets adult mosquitos, and spraying is prohibited within 100 ft of a stream. In addition to spraying, larval mosquitos are controlled by the application of a bacteria, *Bacillus thuringiensis,* directly to the surface of stagnant water. This was applied from mid-April to mid-June in 1994 (pers. comm., Ken Tetz, Valdez Public Works Department, 1995). Mosquito control also occurs at the Valdez Marine Terminal and other sites not covered by the city. Private spraying does not require a permit with the exception of water applications and aerial spraying (pers. comm., Rose Lombardi, ADEC, Palmer, AK).

5.2.3 Accidental Spills and Other Discharges

Early detection of spills limits exposure of organisms to the time it takes for cleanup to occur, however residual amounts not removed by cleanup can prolong exposure. Spills in Port Valdez are associated with the transport or use of petroleum products. Spills on the ground or leaks from underground pipes and storage tanks can enter the Port through contaminated runoff. The largest potential for spills is from the vessel transport of crude oil, jet fuel, and marine diesel fuel. Oil tankers load North Slope crude oil from the Valdez Marine Terminal, while fuel barges load jet fuel and marine diesel from the city's petroleum dock. Spills of other industrial and commercial use chemicals and fuels used for maintenance and repair of vessels can also occur. The USCG and ADEC investigate reported spills on the water and on land, however most of the spills were reported by Alyeska and Petro Star (**Table 5-3**) (1995 Oil Spill Report, ADEC, Anchorage, AK). Alyeska maintains the Service Escort and Response Vessel Service (SERVS) team which responds to these spills. Other spills by other companies or individuals are probably under-reported (pers. comm., C. Agneta Dahl, USCG, 1995).

The largest spill after 1970 occurred on January 3, 1989 when the tanker *Thompson Pass* lost 273,000 L (250 metric tons) of North Slope crude oil through a cracked hull (Oil Spill Library, Anchorage, AK, 1995). Another spill of 32,000 L (30 metric tons) from the *BP Eastern*

Lion occurred on June 2, 1994. Tanker traffic has declined from an average of 1,184 tankers/year (1977 to 1993) to about 636 in 1995 (pers. comm., Tom Sweeney, RCAC, 1995)

Table 5-3. Products spilled and number of events reported in Port Valdez from September 1992 to March 1995 (1995 Oil Spill Report, ADEC, Anchorage, AK).

Product Spilled on Water	Estimated Amount (liters)	Number of Spills
Diesel	1.3	31
Crude	32,000	35
Antifreeze	<4	1
Oil (Engine Lube, Hydraulic, Transmission)	81	53
Jet Fuel	230	1
Gasoline	19	2
Other	8.3	7
Corrosion Inhibitor	<4	1
Creosote	<4	1

Diesel and jet fuels refined at Petro Star are transported in large quantity via land and water. Currently they are transported in tanker trucks from the south side of the Port to tanks near the Valdez Petroleum Dock in downtown Valdez where they are stored until loaded onto barges.

5.2.4 Fish and Seafood Processing Wastes

Fish parts and carcasses discharged into Port Valdez are from seafood processing plants (Nautilus, Peter Pan, and Seahawk Seafoods), the Solomon Gulch Hatchery, and sport and commercial fishing. Because these wastes contain rich organic matter that settles to the seafloor, fish culturing in netpens is included in this category since excess food and feces accumulate within or near netpens (Ellis *et al*., 1991). Seafood processing plants discharge fish wastes from sites near the city docks under an NPDES permit (**Table 5-4**).

Table 5-4 Wastewater discharges permitted for seafood processing plants in Valdez (pers. comm. Ralph Kiehl, ADEC, 1995).

Seafood Processing Plants	**Discharge Characteristics**	
	Quantity (April-Sept.)*	Approximate Depth
Peter Pan	7,607,000 lbs (1995)	60 m
Seahawk Seafoods	Not Operating (1994)	20 m
Nautilus	1,291,494 lbs (1994)	18 m

* Heaviest discharges in July and August

Processing permits require that the wastes be ground into one-half inch or smaller pieces. Much of the processing waste was, until recently, discharged in shallow water near the head of the Port (Feder and Shaw, 1996; Feder and Blanchard, 1996a). The general NPDES permit for seafood processing was reissued in 1995 (#AK-G52-000). The discharge points are now required to be deeper than 60 ft (18 m) in order to protect kelp beds in the shallow subtidal (pers. comm. Burney Hill, U.S. EPA, 1995). The permit also allows the discharge of disinfectants (*e.g*., sodium hypochlorite and ammonium chloride), sanitary wastewaters, and other process wastewaters from the plant. Carcasses of adult fish left after egg extraction at the Solomon Gulch Hatchery produce an additional waste source. The Solomon Gulch Hatchery disposes of pink and silver salmon carcasses in the deep water of Port Valdez unless a market for them can be found or they can be given away. The hatchery has also obtained a processing permit that requires grinding of these wastes.

The Solomon Gulch Hatchery on the south shore raises silver salmon in net pens during the summer. Returning adult pink salmon are also kept in net pens before the eggs are harvested in years when overfishing of this population is a concern (Valdez Fisheries Development Association, 1995). Sediments below net pens are known to collect fecal matter and uneaten food.

Sport fish wastes in the Valdez Small Boat Harbor have been a problem in the past. The harbor is currently experimenting with five fish cleaning stations where fish wastes are collected and transported to deep water by barge (pers. comm., Tim Lopez, City of Valdez, 1995). Organic fish wastes are also released into the boat harbor from rinse water used in the holds of commercial fishing vessels.

5.2.5 Marine Vessel Traffic

In 1994, domestic and foreign ship traffic into the Port of Valdez consisted of 1,799 trips (**Table 5-5**). Commercial fishing, ferry and cruise ships, tour, charter, and private vessels

Table 5-5. Domestic and foreign inbound traffic into Port Valdez (U.S. ACE, 1994).

Inbound Vessel Traffic	**Large Vessels (draft > 5m)**		**Small Vessels (draft < 5m)**	
	Domestic	Foreign	Domestic	Foreign
Passenger and Dry Cargo	0	2	1,065	0
Tanker	550	25	80	0
Tow or Tug	3	0	45	0

operate in the Port, as well as tankers and barges. Vessel traffic enhances the probability of operational or cargo spills. The vessel activity can also physically injure or disturb wildlife, such as sea otters and harbor seals (Anthony, 1995). The underside of marine vessels are generally painted with antifouling paint to prevent the attachment of organisms, such as barnacles and mussels, to the hull. Antifouling paints are commonly copper or lead based and form a small toxic layer which prevents attachment. One very effective and long lasting antifouling agent is tributyltin (TBT); tributyltin has also proved to be very toxic to mollusks, such as clams, oysters, and mussels. Consequently, the use of TBT has been limited in the United States to vessels larger than 25 m since 1988.

Vessel traffic from ports in a different geographical region can also transport non-native species into the Port. If these organisms survive, they may become established and affect local species. Vessel traffic from distant ports in high northern latitudes, is more likely to bring non-native species that could survive in Port Valdez. Lifting of the oil embargo act will allow tankers to transport oil to cold-water ports (*e.g.*, northern Japan, and Russia) and return with ballast water from these regions. These stressors are discussed in more detail in Section 8. Illegal dumping of sewage wastes from boats may also occur in the boat harbor and the Port (pers. comm., C. Agneta Dahl, USCG, 1995).

5.2.6 Hatchery Salmon Enhancement

The salmon raised by the Solomon Gulch Hatchery are all derived from native stocks. However, release of these salmon greatly augments native populations. Several hundred million pink salmon fry are released yearly and feed in nursery areas along the southern shore during their migration out of the Port. The fry remain in the Port for three to five weeks while feeding intensively on zooplankton (Jewett and Stark, 1994). The silver salmon are held in net pens as fingerlings from April to June, when they are released. The adult pink salmon return in June and July, while the silver salmon return in August (Valdez Fisheries Development Association, 1995). The hatchery salmon act as an enhanced species in the Port. Like introduced species, enhanced species can cause disturbances in normal ecological interactions.

5.2.7 Construction and Development

The steepness of the surrounding terrain in Port Valdez minimizes the amount of level ground that is available (City of Valdez, 1992). Consequently, further development will occur on habitat that is already limited, including the coastal zone. Development results in a direct loss of habitat through clearing or covering (*e.g.*, roads, docks, and nearshore facilities). Runoff patterns can also change through restructuring of the land (*e.g.*, roads, berms, or dikes) or by creating surfaces that increase stormwater flow (*e.g.*, paved parking lots). Increased sediment load or other debris in the runoff will increase turbidity and sediment deposition within the Port.

Construction is frequent in the summer, especially at industrial sites such as the Valdez Marine Terminal. Development ranges from small scale residential, such as in the Robe Lake and Robe River Subdivisions, to large scale industrial, such as the projected construction of a Liquid Natural Gas (LNG) plant and marine terminal in Anderson Bay. Such development in the western half of the Port would require an extension of the coastal road system. The city has zoned land for light industrial development (mostly gravel extraction and pipe storage) and is considering expanding the boat harbor as well as altering its structure to improve flushing (City of Valdez, 1992). A current proposal involves creating a channel through the end of the boat harbor into Harbor Cove, adjacent to the Duck Flats. The city is considering using a valve system in this channel to prevent backwash of contaminants from the boat harbor into the Duck Flats marsh (pers. comm. Bill Wilcox, City of Valdez, 1995).

5.2.8 Shoreline Activity

Human activity (recreational, residential, commercial, or industrial) along the shoreline and from near shore boats will disturb sensitive populations of wildlife. Waterfowl, especially diving ducks which are less suited for walking, nest in marshes along the shoreline. Terns and gulls nest on shallow beaches. Noise and activity may cause birds to leave their nests or prevent them from returning to their nests. Feeding or resting of sensitive animals may also be disturbed by noise or activity. Animals that are prevented from foraging by continual disturbance are less likely to obtain adequate levels of nutrition and may be experiencing greater levels of stress. Injury by pets or by contact with machinery (*e.g.*, boat propellers) can affect fish, birds, and mammals.

5.3 Habitat Identification

Habitat characteristics affect the intensity and persistence of the stressor, as well as the type and activity of the receptors present. The probability of exposure can be higher in certain habitat types. For instance, some chemicals accumulate in sediments. Exposure to these chemicals will be greater in habitats with sediments. The effect to a receptor is also dependent on the habitat type. For example, anadromous fishes reproduce in freshwater habitats but live most of their lives in saltwater habitats. Stressors that harm reproductive stages of the fishes will have a greater effect in freshwater habitats than in saltwater habitats. Sections 5.3.1-5.3.8 describe marine and shoreline habitats in Port Valdez. Habitat categories, which were previously defined in Table 2-3, include:

- Intertidal Mudflats
- Saltmarshes
- Spits and Low-Profile Beaches
- Rocky Shoreline
- Shallow Subtidal
- Deep Benthic
- Open Water
- Stream Mouths.

The following sections provide examples of receptors that are likely to occur in the habitat. Many receptors are found in specific habitats. The mussel, *Mytilus trossulus,* normally lives on rocky shores while the pink clam, *Macoma balthica*, lives in intertidal mudflats. Other organisms move between habitats. For instance, otters feed in intertidal and shallow subtidal areas but rest at the water surface. Species that have been noted in each habitat during various studies in the Port are also included in Appendix B.

5.3.1 Intertidal Mudflats

The tidal mudflats in Port Valdez are wide muddy shores formed from the sediment outwash of rivers. The most extensive tidal flats are in the eastern Port. In the western Port, there is a small tidal flat in Anderson Bay and a more extensive one at the head of Shoup Bay. Worms, clams, and other invertebrates common in the sediments are fed on by receptor species, e.g., fishes and birds (**Table 5-6)**. Mudflats are sensitive to contamination due to the affinity of organic and metal contaminants to adsorb and absorb to sediment particles.

5.3.2 Saltmarsh

The Duck Flats (also known as Mineral Island Flats) is the only saltmarsh habitat in Port Valdez. Saltmarshes are intertidal and shoreline areas that support rooted vegetation such as grasses and sedges. Tidal water flows through the salt marsh in sediment channels. Decaying plant material in the saltmarsh releases nutrients into the water and sediments. This enrichment increases the productivity of the area, supports rich invertebrate communities, and, in turn, attracts large numbers of fishes and birds which feed mainly on the abundant polychaete worms and the clam *Macoma balthica.* The complexity of the saltmarsh habitat also provides nesting areas for birds and protective habitat for juvenile organisms, such as salmon fry. Examples of receptors and their probable activity in this habitat are listed in **Table 5-7**.

Table 5-6. Receptors linked to mudflat habitat through residence in or use of the habitat.

Mudflat Habitat

Receptor	*Specific Examples*	*Habitat Use*
Plants	Benthic Algae	Growth and reproduction on mud surface
	Macroalgae	May float onto shore; seasonal growth and reproduction
Invertebrates	Polychaete worms, clams, and other small invertebrates	Burrow in sediment; growth and reproduction dependent on organic matter at sediment surface and in overlying water
Fishes	Intertidal fishes	Feed on invertebrates in sediments, at sediment surface, and in overlying water
	Salmon fry	Feed on invertebrates at sediment surface and in overlying water
Birds	Shorebirds	Feed on invertebrates on and within sediments
	Ducks (especially dabblers)	Feed on invertebrates on or in sediments
	Geese	Feed on invertebrates in sediments and overlying water

Table 5-7. Receptors linked to saltmarsh habitat through residence in or use of the habitat.

Saltmarsh Habitat

Receptor	*Specific Examples*	*Habitat Use*
Plants	Marsh plants	Growth along shoreline and in shallow water; reproduction
	Benthic algae	Growth and reproduction on mud surface
	Macroalgae	Seasonal growth and reproduction; some species occur year-round
Invertebrates	Polychaete worms, clams, and other small invertebrates	Burrow in sediments or live on surface; growth and reproduction typically high due to rich local sources of organic matter available in sediments and overlying water
Fishes	Intertidal fishes	Feed on invertebrates in sediments and overlying water
	Salmon fry and juveniles	Feed on zooplankton and invertebrates at sediment surface; use the area for protective cover
	Adult pink and chum salmon	Some spawning in intertidal areas
Birds	Shorebirds	Feed on invertebrates in sediments
	Ducks	Feed on invertebrates in sediments and overlying water; nesting in vegetated areas
	Geese	Feed on marsh plants, algae and invertebrates
Mammals	River Otters	Feed on invertebrates

5.3.3 Rocky Intertidal and Shoreline Habitat

This habitat, includes rocky shorelines of gravel, cobbles, boulders, and rock outcrops, and is more common along the shores of the western Port than the eastern Port. The rockweed, *Fucus*, which attaches to rocks and other substrates is common in the upper intertidal area. *Fucus* and other algal species support a community of polychaete worms, snails, limpets, and other invertebrates. Barnacles and mussels often dominate the fauna in the mid to lower intertidal regions. The shallow rocky subtidal supports a rich assemblage of algae and associated invertebrates and fishes. Arctic Terns and Black-legged Kittiwakes nest on the cliffs and islands. Birds such as gulls and oystercatchers, sea otters, and terrestrial mammals, such as river otters and occasional deer, are likely to forage in this habitat for food. Seals use the rocky islands for haul out areas. Examples of receptors and their probable activity in this habitat are listed in **Table 5-8**.

5.3.4 Spits and Low Profile Beaches

These habitats occur along sandy mud and gravel shores. The intertidal plants and animals are similar, but are less abundant, than in the steeper rocky areas (McRoy and Stoker, 1969). Spits occur at the mouth of Sawmill Creek, Shoup Bay, Gold Creek, and at Sontag Spit in the Duck Flats (now the container dock). Beaches are formed at areas adjacent to creeks such as Five Mile, Sawmill, and Gold Creeks. Gulls are frequently sighted on spits (Hogan and Colgate, 1980). Otters forage along some of these habitats especially where mussel beds have formed. Examples of receptors and their probable activity in this habitat are listed in **Table 5-9**.

5.3.5 Shallow Subtidal

The shallow subtidal region is the region below tide level and above 50 m. Shallow subtidal areas are limited in Port Valdez due to steep basin walls. The bottom can be either sediment or rocky. In some areas of the Port, there is a sediment shelf in the shallow subtidal region. Shelves have typically formed where sediment is deposited from glacial rivers. A shelf exists outside of the Duck Flats where sediment from the Lowe River and the Valdez Glacier Stream has deposited. There is also a small shelf at the mouth of Mineral Creek. The shelf supports rich populations of invertebrates used as food by crabs, bottom fishes, and sea otters (Feder and Blanchard, 1995a; Feder and Blanchard, 1996a; Lees *et al.*, 1979). Rocky subtidal regions are also rich in plant and animal life. These areas often support stands of kelp which provide protective habitat for invertebrates and fishes. Examples of receptors and their probable activity in this habitat are listed in **Table 5-10**.

Table 5-8. Receptors linked to rocky intertidal habitat, either through residence in or use of the habitat.

Rocky Intertidal and Shoreline Habitat

Receptor	*Specific Examples*	*Habitat Use*
Plants	Macroalgae	Many attach to rocks or other algae; growth and reproduction
Invertebrates	Mussels, barnacles	Attach to rocks; filter water for food; growth and reproduction
	Polychaete worms	Attach to rocks or found in substrates between and under rocks; feeding, growth and reproduction
	Snails, limpets, whelks	Growth and reproduction; snails and limpets feed on algal or detrital films; whelks prey on mussels and barnacles
	Intertidal crabs	Feed on invertebrates; growth and reproduction
Birds	Shorebirds	Feed on invertebrates; nesting on shore
	Kittiwakes, gulls, terns	Nest in colonies or pairs on cliffs and shore; gulls feed on invertebrates
Mammals	Sea otters	Feed on invertebrates, especially mussels
	River otters	Feed on invertebrates
	Harbor seals	Rest on rocky shores
	Deer	Feed on algae

Table 5-9. Receptors linked to spits or low-profile beaches, either through residence in or use of the habitat.

Spits and Shallow Beaches

Receptor	*Specific Examples*	*Habitat Use*
Plants	Macroalgae	Attach to rocks or other seaweed; growth and reproduction
Invertebrates	Mussels, barnacles	Mussels may form beds on gravel beaches which provide habitat for other invertebrates; filter water for food; growth and reproduction
	Snails, limpets, whelks	Feed on algal or detrital films; growth and reproduction
	Intertidal crabs	Feed on invertebrates; growth and reproduction; move along shore
	Shorebirds	Feed on invertebrates; nest along shore
Birds	Gulls, terns	Nest in colonies or pairs
Mammals	Sea otters	Feed on invertebrates, especially mussels
	River otters	Feed on invertebrates
	Other terrestrial mammals	Feed on invertebrates

Table 5-10. Receptors linked to the shallow subtidal habitat, either through residence in or use of the habitat.

Shallow Subtidal Habitat

Receptor	*Specific Examples*	*Habitat Use*
Plants	Kelp and other algae	Attached in sediment and rocky areas; provide protective habitat for invertebrate and fishes; growth and reproduction
Invertebrates	Polychaete worms	Burrow in sediments; feed on organic matter in sediments or overlying water; growth and reproduction
	Clams	Burrow in sediments; feed on organic matter in sediments or overlying water; growth and reproduction
	Dungeness and Tanner crabs	Feed on invertebrates; growth and reproduction
Fishes	Herring	Spawn on kelp; egg hatch
	Pelagic and bottom fishes	Use this habitat during certain life stages for feeding and cover
Mammals	Sea otters	Feeding on invertebrates
	Seals	Feeding on fishes

5.3.6 Deep Benthic Environment

The deep benthic areas of the Port are those on the bottom below approximately 50 meters to over 200m. Sedimentation in the deep basin is high during the summer with greater sediment accumulation at the eastern end. Consequently, the bottom consists of mostly fine, loosely packed, glacially derived sediments. Sediment slumping occurs along the basin walls, especially in the eastern end of the Port. Polychaetous worms and small clams are the predominant invertebrates living within the sediments. Crangonid and pandalid shrimps, Tanner and Dungeness crabs, and bottom fishes were the dominant organisms living on the sediment surface in a study conducted by Feder and Paul (1977). Shrimp, crabs, and bottom fishes feed on the living or dead organic matter found within or on the sediments. The abundance and biomass of invertebrates living in or on sediments tends to be low (100 to 650 individuals/m^2 and biomass 0.3 to 1.2 gC/m^2) (Feder and Jewett, 1988). These invertebrates support low numbers of feeding shrimp, crabs, and bottom fishes compared to other deep benthic environments in PWS and the adjacent Gulf of Alaska shelf (Feder and Jewett, 1987). Examples of receptors and their probable activity in this habitat are listed in **Table 5-11**.

Table 5-11. Receptors linked to the deep benthic habitat, either through residence in or use of the habitat.

Deep Benthic Habitat

Receptor	*Specific Examples*	*Habitat Use*
Invertebrates	Polychaete worms	Burrow in sediments; mostly deposit feeding; some suspension feeders, predators, or scavengers; growth and reproduction
	Clams	Burrow in sediments; suspension feeding, surface and sub-surface deposit feeding; growth and reproduction
	Crabs	Feed on invertebrates; growth and reproduction
	Shrimp	Feed on detritus and small organisms; growth and reproduction
Fishes	Benthic fishes	Feed on invertebrates or other fishes; growth and reproduction

5.3.7 Open Water

The pelagic environment, or the open and unprotected water of the Port, is the largest potential habitat in the Port. Summer phytoplankton blooms in Port Valdez are considered to be fairly productive for a northern fjord and provide food for zooplankton (Cooney and Coyle, 1988). Most of the nutrients in an estuarine system are derived from land and depend on shoreline processes and characteristics. Zooplankton and pandalid shrimp feed in this habitat. Shrimp migrate upward at night, where they feed in the water column, and back down toward the sediments during the day (Rice *et al.*, 1980; Carpenter, 1983). Pelagic fishes, fish larvae, and fish eggs are found in the open water environment. Examples of receptors and their probable activity in this habitat are listed in **Table 5-12**.

5.3.8 Stream

Stream mouths generally have sandy to gravelly substrates deposited at the stream delta. These areas are used by all anadromous fishes for passage to and migration out of the spawning ground. Pink and chum salmon spawn in the intertidal areas near the stream mouths. Examples of receptors and their probable activity in this habitat are listed in **Table 5-13**.

Table 5-12. Receptors linked to the open water habitat, either through residence in or use of the habitat.

Open Water Habitat

Receptor	*Specific Examples*	*Habitat Use*
Algae	Diatoms	Bloom in spring; deplete nutrients in upper water column
	Dinoflagellates	Bloom in fall; deplete nutrients in upper water column
Zooplankton	Copepods and other planktonic invertebrates	Graze on diatoms; prey on other zooplankton; growth and reproduction
	Larval benthic invertebrates	Live and feed in water column until settlement to the bottom
	Fish eggs and larvae	Eggs float in water until hatching; larvae feed in water column
Fishes	Salmon and Dolly Varden	Adults, fry and juveniles migrate through Port; fry feed intensively on zooplankton
	Herring and other pelagic fishes	Feed on zooplankton and other water column invertebrates
Mammals	Sea otters	Rest and travel
	Harbor seals	Feed on fishes and travel

Table 5-13. Receptors linked to the deep benthic habitat, either through residence in or use of the habitat.

Stream and River Mouths

Receptor	*Specific Examples*	*Habitat Use*
Fishes	Pink and chum salmon	Spawning; egg development and fry emergence
	Red and silver salmon, Dolly Varden	Adult migration into spawning streams; juvenile rearing
Birds	Gull, terns, kittiwakes, fish eating birds	Feed on spawning salmon, their eggs and fry
	Eagles	Feed on spawning salmon
Mammals	Harbor seals, bears	Feed on spawning salmon

5.4 Impact Identification

When a receptor (identified in Tables 5-5 through 5-12) is exposed to a stressor (identified in Table 5-1) there is a risk of an ecological effect. In an EcoRA this effect is important when it is related to the assessment endpoints. The assessment endpoints chosen for this study (*i.e.*, water quality, sediment quality, fisheries, and wildlife) were described in Section 4. An effect to an assessment endpoint is defined here as an impact. There is always uncertainty about what types of impacts, and how severe the impacts, could be in a certain area. Changes in the Port, such as the introduction of non-native species, could have many unforeseen consequences. We have chosen a list of impacts that are of importance to the protection and maintenance of the assessment endpoints. These categories were previously define in Table 2-4 and include:

- water quality impairment
- sediment quality impairment
- decreases in hatchery salmon returns
- population declines associated with bottom fisheries
- declines in wild populations of anadromous fishes
- decreased reproduction of bird populations
- decreased food availability for wild fishes, birds, and mammals.

At a regional level the response of a single organism does not necessarily indicate an ecological impact. The Port ecology will not be affected until the individual response is great enough to cause a structural or functional change in the population or community. Single or multiple stressors can stimulate a response. For instance, impacts can result from:

- *a single stressor-caused response* (*e.g.*, decrease in the number of whelks due to the reproductive effect of organotins)
- *a cumulative response caused by multiple stressors* (*e.g.*, change in the benthic community related to increased chemical toxicity, change in sediment characteristics, and an altered organic matter content)

The receptor responses that will result in impacts to the assessment endpoints in Port Valdez are described in **Table 5-14**. An impact occurs when receptors respond to stressors in a way that causes harm to the assessment endpoint.

Table 5-14 Impacts to assessment endpoints linked to relevant receptor responses. The response results from the effect (in italics) of a stressor.

Water and Sediment Quality

<table>
<tr><th>Impact</th><th>Responses</th><th>Link to Receptors</th><th>Link to Stressors</th></tr>
<tr><td rowspan="2">Water Quality Impairment</td><td>Toxicity: decreased survival, growth, and reproduction</td><td>Phytoplankton, zooplankton, and pelagic fishes</td><td>Dissolved or suspended hydrocarbons, metals, or other chemicals</td></tr>
<tr><td>Physical disturbance: decreased survival, growth, or reproduction</td><td>Phytoplankton, zooplankton, and pelagic fishes</td><td>Salinity and temperature changes, sediment or other debris in the water</td></tr>
<tr><td rowspan="5">Sediment Quality Impairment</td><td rowspan="2">Toxicity: effects to survival, growth, and reproduction</td><td rowspan="2">Benthic deposit feeders, suspension feeders, scavengers, and predators</td><td>Chemicals in solid or particulate form that settle to the bottom or that adsorb to settling particles</td></tr>
<tr><td>Toxic byproducts from bacterial decomposition</td></tr>
<tr><td>Enrichment: increased growth of bacterial populations leading to declining oxygen levels</td><td>Benthic bacteria, benthic invertebrates</td><td>Organic matter in solid or particulate form that settle to the bottom</td></tr>
<tr><td>Enrichment: attraction of scavengers and predators to organic wastes or to increased invertebrate populations</td><td>Crabs, benthic fishes, seals, gulls</td><td>Dead or decaying organic matter, particularly fish carcasses or parts</td></tr>
<tr><td>Physical disturbance: decreased survival, growth, or reproduction</td><td>Benthic invertebrates</td><td>Sediment or debris deposited on the bottom, change in physical structure of the sediment</td></tr>
</table>

Table 5-14. **(continued)** Impacts to assessment endpoints linked to relevant receptor responses. The response results from the effect (in italics) of a stressor.

Commercial, Sport, and Personal Use Fisheries

Impact	*Link to Receptors*	*Responses*	*Link to Stressors*
Hatchery Salmon Returns	pink salmon fry and silver salmon released from the hatchery	*Toxicity*: decreased survival or growth of fish migrating out of the Port	dissolved or suspended chemicals
		Predation or Competition: decreased survival or growth of fish migrating out of the Port	new or enhanced species, or a change in community structure within the Port
		Behavioral Disturbance: disruption of migratory behavior such as feeding or patterns of movement	plumes of water containing substances or characteristics (*e.g.*, salinity, temperature) that would cause avoidance behavior
	pink salmon fry released from the hatchery	*Physical Disturbance:* injury or loss of habitat used by salmon fry as nursery areas	land use, sediment
	zooplankton feed on by fry	*Toxicity:* reduced survival or growth in the Port	dissolve or suspended chemicals
	juvenile silver salmon	*Toxicity:* reduced survival or growth during culturing in netpens	chemicals causing reduced survival or growth
Benthic Fishes and Shellfishes	crab, shrimp, and benthic fishes	*Habitat Loss:* loss of protective cover, especially for juveniles	land use, sediment
	crab larvae in the water column and shrimp	*Toxicity:* reduced survival or growth	*see Impacts to Water Quality*
	sediment invertebrates fed on by crab and shrimp	*Toxicity:* reduced survival, growth, or reproduction	chemicals in or deposited on sediments
		Enrichment: increased growth of bacterial populations leading to declining oxygen levels	organic wastes
	water column invertebrates fed on by shrimp	*Toxicity:* reduced survival, growth, or reproduction	chemicals dissolved in or suspended in water
		Predation: reduced survival	feeding hatchery fry
	adult or juvenile crabs	*Toxicity:* reduced survival, growth, or reproduction	chemicals in or deposited on sediments

Table 5-14. (continued) Impacts to assessment endpoints linked to relevant receptor responses. The response results from the effect (in italics) of a stressor.

Wildlife: Fishes, Birds, and Mammals

Impact	*Link to Receptors*	*Responses*	*Link to Stressors*
Wild Anadromous Fishes	wild pink salmon	*Genetic dilution*: change in genes which may alter population characteristics or decrease resilience	cross-breeding with straying pink salmon from the hatchery
	wild pink and chum salmon	*Crowding:* may reduce spawning or number of eggs produces by individual females	straying hatchery fish
	wild red and silver salmon	*Crowding:* may interfere with passage through stream to spawning grounds	straying hatchery fish
	wild fry, juveniles, and adult anadromous fishes	*Toxicity:* reduced survival, growth, or reproduction	chemicals
	eggs and newly hatched fry	*Physical Disturbance:* reduced survival or growth	sediment deposited on spawning beds, disturbance of sediments
Bird Reproduction	nesting ducks, gulls, terns, kittiwakes, shorebirds	*Physical Disturbance:* birds abandoning or neglecting nests and inadequate care of young	noise and activity
		Habitat Loss: reduced number of adequate nesting sites	land use
	eggs or young of birds that nest in the Port	*Toxicity:* reduced survival, growth, or hatching success	chemicals in food or at water surface
		Physical Disturbance: reduced survival	predators, injury
Wildlife Food Availability and Quality	plants and invertebrates fed on by wildlife	*Bioaccumulation:* toxic accumulations in food resources	chemicals dissolved or suspended in water or in the sediments
		Toxicity: reduced survival, growth, or reproduction	chemicals dissolved or suspended in water or in the sediments
	fishes, birds, and mammals with feeding concentrated in the Port	*Physical Disturbance:* disruption of feeding activities	noise and activity

5.4 Exposure and Effects Links

After identifying and categorizing the regional components (sources, habitats, and possible impacts) in the Port, the conceptual model links these components. Sections 5.2 through 5.4 linked each regional component to one of the traditional components of risk assessment: sources to stressors, habitats to receptors, and impacts to responses. The exposure and effects links between the sources, habitats, and impacts complete the set of links necessary for the conceptual model. These links are the basis for the filters used in the relative risk analysis (Section 6). The exposure and effects links are represented in **Figure 5-1 and Table 5-15**.

Risk assessments involving specific stressors or receptors can be developed within the context of this conceptual model. The value of using the model for further risk assessment in the Port is that it requires the analyst to account for multiple exposures and cumulative effects in the system.

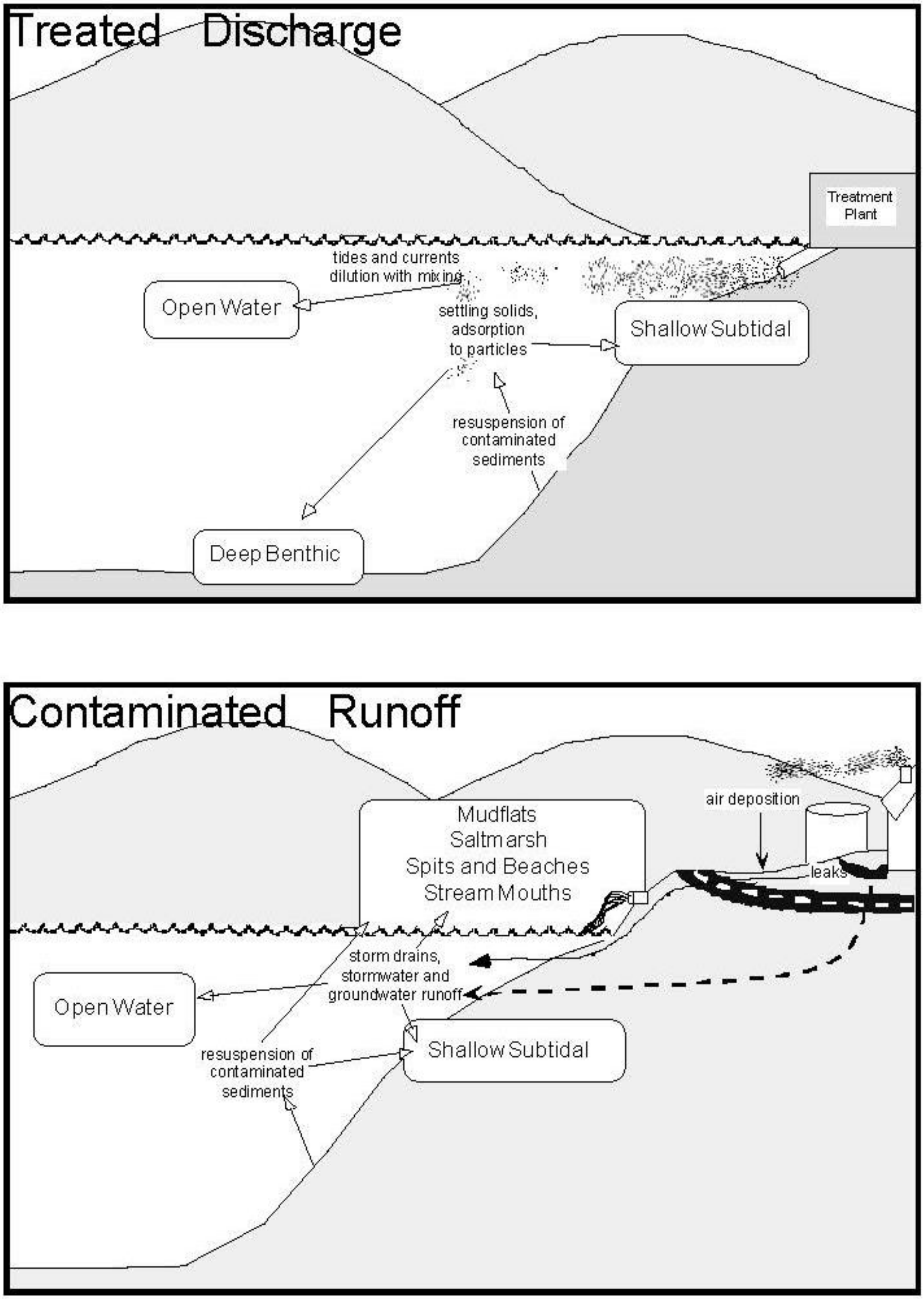
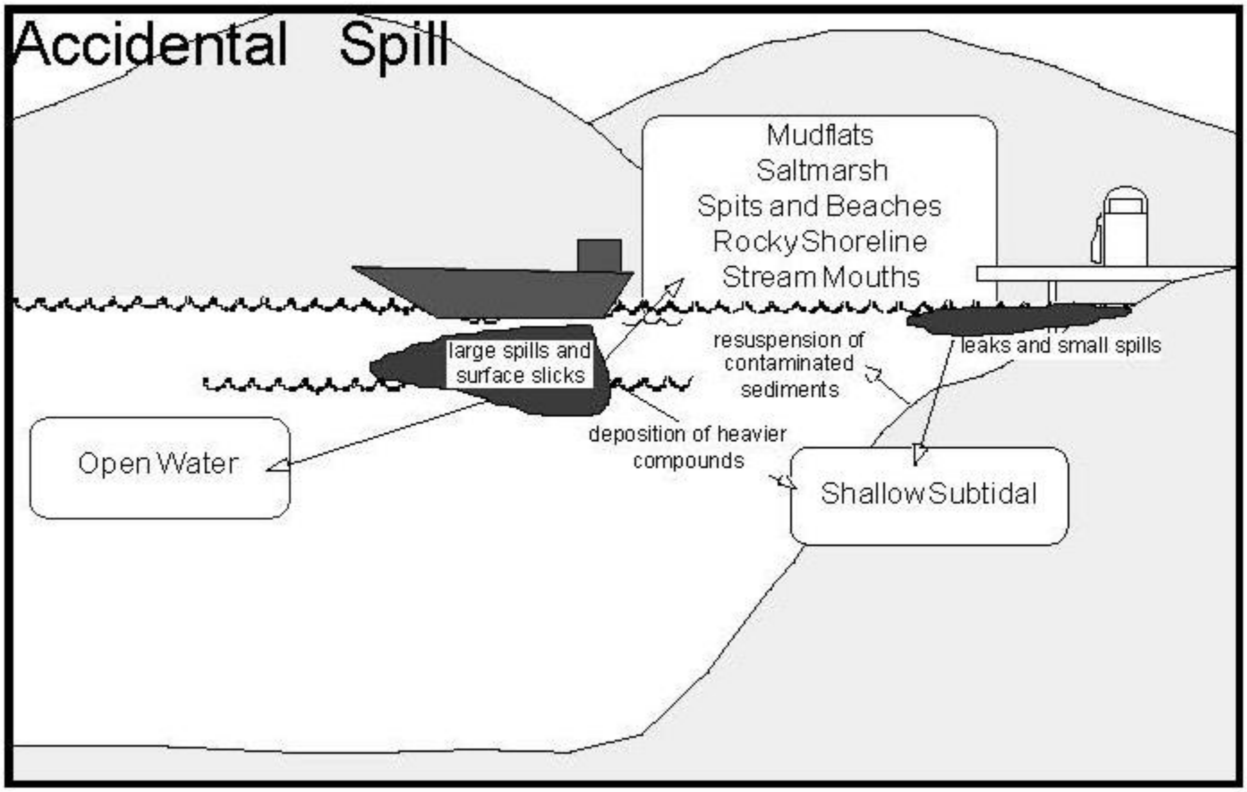


Figure 5-1 Exposure links.



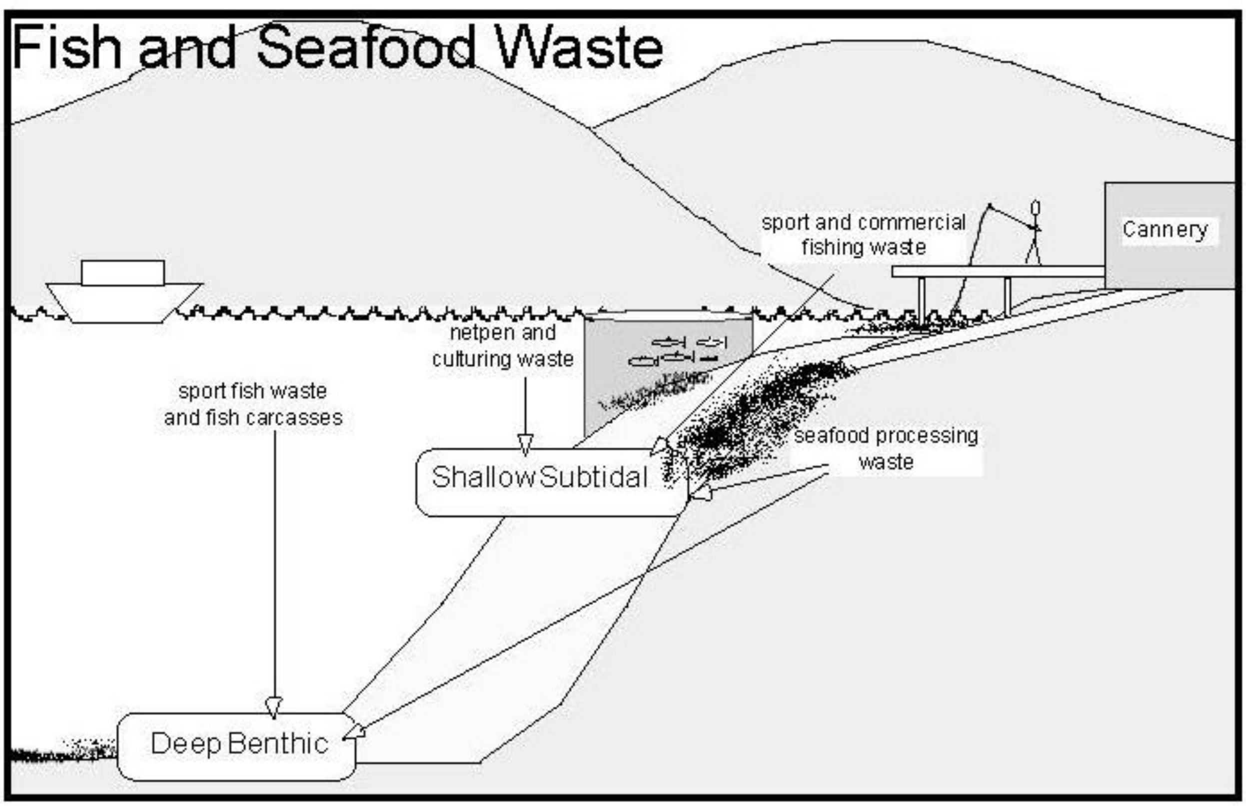
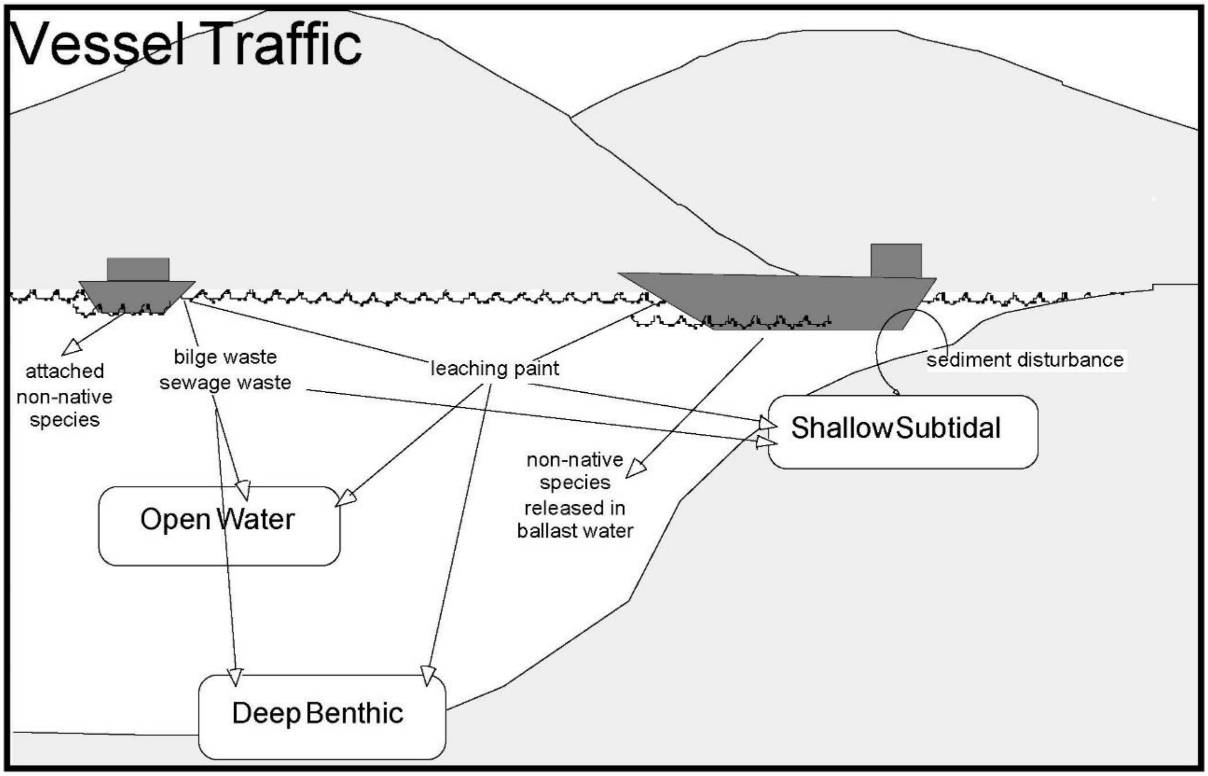


Figure 5-1 **(continued)** Exposure links.



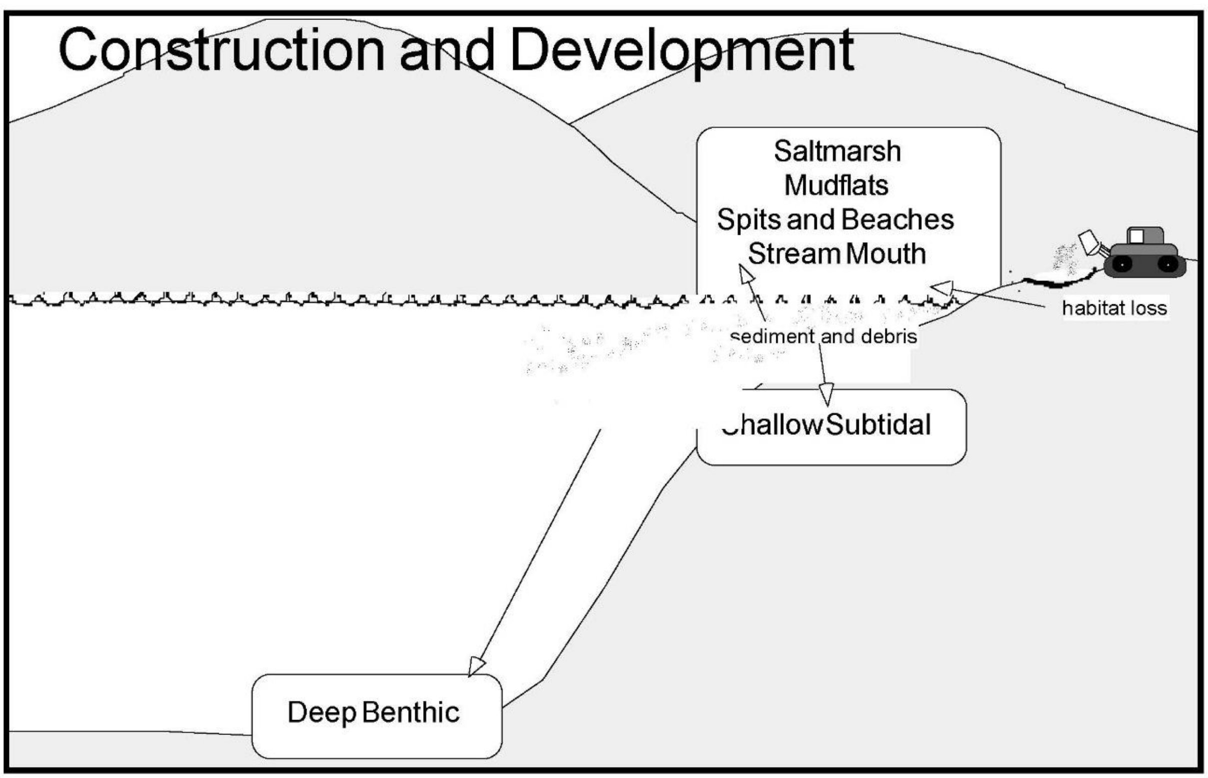
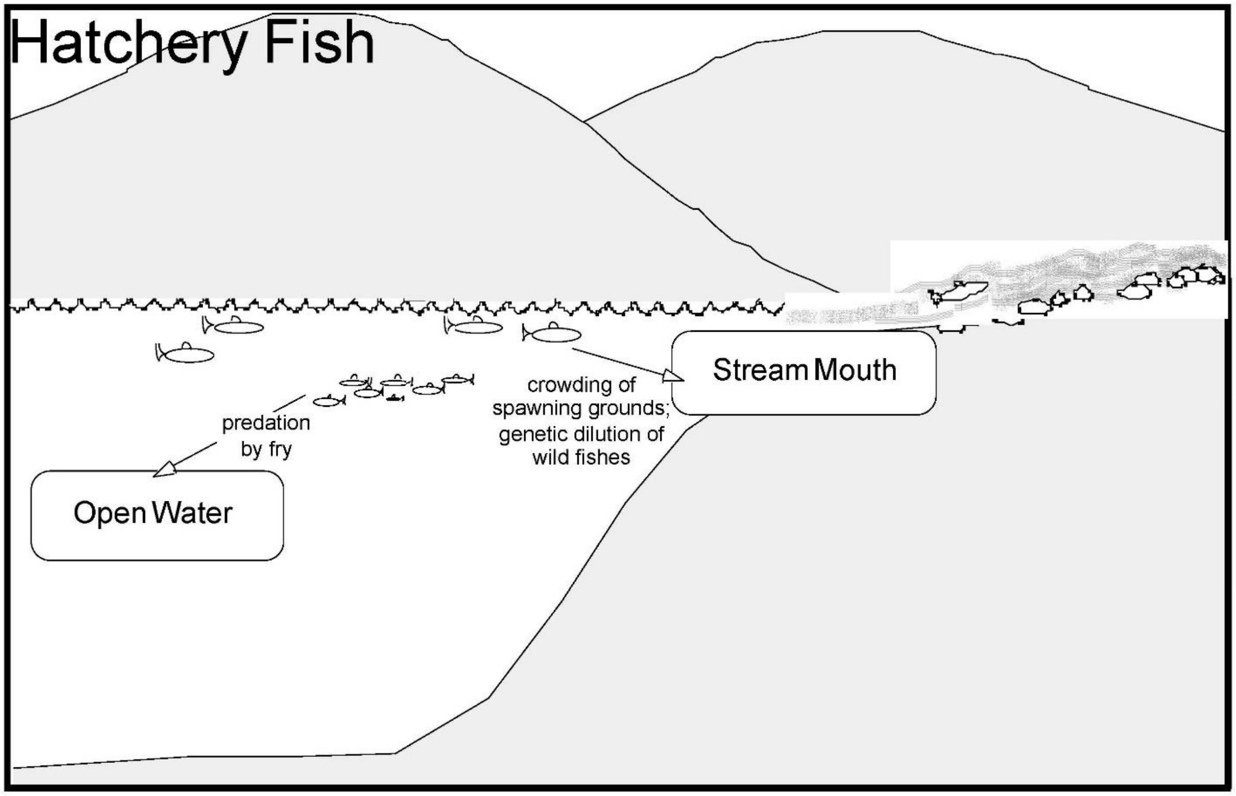


Figure 5-1 **(continued)** Exposure links.



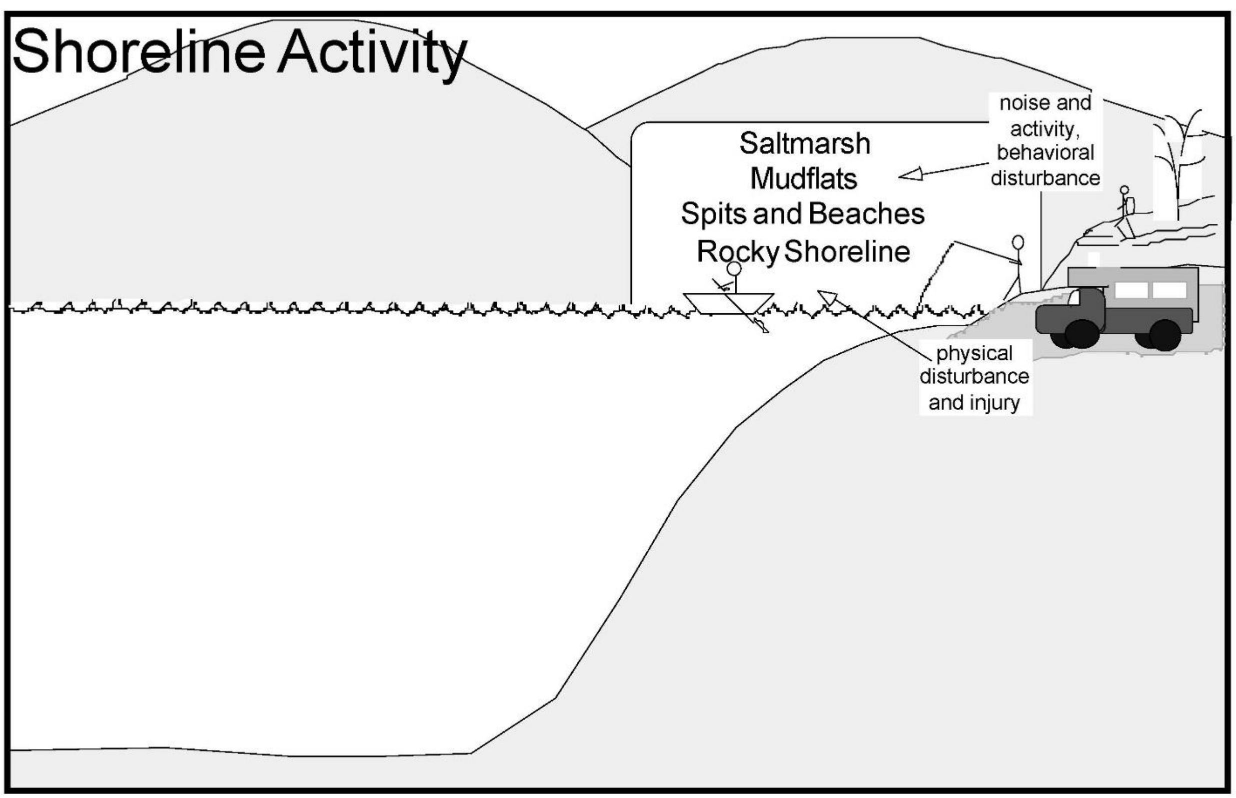


Figure 5-1 **(continued)** Exposure links.

Table 5-15 Effects links.

Exposure		Effects to Assessment Endpoints		
Source	Habitat	Water and Sediment Quality	Fisheries	Wildlife
Treated Discharges	Shallow Subtidal Open Water Deep Benthic	toxicity enrichment leading to anoxia physical disturbance from suspended or settling solids	toxicity oxygen depletion temperature and salinity changes food availability	toxicity bioaccumulation in food food availability
Contaminated Runoff	Saltmarsh Mudflats Spits and Beaches Shallow Subtidal Open Water Stream Mouth	toxicity enrichment leading to anoxia physical disturbance from suspended or settling solids	toxicity oxygen depletion food availability	toxicity bioaccumulation in food food availability
Accidental Spills	Saltmarsh Mudflats Spits and Beaches Rocky Shoreline Shallow Subtidal Open Water Stream Mouth	toxicity physical disturbance from fouling	toxicity physical disturbance from fouling habitat loss	toxicity bioaccumulation in food food availability physical disturbance from fouling habitat loss
Fish Wastes	Shallow Subtidal Deep Benthic	enrichment leading to anoxia toxicity from metabolic byproducts physical disturbance	toxicity oxygen depletion food availability	food availability
Vessel Traffic	Shallow Subtidal Open Water Deep Benthic	toxicity physical disturbance of the water column	injury to organisms habitat loss	bioaccumulation in food food availability behavioral disturbances injury to organisms
Construction and Development	Saltmarsh Mudflats Spits and Beaches Deep Benthic Stream Mouth	physical disturbance from suspended or settling solids	habitat loss	food availability behavioral disturbances habitat loss
Hatchery Fish	Open Water Stream Mouth	enrichment leading to anoxia from salmon carcasses	predation of larval fishes, crab or shrimp	genetic effects crowding in spawning grounds
Shoreline Activity	Saltmarsh Mudflats Spits and Beaches Rocky Shoreline	physical disturbance	no links	behavioral disturbances

6.0 Relative Risks in Port Valdez: Results of the Conceptual Model

Systematic application of the conceptual model to the habitats and risk sources in each of the sub-areas led to a ranking of relative risks to the environment within the Port. These rankings represent a consensus by the authors. Their assessments, judgments, and rankings that went into the conceptual model to yield the final relative risk scores can be examined in Appendix D. This can lead to the identification of specific elements about which disagreement or uncertainty exists and suggest topics where further research may be needed.

It must be emphasized that the conceptual model ranks *relative* risk. The rankings are unitless numbers that judge the relative severity of environmental risks. Relative risk information by itself is important because it generally makes sense to direct available resources toward lowering higher risks. In addition we have used other approaches to associate some of the relative risks to benchmark values for environmental acceptability and other measures of risk (see Section 7). This serves to calibrate our relative ranking against generally accepted standards of environmental quality.

6.1 Characteristics of the Conceptual Model

The estimation of risk associated with the conceptual model (see Section 5) is difficult because of the size and complexity of the ecological system. Like most regions, the number of receptors, endpoints, and potential stressors to be considered is large. It is important to avoid a model so simplified that it provides little guidance about ecological interactions. However, as a model becomes more detailed, the number of potential errors increases. As described in the Methods (see Section 2), our model is used to prioritize risks through ranking and filtering the information available about the risk components: sources, habitats, and impacts to assessment endpoints. Input to the conceptual model is shown in **Tables 6-1** and **6-2**. The input includes a set of ranks for the sources and habitats in each area (**Table 6-1**), an exposure filter (**Table 6-2a**), and a series of effects filters (**Table 6-2b-h**) for specific assessment endpoints.

The model produces two types of output depending on which type of filter is used. (1) If an exposure filter is used, the model produces a set of exposure-based risk scores. The scores are calculated for each combination of source (**Table 6-3**) and habitat (**Table 6-4**) present in the sub-area. (2) The model produces a second type of output when an effects filter is used. Each effects filter corresponds to a particular assessment endpoint. The effect scores are also calculated for each combination of source and habitat present in a sub-area. These calculations can be found in Appendix D. Summing all of the output derived from a single filter for a given sub-area results in a measure of total risk. Total risk can be calculated for exposure (using the first type of output), or for effects to an assessment endpoint (using the second type of output).

6.2 Relative Risk by Sub-Areas

The rankings of total environmental risk for each sub-area in Port Valdez can be determined from the model by summing down the columns in either of the matrices in **Table 6-3** and **Table 6-4**. These rankings range from 40 (Sawmill to Seven-Mile Creeks) to 448 (Duck Flats and Old Valdez). We consider sub-areas with rankings less than 150 to have low relative risk. Sub-areas in this group include Shoup Bay, Sawmill to Seven-Mile Creeks, Anderson Bay, and Western Port. Sub-areas with rankings between 150 and 300 are considered to have moderate relative risk. These include the Mineral and Gold Creeks, City of Valdez, Robe and Lowe Rivers, Dayville Flats and Solomon Gulch, and the Valdez Marine Terminal. Only one sub-area, Duck Flats and Old Valdez, has a ranking greater than 300 and is considered to have high relative risk (**Fig. 6-1**). Because of the uncertainty associated with the ranking process, it is not meaningful to make comparisons of relative risk more detailed than these low, moderate, and high groupings.

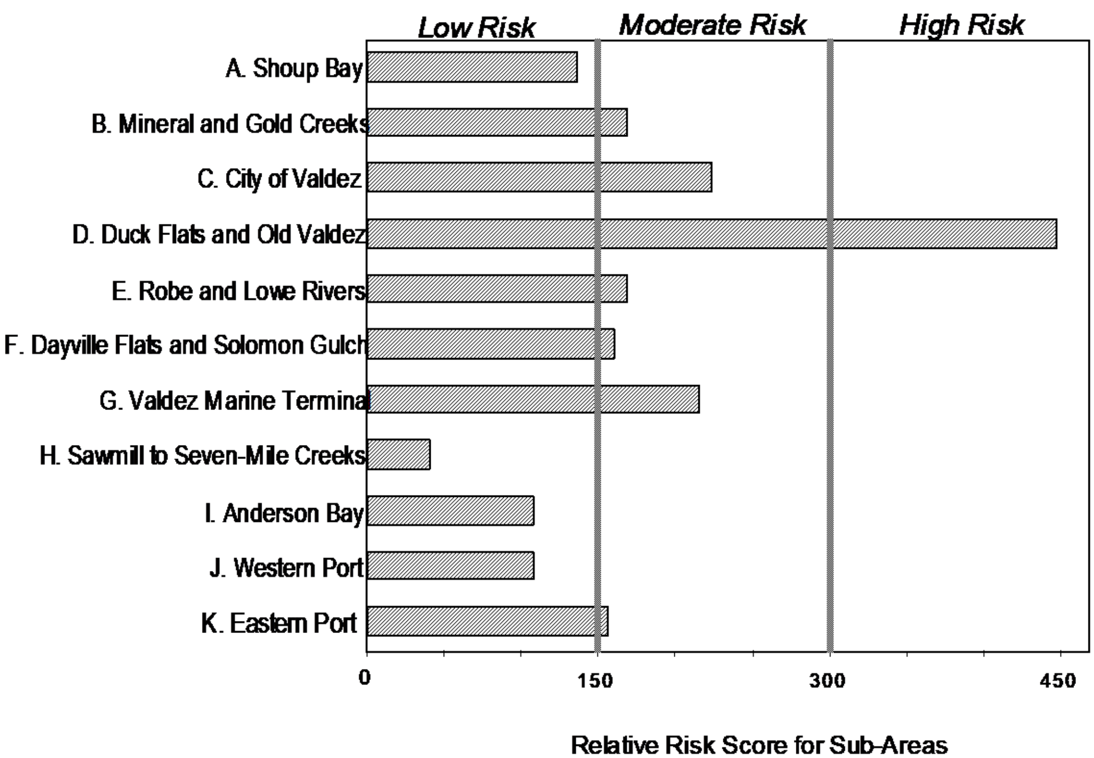


Figure 6-1. Total relative risk scores for each sub-area.

This analysis shows that the pelagic environment and western shoreline, areas of low development impact, are at low relative risk. Most of the eastern shoreline is at moderate relative risk. This includes sub-areas from the City of Valdez to the Alyeska Terminal where development has occurred. Within the developed eastern area exists the one sub-area of high relative risk, Duck Flats and Old Valdez. The greater risk in this sub-area is due primarily to the abundance of potentially sensitive habitats there. It should be noted that "high relative risk" may or may not imply high risk in an absolute sense. Section 7.1 explores the relation of risks in Port Valdez to generally accepted criteria of environmental quality.

6.3 Relative Risk by Source

The relative risk to the entire Port Valdez region from each of the eight categories of stressor sources can be determined by summing across the rows in the first matrix of **Table 6-3**. If the same criteria defined above (low relative risk, <150; moderate relative risk, 150 - 300; and high relative risk, >300) are applied to the risks from sources, groupings can again be obtained. Treated discharges, fish and seafood wastes, and the presence of hatchery fishes are ranked as having low relative risk. Vessel traffic and construction and development activities are ranked as having moderate relative risk. Contaminated runoff, accidental spills, and shoreline activity are ranked as having high relative risk.

The distribution of relative risk by stressor sources is not as intuitively obvious as the distribution by sub-areas discussed above. This is largely because the various sources give rise to variety of stressors including physical, chemical, and biological stressors which in turn can produce a variety of toxic and disturbance effects. No single metric other than ranking can appropriately compare these risks. The Port Valdez environment is too complex for such a ranking to be reliably performed on an intuitive basis. Any reader who finds these rankings by source suspect should carefully study Appendix D to understand how they were derived. Identifying the particular elements in the ranking matrices about which disagreement exists can be very useful. It can pinpoint elements of scientific uncertainty or differences in values. This can transform bottom-line disagreements about overall risk into specific disagreements about individual matrix elements setting the stage for reducing scientific uncertainty or, at least, revealing value differences.

6.4 Relative Risk by Habitat

The relative risk to Port Valdez as a whole from each of the eight habitat categories can be determined by summing across the rows in the second matrix of **Table 6-4**. If the same risk groupings defined above are applied to the total relative risk scores for habitats, saltmarsh and deep benthic habitats are ranked at low relative risk. Spit and low-profile beach, rocky shoreline, and open water habitats are ranked at moderate relative risk. Mudflat, shallow subtidal, and stream mouth habitats are ranked at high relative risk.

Relative risk to habitats in Port Valdez as a whole is strongly influenced by the abundance of habitats across sub-areas. For instance, saltmarsh occurs in only one sub-area: Duck Flats and Old Valdez. Although saltmarsh receives the highest possible ranking *in that sub-area*, that alone still leads to a low relative risk to Port Valdez *as a whole*. The reverse situation occurs for open water habitat. The risk to open water in any individual sub-area is never more than half of the maximum possible, but open water occurs in every sub-area. The result is that open water habitats have high relative risk for Port Valdez as a whole.

Risk management decisions for Port Valdez will require careful interpretation of relative risks to habitat types. Both the importance of rare habitats (such as saltmarsh) and the major habitat types of the Port should be considered.

6.4 Relative Risk within a Sub-area

Another way to evaluate relative risk is to consider the sources or habitats associated with the score for each sub-area. The risk related to a particular source or to a particular habitat can be found within the matrices shown in **Table 6-3** and **Table 6-4**. For instance, in the Eastern Port sub-area, the largest score for a source, 72, is associated with treated discharge. The largest score for a habitat in this sub-area, 84, is associated with the open water.

When we consider the maximum source and habitat score in each sub-area, the Duck Flats and Old Valdez sub-area ranks the highest for both (**Fig. 6-2**). The risk perspective depends on whether it is associated with a source or a habitat. For instance, the largest score for a source in the Duck Flats and Old Valdez (Sub-Area D) is associated with the accidental spill category. This means that accidental spills pose the greatest relative risk to all of the combined habitats in this sub-area (**Fig. 6-3**). The largest score for a habitat is associated with the shallow subtidal category (**Fig. 6-4**). Thus shallow subtidal habitat in the Duck Flats and Old Valdez area is at the most risk from all of the sources identified in that sub-area.

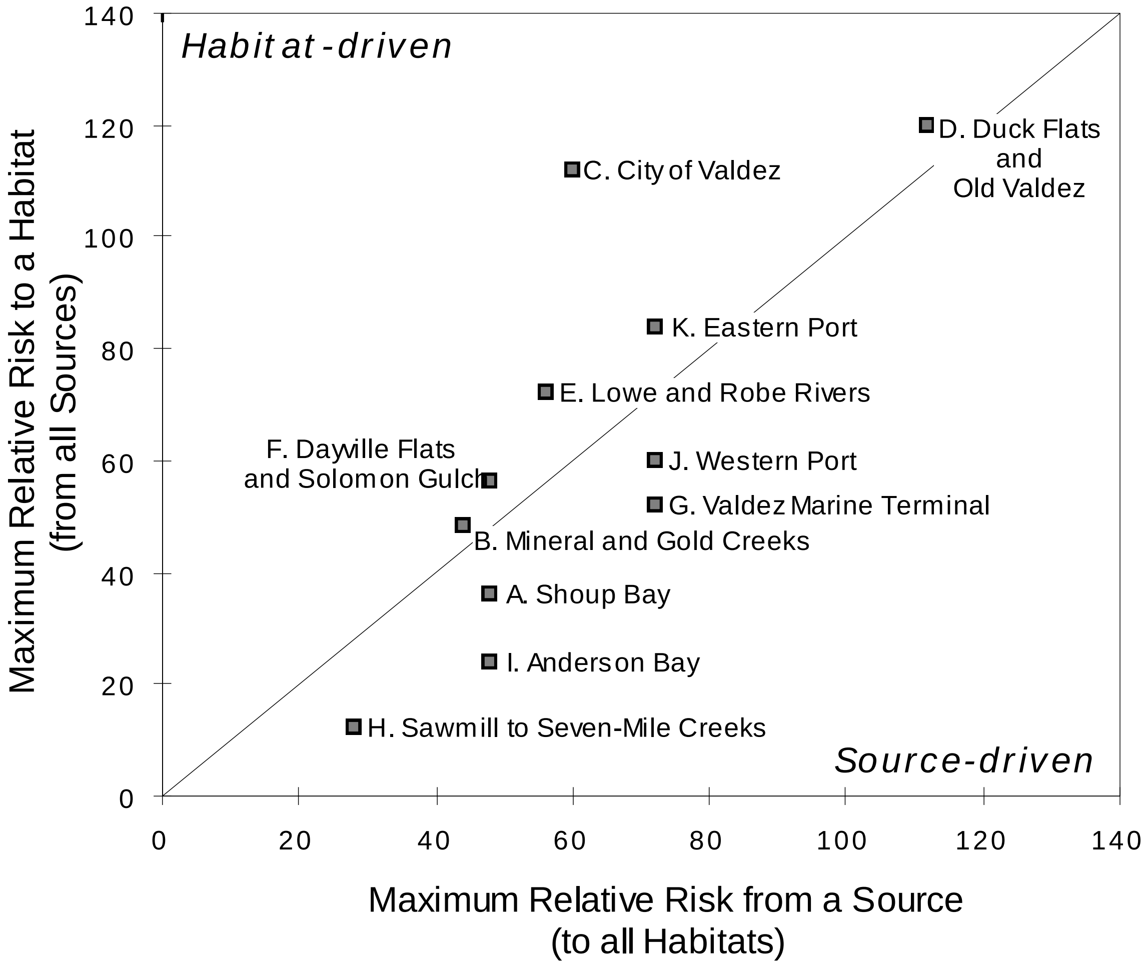


Figure 6-2. Sources and habitats with the maximum relative risk score in each sub-area. If the point falls above the diagonal line, the cumulative risk to a specific habitat type was greater than the risk from any one source. If the point falls below the diagonal line, the risk from a source type was greater than the combined risks to any one habitat.

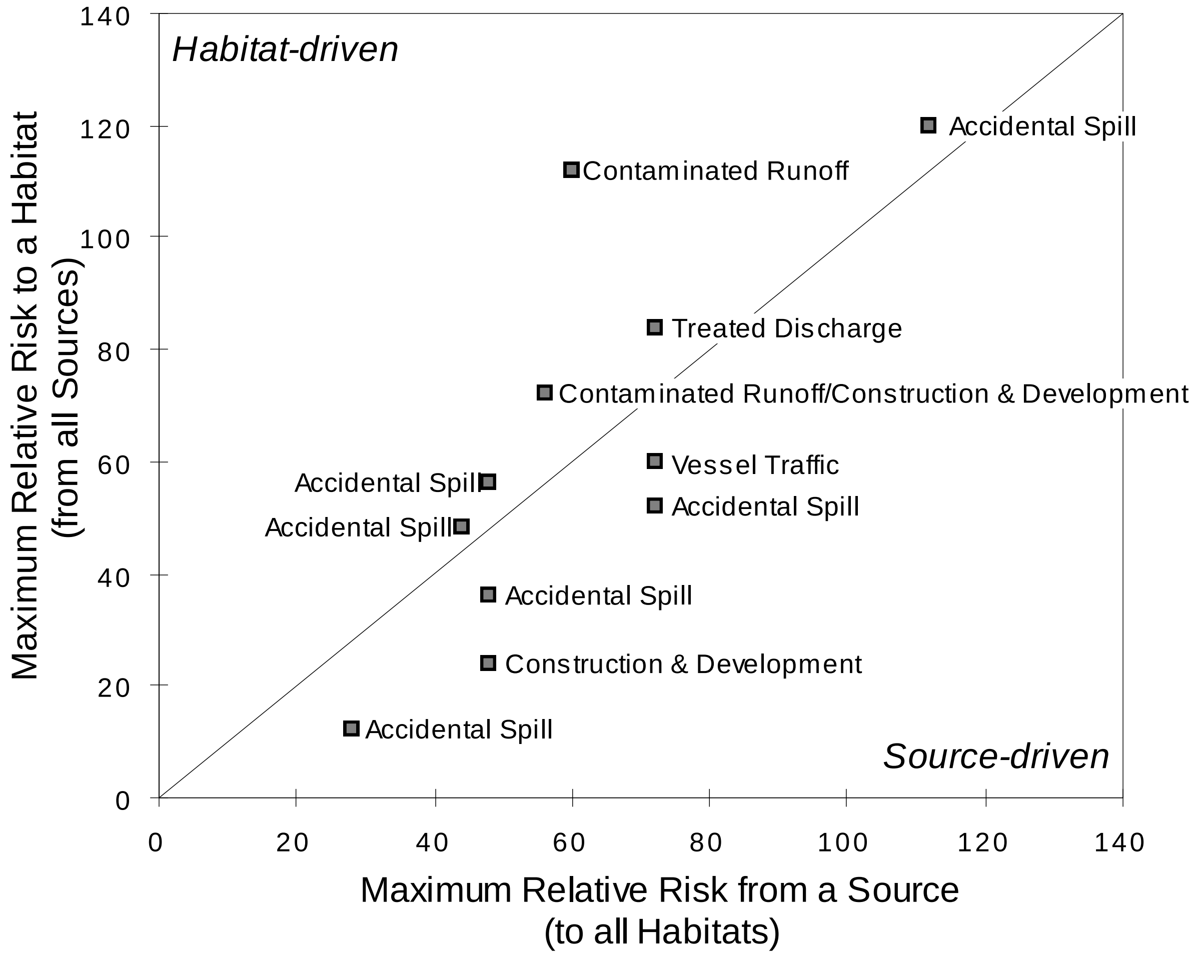


Figure 6-3. Source or sources driving the maximum relative risks shown in Fig. 6-2.

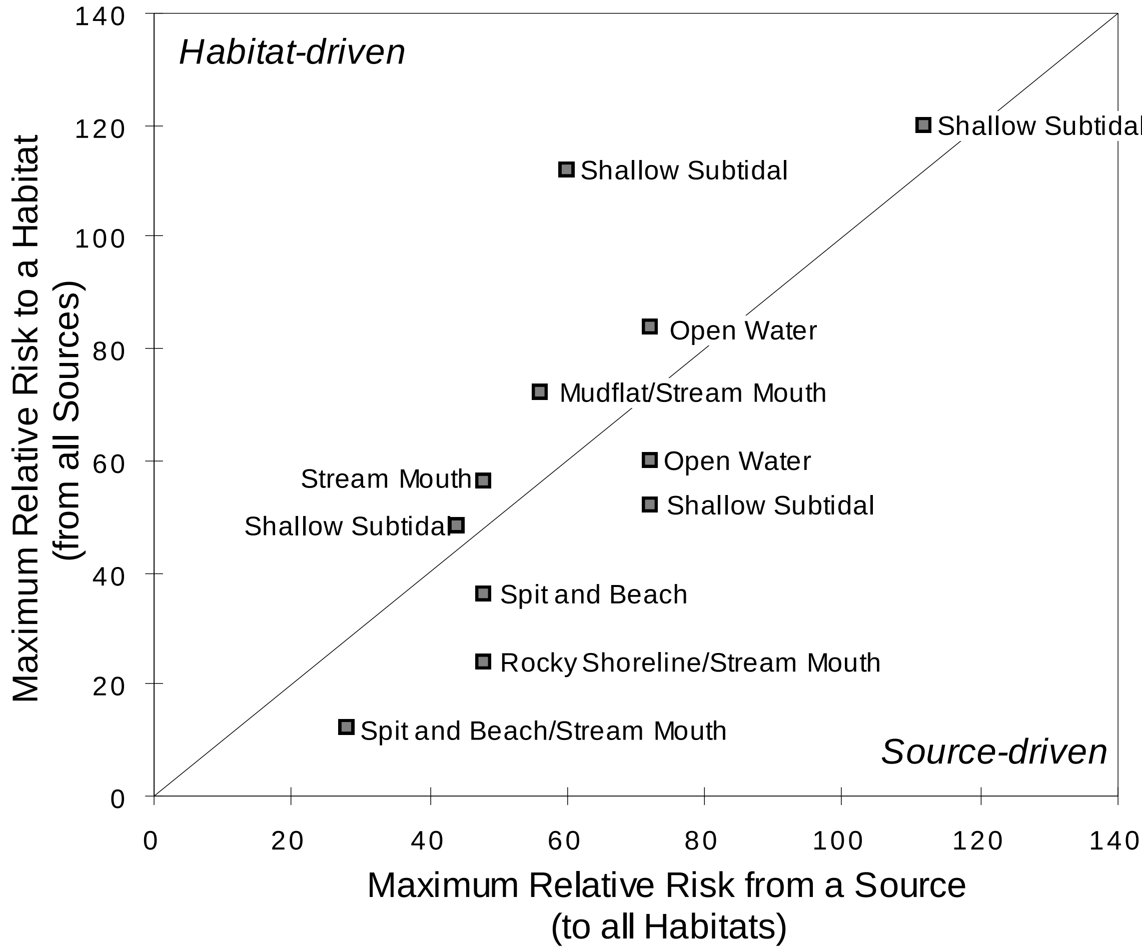


Figure 6-4. Habitat or habitats driving the maximum relative risks shown in Fig. 6-2.

Table 6-1. Inputs into the Relative Risk Model: Rankings for a) sources and b) habitats by sub-areas. Criteria for generation of these matrices are presented in Tables 2-5 and 2-6.

a) Model Source Ranks

Sub-Area	Treated Discharg.	Contam. Runoff	Accident. Spills	Fish Waste	Vessel Traffic	Construc. Develop.	Hatchery Fish	Shoreline Activity
A. Shoup Bay	0	2	2	0	2	0	0	2
B. Mineral & Gold Creeks	0	2	2	0	2	2	0	4
C. City of Valdez	0	6	6	6	6	4	0	6
D. Duck Flats & Old Valdez	4	4	4	0	4	4	0	6
E. Lowe and Robe Rivers	0	4	2	0	2	4	2	2
F. Dayville & Solomon Gulch	0	2	4	4	4	2	6	4
G. Valdez Marine Terminal	6	4	6	2	6	4	4	6
H. Sawmill to Seven-Mile Creeks	0	0	2	0	2	0	4	0
I. Anderson Bay	0	0	2	0	2	6	4	2
J. Western Port	0	0	4	2	6	0	0	0
K. Eastern Port	6	0	4	2	4	0	0	0

b) Model Habitat Ranks

Sub-Area	Mudflat	Salt-marsh	Spits & Beaches	Rocky Shore	Shallow Subtidal	Deep Benthic	Open Water	Stream Mouth
A. Shoup Bay	2	0	6	6	4	4	4	2
B. Mineral and Gold Creeks	4	0	2	4	6	0	0	6
C. City of Valdez	0	0	4	2	4	0	0	0
D. Duck Flats and Old Valdez	6	6	0	4	6	0	0	6
E. Lowe and Robe Rivers	6	0	0	0	2	0	0	6
F. Dayville and Solomon Gulch	4	0	2	0	2	0	0	4
G. Valdez Marine Terminal	2	0	2	4	2	0	0	2
H. Sawmill to Seven-Mile Creeks	2	0	6	2	2	0	0	2
I. Anderson Bay	2	0	2	6	2	0	0	2
J. Western Port	0	0	0	0	0	6	6	0
K. Eastern Port	0	0	0	0	0	6	6	0

Table 6-2. Inputs into the Relative Risk Model: a) exposure filter and b) effect filter for water quality.

a) Model Exposure Filter

Habitats	**Sources**							
	Treated Discharge	Contam. Runoff	Accid. Spills	Fish Waste	Vessel Traffic	Construc. Develop.	Hatchery Fish	Shoreline Activity
Saltmarsh	0	1	1	0	0	1	0	0
Mudflat	0	1	1	0	0	1	0	0
Spits and Beaches	0	1	1	0	0	1	0	0
Rocky Shoreline	0	0	1	0	0	0	0	0
Shallow Subtidal	1	1	1	1	1	0	0	0
Deep Benthic	1	0	0	1	1	1	0	0
Open Water	1	1	1	0	1	0	0	0
Stream Mouths	0	1	1	0	0	1	1	0

b) Model Effects Filter: Water Quality

Habitats	**Sources**							
	Treated Discharge	Contam. Runoff	Accid. Spills	Fish Waste	Vessel Traffic	Construc. Develop.	Hatchery Fish	Shoreline Activity
Saltmarsh	0	1	1	0	0	1	0	1
Mudflat	0	1	1	0	0	1	0	1
Spits and Beaches	0	1	1	0	0	1	0	1
Rocky Shoreline	0	0	1	0	0	0	0	1
Shallow Subtidal	1	1	1	1	1	0	0	0
Deep Benthic	1	0	0	1	1	1	0	0
Open Water	1	1	1	0	1	0	1	0
Stream Mouth	0	1	1	0	0	1	1	0

Table 6-2. **(continued)** Inputs to the Relative Risk Model: effects filter for c) sediment quality and d) hatchery salmon returns.

c) Model Effects Filter: Sediment Quality

Habitats	Sources							
	Treated Discharge	Contam. Runoff	Accid. Spills	Fish Waste	Vessel Traffic	Construc. Develop.	Hatchery Fish	Shoreline Activity
Saltmarsh	0	1	1	0	0	1	0	1
Mudflat	0	1	1	0	0	1	0	1
Spits and Beaches	0	1	1	0	0	1	0	1
Rocky Shoreline	0	0	1	0	0	0	0	1
Shallow Subtidal	1	1	1	1	1	0	0	0
Deep Benthic	1	0	0	1	1	1	0	0
Open Water	1	1	1	0	1	0	1	0
Stream Mouths	0	1	1	0	0	1	1	0

d) Model Effects Filter: Hatchery Salmon Returns

Habitats	Sources							
	Treated Discharge	Contam. Runoff	Accid. Spills	Fish Waste	Vessel Traffic	Construc. Develop.	Hatchery Fish	Shoreline Activity
Saltmarsh	0	1	1	0	0	1	0	0
Mudflat	0	1	1	0	0	1	0	0
Spits and Beaches	0	1	1	0	0	1	0	0
Rocky Shoreline	0	0	1	0	0	0	0	0
Shallow Subtidal	1	1	1	1	1	0	0	0
Deep Benthic	0	0	0	0	0	0	0	0
Open Water	1	1	1	0	1	0	1	0
Stream Mouths	0	1	1	0	0	1	1	0

Table 6-2. **(continued)** Inputs to the Relative Risk Model: effect filters for e) bottom fishes and shellfishes and f) wild anadromous fishes.

e) Model Effects Filter: Bottom Fishes and Shellfishes

Habitats	Sources							
	Treated Discharge	Contam. Runoff	Accid. Spills	Fish Waste	Vessel Traffic	Construc. Develop.	Hatchery Fish	Shoreline Activity
Saltmarsh	0	0	0	0	0	0	0	0
Mudflat	0	0	0	0	0	0	0	0
Spits and Beaches	0	0	0	0	0	0	0	0
Rocky Shoreline	0	0	1	0	0	0	0	0
Shallow Subtidal	1	1	1	1	1	0	0	0
Deep Benthic	1	0	0	1	1	1	0	0
Open Water	0	0	0	0	0	0	0	0
Stream Mouths	0	0	0	0	0	0	0	0

f) Model Effects Filter: Wild Anadromous Fishes

Habitats	Sources							
	Treated Discharge	Contam. Runoff	Accid. Spills	Fish Waste	Vessel Traffic	Construc. Develop.	Hatchery Fish	Shoreline Activity
Saltmarsh	0	1	1	0	0	1	0	0
Mudflat	0	1	1	0	0	1	0	0
Spits and Beaches	0	1	1	0	0	1	0	0
Rocky Shoreline	0	0	1	0	0	0	0	0
Shallow Subtidal	1	1	1	1	1	0	0	0
Deep Benthic	0	0	0	0	0	0	0	0
Open Water	1	1	1	0	1	0	1	0
Stream Mouths	0	1	1	0	0	1	1	0

Table 6-2. **(continued)** Inputs to the Relative Risk Model: effect filters for g) bird reproduction and h) wildlife (fishes, birds, mammals) food availability and quality.

g) Model Effects Filter: Bird Reproduction

Habitats	Sources							
	Treated Discharge	Contam. Runoff	Accid. Spills	Fish Waste	Vessel Traffic	Construc. Develop.	Hatchery Fish	Shoreline Activity
Saltmarsh	0	1	1	0	0	1	0	1
Mudflat	0	1	1	0	0	1	0	1
Spits and Beaches	0	1	1	0	0	1	0	1
Rocky Shore	0	0	1	0	0	0	0	1
Shallow Subtidal	1	1	1	0	1	0	0	0
Deep Benthos	0	0	0	0	0	0	0	0
Open Water	1	1	1	0	1	0	0	0
Stream Mouths	0	1	1	0	0	1	0	0

h) Model Effects Filter: Wildlife Food Availability and Quality

Habitats	Sources							
	Treated Discharge	Contam. Runoff	Accid. Spills	Fish Waste	Vessel Traffic	Construc. Develop.	Hatchery Fish	Shoreline Activity
Saltmarsh	0	1	1	0	0	1	0	1
Mudflat	0	1	1	0	0	1	0	1
Spits and Beaches	0	1	1	0	0	1	0	1
Rocky Shoreline	0	0	1	0	0	0	0	1
Shallow Subtidal	1	1	1	1	1	0	0	0
Deep Benthic	1	0	0	1	1	1	0	0
Open Water	1	1	1	0	1	0	1	0
Stream Mouths	0	1	1	0	0	1	1	0

Table 6-3. Ranked relative risk outputs of the conceptual model by source and sub-area. All values are summed for all assessment endpoints. The far right column is summed for the sub-areas. The bottom row is the sum of the columns.

	Source								
Sub-Area	Treated Discharge	Contam. Runoff	Accid. Spills	Fish Waste	Vessel Traffic	Construc. Develop.	Hatchery Fish	Shoreline Activity	**Total Relative Risk**
Shoup Bay	0	36	48	0	24	0	0	28	**136**
Mineral and Gold Creeks	0	36	44	0	12	24	0	40	**156**
City of Valdez	0	48	60	24	24	16	0	36	**208**
Duck Flats and Old Valdez	24	96	112	0	24	72	0	96	**424**
Lowe and Robe Rivers	0	56	28	0	4	48	12	12	**160**
Dayville and Solomon Gulch	0	24	48	8	8	20	24	24	**156**
Valdez Marine Terminal	12	32	72	0	12	24	8	48	**208**
Sawmill to Seven-Mile Creeks	0	0	28	0	4	0	8	0	**40**
Anderson Bay	0	0	28	0	4	36	8	20	**96**
Western Port	0	0	24	12	72	0	0	0	**108**
Eastern Port	72	0	24	12	48	0	0	0	**156**
Total Relative Risk	**108**	**328**	**516**	**56**	**239**	**240**	**60**	**304**	

Table 6-4. Ranked relative risk outputs of the conceptual model by habitat and sub-area. All values are summed for all assessment endpoints. The far right column is summed for the sub-areas. The bottom row is the sum of the columns.

	Habitat								
Sub-Area	Mudflat	Saltmarsh	Spits and Beaches	Rocky Shoreline	Shallow Subtidal	Deep Benthic	Open Water	Stream Mouth	**Total Relative Risk**
Shoup Bay	12	0	36	24	24	8	24	8	**136**
Mineral and Gold Creeks	40	0	20	24	36	0	0	36	**156**
City of Valdez	0	0	88	24	96	0	0	0	**208**
Duck Flats and Old Valdez	108	108	0	40	96	0	0	72	**424**
Lowe and Robe Rivers	72	0	0	0	16	0	0	72	**160**
Dayville and Solomon Gulch	48	0	24	0	28	0	0	56	**156**
Valdez Marine Terminal	40	0	40	48	48	0	0	36	**208**
Sawmill to Seven-Mile Creeks	4	0	12	4	8	0	0	12	**40**
Anderson Bay	20	0	20	24	8	0	0	24	**96**
Western Port	0	0	0	0	0	48	60	0	**108**
Eastern Port	0	0	0	0	0	72	84	0	**156**
Total Relative Risk	**344**	**108**	**240**	**188**	**360**	**128**	**168**	**316**	

7.0 Confirmation of Risk Rankings in Port Valdez

The rankings of relative risk in Port Valdez (Section 6) can be compared to generally accepted measures of environmental risk. For these comparisons we have used data collected in Port Valdez: measures of petroleum hydrocarbons, metals, and toxicity. Unless otherwise stated, we chose to exclude data collected prior to 1992 to prevent complications from the upgrading of the BWTP in 1991. Data that were available for more than one year since 1992 were included to allow for temporal changes. Because of the types of data available, comparisons are only made to the risk from chemical stressors. Three techniques were used to evaluate the risk of chemical effects in the Port:

1) Comparison of chemical concentrations in effluent, sediment, and tissues to chosen benchmark values.
2) Use of a model to predict the acute toxicity to amphipods of 10 hydrocarbon compounds in Port Valdez sediments.
3) Summary of the results from bioassays testing the acute or chronic toxicity of the BWTP effluent and of Port Valdez sediments.

The first two techniques determine the probability of a toxic response based on chemical concentrations in the Port. The third technique directly measures toxicity from samples collected in the Port. Using multiple techniques to evaluate chemical risks provides more than one line of evidence to support the final conclusions. A weight-of-evidence approach increases certainty in the risk estimate (Menzie *et al*., 1996).

7.1 Comparison to Benchmark Values

In using benchmark values (see Section 1.1), it is important to consider several points. First, benchmark values have been selected for chemical stressors, but not for physical or biological stressors. The effects of chemical stressors on individual organisms are more easily measured in the laboratory, whereas biological and physical stressors cause effects that are often more easily measured at the population or community level. Second, benchmark values have been calculated for single chemicals. In the environment, additive or synergistic effects from multiple stressors may occur, thus potentially negating the protective objective of the benchmark. Finally, for compounds that bioaccumulate, benchmark values may not be low enough (U.S. EPA, 1996). Chemicals that bioaccumulate (*e.g.*, PCBs, dioxins, DDT, and methyl mercury) can be transported over long distances through physical processes (*e.g*., wind, currents) and biological processes (*e.g*., migratory or wide ranging animals). These types of chemicals are not likely contaminants in the Port Valdez environment based on the sources of stressors that were identified in the conceptual model (Section 5.2). These compounds may, however, be transported in or released from unidentified or unexpected sources in the Port.

7.1.1 Benchmark Values for Water and Sediments

Ecotox Thresholds (ET) were developed as water and sediment specific benchmark values for screening risk assessment purposes in the U.S. EPA's Superfund program (U.S. EPA, 1996). Following chemical analysis of a sample, the maximum measured concentration can be compared to ET values for those chemicals. If the maximum concentrations are below ET values, then the chance of ecological risk occurring is small. On the other hand, maximum concentrations above ET values warrant further investigation into potential ecological effects. In some cases, the maximum measured concentration may not indicate the true upper concentration of the chemical. Some sources release a concentrated pulse of a contaminant that can be >100 times the concentration normally detected. For example, contaminates in road stormwater runoff are much more concentrated during the first hours of a rain event following a long dry spell. Detection of these pulses depends on their frequency and sampling frequency.

Several assumptions were made regarding the derivation of the Ecotox Thresholds. Water hardness was assumed to be 100mg/L, the pH was 7.8, and the sediment organic content was 1%. Each of these factors can affect the toxicity of a chemical to an organism. Resources used for determining ET values included: Ambient Water Quality Criteria (U.S. EPA, 1986a, 1986b, 1987), Sediment Quality Criteria (U.S. EPA, 1993a, 1993b, 1993c), Sediment Quality Benchmarks (developed internally at the U.S. EPA) and Effects Range Low (ERL) values (Long *et al.*, 1995). Several ET values are listed in **Table 7-1**.

Suter (1996) provides an excellent reference that can be used to select benchmarks for freshwater systems. Freshwater benchmark values from this study are listed in **Table 7-2** for those compounds not covered by the marine and freshwater ET benchmarks.

Table 7-3 includes marine sediment hydrocarbon benchmarks for which there were no sediment ET values. These benchmarks are effect ranges set by the National Oceanic and Atmospheric Administration (NOAA). Long and Morgan (1990) developed effects ranges by compiling toxicity data and associated chemical data for a variety of contaminated sites. The ERL is set at the chemical level where there appear to be negligible effects. As noted above, ERL values were considered in the derivation of many of the ET values.

Table 7-1. Marine and freshwater ECOTOX Threshold Values for various potential stressors; NA = Not Available.

Criteria	Compound	Water (µg/L)	Sediment (µg/kg)
***Marine Benchmarks* (ET-M)**	***Metals***		
	Arsenic III	36	8,200
	Cadmium	9.3	1,200
	Chromium III	NA	81,000
	Chromium VI	50	NA
	Copper	2.4	34,000
	Lead	8.1	47,000
	Mercury	1.1	150
	Nickel	8.2	21,000
	Zinc	81	150,000
	Hydrocarbons		
	Acenaphthene	40	16
	Fluoranthene	11	600
	Phenanthrene	8.3	240
	Pyrene	NA	660
	Total PAH	NA	4,000
***Freshwater Benchmarks* (ET-F)**	***Metals***		
	Barium	3.9	NA
	Hydrocarbon		
	Benzo[a]pyrene	0.014	430
	Biphenyl	14	1,100
	Fluorene	3.9	540
	Naphthalene	24	160

Table 7-2. Other benchmark values for potential stressors; NA = Not Available; SAV = Secondary Acute Value; SCV = Secondary Chronic Value; LCV = Lowest Chronic Value; EC_{20} = (Lowest Test) Effective Concentration at which 20% of individuals are effected; pop EC_{25} = Effective Concentration at which 25% of the population is killed.

Compound	Tier II Values		LCV's			EC_{20}		Pop EC_{25}
	SAV	SCV*	fish	daphnid	algae	fish	daphnid	
Metals								
Antimony	985	104	1600	5400	610	2310	1900	79
Thallium	164	18.0	57	130	100	81	64	67
Hydrocarbons								
Anthracene	0.024	0.0013	0.09	<2.1	NA	0.35	>8.2	NA
Benzo[a]anthracene	0.49	0.027	620	1163	NA	NA	NA	NA

* Tier II SCV values selected as benchmarks for comparison to Port Valdez data in the Tables below. Other benchmark categories listed in the text but not available for all of the compounds considered here were NAWQC and sensitive species test EC_{20}.

Table 7-3. Sediment Effects Range Low (ERL) for hydrocarbons.

Compound	**ERL Sediment** (µg/kg)
Anthracene	85.3
Benzo[a]anthracene	261
Chrysene	384
Dibenzo[a,h]anthracene	63.4
2-methylnaphthalene	70

We selected benchmark values for comparison with data from Port Valdez that was collected during or after 1992. If available, marine ET values were chosen as the benchmark for both aquatic and sediment data. When ET values to compare with sediment data were unavailable, ERL values were used. Benchmarks for aquatic data were selected from those listed by Suter (1996). **Table 7-4** contains the range of metals and hydrocarbons measured in the sediments of the Small Boat Harbor in Port Valdez in 1995 (U.S. ACE, 1995). Information in parentheses in the benchmark column describes the source of the benchmark.

Table 7-4. Sediment metal and hydrocarbon concentrations in 1995 from the Small Boat Harbor in Port Valdez. ND = Non-Detect, NA = Not Available, ET-M: the marine ET, ERL = sediment effects range low.

Compound in Boat Harbor Sediments	**Chosen Benchmark** (µg/kg)	**Samples Collected in Port Valdez**			
		Concentration (µg/kg)	n	Benchmark Exceeded?	Frequency Exceeded
Metals					
Arsenic	8,200 (ET-M)	11-18	6	No	0%
Barium	NA	60-103	6	No	0%
Cadmium	1,200 (ET-M)	ND-<5	6	No	0%
Chromium	81,000 (ET-M)	55-71	6	No	0%
Mercury	150 (ET-M)	14-21	6	No	0%
Lead	47,000 (ET-M)	ND	6	No	0%
Hydrocarbons					
Anthracene	85.3 (ERL)	ND-930	6	Yes	16%
Benzo[a]anthracene	261 (ERL)	ND-754	6	Yes	16%
Chrysene	384 (ERL)	ND-2630	6	Yes	33%
Fluoranthene	600 (ET-M)	ND-5610	6	Yes	50%
Phenanthrene	240 (ET-M)	0.50-2980	6	Yes	33%
Pyrene	660 (ET-M)	ND-3860	6	Yes	33%

Table 7-5 contains sediment data collected in years 1992-1995 from a station adjacent to the BWTP diffuser and other sampling stations defined by the Alyeska Environmental Monitoring Program (Feder and Shaw, 1993, 1994b, 1995, 1996). The only compound that exceeded the benchmarks was 2-methylnaphthalene. Feder and Shaw (1992) presented gas chromatography-mass spectrometry data which indicated that some of the reported values for 2-methylnaphthylene were overestimates. Since the same analytical method was used in the 1992-1995 period, some of these high values for 2-methylnaphthalene may be an analytical artifact. For clarity, the data for 2-methylnaphthalene have been sorted based on the defined EcoRA sub-areas (**Table 7-6**).

Table 7-5. Sediment hydrocarbon concentrations from stations sampled as part of Alyeska's Environmental Monitoring Program from 1992-1995. ND = Non-Detect, ET-F = freshwater ET values, ET-M: the marine ET values, ERL = effects range low.

Compound in Port Sediments	**Chosen Benchmark** (µg/kg)	**Samples Collected in Port Valdez**			
		Concentration (µg/kg)	n	Benchmark Exceeded?	Frequency Exceeded
Hydrocarbons					
Anthracene	85.3 (ERL)	ND-19.7	205	No	0%
Acenaphthene	16 (ET-M)	ND-11.5	205	No	0%
Benzo[a]anthracene	261 (ERL)	ND-42.2	205	No	0%
Benzo[a]pyrene	400 (ET-F)	ND-79.0	205	No	0%
Biphenyl	1,100(ET-F)	ND-12.7	205	No	0%
Chrysene	384 (ERL)	ND-88.7	205	No	0%
Dibenzo[a,h]anthracene	63.4 (ERL)	ND-8.7	205	No	0%
Fluoranthene	600 (ET-M)	0.3-105.5	205	No	0%
Flourene	540 (ET-F)	0.3-13.0	205	No	0%
2-methylnaphthalene	70 (ERL)	ND-189.4	205	Yes	4%
Naphthalene	160 (ET-F)	ND-7.6	205	No	0%
Phenanthrene	240 (ET-M)	0.8-102.6	205	No	0%
Pyrene	660 (ET-M)	0.3-112.1	205	No	0%

Note: Maximum concentrations all occurred in 1992 except for the maximums for biphenyl, dibenz[a,h]anthracene and 2-methylnaphthalene which occurred in 1994. All maximum values are from samples collected at BWTP diffuser station (D33).

Table 7-7 contains minimum and maximum aquatic metals and hydrocarbon concentrations measured in BWTP effluent in 1995 (APSC, 1995). Zinc exceeds the benchmark in 77% of the samples.

Table 7-6. Sub-area sediment 2-methylnaphthalene concentrations. ERL = effects range low**.**

Sub-Area	Sediment Sampling Stations	2-methylnaphthalene*			
		Concentration (µg/kg)	n	Benchmark Exceeded?	Frequency Exceeded
B: Mineral/ Gold Creeks	37	0.0-56.3	12	No	0%
G/K: Valdez Marine Terminal	D25, D33, D51, D69, D73, D77	0.0-189.4	63	Yes	6%
I: Anderson Bay	91	0.0-108.7	15	Yes	7%
J: Western Port	40,45,50	0.0-120.6	46	Yes	4%
K: Eastern Port	11 and 16	0.0-98.1	69	Yes	3%

*Benchmark (ERL) = 70 (µg/kg)

Table 7-7 contains minimum and maximum aquatic metals and hydrocarbon concentrations measured in BWTP effluent in 1995 (APSC, 1995). Zinc exceeds the benchmark in 77% of the samples.

Table 7-7. Metal and hydrocarbon concentrations in samples of undiluted BWTP effluent. NA = Not Available, LOQ = Limit of Quantification, SCV = Tier II SCV, ET-F = freshwater ET values, ET-M: the marine ET values.

Compound in Effluent	Chosen Benchmark (µg/L)	Samples Collected in Port Valdez			
		Concentration (mg/L)	n	Benchmark Exceeded?	Frequency Exceeded
Metals					
Antimony	104 (SCV)	<LOQ-490	26	Yes	8%
Arsenic	36 (ET-M)	<LOQ-370	25	Yes	12%
Cadmium	9.3 (ET-M)	<LOQ-24	26	Yes	15%
Chromium	50 (ET-M)	<LOQ-830	26	Yes	8%
Lead	8.1 (ET-M)	<LOQ-570	24	Yes	4%
Nickel	8.2 (ET-M)	<LOQ-490	26	Yes	8%
Thallium	18.0 (SCV)	<LOQ-11300	21	Yes	19%
Zinc	81 (ET-M)	<LOQ-8700	26	Yes	77%
Hydrocarbons					
Acenaphthene	40 (ET-M)	<LOQ-2.89	26	No	0%
Benzo[a]anthracene	0.027 (SCV)	<LOQ-0.807	25	No	4%
Chrysene	NA	<LOQ-0.274	25	NA	NA
Fluoranthene	11 (ET-M)	<LOQ-0.583	25	No	0%
Flourene	3.9 (ET-F)	<LOQ-1.39	25	No	0%
Naphthalene	24 (ET-F)	<LOQ-13.1	26	No	0%
Phenanthrene	8.3 (ET-M)	<LOQ-3.80	25	No	0%
Pyrene	NA	<LOQ-0.102	25	No	0%

7.1.2 Benchmark Values for Wildlife

Opresko *et al.* (1995) derived wildlife benchmark values for 8 mammalian species and 11 avian species with 85 tested chemicals. They considered water, sediment, soil, and food as routes of exposure to wildlife. Benchmark values were set at the daily dose concentration that resulted in the No Observed Adverse Effects Level (NOAEL) or the Lowest Observed Adverse Effects Level (LOAEL). The LOAEL refers to the lowest chemical concentration which causes adverse-effects to the wildlife in toxicological tests.

Two wildlife species, mink and red fox, were selected from those for which benchmark values exist. An assumed body weight, food intake, and water intake for both of these species are included in the calculation of benchmark values. Sea otters have a metabolic rate approximately 3 times that of similar sized terrestrial mammals (Anthony, 1995). Food intake for a sea otter is high (at 23-37% of their body weight per day) when compared to the food intake values used for mink and red fox (10% and 14% consecutively). With this in mind, benchmark values for mink and fox may underestimate toxicity of Port Valdez mussels to the otters.

Table 7-8 contains benchmark values for benzo[a]pyrene for both species. These benchmarks are derived from NOAEL data on the species and toxicant in question, food and water intake, and body weight. **Table 7-9** contains benzo[a]pyrene values from mussel tissue data collected from Port Valdez from 1992 to 1995.

Table 7-8. Benchmark values for benzo[a]pyrene in mink and red fox; NA = not applicable.

Species	**NOAEL (mg/kg-day)**	**Toxicological Benchmarks**		
		Diet (mg/kg)	Water (mg/L)	Piscivore Water Value (mg/L)
mink	310	2290	3180	3.60×10^{-9}
red fox	190	1910	2270	NA

Table 7-9. Tissue concentrations of benzo[a]pyrene in mussels (1992-1995), and number of samples exceeding the benchmark value for this chemical.

Sub-Area Location	**Mussels** (µg/kg dry tissue)	n	**Exceeds Benchmark?**			
			NOAEL	Diet	Water	Piscivore
B. Gold Creek	0-18.1	36	No	No	No	No
G. Valdez Marine Terminal	0.2-71.1	39	No	No	No	No
H. Sawmill to Seven-Mile Creeks (5 Mile Beach)	0-48.5	24	No	No	No	No

7.2 Estimating the Risk of Toxicity

Hydrocarbons are the most ubiquitous chemical stressor in the Port. Treated discharges, air emissions, city and industrial runoff, transport and fueling spills, and normal boat operation all release hydrocarbons into the environment. However, these sources usually release a mixture of hydrocarbons and any resulting contamination can include many different compounds. Polyaromatic hydrocarbons (PAHs) are a group of compounds that are often toxic and may persist in the sediments. In Section 7.1, benchmark values were applied to concentrations of PAHs in the Port in order to determine the risk from individual compounds. In the environment, organisms are more likely to be exposed to more than one compound at a time. Toxicologists have hypothesized that effects caused by more than one hydrocarbon compound are additive in the organism. Swartz *et al.* (1995) have developed ∑PAH Model, which applies the additivity concept to predict the acute toxicity of a mixture of 13 PAHs to marine amphipods. We have applied the model to PAH concentrations measured in the sediments of Port Valdez. The PAH sediment concentrations from the Port, the model, and model results are in Appendix E.

The model uses sediment concentrations of 13 PAHs from samples collected in the area of interest, predicts the concentration in the sediment pore water, and then predicts the toxicity of these concentrations to amphipods as determined by a large toxicity data set. Since the sediment data from the Port did not consistently include all 13 PAHs used by Swartz *et al*. (1995), we applied the model to ten PAHs. The data to which the model is applied come from several sources. Alyeska sponsors a yearly monitoring program that collects data on the sediment hydrocarbon concentrations in various locations of the Port (Feder and Shaw, 1992, 1993, 1994a, 1994b, 1995, 1996). The Regional Citizens' Advisory Council's Long Term Environmental Monitoring Program (LTEMP) collects similar data with a limited number of stations. The U.S. Army Corps of Engineers has also collected and analyzed sediment samples from the Small Boat Harbor (Chemical Data report, U.S. ACE, 1995). Most of the samples were collected in deep offshore areas of the Port, although samples from the Small Boat Harbor in the city, and nearshore areas by Mineral Creek, the Valdez Marine Terminal, and the Solomon Gulch Hatchery have also been collected.

The results in **Table 7-10** show that none of the acute toxicity levels predicted in Port Valdez occur above the lowest levels set by the model (5% chance of a toxic response). The sum of the toxic units (∑ TU) is included in the table. This value is a measure of the total toxicity associated with environmental concentrations (*i.e.*, field concentration/literature-derived LC_{50}). Although the model indicates little probability of effects in Port Valdez, the ∑ TU values are greater in Sub-Area C (City of Valdez) than in other areas. Sediment samples from this area were collected in the Small Boat Harbor where boat traffic, boat maintenance and repair, and city runoff are likely to contribute to the higher PAH levels in the sediment. The ∑ TU in Sub Area C was elevated above the other sub-areas in the Port. The ∑ TU was slightly elevated in samples collected at stations on the border between the Valdez Marine Terminal sub-area and the deeper eastern Port. These samples were the closest to the discharge of the BWTP.

Estimating the toxicity of the sediments through use of this model is another line of evidence to compare with results discussed in Section 7.1. Benchmark values are based on a wide sweep of scientific studies conducted for single compounds under a variety of conditions and are applied universally to all environmental concentrations. The PAH model uses effects levels derived from a number of laboratory tests, but also incorporates some site-specific information predicting bioavailability, and considers multiple compounds. Specifically, this approach differs from the benchmark approach by: (1) predicting the bioavailability of the contaminants based on the environmental concentration of organic carbon; (2) evaluating the toxicity of 10 compounds by assuming the effect levels are additive; and (3) basing the effects levels on tests that were conducted on field samples containing a mixture of contaminants.

Table 7-10. Acute toxicity to amphipods predicted from sediment concentrations of 10 PAHs. The sum of the toxic units, averaged for all samples, is listed with the standard deviations in the second column.

Sub-Area and Location	**Mean ∑ TU** ± Std. Dev.	n	**Probability of:**		
			Toxicity	Uncertain Toxicity	No Toxicity
B. Mineral and Gold Creek	0.001 ± 0.001	24	5%	20%	80%
C. City of Valdez (Small Boat Harbor)	0.094 ± 0.148	22	5%	20%	80%
F. Dayville and Solomon Gulch	0.001 ± 0.001	6	5%	20%	80%
***G/K.** Station nearest the BWTP diffuser	0.011 ± 0.007	12	5%	20%	80%
***G/K.** BWTP Mixing Zone Stations**	0.002 ± 0.002	75	5%	20%	80%
J. Western Port	0.001 ± 0.001	36	5%	20%	80%
K. Eastern Port	0.002 ± 0.002	66	5%	20%	80%

* These stations are located on the border of or in both Sub-Areas G and K.
** Not including Station D33, the station nearest the BWTP diffuser.

A third line of evidence can be drawn from acute toxicity tests conducted on sediment samples from Port Valdez (CAS, 1993, 1994d; Karle *et al*., 1994). The tests measure the actual toxicity of the sediments to amphipods in laboratory experiments. They showed that the sediments from Port Valdez and another Alaskan site (Heather Bay) did not, in most cases, support amphipod survival. Toxicity is difficult to evaluate in circumstances where the site-specific conditions prove to be a poor substrate for the test organism. In tests with amphipods that seemed to tolerate the fine sediment structure found in Port Valdez, no acute toxicity was detected. These tests are summarized in the Section 7.3.2.

7.3 Bioassay Testing in the Field

The third approach involves assessing effects of water or sediment samples collected directly from the Port Valdez environment or from effluents released into the environment. These samples are tested for their toxicity to laboratory plants and animals. The intention of this type of testing is to identify contamination at high enough levels to cause a detrimental effect. These effects range from decreased survival, growth, or reproduction to abnormal development or behaviors. The advantage that toxicity testing offers is the ability to measure effects from multiple chemical stressors. However, it can be difficult to link any measured effect to a causative stressor or set of stressors. In Port Valdez, bioassays have been conducted on (1) the BWTP effluent, (2) sediments collected from within the mixing zone of the BWTP, and (3) sediments collected from the western portion of the deep basin.

7.3.1 Effluent Bioassays

Tests are run on the BWTP effluent as part of the NPDES monitoring program. Organisms frequently tested in this program include mysids (*Mysidopsis bahia*), pandalid shrimp larvae (*Pandalus* sp.), pink salmon smolts (*Oncorhynchus gorbuscha)*, and Inland Silversides (*Menidia beryllina)*. The animals are exposed to the effluent for a period of 96 hours, after which the number of survivors is counted. Acute tests such as these are often reported in terms of the LC_{50}, or the effluent concentration at which 50% of the organisms died. **Figure 7-1** reports the toxicity values of the BWTP effluent as the reciprocal, or one divided by the LC_{50}. A toxicity value of one or less means little or no toxicity. A toxicity value equal to two indicates that half of the test organisms died in the effluent diluted to half its strength. A toxicity value equal to 10 would indicate that half of the test organisms died in the effluent diluted to one-tenth of its strength.

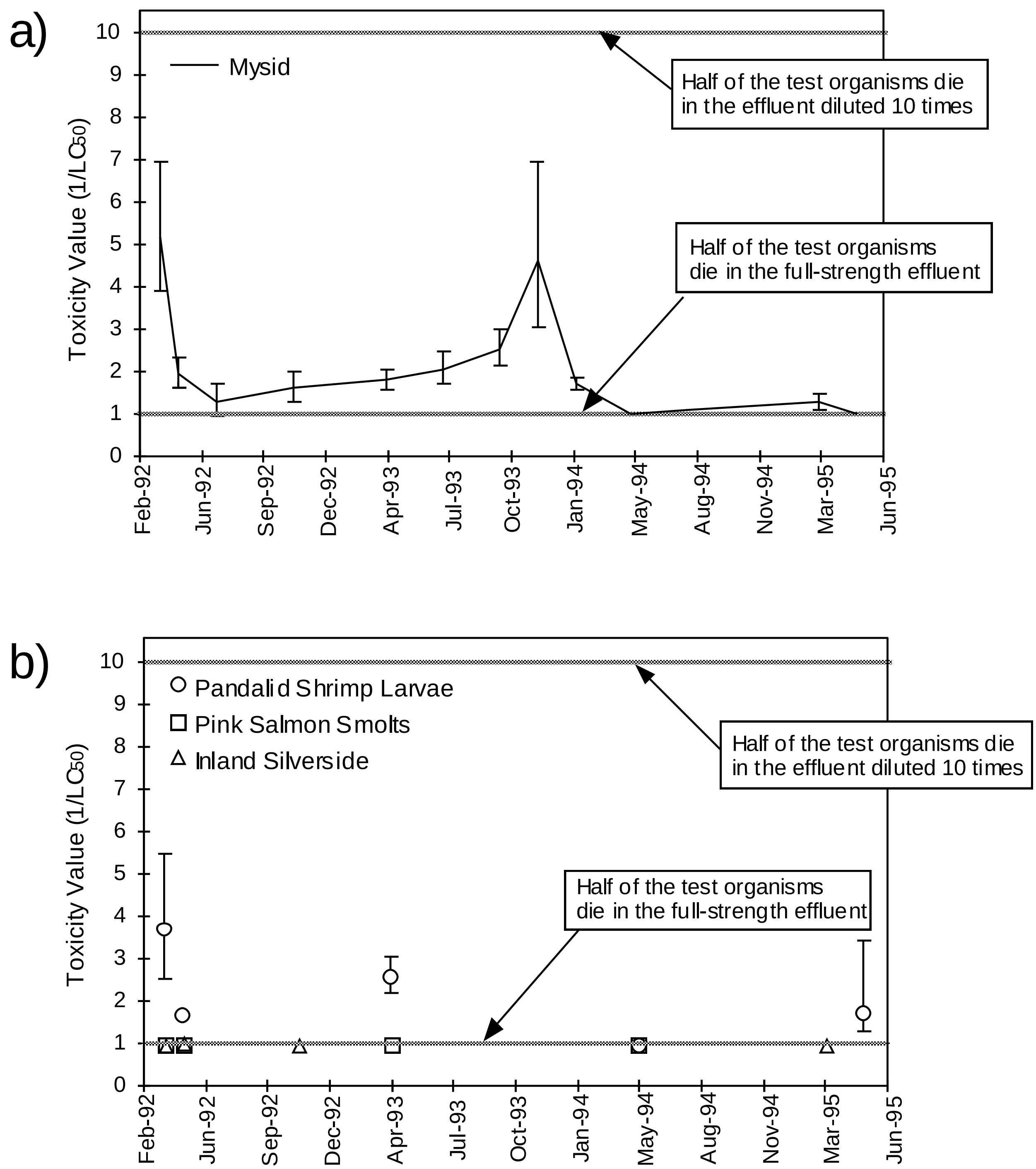
A toxic unit of 6.9 occurred at the upper confidence limit for mysids in December of 1993. At this toxicity level, half of the test organisms would be expected to die in a solution consisting of only 14% of the BWTP effluent. However, on average, toxicity was 1.0 for salmon and silversides, and closer to two for mysids and shrimp. These results indicate that the fish species are subject to 50% mortality or less in only the undiluted effluent, while the same level of mortality can affect crustaceans in an effluent solution half of that strength. Thus crustaceans appear to be more sensitive than fish to the effluent.

Chronic tests are also conducted on the BWTP effluent. Historically, the chronic echinoderm sperm fertilization bioassay has proven to the most sensitive test to toxicity in the effluent (see APSC, 1995 for a review). In this test, sperm cells are exposed to varied concentrations of the effluent for one hour, after which the number of eggs that are successfully fertilized by the sperm are counted. Sea urchins (*Strongylocentrotus purpuratus)* and sand dollars (*Dendraster excentricus)* are both used as test organisms. Because of the frequency and sensitivity of this test, Alyeska and the U.S. EPA have compiled the data from five years of testing (CAS, 1995a; recalculated data acquired from Anne Dailey, U.S. EPA). The yearly mean toxicities over the past five years are shown in **Figure 7-2** as toxic units calculated from the IC_{25} (the concentration at which 25% inhibition occurs). The chronic toxicity of the effluent appears to be consistent, and possibly decreasing from 1993 to 1995. In 1992 the average toxicity, as well as the variance between these tests, was high. However, APSC (1995) notes that the test laboratory reported that in two cases, independent reference tests showed that the sperm cells were more sensitive than usual and may have overestimated the toxicity. Removal of the anomalous results indicate a fairly consistent low-level toxicity.

7.3.2 Sediment Bioassays

Effluent testing allows for evaluation directly at the source. In general, toxicity detected in the effluent will decrease as it mixes with the receiving waters. Once the effluent enters the environment, the fate and concentration of its constituents depend on many factors other than the initial dilution. Some chemical components tend to settle and accumulate in sediments, where the exposure to organisms living and feeding off the bottom may be quite different than exposures in the water column. Toxicity tests of sediment samples collected in the field provide a tool for assessing the effects from these exposures.

The NPDES permit for Alyeska's BWTP required a short-term monitoring program designed to determine if the effluent was contributing to sediment toxicity in the Port. These tests were conducted on two species of amphipod (*Eohaustorius estuarius* and *Rhepoxynius abronius)*. The survival of sediment dwelling invertebrates is often related to the grain size of the sediments. For instance, amphipods tend to live in the coarser grained, sandier sediments. Consequently, amphipods are not common in Port Valdez, which contains mostly silt and clay sediments (Howard Feder, unpublished data, 1995). The tests conducted with the Port Valdez



Figures 7-1. BWTP effluent bioassay results conducted with four test organisms: a) mysids and b) pandalid shrimp larvae, c) pink salmon smolts, and 4) inland silversides. The values, with their 95% confidence intervals (bars) were converted from the LC_{50} to toxicity values (TV) by taking the reciprocal ($1/LC_{50}$). This value is often referred to as the Toxic Units but is a different value than that reported in Section 7.2 for the $\sum$PAH model.

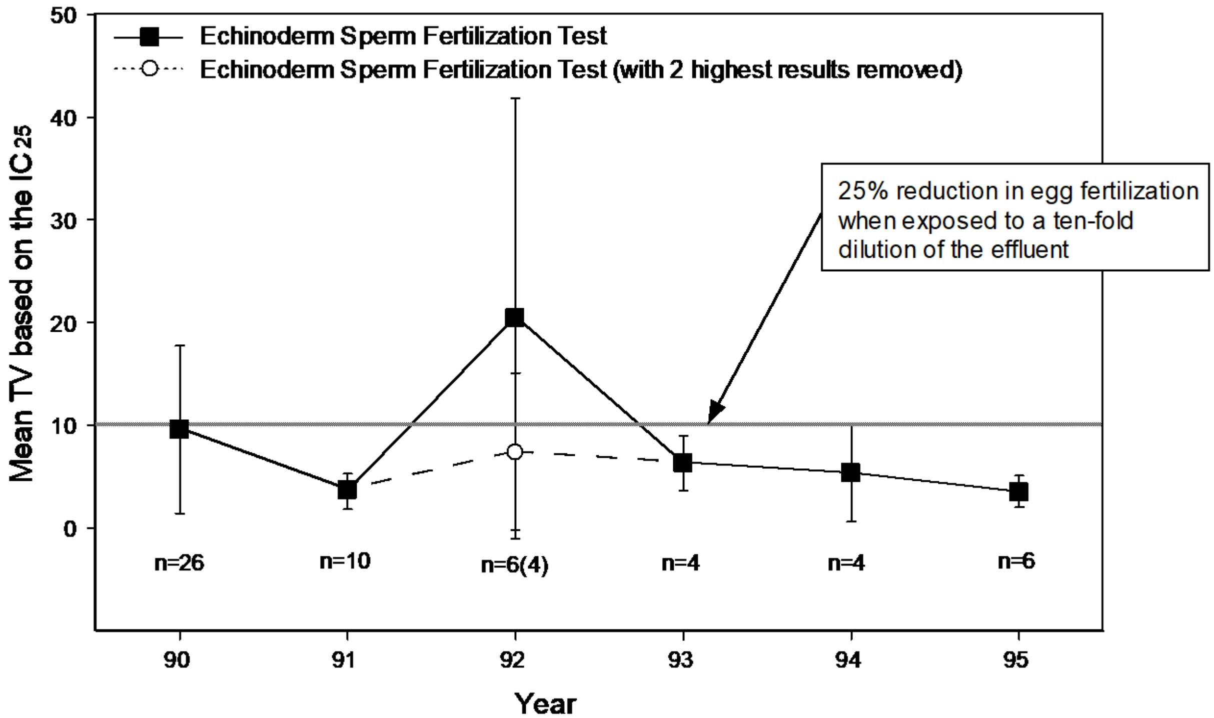


Figure 7-2. Chronic toxicity of BWTP effluent to echinoderm (mean ± 1 standard deviation) between 1990 and 1995. The number of tests (n) varied between years. Results from 1992 are shown with and without the two highest values, which were possibly an over-estimate.

Table 7-11. Summary of the amphipod toxicity test results as part of the Alyeska Sediment Monitoring Program 1990-1993 (Karle et. al., 1994).

Sub-Area and Location	Alyeska Sampling Station	Amphipod Mean Survival (%)	
		Eohaustorius estuarius	*Rhepoxyniums abronius*
G. Valdez Marine Terminal	D-69	89	49
J. Western Port	40	79	62
J. Western Port	50	76	67
J/K. Deep Central Port	32	82	61
K. Eastern Port	D-33	93	75
K. Eastern Port	D-77	81	61
Reference and Control Sediments	Heather Bay (AK)	76	78
	Sequim Bay (WA)	100	92
	Eoh control	95	93
	Rhe control	98	96

sediments reflect the confounding factor of grain size (**Table 7-11**). The highest survival rate (95 to 100% for *E. estuarius* and 92 to 96% for *R. abronius)* occurs in the control sediments and the reference sediment from Sequim Bay, Washington. Reference sediments were also collected from an Alaskan site (Heather Bay) which had sediments similar to those in Port Valdez, but were assumed to be unpolluted. Amphipods in the Heather Bay sediments had lower survival rates (76% for *E. estuarius* and 78% for *R. abronius).* No toxicity could be determined due to control mortality.

8.0 Exposure and Effects in Port Valdez

We developed the conceptual model (Section 6) to systematically estimate relative environmental risks for a wide range of possible impacts to Port Valdez. However, it became clear in meetings with stakeholders that some risks are of particular public concern. These "high profile" risks are treated separately in this section.

Many of the concerns in the Port are not amenable to conventional risk assessment at this time. Some of these risks are especially difficult to quantify because they combine very low likelihood of occurrence (exposure) with extreme effects. Examples in this category include large oil spills and introduction of non-native species. Other risks considered here are highly uncertain because of a total lack of empirical data for Port Valdez. An example in this category is organotin compounds.

In Sections 8.1 to 8.7 we examine in more detail the particular concerns in the Port. The exposures and effects described below are based on literature review of the stressors that are known or suspected to occur in the Port. As demonstrated by review of the literature, severe or persistent effects can result from these stressors; however, extreme impacts are not known to occur in the Port at this time. Risk assessment in the Port can also be based on effects. Environmental effects can be cumulative. For instance, low levels of chemical toxicity can reduce the growth in an organism, which may make it more susceptible to predation. Assessments driven by evaluation of the effects in the environment circumvent the difficulties of evaluating exposures from multiple stressors. This section summarizes the types of effects that could be expected in Port Valdez. The following information can be used as a guideline for designing assessments to estimate the risks of:

- Chemicals in the water column and absorbed in sediments
- Toxicity of organotin compounds
- Deposition of organic matter and enrichment of benthic populations
- Effects of large oil spills
- Effects of non-native species
- Behavioral and physical disturbances of wildlife
- Population impacts.

Section 8 provides the groundwork for planning future assessments of risk in the Port. Using this information within the context of the conceptual model and relative risk analysis (Sections 5 and 6) will direct the risk assessment process towards a Port-wide perspective. Section 9 follows up this section with an example of ecological risks to a single receptor from a multiple stressor and cumulative effects approach.

The following sub-sections should be considered as indications of possible risks to Port Valdez which cannot be more precisely quantified at the present time.

8.1 Chemicals Dissolved or Suspended in the Water Column

An unknown number of chemicals are possible in the water column. Some of the chemicals used in the Port include:

- Crude oil, gasoline, and diesel
- Engine lube and hydraulic oils
- Commercial and industrial cleansers
- Corrosion inhibitors, solvents, and degreasers
- Paint chips and leachates
- Pesticides
- Antibiotics for fish culturing, such as formaldehyde and erythromyacin
- Other chemical products.

Except for limited areas with reduced water movement, chemicals that remain in the water column are likely to be diluted and flushed out of the Port within approximately 2 to 4 weeks (Hood *et al*., 1973). Areas in the Port that are more likely to retain chemical pollution in the water include the Small boat harbor, the deep bottom during summer when waters are stratified, and the far eastern Port where flushing appears to be slower. Toxicity in the water column results from chemicals released continuously or frequently, or those released into a body of water with limited movement.

Toxicity in the sediments is more likely to occur when chemicals that tend to adsorb to particles are released into areas where sediment environments exist. Sediments with high organic and clay contents are more likely to adsorb to many of these chemicals. Treated discharges, contaminated runoff, vessel traffic, and spills can release toxic chemicals into the water. Based on exposure, the potential for chronic effects from discharges is highest in the Duck Flats, the deep section of the eastern Port, and near the Valdez Marine Terminal. The potential for acute and chronic effects of spills and runoff are more ubiquitous throughout the Port but the risk for both is greater in the Duck Flats.

Chemicals such as hydrocarbons, metals, and organotins adsorb to and persist in sediments. These chemicals are more likely to reach the sediments when they are in solid or semi-solid form (*e.g.,* paint chips, tar) and released in shallow water, or when there is little water exchange. In deep water most chemicals in the water column are flushed out by tidal exchange. The poor flushing rate, shallow water, and frequent use of the Small boat harbor makes this area particularly susceptible to chemical accumulations in the sediments. The disposal of sport fish wastes in the boat harbor and seafood processing wastes outside of the boat harbor could attract predators and scavengers that would be exposed to any sediment contaminants in these areas.

Chemicals which are bound to sediments are less bio-available. Feder *et al*. (1990) demonstrated that hydrocarbons derived from a simulated crude oil spill on a mudflat in Port Valdez had a short residence time in the sediments. The hydrocarbon levels decreased rapidly due to physical removal by tides, low sediment permeability, and low affinity of the hydrocarbons to glacial sediments. Yearly sediment deposition contributes to both the transport of chemicals to the bottom and burial of contaminants within the sediment.

Sediment-dwelling invertebrates come into contact with chemicals in the pore water or ingest chemicals with organic matter in or on the sediments. Organisms with a protective exterior, such as clams, may have less exposure. Mobile predators and scavengers that feed on benthic invertebrates can ingest contaminants through their food or through incidental ingestion of sediment. High levels of exposure can cause death in invertebrates, whereas lower levels can cause other effects such as decreased growth and reproductive capacity. Tolerant or opportunistic species may persist in or colonize disturbed areas, causing changes in the composition of the benthic community. The result may be either an increase or decrease in biomass and alter the feeding resources of predators and scavengers in the area. The effect on these populations depends on the nutritional needs of each species.

8.2 Organotins

The highly toxic nature of some organotins increases the chance that exposure will cause severe effects to organisms. Tributyltin is of particular concern in the environment because it is toxic at very low levels (Ruiz *et al*., 1994). The use of organotins has declined since 1988 when legislation banned the application of bottom paints containing tin to vessels smaller than 25 m. As an antifouling paint, TBT is very effective and was widely used prior to 1988. Organotin contamination in the sediments occurs in many harbors (Evans *et al*., 1995). TBT is degraded by bacteria and does not persist in the water column; however, the half-life in sediments has been estimated at 16 weeks in the lab to as much as 15 years in anaerobic sediments (Stewart and de Mora, 1990).

Organotins, as well as other metals associated with bottom paint (*e.g.*, copper), will induce imposex in some species of gastropods, a condition where female genitalia begins to mimic male genitalia. Imposex leads to sterility, and may drastically reduce the population size of subsequent generations. Imposex can be correlated to vessel traffic, increasing in coastal waters near marinas and shipping lanes (Axiak *et al.*, 1995; Ten Hallers-Tjabbes *et al.*, 1994).

Large vessels (oil tankers, cruise ships, barges, ferries) in Port Valdez travel to several docks in the city, the container dock in the Duck Flats, and to berths at the VMT. Investigation into the types of bottom paint used on large vessels entering Port Valdez revealed only one bottom paint containing an organotin complex. In general, vessels traveling to Port Valdez would have little trouble with fouling, as most nuisance species are controlled by cold temperatures and salinity changes. Regulation and increasing environmental concern about the toxicity of TBT has made purchase and application of the paint more difficult. Vessels most likely to use TBT are those that spend time in warm water ports where fouling of the hulls is a much greater problem. Some cruise ships and oil tankers travel to southern ports as part of their itinerary or for maintenance and repair.

The likelihood of TBT contamination in Port Valdez is difficult to evaluate in the absence of definitive data. There are no facilities for maintenance or repair of large vessels in the Port. Additionally the deep waters and tidal flushing decrease the probability that commercial shipping, including tankers, are contributing TBT to Port Valdez sediments.

Anaerobic sediments, resulting from organic wastes such as boat sewage and fish cleaning wastes, can increase the half-life of organotins in the sediments by slowing down degradative processes. These conditions may occur in limited areas of the Port such as the Small boat harbor and near the discharges of the seafood processing plants. The Small boat harbor in Valdez does not accommodate boats larger than 25 m. It is possible that smaller recreational and fishing boats, whose hulls were maintained in the Port, may have contributed TBT in the past. Although this source should have declined sharply since 1988, some residual contamination may exist in the sediments.

8.3 Organics in the Sediments

Organic loading of the sediments in Port Valdez increases with the presence of processed fish and seafood wastes, fish culturing wastes, sportfish wastes, and sewage wastes that come from treated effluents or improper disposal by boats. Bacterial growth is enhanced in the sediments and on suspended organic particles that in turn serve as a source of food for benthic invertebrates. Species abundance, biomass, and colonization rates in the area may also increase, attracting mobile predators such as crabs and benthic fishes. However, if the bacterial increases are too great, or too rapid, oxygen demand increases, resulting in anoxic conditions within the sediment and reduced survival or death of the benthic organisms. If oxygen levels also decrease in the overlying water, mortality of pelagic organisms can result. Anaerobic conditions increase the number and diversity of specialized bacteria that produce such toxic metabolic byproducts as methane and hydrogen sulfide. These gases are released at greater rates from sediments in shallow water as pressure from the overlying waters decreases during low tide (U.S. EPA, 1995).

Carbon enrichment results from the deposition of organic materials on the sediments or in the water. Runoff contaminated by septic tank or other waste leachates, as well as fish wastes and sewage released directly from boats can contribute to enrichment. Although the fate of solids may be fairly localized, enrichment can result in increased growth and reproduction of some resident organisms. Localized carbon enrichment will increase carbon flow to other areas of the Port.

Organic enrichment may also attract organisms into areas subject to other types of stressors. For instance, as scavengers, crabs are attracted to fish wastes. Crabs attracted to the boat harbor, where the bottom is enriched by sportfish wastes and other organic matter, are also likely to be exposed to sediments contaminated with toxic chemicals.

Enrichment resulting from solid organic wastes is potentially highest near the City. The Duck Flats, as well as areas near the hatchery and the Valdez Marine Terminal, are also subject to possible sources of organics, mostly in the form of dissolved organic compounds and suspended particulates. A potential for enrichment of the bottom water also exists in the deep Port where sewage wastes from boats and fish wastes may settle; however, the depth of the Port and tidal flushing may lessen the chance of large enrichment effects. Excessive organic input to the bottom can lead to toxicity as discussed in Section 8.2.1.

8.4 Large Oil Spills

The impact of a large crude oil spill in Port Valdez depends initially on the control and cleanup of the spill. The Alyeska Pipeline Service Company staffs a Ship Escort/Response Vessel System (SERVS) which is responsible for tanker escort into the Port and response to spills. This service operates five escort response vessels, three escort tugs, and five skimming barges capable of recovering 4,200 barrels per hour. A fleet of fishing vessels is also contracted to respond in the event of a spill. Although SERVS is equipped to respond quickly to tanker spills reported in PWS, weather conditions and the location of the spill may interfere with cleanup.

Although the *Exxon Valdez* spill of 260,000 barrels into PWS did not reach Port Valdez, it provides an example of a large localized oil spill. Impacts from that spill are summarized in the *Exxon Valdez* Oil Spill Symposium Abstracts compiled in 1993 (*Exxon Valdez Oil Spill Trustee Council*, 1993). Despite numerous studies prompted by the spill, there is still much disagreement and uncertainty concerning long-term effects to populations in the PWS area. However, certain effects can be anticipated following a large oil spill and are briefly described below.

The two vertebrate species most affected by the spill were sea otters and guillemots (Paine, 1993). Hogan and Irons (1988) reported pigeon guillemots breeding in the Port Valdez area. Although sea otters do not reproduce in the Port, the juvenile male otter population is near its maximum level (Anthony, 1995). A decrease in the otter population in Port Valdez as a result of a spill would decrease predation on intertidal and shallow subtidal communities, particularly in Shoup Bay and near the Valdez Marine Terminal where the most otters are located. The prey items of otters, such as mussels and crabs, could increase in number.

Invertebrates, particularly mussels, are able to accumulate high levels of hydrocarbons in their tissues. As a heavily utilized food resource for otters and sea ducks, invertebrates provide a potential exposure route to chemical contaminants after a spill. Similar exposures were documented following the *Exxon Valdez* oil spill in 1989 (Patten, 1993; Paine, 1993).

After the *Exxon Valdez* spill, sea duck populations suffered impaired reproduction, altered yolk structure, and decreased hatching success for up to a year after the spill. Clean-up efforts also affected the birds by creating a disturbance that displaced ducks and potentially disrupted reproductive behavior (Patten, 1993). During the *Exxon Valdez* spill, shorebirds suffered breeding and reproductive effects. In some cases, bioremediation increased spill effects. For example, no chicks fledged in areas to which Inipol, a biodegradation compound, was applied; however, a minimal number of chicks fledged in areas affected only by oil (Sharp and Cody, 1993). Although the number of breeding pairs of black-legged kittiwakes studied in PWS after the spill did not change, the reproductive success in oiled areas decreased by half (Laing and Klowiewski, 1993). In Port Valdez most sea ducks arrive in winter for feeding. Few sea ducks are known to breed in the Port, although Hogan and Irons (1988) indicate that breeding populations of harlequin ducks are present. Shorebird populations, such as the black oystercatcher, feed and breed along the shoreline of the Port and nearby at Robe Lake. A large colony of black-legged kittiwakes nests at Shoup Bay. The severity of a spill to marine birds would depend on the timing, size, and location of the spill, as well as the duration of the clean-up effort. For instance, a spill near the Duck Flats during a sea duck migration could result in a high mortality rate to these birds. Additionally, chronic effects could include the loss of critical food resources (small clams and worms). Reproductive effects could be expected in the shorebird populations and other nesting birds, such as the kittiwake population.

Pink salmon spawn in intertidal areas and are potentially more exposed to oil spills than other salmon populations (Bue *et al.*, 1993). Decreased survival of salmon embryos occurred in oiled spawning sites when compared to unoiled sites. Follow-up lab tests indicated a lower survival rate of embryos from fish in oiled streams than from non-oiled streams. This indicates that genetic damage from the oil resulted in the reduced survival. Juvenile growth rates also declined in oiled areas, which has been correlated to decreased adult survival (Willette, 1993). Juvenile chum salmon, which feed more along low gradient shores than do juvenile pink salmon, may have an increased exposure to spills, but studies have revealed that juvenile chum from oiled areas were larger than those from non-oiled areas (Wertheimer *et al.*, 1993, 1996). This may be explained by the greater abundance of harpacticoid copepods, a primary prey item for juvenile salmon, in oiled areas (Wertheimer *et al.*, 1993). Feder *et al*. (1976, 1990) found that harpacticoid copepods appear to survive and increase in number in lightly oiled sediments.

In Port Valdez, large numbers of hatchery reared pink salmon fry migrate through and feed along the southern coast in spring and summer. An oil spill in the nearshore waters along the southern coast would affect survival of the hatchery fry, as well as wild fry along the coasts. Oil in the intertidal regions, particularly near the Duck Flats, Mineral Creek Flats, or the mouth of the Robe and Lowe Rivers, could severely affect spawning success for pink and chum salmon, and health of juvenile red and silver salmon. The type and degree of effect on the populations depends largely on the size and timing of the spill. Bottom fish survival would also be expected to decrease after exposure to oil due to tissue damage and parasitism (Khan, 1990).

Gundlach *et al.* (1983) evaluated shoreline habitats prior to the *Exxon Valdez* Oil Spill and determined the order of increasing sensitivity to oil spills to be: exposed rocky shores, exposed wave-cut platforms, fine-grained sand beaches, coarse-grained sand beaches, mixed sand and gravel beaches, gravel beaches, exposed tidal flats, sheltered rocky shores, sheltered tidal flats and marshes. They concluded that the more sensitive habitats retain hydrocarbons in the sediments, increasing the duration of exposure to resident organisms. Four years after the *Exxon Valdez* Oil Spill Roberts *et al*. (1996) still found some samples of oil contaminated sediments. The weathering varied by site, from highly weathered to unweathered oil that would still produce a sheen in the water. Sediment covered by mussel beds provided a source of hydrocarbons that continued to leach into the water long after the surface oil had disappeared. In Port Valdez, mussel beds adjacent to Mineral and Sawmill Creeks would be susceptible to this type of long-term leaching effect. In PWS, algae attached to the rocky regions were susceptible to severe damage by oiling and clean-up efforts after the *Exxon Valdez* Oil Spill. Recruitment of new plants and animals was slow when the protective canopy of rockweed (*Fucus distichus*) was removed (Peterson, 1993). In addition, young seaweed recruits established themselves in oiled areas, only to die in the following months (Paine, 1993). Gastropods, (*e.g*. the intertidal snail, *Nucella lamellosa*) were very sensitive to spilled oil. The survival rate in unoiled areas was four times that of oiled areas (Ebert *et al.,* 1993).

In Port Valdez the muddy shores generally consist of fine, silty sediments that do not readily retain hydrocarbons (Feder *et al.,* 1990). Pockets of oily material in coarser sediments or protected areas, however could be expected to persist. Sediments in Port Valdez are rarely anaerobic, yet areas influenced by solid organic wastes are more likely to become anoxic. This includes the boat harbor, seafood processing discharges, and hatchery net pens.

8.5 Non-native Species

Non-native species may be introduced into new areas by vessel traffic, especially from distant ports where environmental conditions (water temperature, salinity) are similar. Ballast water has been implicated as the source for a number of algal, invertebrate, and fish species introduced into the estuarine waters of Australia, California, and Oregon (Hutchings, 1992; Moyle, 1991). Most seagoing vessels have seawater ballast tanks and potentially carry non-native organisms. Oil tankers transport ballast water in two ways: 1) as segregated ballast in tanks dedicated only for ballast water, and 2) as non-segregated ballast in tanks that are also used for crude oil cargo. Non-segregated ballast water is discharged to the Ballast Water Treatment Plant, while segregated water is discharged directly into the ocean. Ballast water contaminated by storage in oily ballast tanks is discharged to the BWTP and less likely to be a source of introductions. Currently, there are no regulations preventing ballast water release from segregated tanks into ports or harbors (pers. comm. James Carlton, Williams College, 1995). However, as shippers are becoming aware of the problem of non-native species transport in ballast water, the practice of exchanging ballast water at sea is becoming widespread. This practice ensures that seawater from a coastal environment is not transported to another coastal location. Vessels may also carry in non-native species attached to their hulls, in fishing nets, or in other cargo.

For ballast transport of non-native species to occur, three criteria must be met: 1) organisms must be small enough during their life cycle to be taken up with ballast water (usually pumped through gratings with 1 to 1.5 cm openings, although corrosion can enlarge these openings), 2) organisms must be able to survive dark and stagnant conditions for the duration of the voyage, and 3) organisms must be able to survive and establish in the Port Valdez environment (Locke *et al.*, 1993). Viable bacteria, phytoplankton, and zooplankton have been found in transported ballast water (Carlton, 1989; Hallegraeff and Bolch, 1991; Locke *et al.*, 1993; McCarthy and Khambaty, 1994). Some algal species form resistant cysts that improve survival during transport. These cysts can be picked up in sediment from harbors or from the water during an algal bloom (Hallegraeff and Bolch, 1992).

Vessel traffic from ports in high northern latitudes is more likely to bring non-native species that could survive in Port Valdez. Lifting of the ban on exporting Alaska North Slope crude oil will allow tankers to transport oil to cold-water ports (*e.g.*, northern Japan and Russia) and return with ballast water. Once introduced, the effects caused by non-native species may range from increased predation or competition for resources to the introduction of disease resulting in severe ecological impacts (Hutchings, 1992). Currently, there is no indication that non-native species have been transported into Port Valdez (Feder and Bryson-Schwafel, 1988; Feder and Blanchard, 1996a; 1996b). Moreover, the likelihood of them becoming established may be lower than in other major ports due to the small number of vessels arriving in Port Valdez from non-Alaskan ports at similar latitudes.

8.6 Behavioral and Physical Disturbances

Human activities, such as vessel traffic, construction or development, or other shoreline activity, can disturb animal behaviors crucial to survival of the organism or its young. For instance, the survival of waterfowl populations that are continually disturbed while feeding, or forced to leave nests unattended for too long, will be affected. The potential for these disturbances is again high in the Duck Flats area.

8.7 Impacts to Populations

Impacts to a population occur when the compensatory mechanisms of the individuals are overwhelmed. Alteration in either reproductive output, behavior, or in the utilization of resources can have impacts that alter the structure or dynamics of a population. Organisms in the Port have evolved to effectively cope with many of the natural stressors present in the area. Novel anthropogenic additions, however, could alter important characteristics of the population. At sufficient levels, the previously listed effects can impact populations.

9.0 Follow-up Scenario: An Example of a Multiple Stressor Scenario

Integrating estimates of exposure and effects is an alternative to detecting effects in the field. Effects to organisms in the environment are difficult to detect before damage has already occurred. The source or cause of an effect is even more difficult to prove. Risk assessment provides a means of gathering evidence with which to predict possible anthropogenic effects in the environment. In this section we provide an example of how to use the Relative Risk Model to investigate exposures and effects for a specific risk scenario. We chose clams as a specific receptor because they live in a variety of habitats and are an important food resource for fishes, birds, and some mammals in the Port. Sections 9.1 and 9.2 provide instructions and references to the Relative Risk Model in Appendix D. Section 9.3 describes ways to reduce the uncertainty about risks to the clam population in Port Valdez.

9.1 Risk of Exposure Related to Habitat

Clams live in all areas of the Port sediments. Depending on the species, they can occur in intertidal, shallow subtidal, and deep water habitats. There are several common clam species in Port Valdez. The pink clam, *Macoma balthica*, is found in muddy intertidal and occasionally in subtidal areas. The small clams *Axinopsida* sp. and *Adontorhina* sp., and larger *Macoma* spp. live in shallow to deep subtidal areas of the Port (Feder and Jewett, 1988). Other clam species live in the Port, particularly in the deep benthic habitat (see Appendix B), but are not common. Clams are particularly common in the intertidal and subtidal habitats of sub-areas D (Duck Flats and Old Valdez) and F (Dayville Flats and Solomon Gulch), and the deep water habitats of Sub-Areas J (Western Port) and K (Eastern Port) (Lees *et al.*, 1979; Feder and Bryson-Schwafel, 1988; Feder and Jewett, 1988; Naidu and Feder, 1992; Feder and Shaw, 1994a; Feder and Blanchard, 1996b). The relative risk scores associated with exposure in these habitats are listed in **Table 9-1** and found in the exposure results listed in Appendix D (page D-43).

Table 9-1 Relative risk scores for locations and habitat types in which clams could be exposed.

Sub-Area	mudflats	shallow subtidal	deep benthic
B. Mineral and Gold Creeks	40	36	0
D. Duck Flats and Old Valdez	108	96	0
F. Dayville Flats and Solomon Gulch	48	28	0
J. Western Port	0	0	48
K. Eastern Port	0	0	72

The relative risk scores indicate the highest risk of exposure is in mudflat and shallow subtidal areas of the Duck Flats, and the deep benthic habitat of the eastern Port.

Exposure to clams also depend on their location and activity in the habitat. *Axinopsida* and *Adontorhina* are suspension feeders that feed on phytoplankton and other organic particles suspended above the sediment or mud surface. *Macoma* spp. are mainly surface deposit feeders but can suspension feed. Surface deposit feeders ingest organic particles on the sediment surface. Since clams burrow in the sediment, they are susceptible to changes in sediment quality such as contamination or disturbance on the bottom. The sources contributing to clam's relative risk of exposure to stressors in the mudflats, subtidal, and deep benthic habitats of each sub-area are listed in **Table 9-2** and can be further examined in the filtered output of the model (pages D-11 to D-14 of Appendix D).

Table 9-2. Sources that could affect locations in which clams could be found.

B. Mineral and Gold Creeks

mudflats	shallow subtidal	deep benthic
contaminated runoff accidental spills construction and development shoreline activity	contaminated runoff accidental spills vessel traffic	———

D. Duck Flats and Old Valdez

mudflats	shallow subtidal	deep benthic
contaminated runoff accidental spills construction and development shoreline activity	treated discharge contaminated runoff accidental spills vessel traffic	———

F. Dayville Flats and Solomon Gulch

mudflats	shallow subtidal	deep benthic
contaminated runoff accidental spills construction and development shoreline activity	contaminated runoff accidental spills fish wastes vessel traffic	———

J. Western Port

mudflats	shallow subtidal	deep benthic
———	———	fish wastes vessel traffic

K. Eastern Port

mudflats	shallow subtidal	deep benthic
———	———	treated discharges fish wastes vessel traffic.

These sources can produce a variety of stressors. Chemicals such as hydrocarbons and metals enter the environment through spills from commercial and recreational boats, run-off from the city, sewage wastewater and ballast water treatment effluents, road or site run-off from developed areas, active or closed mines, and spills from tanker activity. Physical stressors include burial by sediment following dredging activities, propeller wash, and seismic sediment disturbances. Wood particles from log storage and loading at the container dock may contribute to debris deposits in the Duck Flats. Occasional sand-blasting of the container dock could also deposit some debris on the sediments. Organic wastes may also be released from the sewage treatment plants, discharges from vessel holding tanks, wastes from fish netpens at the Solomon Gulch Hatchery, and from the disposal of fish carcasses into the Port. Moreover, non-native species could alter the ecological interactions in the Port and affect clam populations; however, this potential stressor is not included in this risk scenario.

9.2 Risk of Effects Related to Impacts

The risk of exposure is followed by the risk of an effect. The severity of the effect depends on the frequency of the exposure and the amount or concentration of the stressor. Effects can influence an individual clam, a population of clams, or extend to a community which includes other species. Direct effects to the clam can reduce its survival, growth, or reproductive viability. Indirect effects extend beyond the individual clam. A population of clams will decline if enough individuals die, reproduction decreases, or the young do not successfully settle in the area. These larger population effects can create impacts to the ecological system of the Port. For instance, reductions in or contamination of a clam population can effect species that normally feed on clams and their larvae, such as sea otters, ducks, migratory birds, and benthic and larval fishes. Impacts that can be associated with clam populations include the degradation of sediment quality and the loss or decline in wildlife food resources. In the sub-areas where clams are expected, both sediment quality and wildlife food availability appear to be at the most risk in the Duck Flats area (**Table 9-3**). The relative risk scores of these impacts are found in pages D-48 and D-58 of Appendix D.

Table 9-3. Relative risk ratings for impacts that can be associated with clam populations in the Port.

Sub-Area	Sediment quality	Wildlife food availability and quality
B. Mineral and Gold Creeks	moderate	moderate
D. Duck Flats and Old Valdez	high	high
F. Dayville Flats and Solomon Gulch	moderate	moderate
J. Western Port	low	low
K. Eastern Port	moderate	moderate

9.3 Uncertainty

The exposures and effects that can occur to clams in the Port, along with the impacts to which they can lead, form a risk scenario (**Figure 9-1**). The risk scenario provides a format for assessing the risk to clams in the Port. Uncertainty is an inevitable part of any risk assessment and is recognized as such by risk assessors (see Section 10 for further analysis of uncertainty in this risk assessment). However, there are many measures that can be taken to reduce uncertainty in a risk analysis. This section discusses methods that reduce the uncertainty associated with the risk of hydrocarbons, metals, or debris causing an impact to clams. As uncertainty in a risk analysis is reduced, the confidence in the risk estimation is increased.

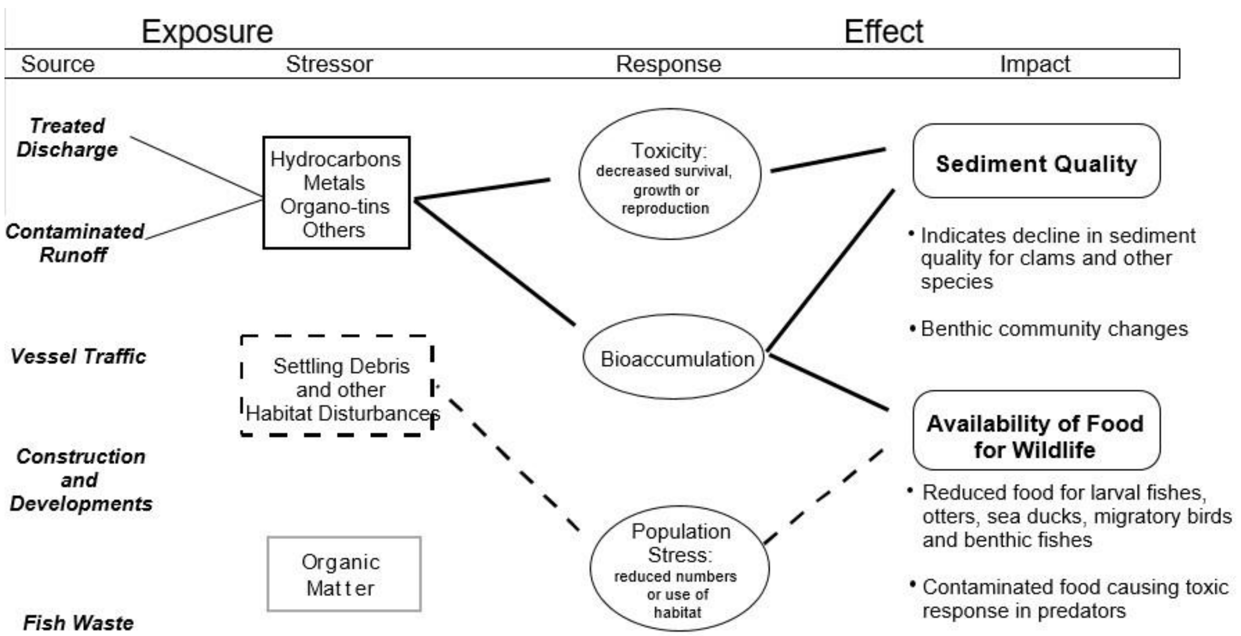


Figure 9-1. Risk scenario for clams in Port Valdez. The stressor pathway in the environment is represented by the lines: solid light line (——) represents chemicals; dashed line (**– –)** represents sediment and debris.

Exposure and effects are central to predicting risk of an impact. Among other things, the duration and type of exposure are linked to the severity of effect. For example, clams exposed to low levels of deposited debris might only be stressed as a result, whereas a higher quantity of deposited debris would result in death. Further, exposure is a result of a stressor coming in contact with a receptor. To reduce uncertainty, both the exposure and the effects need to be assessed by laboratory or field measurements.

An assessment of the local clam populations' potential exposure to hydrocarbons, metals, or debris needs to be conducted. A field assessment would also establish the species of clams present and their density. In addition, quantifying the types and concentrations of the stressors aids in establishing the degree of exposure, which is linked to the severity of effects (**Table 9-4**). Measurements of hydrocarbon or metal content of particulate matter and sediment in the clam habitat establishes the environmental concentration at which clams may be exposed. The measurement of tissue concentration of hydrocarbons or metals in clams establishes exposure levels. These exposure levels are then linked to toxicity or bioconcentration impacts. For debris, field assessments or observations define exposure levels. Field assessments would include total suspended solids or turbidity measurements that quantify the amount of debris that may eventually be deposited on the clams. Observations of water currents around clam habitat provide information regarding the fate of falling debris and how much debris might be deposited on the clams.

Table 9-4. Assessments that would reduce uncertainty in determining the potential exposure of clams to hydrocarbons, metals, and wood, sediment, and debris associated stressors.

Stressor	***Assessment***
Hydrocarbons above and in sediment	□ Analysis of field collected sediment samples for hydrocarbons (intertidal and subtidal) □ Analysis of hydrocarbons in water and particulate matter suspended above the sediment □ Measurement of tissue concentration of hydrocarbons in field collected clams □ Studies with caged bivalves located near the sediments
Metals above and in sediment	□ Analysis of field collected sediment samples for metals □ Analysis of metals in particulate matter suspended above sediment bottom and phytoplankton □ Measurement of tissue concentration of metals in field collected clams □ Studies with cage bivalves located near the sediments
Wood, sediment, and other debris	□ Observation of activity at floating dock and other docks and analysis of water samples for turbidity or suspended solids □ Analysis of sub-surface water currents in areas of falling debris □ Analysis of deposition patterns

There is uncertainty in the type and severity of effect resulting from an exposure. Assessments of direct effects from various exposure levels are used to address possible indirect effects (**Table 9-5**). In order to reduce uncertainty, exposure levels need to be linked to effects. For example, bioassay tests with either native or test species of clams link exposure to hydrocarbons or metals to an effect, such as reduced growth or reproduction. Field studies using caged clams or other bivalve tests reduce uncertainty even further. By quantifying the amount of debris that causes suffocation in clams, a field exposure level can be correlated with that effect.

Table 9-5. Assessments that would reduce uncertainty about effects on clams exposed to hydrocarbons, metals, and debris.

Effect	*Assessment*
Chronic toxicity and bioaccumulation	• Measurement of tissue concentration of hydrocarbons/metals in field collected clams • Bioassay tests measuring survival, growth, and reproductive endpoints in clams or surrogate organisms exposed to local effluents, waters, and sediments • *in situ* study with caged clam (or other bivalve placed directly above the sediment and used as a surrogate)
Death or injury from physical disturbance	• The amount and structural characteristics of debris that would cause death to clams as determined by laboratory testing
Population decrease	• Bioassay tests that would measure survival, growth, and reproduction of clams exposed to hydrocarbon and metal concentration • Population modeling (*Unless long-term population studies related to decreased growth and reproduction are performed, extrapolation from individual effects to population effects will have uncertainty associated with it.)*
Food chain effects	• Observation or measurement of the amount of clams/clam larvae consumed by otters, sea ducks, migratory birds, and benthic fishes • Dietary dependence (proportion of diet) of otters, sea ducks, migratory birds, and benthic fishes on clams or clam larvae • For chronic toxicity from bioaccumulation, the level of hydrocarbons and metals that causes chronic toxicity to otters, sea ducks, migratory birds, and benthic fishes • Tissue concentration of hydrocarbons/metals in otters and sea ducks

It is more difficult to reduce uncertainty when assessing indirect effects. In order to assess a reduction in population, long-term studies need to be performed. However, extrapolation from bioassay tests measuring chronic toxicity is an alternative. This involves population modeling that predicts the reduction of clams in a population resulting from decreased growth or reproduction. In order to link the effect of a reduced clam population to predator species, the role that clams play in the diet of each species needs to be determined. This assessment includes the quantity of clams consumed by each predator and the importance of clams to their nutrition.

The same type of assessment is needed to determine the effects on predators of consuming contaminated clams. The quantity of contaminated clams consumed by each predator could be linked to toxicity levels for each species. Uncertainty would be reduced further by measuring and comparing tissue concentrations of the chemical in clams and their predators.

10.0 Uncertainty Analysis

Risk assessment asserts that knowledge about exposure can be combined with knowledge about effects to give an estimate of risk. The paradigm recognizes that knowledge will never be perfect and every risk assessment will contain some degree of uncertainty.

This assessment has several features that contribute to uncertainty. First this is a *preliminary* assessment. No new field or laboratory studies were undertaken to fill in data gaps or to refine existing data. This assessment is also regional. The breadth limits the detail with which any one habitat, community, or other ecological unit could be examined. The ranks computed in the relative risk analysis are approximate values that are based on broad comparisons between different areas of the Port. Finally, Port Valdez is a high latitude environment with a considerable degree of natural variability. This variability acts as an unpredictable modulator of both exposure and effects. These characteristics of the environment and scope of the risk assessment add to uncertainty. As with any system, there are additional aspects of risk in the Port that remain unknown and cannot be approximated. While the magnitude of this kind of uncertainty can be measured and evaluated, the importance of the unknowns cannot be approximated.

In addition, the available information is not uniform for all locations of the Port. Near the Valdez Marine Terminal, where considerable environmental monitoring and related studies have been performed, the level of uncertainty is lower compared to other less well-studied areas. Confirmatory risk analyses based on the data obtained in the Port focus on such areas.

These features of the risk assessment give rise to five general sources of uncertainty:

- ***Missing Information*****:** Information gaps occur where sources or stressors in the Port were not identified or important aspects of the ecology were not developed.
- ***Ambiguities in the Available Information***: Ambiguity exists in the anecdotal, regulatory, and scientific data collected regarding the purposes of this study. For example, studies providing information on birds in the Port did not necessarily include sites in all of the delineated sub-areas, while Port-wide studies of chemical contaminants in the sediments focus on hydrocarbon concentrations, but do not measure metal concentrations.
- ***Error in the Conceptual Model:*** The conceptual model defines risk components and the links between these components in the Port Valdez system. Undefined links or links

interpreted incorrectly would cause errors in accuracy or precision of the relative risk descriptions.

- ***Error in the Estimate of Relative Risk:*** Relative ranks are determined by general information, which provides a system for numerically combining decisions regarding exposure and effects. Correct output from the model depends on relevance of the input criteria and accuracy of the model calculations in simulating risk in the Port. As with all models, confirmation and refinement are necessary.
- ***Variability in the Environment:*** The combination of nonlinear and stochastic properties of nature create variability in plant and animal populations and cause variable responses to stressors. This form of uncertainty can be described but not reduced.

Considering all of the sources and kinds of uncertainty that are present, the estimates of ecological risk to Port Valdez derived from our Relative Risk Model contain substantial uncertainty. This uncertainty is reflected in categorizing the risk estimates as "low", "moderate", and "high" relative risk.

One way to explore the uncertainty of the model and the relative risk analysis is to have stakeholders examine the inputs to the model. These inputs encapsulate judgments about the likely levels of exposure and severity of effects for a multitude of stressors and receptors in Port Valdez. Inputs about which stakeholders disagree are, de facto, points of uncertainty and also candidates for additional study. This process of stakeholder review could also be used as a risk management tool to help in the identification of community issues. Another way to explore the uncertainty is to perform a sensitivity analysis. A sensitivity analysis of the model is presented in Section 10.1. The degree of verification provided by the confirmatory analyses of Section 7 is discussed in Section 10.2.

10.1 Sensitivity Analysis for the Relative Risk Model

The sensitivity of the model depends on its ability to identify the difference between high and low risk areas. The model operates on input that ranks habitats and sources, and filters out the probable exposures or effects. The ranks and filters used for the Port Valdez analysis are in **Table 6-1**. To analyze the sensitivity of this model, we incorporated randomly chosen input and examined the results for each sub-area. The sensitivity analysis is based on the premise that when input is randomly chosen, the model results will not discriminate between different sub-areas of the Port. Input that is risk-related, instead of random, will cause the model to detect the high risk areas. The sensitivity analysis was conducted in two phases. Initially, the factors influencing the model were investigated. In the second part, the model results were examined when different ranks were chosen for the input.

The three types of input (source ranks, habitat ranks, and filter values) affect the results in different ways. **Figure 10-1** shows what happens to the relative risk results when some of the input is left out of the model. The thick solid line in the figure depicts the complete risk score results from the Relative Risk Model analysis for Port Valdez (Section 6.3) These results combined characteristics of the source, habitat, and exposure components. When the exposure filter is left out of the analysis the results vary in magnitude from the original results (**Line a**). The exposure filter has little effect on the comparative results: Sub-Area D still had the highest relative risk score. The effects filters would have a similar influence on the model results and were not examined in the following uncertainty analysis. However, the ranks affect the model in a different manner than the filters. When habitat ranks are not used, the sources data dominate the analysis and cause Sub-Areas C and G to have the highest scores (**Line b**). When source ranks are not used, habitats dominate the analysis and cause Sub-Areas A and D to have the highest relative risk scores (**Line c**).

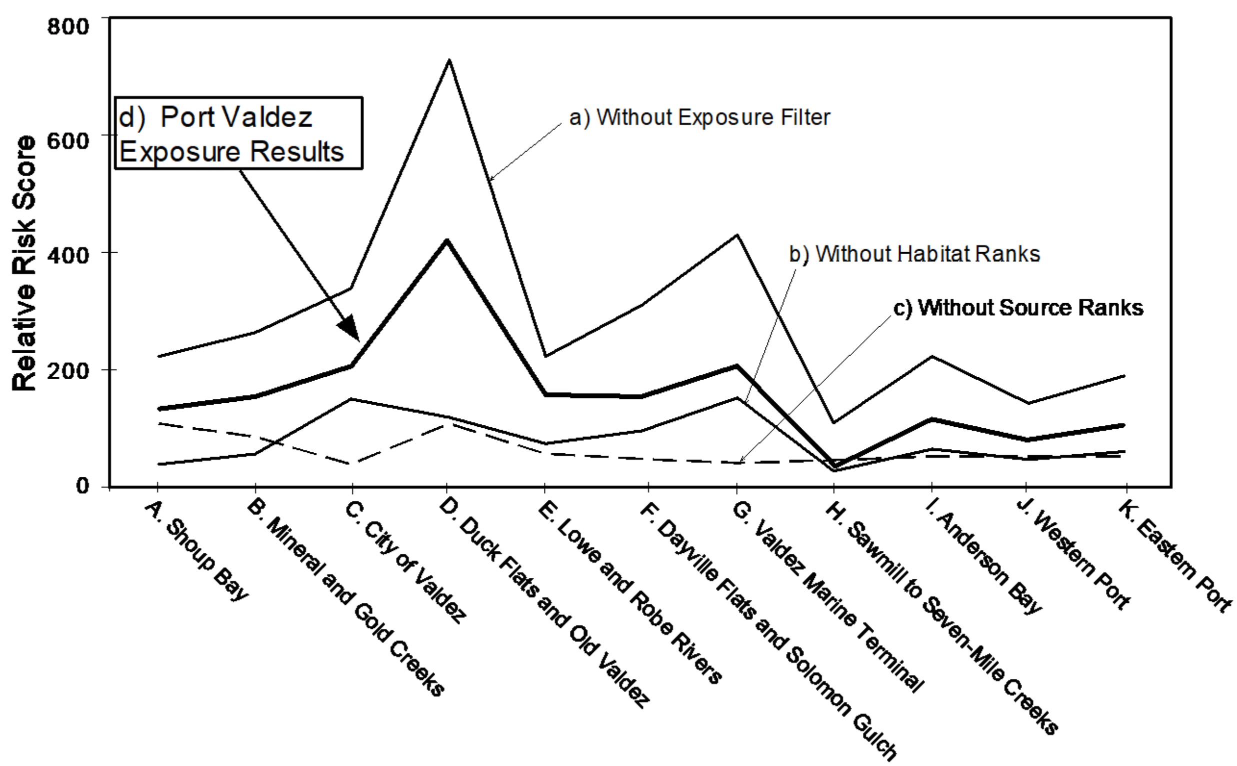


Figure 10-1 Model results when the model is influenced by a) source and habitat ranks, b) habitat ranks and the exposure filter, c) source ranks and the exposure filter, and d) all of these components.

Uncertainty in the ranking process depends on the accuracy of the ranks chosen to represent risks from sources to habitats. To explore uncertainty in these choices, we established a range of values around each rank originally used in the relative risk analysis (see Table 6-1). The range included numbers used in the ranking process: 0, 2, 4, and 6 (**Table 10-1**). High values represent the highest rank that could be expected for the source or habitat in the sub-area. Low values represent the lowest rank that could be expected. These values were chosen conservatively, so that even a slight uncertainty is represented within the range. Single values were only used when there was little doubt that the source or habitat was not present in the sub-area. A zero was assigned in these cases.

To test the sensitivity, the model was run 20 times with two different sets of input: 1) all ranks and exposure filter values chosen randomly, and 2) ranks chosen from within the specified uncertainty ranges in **Table 10-1**. Allowing only random input into the model produced the least sensitive result (**Table 10-2a**). In this case, the model was only able to detect the same high risk area (E. Lowe and Robe Rivers) five times in 20 runs. When the ranked input was limited by the ranges of possible values and the exposure filter was not random (**Table 10-2b**) the model detected the same high risk area (D. Duckflats and Old Valdez) more than 55% of the time. This result agreed with the result from the relative risk analysis (**Table 10-2c**).

Figure 10-2 compares the original Port Valdez results (middle line) to the 20 sets of results obtained with the uncertainty analysis (points). The dark lines represent the highest and lowest possible results of the uncertainty analysis. The two most notable differences resulting from the uncertainty analysis are that:

- Sub-Areas A (Shoup Bay) and B (Mineral and Gold Creeks) could be at a higher risk than established in the original results; and
- Sub-Area C (City of Valdez) could be at a lower risk than established in the original results.

In summary, the model is most sensitive to a reduction in uncertainty in the source and habitat ranks. Reducing uncertainty in the filters would have little effect on the comparative results of the model, but would affect the magnitude of the final scores. However, reducing uncertainty in the process of ranking sources and habitats would affect the comparative results and the determination of the high risk sub-area in the Port.

Table 10-1. Ranges for a) source and b) habitat ranks representing uncertainty of the contribution to the risk of an impact in that sub-area.

a) Sources

Sub-Area	Treated Discharge	Contam. Runoff	Accident. Spills	Fish Waste	Vessel Traffic	Construc. Develop.	Hatchery Fish	Shoreline Activity
A. Shoup Bay	0	0-6	2-6	0	2-6	0	0-6	0-6
B. Mineral and Gold Creeks	0-6	2-6	2-6	0-6	2-6	2-6	0-6	0-6
C. City of Valdez	0-6	0-6	2-6	2-6	2-6	2-6	0-6	0-6
D. Duck Flats and Old Valdez	2-6	0-6	2-6	0-6	2-6	2-6	0-6	0-6
E. Lowe and Robe Rivers	2-6	0-6	2-6	0-6	2-6	2-6	0-6	0-6
F. Dayville and Solomon Gulch	2-6	0-6	2-6	2-6	2-6	2-6	0-6	0-6
G. Valdez Marine Terminal	2-6	0-6	2-6	0	2-6	2-6	0-6	0-6
H. Sawmill to Seven-Mile Creeks	2-6	0	2-6	0	2-6	0-6	0-6	0-6
I. Anderson Bay	0	0	2-6	0	2-6	0-6	0-6	0-6
J. Western Port	0	0	2-6	0-4	2-6	0	0-6	0
K. Eastern Port	2-6	0-6	2-6	0-6	2-6	0	0-6	0

b) Habitats

Sub-Area	Mudflat	Saltmarsh	Spits and Beaches	Rocky Shore	Shallow Subtidal	Deep Benthic	Open Water	Stream Mouth
A. Shoup Bay	0-4	0-2	2-6	2-6	0-6	2-6	0-6	0-6
B. Mineral and Gold Creeks	4-6	0-2	0-6	2-6	2-6	0	0-6	2-6
C. City of Valdez	0	0	2-6	2-6	0-6	0	0-6	0
D. Duck Flats and Old Valdez	4-6	2-6	0-6	2-6	4-6	0-6	0-6	2-6
E. Lowe and Robe Rivers	4-6	0-2	0	0	0-6	0	0-6	2-6
F. Dayville and Solomon Gulch	2-6	0	0	0	0-6	0	0-6	2-6
G. Valdez Marine Terminal	0-6	0	0-6	2-6	0-6	0	0-6	0-6
H. Sawmill to Seven-Mile Creeks	0	0	2-6	2-6	0-6	0	0-6	0-6
I. Anderson Bay	0-6	0	0	2-6	0-6	0	0-6	0-6
J. Western Port	0	0	0	0	0	2-6	0-6	0
K. Eastern Port	0	0	0	0	0	2-6	0-6	0

Table 10-2. Sub-areas with the highest relative risk score in 20 iterations of the model with a) random input and b) input from uncertainty ranges. Shading highlights the sub-areas that most frequently receive the maximum relative risk score.

Sub-Area with Maximum Relative Risk	Percent of the Time Chosen by the Model (% of 20 trials of the model)		
	a) All Input Random	b) Range of Ranks	c) No Random Input
A. Shoup Bay	7%	5%	
B. Mineral and Gold Creeks	10%	10%	
C. City of Valdez	0%	5%	
D. Duckflats and Old Valdez	15%	55%	100%
E. Lowe and Robe Rivers	25%	5%	
F. Dayville Flats and Solomon Gulch	10%	0%	
G. Valdez Marine Terminal	7%	20%	
H. Sawmill to Seven-Mile Creeks	5%	0%	
I. Anderson Bay	0%	0%	
J. Western Port	5%	0%	
K. Eastern Port	15%	0%	

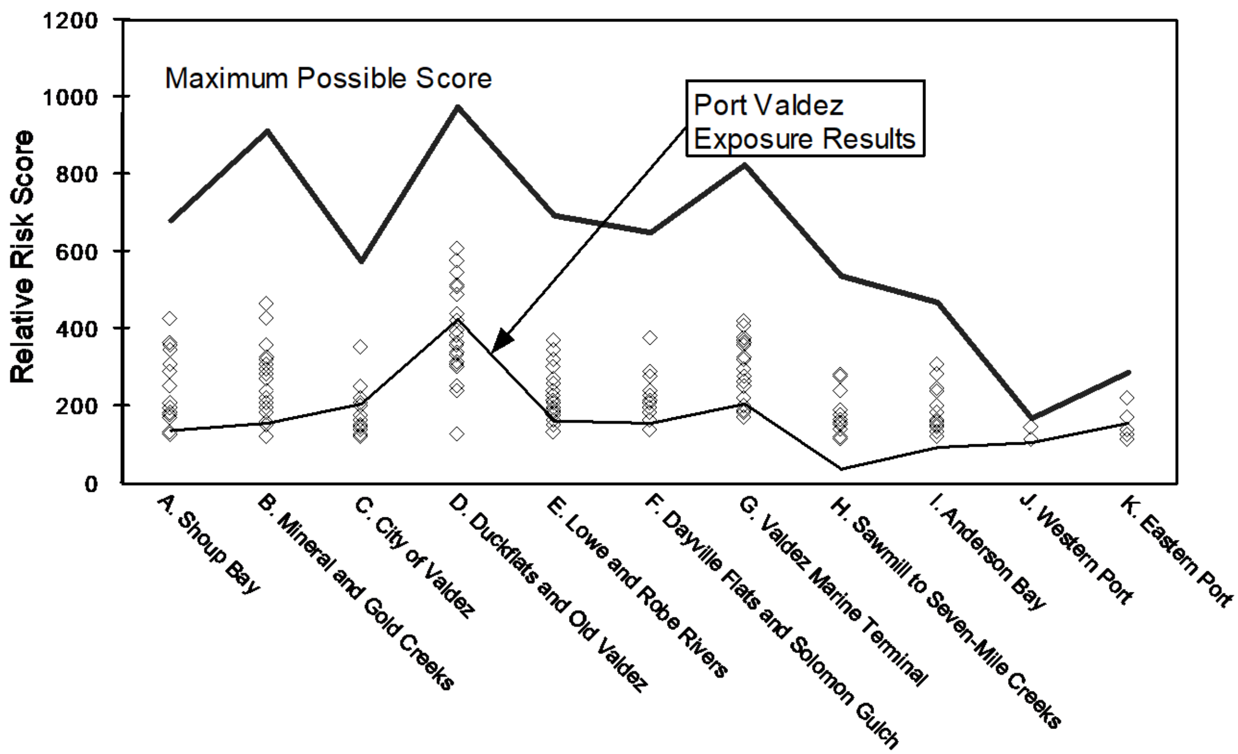


Figure 10-2. Relative risk scores for exposure based on 20 iterations of the model with source and habitat ranks randomly input from within a specified range of values representing uncertainty in the ranks. The upper and lower lines are the maximum and minimum results that could be obtained in this uncertainty analysis. The middle line is the result of the original relative risk analysis.

10.2 Uncertainty in the Confirmatory Analyses

Another means of determining confidence in the assessment is to compare the results from different techniques. This assessment uses analyses targeted at a regional approach (Section 6) and a conventional approach (Section 7).

1. Regional Approach: Relative Risk Analysis
2. Conventional Approach: Benchmark Analysis
∑PAH Model Analysis
Bioassay Analysis

The data, as well as the means of integrating the data, vary in each of the three methods used. By using more than one technique, gaps in one method may be addressed in another method. For instance, while we were only able to analyze certain metals and PAHs with benchmarks and modeling, bioassays provided a measure of the toxicity of all chemicals present in the samples.

With this variety of approaches, the results can be combined into an overall weight-of-evidence approach. A weight-of-evidence approach assumes that if a variety of evidence agrees with a single result, there is more certainty in that result (see Menzie *et al.,* 1996). The conventional risk estimates or evaluations can be used as confirmatory analyses that are compared to results of the Relative Risk Model (**Tables 10-3** to **10-5**). The conceptual model identifies seven categories of impacts that are evaluated by the relative risk analysis (see Table 2-4). The confirmatory analyses can be related to water quality (**Table 10-3**), sediment quality (**Table 10-4**), and the quality of wildlife food (**Table 10-5**).

Confidence in the accuracy, precision, and reliability of the data from the Port increases with the number of samples collected. These numbers can be compared in the tables presented in Section 7.1 to 7.3. Data is more prevalent in certain sub-areas of the Port, such as the Valdez Marine Terminal (Sub-Area G) and in the deep Eastern Port (Sub-Area K) where the effluent from the BWTP has prompted more sample collection. Confidence in results from these areas is greater. There was also more data collected and analyzed for PAHs throughout the Port than for heavy metals or toxicity.

Table 10-3 Comparison of results from the relative risk analysis to results from the confirmatory analyses of impacts and effects related to water quality. Data for the confirmatory analyses come from samples of the undiluted BWTP effluent. A dash indicates that no data was available.

Water Quality

Sub-Area	**Relative Risk**	**Risk Confirmed by Analysis?**		
		PAH Benchmarks	Metal Benchmarks	Toxicity
Shoup Bay	Low	-	-	-
Mineral and Gold Creeks	Moderate	-	-	-
City of Valdez	Moderate	-	-	-
Duck Flats and Old Valdez	High	-	-	-
Lowe and Robe Rivers	Moderate	-	-	-
Dayville Flats and Solomon Gulch	Moderate	-	-	-
Valdez Marine Terminal	Moderate	no	yes[1]	yes[2]
Sawmill to Seven-Mile Creeks	Low	-	-	-
Anderson Bay	Low	-	-	-
Western Port	Low	-	-	-
Eastern Port	Moderate	-	-	-

[1] antimony, arsenic, cadmium, chromium, lead, nickel, thallium, and zinc in undiluted effluent from the BWTP

[2] low-level toxicity to pandalid shrimp larvae, mysids, and echinoderm sperm fertilization in undiluted effluent from the BWTP

Table 10-4 Comparison of results from the relative risk analysis to results from the confirmatory analyses of impacts and effects related to sediment quality. Data for the confirmatory analyses come from sediment samples collected from various locations in the Port. A dash indicates that no data were available.

Sediment Quality

Sub-Area	**Relative Risk**	**A Risk Confirmed by Analysis?**			
		PAH Benchmarks	∑PAH Model	Metal Benchmarks	Toxicity
Shoup Bay	Low	-	-	-	-
Mineral and Gold Creeks	Moderate	yes[1]	no	-	-
City of Valdez	Moderate	yes[2]	no	no	-
Duckflats and Old Valdez	High	-	-	-	-
Lowe and Robe Rivers	Moderate	-	-	-	-
Dayville Flats and Solomon Gulch	Moderate	-	no	-	-
Valdez Marine Terminal	Moderate	yes[1]	no	-	und.[3]
Sawmill to Seven-Mile Creeks	Low	-	-	-	-
Anderson Bay	Low	yes[1]	no	-	-
Western Port	Low	yes[1]	no	-	und.[3]
Eastern Port	Moderate	yes[1]	no	-	und.[3]

[1]2-methylnaphthalene in sediments

[2]anthracene, benzo[a]anthracene, chrysene, fluoranthene, phenanthrene, and pyrene in boat harbor sediments

[3]toxicity to amphipods tested but undetermined

Table 10-5 Comparison of results from the relative risk analysis to results from the confirmatory analyses of impacts and effects related to wildlife food quality. Data for the confirmatory analyses are PAH concentrations in mussel tissue samples collected from beaches in the Port. A dash indicates that no data were available.

Wildlife Food Quality

Sub-Area	**Relative Risk**	**Risk Confirmed by Analysis?** PAH Benchmarks
Shoup Bay	Low	-
Mineral and Gold Creeks	Moderate	no
City of Valdez	Moderate	-
Duckflats and Old Valdez	High	-
Lowe and Robe Rivers	Moderate	-
Dayville Flats and Solomon Gulch	Moderate	-
Valdez Marine Terminal	Moderate	no
Sawmill to Seven-Mile Creeks	Low	no
Anderson Bay	Low	-
Western Port	Low	-
Eastern Port	Moderate	-

11.0 Risk Summary

Chemical and biological monitoring in Port Valdez has found few indications of severely contaminated sites or ecological impacts. As with all monitoring studies, environmental and field data are based on limited tests and measurements under specific conditions. We have developed a framework that systematically analyzes concerns about the environment and identified risks in the Port. This unified Port-wide perspective of risk assessment will aid in prioritization for future studies, interpretation, or decision-making. The framework divides the Port into sub-areas that contain specific ecological and anthropogenic structures or activities. These sub-areas function as units which can be compared to form a Port-wide perspective of ecological risk.

The ecological risks analyzed in each sub-area are described in Section 11.1. During the research conducted to develop this ecological risk assessment framework, several Port-wide issues became apparent. These issues included (1) the widespread release of hydrocarbons throughout the Port, (2) the possibility of organotins released from the paint on the bottom of large vessels, (3) the potential for a large crude oil spill, (4) the potential for the introduction of a non-native species, and (5) continued land use and development around the shoreline of the Port. These issues are described briefly in Section 11.2.

11.1 Summary of Relative Risk between Sub-areas of the Port

The relative risks predicted by the model developed in this document can be generalized in the following terms:

- the risk of plants or animals in the Port being exposed to agents that can cause them stress or harm is highest in the eastern Port, particularly in the Duck Flats area (**Figure 11-1a**)
- the risk of a decline in the water quality of the Port is greatest in the eastern Port, the Duck Flats area and near the two most developed areas of the Port (the City and the Valdez Marine Terminal) (**Figure 11-1b**)
- the risk of a decline in sediment quality is also greater in the eastern Port (**Figure 11-1c**)
- the model detects little risk to commercial fishes and shellfishes, wild fishes, and to bird reproductive behaviors (**Figure 11-1d-g**)
- the risk to food availability and quality for wildlife is similar to the risk to sediment quality (**Figure 11-1h**)

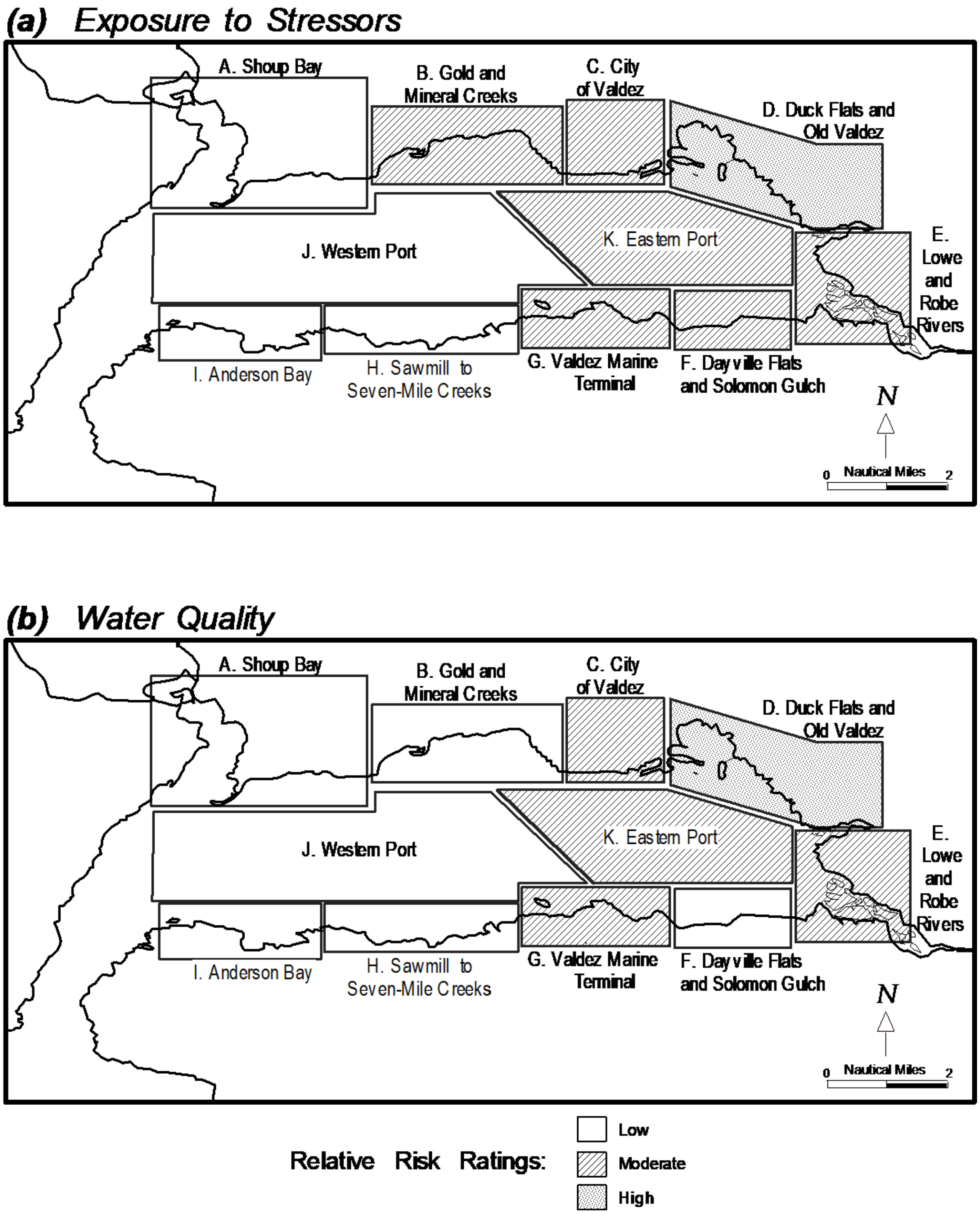
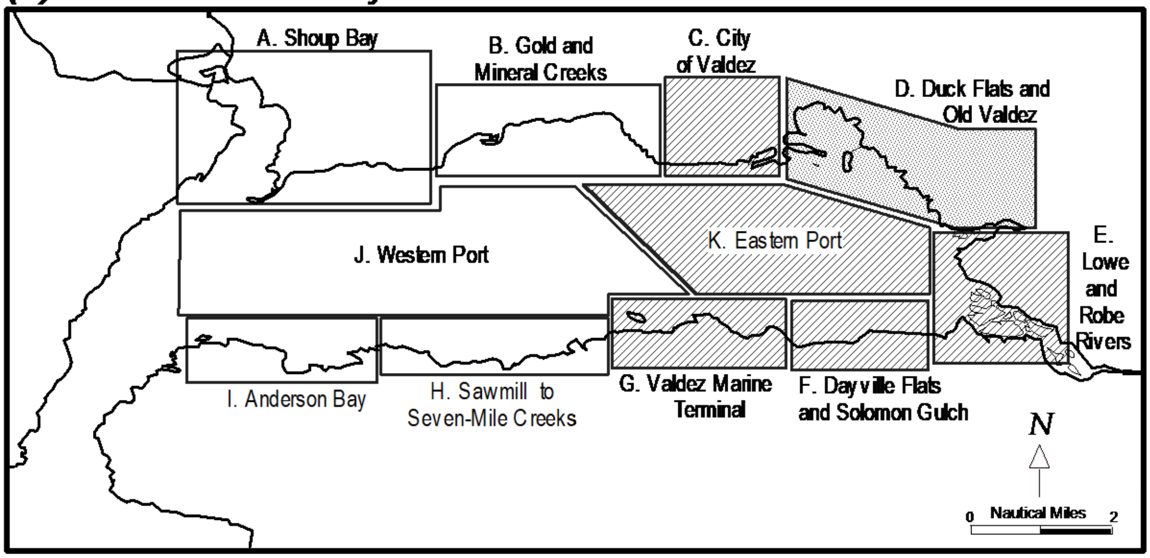


Figure 11-1 Relative risks associated with a) exposure to stressors and b) impacts to water quality.

(c) Sediment Quality



(d) Hatchery Salmon Returns

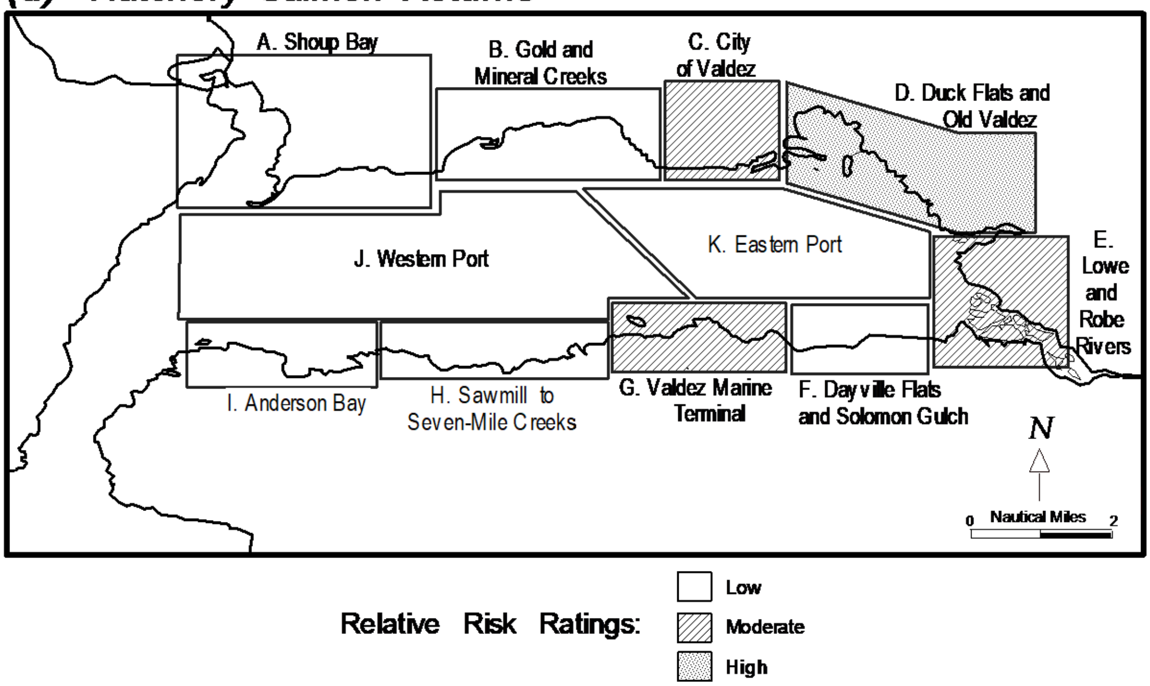
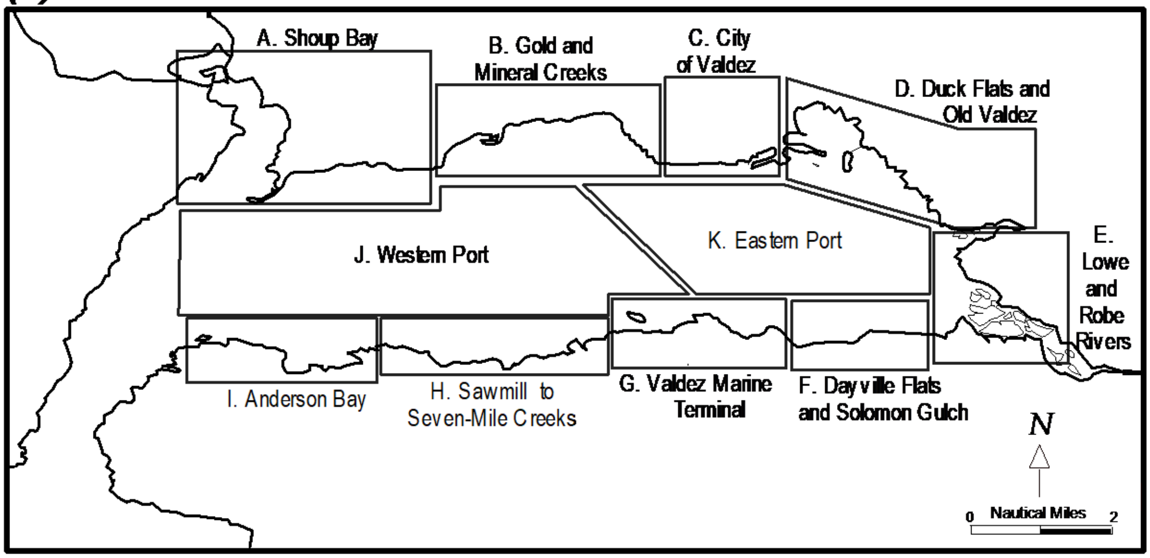


Figure 11-1 **(continued)** Relative risks associated with impacts to c) sediment quality and b) hatchery fishes.

(e) Bottom Fishes and Shellfishes



(f) Wild Anadromous Fishes

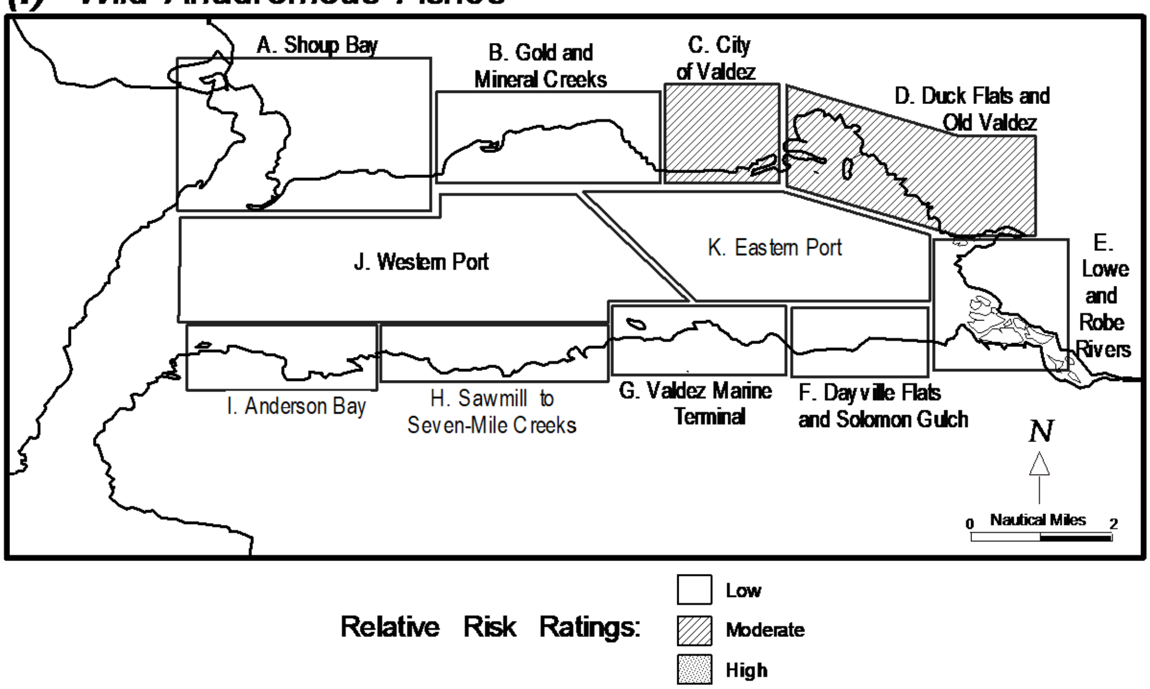
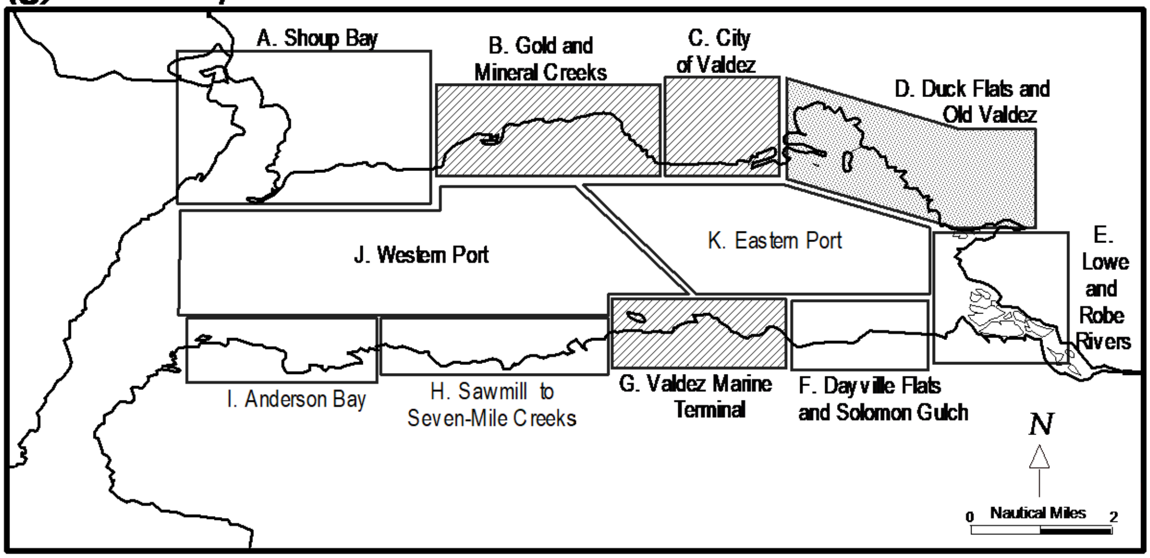


Figure 11-1 (continued) Relative risks associated with impacts to e) benthic fishes and shellfishes, and f) wild anadromous fishes.

(g) Bird Reproduction



(h) Wildlife Food Availability and Quality

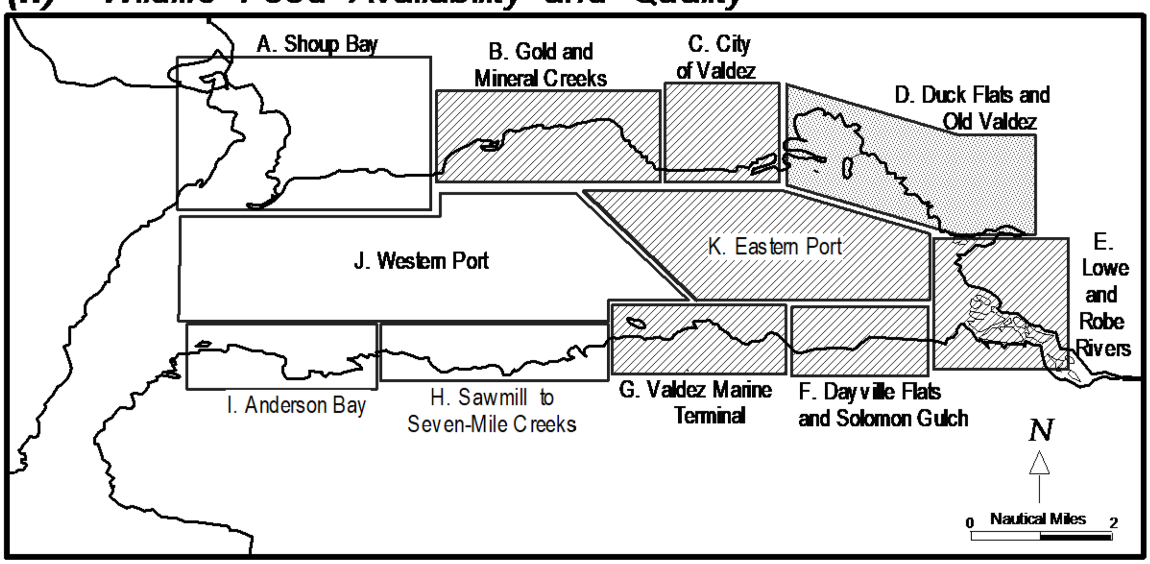


Figure 11-1 **(continued)** Relative risks associated with impacts to g) bird reproduction and h) wildlife food availability and quality.

11.2 Port-Wide Risks

Several risks were identified as concerns to members of the community and as issues affecting the entire Port. Port-wide risks are possible from

- the release and persistence of hydrocarbons,
- the potential for organotins in the environment,
- a large crude oil spill,
- the introduction of a non-native species, and
- continued development of the Port.

The probability of exposure from each of these concerns is in most cases very uncertain and in some cases very low. However, the effects that can result from exposure to some of these agents or events can be quite severe. The expected severity and duration of impacts from these effects are described below (**Table 11-1**). A description of the possible uncertainty associated with the stressor occurring in the port and causing an impact is included.

11.3 Conclusions

Sources and habitats were ranked between sub-areas to provide an initial comparison. Results from this exercise reflected domestic and private, commercial, and industrial development in the eastern Port and indicated greater risks in the eastern sub-areas. The maximum risk occurred in the Duck Flats and Old Valdez sub-areas (Sub-Area D) based on the variety of habitats susceptible to impacts, and the number of sources of contaminants.

Ranking criteria were chosen so that they could be applied to each sub-area. The quantity of data collected in certain sub-areas, such as the Valdez Marine Terminal (Sub-Area G), were much greater than in other sub-areas. This disparity made it necessary to choose relatively basic criteria for this preliminary ranking, and not all of the available data (*e.g.*, volatile hydrocarbons in the BWTP effluent) were reflected in the sub-area comparisons.

Analysis was completed at a more specific scale using data available in certain locations, but not Port-wide. These data consisted of site-specific environmental chemical measurements evaluated against benchmark values of toxicity. The data included metals and hydrocarbon concentrations in mussel tissues, sediments, and in a single point wastewater effluent discharge (*i.e.*, the BWTP effluent). Integration of the site-specific exposure data with the chemical effects data show some of the benchmarks were exceeded. The highest

Table 11-1. Port-wide risks identified for Port Valdez.

Port-wide Risks	***Severity of Impact***	***Duration of Impact***	***Uncertainty in Port Valdez***
Hydrocarbons	*low to moderate* - although effects to individuals can be severe, hydrocarbons typically volatilize or degrade in the environment	*short to moderate* - many organisms can detoxify hydrocarbons at sublethal doses - some animals, such as mussels, will accumulate hydrocarbons if there is a continuous source	- exposure and effects depend on the type of hydrocarbons, the frequency of their release, and their persistence
Organotins	*severe, acute and chronic* - can lead to sterilization in the whelk population - accumulation in sediments possible, especially in areas with high boat traffic or stagnant water	*short- to long-term* - effects may last lifetime of the organism (due to changes in sex characteristics) - duration of the exposure and residence time in the sediments - eventual degradation	- there has probably been exposure in the past by small and large vessels - current exposure appears to be limited to tanker traffic but not all tankers necessarily use TBT - possible use of TBT paints inside tanker holds and subsequent discharge of leachate to BWTP
Large Oil Spills	*moderate to severe* - toxicity moderate depending on organism and life stage - oiling can cause physical harm	*moderate to long-term* - studies indicate oil spill effects can last between 1 to 10 years - sediments can become contaminated and leach hydrocarbons into the water - eventual degradation	- uncertainty exists in the chance of a large spill and exposure - cleanup procedures can reduce exposure but can also cause damage - once a spill occurs, exposure depends on the location and fate of the oil
Introduced Species	*low to very severe* - successful introductions may have little impact or may cause drastic changes to both the physical and biological environment	*long-term* - introduced species reproduce and grow, unlike chemical contaminants which diminish over time - persistent, may be difficult to impossible to control new species	- although establishment of introduced species is a low probability event, the persistence of some non-native species increases the risk of impact
Development	*low to severe* - the steep rise of the land around Port Valdez limits the amount of land available for development	*short-term to long-term* - habitat loss or degradation occurs for the life of the development	- loss of habitat that is unique to the area (Duck Flats) will cause greater impact on the overall system -all shoreline areas of the Port are susceptible to future or continued development except for Shoup Bay which is a state park.

probability of benchmarks for hydrocarbons being exceeded was in the Small Boat Harbor (50% for fluoranthene). The benchmark for the hydrocarbon compound 2-methylnaphthalene was also exceeded in all areas tested (3 to 17%). Although the exposure data used in this analysis comes directly from the Port Valdez environment, the benchmark values are derived from the scientific literature and are not directly associated with the Port. As such, values may not reflect the specific conditions or ecological interactions of the Port and care must be taken in interpretation of these results. However, as a preliminary screening device, the risks reflect the previous conclusions.

Risks from sediment hydrocarbon levels, which were assessed in several sub-areas, were highest in the boat harbor (Sub-Area C). However, the uncertainty associated with this sub-area is higher than with other sub-areas.

Additional assessment of the available data involved the application of a model predicting the acute toxicity of these sediments to amphipods, a standard laboratory test animal. Unlike the benchmark approach described above, the PAH model predicts the effects from more than just one hydrocarbon at a time by assuming that the effects from each PAH are additive. This approach predicted no acute toxicity in any of the samples, including those that exceeded benchmark values. However, the potential for chronic toxicity is not predicted by the model.

In summary, we have categorized and defined the source of stressors and the habitats used by receptors in Port Valdez. This design is intended to provide a format for integration and interpretation of environmental studies in the region and to provide a tool for management purposes.

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