SCOPING RISK ASSESSMENT
PROTECTION AGAINST OIL SPILLS IN THE MARINE WATERS OF NORTHWEST WASHINGTON STATE

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2100 2nd Street SW
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July 18, 1997

PREFACE

Natural resources, both productive and beautiful, coexist with booming international trade and shipping in the marine waters of Washington State. Human use of the waterway brings an element of exposure to the hazards of society's machines. The environmental consequences of accidents have been seen in a number of serious oil spills in the region and elsewhere in United States and worldwide waters. These hard learned lessons in safety management continually drive efforts towards improvements.

Hazard and consequence taken together constitute risk. This report is an assessment of that risk and is meant to inform the public and assist policy makers in the management of Puget Sound and the surrounding waters. The job of maintaining waterway safety is continuous, requiring frequent reappraisals, and needs the attention of all who use and enjoy the resource. The authors hope that this work advances the process and provides the basis for effectively continuing it into the future.

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ACKNOWLEDGMENTS

The project team wishes to extend heartfelt thanks to the many people who gave their time and energy to help with the preparation of the report. It would not have been possible to complete our work without their extensive knowledge and experience of Washington's coastal waters.

Jon Neel, Paul Heimewitz, and Dick Logan of the Washington Department of Ecology Spill Damage Assessment Unit provided enormous assistance in the calculations of oil spill sensitivity. Maps and traffic flow tables were reviewed and critiqued by Richard Softeye at the Marine Exchange of Puget Sound, Captain Bill Bock of Puget Sound Pilots, Lieutenant Dan Precourt of the Seattle Vessel Traffic System (U.S. Coast Guard), and Ralph Hughes of Canada Vessel Traffic Services.

The Puget Sound Risk Assessment Expert Panel played a critical role, providing the local knowledge essential to any waterway assessment. Its members are too many to list here, but special thanks must go to the chairpersons of the Panel's two working groups. Dr. Ed Wenk, Jr. and Dr. Sharon Christopherson were diligent, fair, and tireless in the execution of their tasks and deserve the gratitude of all the people in the State of Washington.

Finally, we must acknowledge the hard work, advice, and patience of our sponsors at Coast Guard Headquarters, including Mr. Joe Angelo, Captain George Wright, and Captain Mark VanHaverbeke.

Michael Dyer, Volpe Center
Judy Schwenk, Volpe Center
Gary Watros, Volpe Center
Lt Duane Boniface, U.S. Coast Guard

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LIST OF ACRONYMS

ACP	Area Contingency Plan
ANE	Advance notice of entry
ATBA	Area to be avoided; for the purpose of this report, the area designated by the International Maritime Organization off the Washington coast consisting largely of the Olympic Coast National Marine Sanctuary
AtoN	Aid to navigation
CCG	Canadian Coast Guard
CFR	Code of Federal Regulations
CG MSEP	Coast Guard marine safety and environmental protection regulations
COTP	Coast Guard Captain of the Port
CVTS	Cooperative Vessel Traffic Service
DOE	Washington Department of Ecology
DOI	U.S. Department of Interior
DWT	Deadweight tonnage, the cargo capacity of tank vessels
EI WG	Environmental Impact Working Group
GIS	Geographic Information System
GPS	Global Positioning System
GRP	Geographic Response Plan
HOE	Human and Organizational Error
ISM	International Safety Management Code
IMO	International Maritime Organization
ITOS	International tug of opportunity system
MCTS	Canadian Coast Guard, Marine Communications and Traffic Services
MSIS	Coast Guard Marine Safety Information System
MT WG	Marine Transportation Working Group
NM	Non-universal safety measures
NOAA	National Oceanic and Atmospheric Administration
NRDAM	Natural Resources Damage Assessment Model

OCNMS	Olympic Coast National Marine Sanctuary
OMS	Washington Office of Marine Safety
OPA 90	Oil Pollution Act of 1990
OSCM	Oil Spill Compensation Model
STCW	Standards for Training and Certification of Watchkeepers
TAPS	Trans Alaska Pipeline Service
TEZ	Tanker exclusion zone
TSS	Traffic separation scheme
UM	Universal safety measures
USACE	United States Army Corps of Engineers
USCG	United States Coast Guard
VLCC	Very large crude carrier
Volpe Center	Volpe National Transportation Systems Center
VTS	Vessel Traffic System
WAMS	U.S. Coast Guard Waterway Analysis and Management System

GLOSSARY

RISK TERMINOLOGY

Accident	Reportable marine casualty, including vessel impact with some other object.
Causality	Precursor event for casualty
Consequence	Result of net oil outflow from accident, after salvage and response efforts.
Hazard	As used herein, combination of accident type and causality.
Risk	Product of hazard likelihood and consequence.
Sensitivity	Susceptibility to damage from oil pollution.
Significance	Characterization of hazard accounting for its likelihood and the severity of its consequences.

MARINE ACCIDENT TERMINOLOGY

Allision	Impact of underway vessel with a fixed object other than the bottom.
Collision	Impact of underway vessel with another vessel.
Drift grounding	Vessel impact with ground, shore or bottom, resulting from lack of propulsion.
Powered grounding	Vessel impact with ground, shore or bottom while vessel is under power.

EXECUTIVE SUMMARY

On April 28, 1996 the White House issued the Department of Transportation (DOT) Action Plan to Address Vessel and Environmental Safety in Puget Sound-Area Waters. The Action Plan outlines several related tasks which comprise a three stage process. The first stage was to report to Congress on the development and implementation of a plan for a private sector international tug-of-opportunity system (ITOS) to provide emergency response in the waters off of the Olympic Coast National Marine Sanctuary and the Strait of Juan de Fuca. ITOS is primarily intended to prevent drift groundings--i.e., the accidental grounding of a vessel which has lost propulsion or steering. The Coast Guard issued its Report to Congress on January 31, 1997 and will issue an addendum to address pending ITOS items later this summer.

The second stage is the Secretary's review of the overall marine safety regime to determine whether other hazards--beyond those examined in the development of ITOS--warrant consideration of specific mitigation measures. This report has been prepared to facilitate the Secretary's review. The third stage will be to evaluate specific additional measures to mitigate hazards that may be identified for further consideration through the Secretary's determination or from the ITOS report.

This report is intended to provide the Secretary of Transportation with information relevant to possible actions to increase safety of the waterways of northwest Washington State, including Puget Sound, Strait of Juan de Fuca, passages around and through the San Juan Islands, and the offshore waters of the Olympic Coast National Marine Sanctuary. This scoping risk assessment is an initial characterization of the hazards which can cause oil spills by ships underway and the environmental sensitivity to such spills; deaths, injuries, and property losses are not accounted for in the consequences of accidents. As such, it is one step in a larger, iterative process in which refined methods and new data can be added and waterway safety periodically reviewed.

The risk assessment approach taken had three key aspects. First, the risk assessment blends quantified values derived from the best available data and qualitative assessments by local and national experts in marine operations, safety, and environmental science. The results, while expressed quantitatively, express relative values and contain a substantial element of subjectivity. Second, the waterway was divided into discrete "segments" for evaluation of their accident probabilities and environmental sensitivity. Therefore, the results are expressed in terms of "significance", denoting accident probabilities weighted by the severity of potential oil pollution consequences. Finally, the study assigns values only of relative risk of accidental spills within this waterway.

Accident likelihood and risk significance calculated herein cannot be used to make a quantitative comparison to other waterways. Such a comparison is difficult to make on the basis of accident rates, where local factors such as traffic patterns, hydrology and weather influence the data, and near to impossible for environmental consequences, where ground types, wind and currents, and local ecological factors are confounding. However, one study that did compare this waterway to others in the United States, the Port Needs Study, found that this waterway has a lower accident rate (accidents normalized by the number of transits) than the national average. Furthermore, research into oil spills for vessels underway during the period from 1986 to 1996 indicate a low spill rate, with only 10 spills greater than 50 gallons noted. This assessment that the waterway is relatively safe was echoed in the comments of the Expert Panel that assisted in preparation of this study, although specific weaknesses were identified. However, the Expert Panel also noted large consequences should oil be spilled in the region, thereby offsetting the lower likelihood to some degree.

The future of waterway risk management is addressed by an analysis of waterway hazards and the corresponding safety measures, both existing and proposed. These comparisons suggest general strategies, but the effectiveness of specific new measures is not characterized.

The substantive findings follow.

Risk assessment

- The northwest Washington State marine waterway has extraordinary environmental, aesthetic, economic, and cultural significance. It also features complexities of vessel traffic flow, weather, geography, hydrography, and governmental jurisdiction. Native American treaty interests also present an important waterway management challenge. The hydrography here is quite severe relative to other waterways because of large tidal heights and strong currents, and has significant import for accident causality as well as spill consequences.
- Relative to other areas of the waterway, the highest probability of accidents which could result in serious oil spills is in Puget Sound from Admiralty Inlet to Tacoma. Second highest are Rosario Strait and the associated terminal approaches, and the offshore approaches to the western entrance to the Strait of Juan de Fuca. In the latter case, the likelihood of such accidents is roughly half of that found in Puget Sound. The accident types most likely to cause a spill are collisions and both powered and drift groundings. Human and organizational error (HOE; the influence of individual and/or group behaviors/performance on accident rates) is the most likely causal factor, followed by conflicting vessel operations (e.g., high traffic density, crossing traffic), and severe environmental conditions (e.g., visibility, wind, width of traffic lane). These results were based on both Expert Panel input and casualty data for all vessel types. Checks on the resiliency of these results were made taking into account the oil capacity (bunker and cargo) of vessel types, which found consistent results when focusing on casualty data for large oil capacity vessels. This re-analysis is described in Appendix D.
- All areas of the waterway are highly sensitive to oil spills because of the richness and diversity of marine life, the economic and cultural value of fin and shell fisheries, and aesthetic and recreational values. The "net consequence" ratings had a wider range because of variations in spill response resources and the environmental and weather conditions under which response operations must take place.

- Risk, as measured by accident probability and likely consequences in the event of accidental oil spillage, is highest in Puget Sound from Admiralty Inlet to Tacoma, due mainly to high traffic density and the preponderance of historical accidents there. Rosario Strait and its contiguous waters have approximately the same risk rating, due to a combination of high accident likelihood and high environmental consequence rating. The highest environmental sensitivity rating drives the high consequence rating, in spite of effective response resources there.
- The next highest risk area is the waters offshore from the Washington and Vancouver Island Pacific coast. Environmental sensitivity is the second highest here and net consequence the highest, because of the obstacles to performing spill response in extremely difficult conditions. The relative likelihood of an accident resulting in a serious oil spill is above average for the waterway, due to proximity of the traffic lane to shore, congested traffic at the entrance of the Strait of Juan de Fuca and the most severe weather and sea conditions in the study area.
- The entire Strait of Juan de Fuca was found to be at average risk for the waterway. Lower Puget Sound (Tacoma to Olympia) and eastern Puget Sound (Everett/Skagit Bay) drew low risk ratings. The waters west of the San Juan Islands (Haro Strait and Boundary Pass) were rated at lower than average risk. This result is artificially low due to the lack of specific accident data from Canadian waters in that area. It is likely that the risk in Haro Strait is roughly equivalent to that in Rosario Strait.

Risk management

Accident prevention

- Spill prevention must be the main focus of a risk management strategy. In spite of advances in response technology, most spilled oil remains in the environment even under the best cleanup conditions.
- There are a great many safety measures in place addressing human and organizational error, including personnel licensing, work-rest rules, and such new measures as the revised Standards for Training and Certification of Watchkeepers (STCW) and impending International Safety Management (ISM) Code requirements. However, statistics and expert judgment find that HOE remains the dominant safety challenge in the waterway. This suggests that improved enforcement of those measures may be a potential corrective course, particularly while long term internal cultural changes in industry come to fruition in response to new national and international initiatives.
- Conflicting operations are currently addressed by eleven external control, equipment, and procedural measures. Commercial cargo traffic is, for the most part, well controlled, particularly in light of human performance measures now coming into effect. Among the possible risk reduction measures, enhanced qualifications and licensing for presently unregulated vessel operators (recreational and small fishing boats) were noted by the Expert Panel as possible measures to improve safety in the densely populated eastern waterway, where recreational boating is a concern,

and in the offshore areas, where fishing vessel concentrations can exacerbate other traffic problems.

- Severe environmental conditions (e.g., visibility) emerged as a high risk item, particularly in the offshore area and in Rosario Strait. One possible mitigation measure is improved monitoring and reporting, e.g., better marine weather reporting.
- High risk ratings for HOE, conflicting operations, and severe environmental conditions in the offshore waters suggest that the traffic management system there be re-examined. Several special area designations have changed in that area since the original traffic separation scheme was put in place. The relatively high risk profile there (confirmed by the incidence of serious spills over the last 25 years reported by Washington DOE- three out of the ten spills greater than 10,000 gallons since 1970 were in the approaches to the Strait) indicates the need for a system review.
- There is an overarching need for better accident, causality, and incident data. No maritime data base has been found which satisfies the need for detailed insight into accident growth from root causes to impact. All safety managers in the area should work together on an improved, common basis for data management.
- The Coast Guard and other waterway managers should investigate the possibilities for enhanced public involvement in waterway safety. A properly chartered citizens' advisory committee could have a positive influence, although care would have to be taken to avoid complications in a complex jurisdiction.

Spill Response

- Enhanced salvage capability, defined to include fire fighting, structural patching, ballast adjustments, lightering and towing, was identified by the Expert Panel as an effective measure in spill mitigation, benefiting all areas of the waterway.
- Several measures were identified as having potential to improve outer coastal response capabilities and reduce spill risk, including dedicated spill response assets and more expeditious procedures for approval and use of alternate spill response technologies. These and other potential additional measures are listed in Appendix G.

Future trends

Maritime Traffic

- Projected commercial trade and traffic trends were briefly reviewed to assess their effects on the results obtained in this study. While great concern over tanker demographics shifting to more foreign flagged vessels as a result of the lifting of the Alaska North Slope Export Ban was expressed, no evidence was found which supported these predictions. Instead, Puget Sound and other West Coast ports will likely continue to be the primary destination for oil from Prudhoe Bay, due to transportation economics and various other issues. As this requires the use of U.S. flagged vessels (due to Jones Act requirements), foreign flags will likely remain the exception rather than the rule.

- The dry cargo trade (largely with Pacific Rim nations) was also reviewed. Although increased trade volumes are expected for the waterway as a whole, this does not necessarily mean an increase in the number of vessels (and therefore collision risk). Instead, dry cargo vessels have the flexibility to meet increased trade with increased capacity, not having the size restriction imposed on tankers. With larger vessels, therefore, transits may remain relatively constant. As such, risks should remain relatively constant as well, given a concomitant increase in vessel capabilities.

Safety Management

- Two primary safety management measures targeting HOE, the ISM Code and the STCW are currently in various stages of implementation. While the STCW targets individual (mariner) errors, the ISM Code, which requires use of safety management systems, targets the organizational influences on safety and environmental protection. These measures should serve to reduce the risks due to human and organizational errors, although the degree to which they will reduce is unknown.

Spill Likelihood

- Review of national spill statistics show downward trends in terms of the spill rate (spills normalized by volume of oil transported). While similar analysis for the Puget Sound area waterway is impossible (due to the low incidence of spills), this does indicate an increasing effectiveness of efforts to minimize pollution.

Spill Consequences

- Although trends in pollution sensitivity were not examined in the course of this study, increasing consequences were identified. These consequences, arising from direct users (e.g., tribal fisheries and marine transportation) and indirect users (e.g., businesses using the beauty of the environment as a draw for prospective workers), will be directly linked to the growth in trade and population for the region.

CHAPTER 1 - INTRODUCTION

This is the report of a study conducted by the Volpe National Transportation Systems Center and the United States Coast Guard for the Secretary of the Department of Transportation. The analysis and findings herein constitute an initial risk assessment to assist the Secretary in directing future efforts to characterize the waterway and to provide the safest possible marine transportation system.

1.1 Project history

The Alaska Power Administration Asset Sale and Termination Act, P.L. 104-58, was signed into law by the President on November 28, 1995. It allows overseas export of Alaskan North Slope crude oil, removing the original legislative stricture on such shipments. Congressional inquiry following the Act's signing into law focused on concerns of changes in maritime traffic patterns, particularly the potential for an influx of oil on foreign tankers. The President responded to this concern by issuing a directive to the Secretary of Transportation to study the safety of maritime transportation through certain Washington State marine waters.

In response to the Presidential directive, the Office of the Secretary of Transportation (OST) developed an action plan which identified two projects: 1) a study on a new public/private safety initiative, the international tug of opportunity system (ITOS); and 2) a scoping analysis of the complete marine transport and safety systems, and of the risk due to oil spills. The first project, completed by the Coast Guard in February, 1997, addressed "saving" stricken merchant ships (most likely in a drift grounding scenario) in the Strait of Juan de Fuca and adjacent waters. This document reports on the second project.

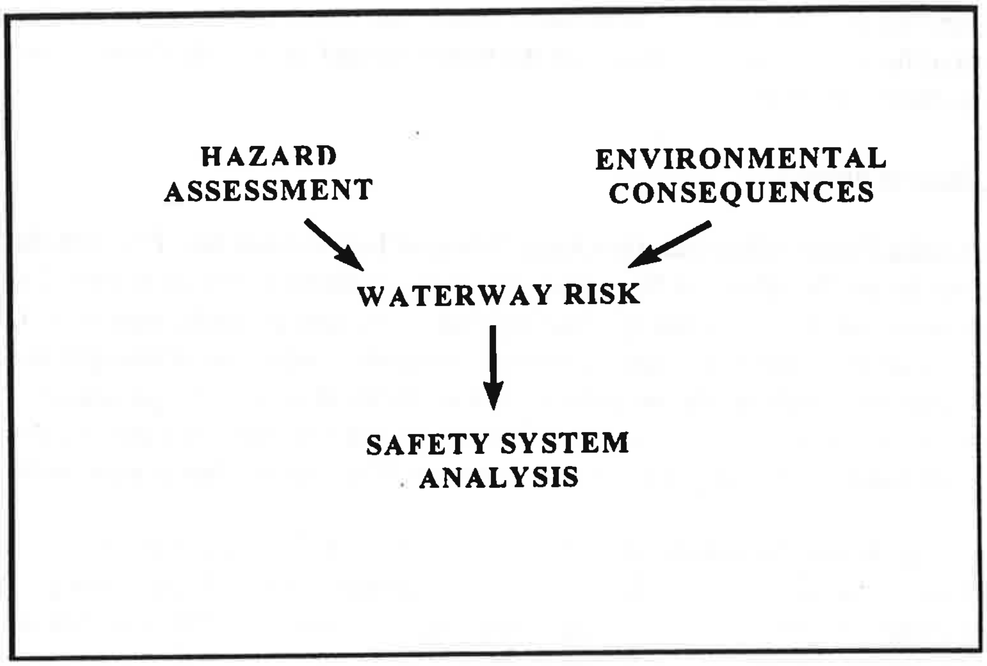
1.2 Organization of report

The report is organized as follows:

- Chapter 1—Introductory and background material
- Chapter 2—Description of methodology
- Chapter 3—Characterization of the waterway
- Chapters 4, 5, and 6—Risk assessment
- Chapter 7—Future trends and analysis of sensitivity
- Chapter 8--Findings

The general approach is as depicted in the following diagram.

Figure 1-1
General approach



1.3 Background

The marine waterways and adjacent coastlines of the State of Washington and the Province of British Columbia have always been vital to the social and economic well-being of the region's people. Waterborne trade powers the regional economy but brings with it an element of risk. The mariner has always known of the risk to ship and crew, but the aspect of environmental damage has only recently come into focus.

The post-war economy has been dependent on progressively higher levels of oil consumption, which have brought the danger of the catastrophic oil spills first seen worldwide in the late 1960s. The Alaska Pipeline opened in 1977, bringing a reliable supply of domestically produced oil to the United States west coast. Increased flow of bulk oil along with trade of other commodities, carried in larger and more numerous ships, has increased the exposure of the marine environment to oil pollution.

All who use and enjoy the resources of this unique waterway have concern for its protection, but none more so than the Native American nations living in coastal areas. They have relied on the marine and coastal resources of the Pacific Ocean for thousands of years for their cultural and economic well-being. When the Makah Nation states that these coastal resources have value for them beyond quantifiable or material description, they also voice the heartfelt sentiment of many others who live in or who have visited the region.

The coastal and inland marine waters of Washington State are among the most environmentally rich and sensitive in the United States, including high environmental and aesthetic values and important fin and shell fisheries. These waters comprise one of the nation's busiest waterways, serving the robust and growing economies of the United States northwest region and Canada's British Columbia, particularly in trade with the Pacific Rim. Complexity abounds in this waterway, in terms of traffic types, volumes, and patterns, its international nature, utilization by Native American tribes, and its environmental sensitivity.

Fear of catastrophic spills in the region, similar to TORREY CANYON and AMOCO CADIZ, began with the onset of the flow of North Slope crude oil through its waters to terminals in Puget Sound. Washington State first enacted oil tanker regulations which were later incorporated into the Code of Federal Regulations (CFR) by the Coast Guard.

Later, in the aftermath of the EXXON VALDEZ accident in Alaska, the International Maritime Organization (IMO), the United States, and Washington State put a panoply of significant new safety regulations in place. No less significant are the internal cultural changes which have reshaped the safety regime of many tank vessel operators (an expert panel assessing the overall effectiveness of the 1990 Oil Pollution Act found that the pollution liability provisions were its most effective measure). Even so, the Export Act raised anew concerns about shifts in the patterns of vessel traffic in the region and the possible implications for safety and oil spills.

Accidents and serious oil spills in the United States have abated in recent years[47]*, but the perception of substantial risk remains in spite of regulatory and private sector measures. Serious, and in some cases catastrophic, oil spills still occur with regularity worldwide. Worries about substandard owners, operators, flag states, classification societies, and protection and indemnity clubs persist. Both the Alaska Oil Spill Commission[1] and Wenk[52] concluded that the world megasystem of oil transport, including the regulatory apparatus, needs careful scrutiny in all its aspects. The implications for possible joint management of the waterway include the complication of an already complex situation; there is, however, a undeniably positive role for a citizen's advisory committee to play.

It is an in escapable fact that incidents and accidents can take place even with the best technology and human capabilities in place. Studies in the United Kingdom following the BRAER spill concluded that even the best men, equipment, flags, port states, and navigation aids will not eliminate the threat of a spill while ships "pass or trade while upon their lawful occasions"[13]. The question then is how to reduce the risk of such occurrences as logically and effectively as possible.

* References are alphabetized by author and numbered. Citations do not appear in numerical order.

Industry and regulatory agencies must insure safe operations in a climate of limited resources and greater public expectations. Symptomatic of the former trend is the merger of the Washington State Office of Marine Safety (OMS) with its Department of Ecology (DOE). In addition, the Coast Guard is using its Risk Based Decision Making Guidance, recently issued to field units, to maximize marine safety and environmental protection effectiveness in a time of constrained resources.

The Puget Sound waters are among the safer waterways in the United States. The Coast Guard Port Needs Study conducted in 1991 concluded that historical and predicted accident rates for Puget Sound were approximately 12.75 per 100,000 transits, at the low end of the spectrum for the largest ports (New Orleans was highest at 220/100,000). Yet the consequences of a major spill in this waterway could be among the highest anywhere in the country. It is for the latter reason that the President issued the directive and for the same reason that renewed study and review are worthwhile.

1.4 Scope and objectives

The aim of this report is to identify and rate risk throughout the Puget Sound waterway system and to suggest avenues of improvement, or risk reduction. The reader should bear in mind the following basic definitions.

Risk = accident likelihood X consequence

Accident likelihood: probability of accidents based upon exposure to hazards

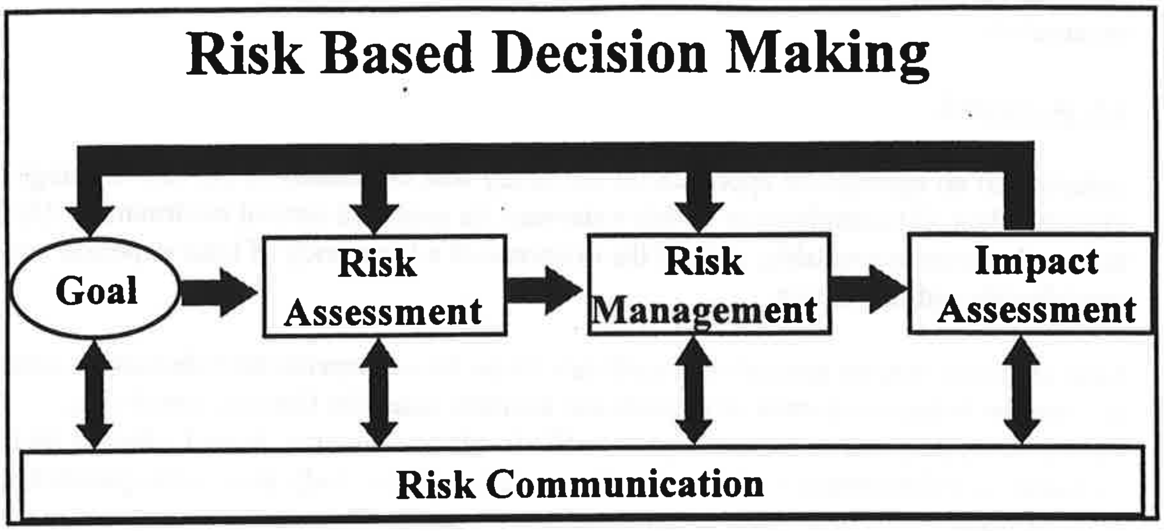
Consequence: undesirable outcomes of accidents; in this case, environmental damages

The primary objectives of the study were the following:

1. Provide an initial assessment of risk on the basis of a geographic distribution in the waterway.
2. Identify gaps in the waterway safety system.
3. Identify safety issues for further risk management study and analysis.

Steps 1 and 2 describe the current state of the waterway and yield a ranking by risk of the hazards. In so doing, the analysis makes use of "universal" hazards and safety measures (those affecting the entire waterway) and those whose effects are localized. The result is the identification of problem areas, and candidate solutions (Step 3) for which later detailed study of new measures may be fruitful. The process is illustrated in Figure 1-2. This study brings the Coast Guard and the Department of Transportation to the threshold of the risk management phase.

Figure 1-2
Risk based decision making



The scope of the study is focused on the risk due to underway accidents leading to serious spills involving all types of oil, including all cargo oils and commercial vessels' bunker fuels. Spills resulting from accidents in transfer operations occurring at facilities and during lightering and bunkering are not included. Nor does the study address loss of life, injury, or United States Navy spills. The nature and management of those risks are entirely different from underway merchant vessel spills.

The consideration of candidate safety measures is limited to matching of the measures to the risk-ranked list of hazards and identifying promising measures for further study. Cost-benefit and technical feasibility analyses are not part of this study; it includes no detailed assessment of ITOS or new measures. The details of an expert panel's discussions of this subject are included in the appendices and are available for later use.

The subject waters are Puget Sound, the Strait of Juan de Fuca in its entirety, the Olympic Coast National Marine Sanctuary (OCNMS), and the passages around the San Juan Islands north to the Canadian border, including Haro and Rosario Straits. The offshore area is the overlay of the Olympic Coast National Marine Sanctuary and the International Maritime Organization's (IMO) designated Area to be Avoided (ATBA), as well the northern and southern approaches to the entrance of the Strait of Juan de Fuca. In short, the study included all the waters involved in substantial maritime trade in the State except for the Columbia River waterway. They are collectively referred to in this report as the "waterway". The chartlets included herein all show the area of study.

It is noteworthy that the project team received many suggestions that the area of consideration be contracted to focus on perceived high-risk areas. Instead, our approach has focused from the start on an investigation of the entire waterway where substantial commercial vessel traffic poses risk. The result is the more useful for this broad view as it illuminates disparities between risk and the safety system. In a.Jd. .ion, an important product of the study is a waterway risk model which the Captain of the Port (COTP) Puget Sound, Coast Guard 13th District,a d Coast Guard Headquarters can update and use as future traffic and accident data accumulate.

1.5 Approach

Selection of an appropriate approach for this study was influenced by (1) shortcomings in available data, (2) complexities of this waterway, its uses, and natural environment, (3) the time and resources available, and (4) the existence of a large body of local expertise and considerable public interest.

First, available marine casualty and spill data alone do not provide the information necessary to draw the definitive picture of hazards and accident causality that one would like. Furthermore, they reflect the past--prior traffic levels and patterns, hazard, climate, and safety measures--not the present or future conditions. Second, the study area encompasses diverse types of waterways (from open ocean to narrow passages), uses and users (e.g., recreational and fishing vessels and the heaviest ferry traffic in the U.S.), hydrological conditions, weather, and ecology. To characterize all this would require amassing a staggering amount of information.

Given the considerable interest and active involvement of public and private entities and individuals, it made sense to promote wide involvement and contribution to this assessment in an open public process. Therefore, a cornerstone of this approach was reliance on local knowledge of these waters, hazards as they exist today, and proposals to enhance safety.

The elicitation of local expertise had two elements:1) public input through workshops and Coast Guard dockets to comprehensively list known hazards and suggested safety measures; and 2) the judgment and opinion of both local and nationally recognized experts in assessment of marine risk from oil spills. Other researchers have found this approach indispensable in the study of a particular waterway[19]. A three-day meeting brought this expertise to bear on the problem of determining which hazards were more significant, where the more sensitive environments were located, and, thus, where the greatest risks lie and what might be done to reduce them.

Available data for vessel traffic, crude oil and product flows, and accidents and spills were used, of course. Environmental damage assessment models were also used to estimate impact data. Such data, however, were not the sole or even primary foundation of this risk assessment. They were treated as another source of information, no more important than local knowledge or expert judgment.

The approach to this assessment was to blend all appropriate types of information, both objective and subjective, into as balanced and comprehensive evaluation of the situation as possible. It is an adaptation using elements of standard reliability and risk analyses. Specifically, a Bayesian method was employed, in which prior estimates, in the form of expert judgment, were updated with relevant data. Public meetings and workshops in the local area were effectively used to elicit critical subjective information. A means of combining objective and subjective data was developed so that this information was not relegated to background material--it was used analytically, along with objective data and model estimates to derive the study findings. As such, this triad approach was the best way to draw the risk/safety picture for the subject waters under the circumstances.

Another principle feature of the approach was the division of the study area into nine segments (see Chartlet 3-1). This was done for two reasons. First, comparisons among the segments made it possible to locate where the hazards, accident rates, and environmental impacts are the greatest and where response conditions and capabilities are the poorest--that is, where the risks are highest. This, in turn, focuses attention on the appropriate part(s) of this large area. Second, segmentation helps simplify some of the complexities of the study area. As a result, traffic, weather, hydrographic conditions, and other characteristics become more homogenous for a given area and therefore more easily described/measured and incorporated into the analysis.

Additional details on the approach and risk methodology are found in Appendix A.

1.6 Future prospects

The development of this study has gone forward with the knowledge that it is one step in an ongoing waterway risk management process by the Coast Guard and the Department of Transportation. As such, the approach has many parallels with that outlined in the Coast Guard's Risk Based Decision Making Guidelines. Among the products of this project is a set of Microsoft Excel files containing data, expert judgment and the analysis, which the Coast Guard Captain of the Port (COTP), Puget Sound will have for future risk management efforts. These files will allow the COTP to continually update the analysis with new accident data. The Marine Safety Office Puget Sound will have a significant advantage in analyzing and improving waterway management in comparison to other port areas.

CHAPTER 2: METHODOLOGY

2.1 General

Given the complexities and limits of the study, the approach adopted has the following elements:

- Relative. The significance of the various elements of risk are treated in relative, not absolute terms; and
- Qualitative and quantitative. A blended rating algorithm combines expert knowledge, data, and model outputs.

The methodology required the following steps:

- Incorporate all considerations that form the total picture: all perceived hazards (both universal and localized), the full range of impacts of spills on the environment, all current and proposed safety measures.
- Decompose this complex issue into a set of narrow, answerable questions. Then, aggregate those answers into overall 'truths.'
- Apply the best information readily available to answer each question; where appropriate, blend information from multiple sources (e.g., two different damage assessment models).
- Use local knowledge, expert judgment, and stakeholder input wherever appropriate.
- Make the methodology totally open, easily understood, and readily modified in response to inputs/reviews.
- Where appropriate, use weighting to reflect the relative importance of several factors or the relative confidence/relevancy of multiple sources of information.

The fundamental approach to conducting this comprehensive, qualitative analysis was to decompose this very complex issue into a hierarchy of narrow, and therefore, addressable questions. Each of the basic elements of the risk assessment were broken down into questions limited enough in scope such that either data, local knowledge, or expert judgment could be applied to provide an answer. For example, the waterway itself is a complex of channels, islands, traffic lanes, and ports. In order to identify the most serious hazards throughout this complicated waterway, it was first divided into areas of fairly homogenous traffic, called segments. Assessing the significance of hazards in each of these segments separately was more tractable than tackling the entire waterway as a whole. Results from the segment assessments are then compared to develop an overall picture of hazards in the waterway.

To combine the answers to these narrow questions into an overview of hazards and the effectiveness of safety measures, a rating and conversion methodology is utilized. Subjective information is defined in terms of a 1-5 scale (known as a Likert scale). For example, typical spill response conditions for a given segment might be rated a 5 ("very good") compared to study area as a whole (a 3, or "average"). When a set of subjective ratings is to be combined with a set of numerical information (e.g., dollar damages/segment), the latter is converted to a 1-5 scale in which the maximum value becomes 5.0 and the minimum a 1.0.

On the other hand, when conditional accident probabilities/likelihood are involved, both subjective and objective information are converted to a 0-1 scale (proportional scale) whereby each value is divided by the sum of the set. This makes the sum of accident likelihood ratings sum to 1.0, which is appropriate. When information expressed in a proportional scale is to be combined with subjective information expressed by the Likert scale, the latter is first converted to a 0-1 scale (using the same transformation as for numeric data) to obtain a neutral weighting. Use of this rating and conversion methodology does the following:

- Permits blending of disparate forms of information (e.g., numbers of accidents and spills that occurred in each segment during the past decade and expert judgment on the relative likelihood of an accident for each segment).
- Highlights the comparative nature of the analysis and makes it more comprehensible (results at each stage are converted into a standard set of relative terms). This study gives broad insights into waterway safety, but the quantitative results should not be taken as hard statistical analysis, particularly for detailed scenarios.

The chosen methodological approach and analytic principles and techniques became the basis for defining the tasks and task flow described below.

2.2 Analytic tasks and task flow

2.2.1 Segmentation of the study area

Before the formal analysis could begin, the waterway had to be divided into segments. There were two reasons for this. First, the waterway had to be divided spatially so that a comparative analysis could determine where the greater risks lie. Second, the study area is extremely complex and must be divided into somewhat homogenous areas to be analytically manageable. The geography is complex, comprised of open ocean, a wide strait, relatively narrow passages and a large junction area.

The study area also encompasses a wide variety of natural environments and species that could be affected. Finally, the pattern of large vessel traffic and flows of crude and product is complicated. The study area was divided into segments characterized by roughly constant traffic density, following logically the traffic flows and geographic forms of the waterway.

Some segments contain a single traffic route, beginning and ending at junction points. For example, Segment #1 is the northern approach to the Strait of Juan de Fuca, ending at the J buoy, Segment #2 the southern approach and so on. In all, nine segments were defined (see any of the chartlets included herein). Areas with low traffic levels and/or little or no tank vessel activity were excluded On that basis, the Hood Canal was not included although it was considered for environmental impacts resulting from a spill in segment 7.

For each of these segments, the study addressed hazards, environmental impacts of spills, risks, and current and proposed safety measures that apply. An overview of this study methodology is shown in Figure 2.1 below; details are given in Appendix B. The study was comprised of four related steps:

1. Determination of the significance of segment hazards
2. Estimation of spill consequences
3. Weighting of hazards by the risk posed
4. Assessment of current and proposed safety measures

Each of these are discussed in sections that follow.

2.2.2 Determination of the significance of segment hazards

Hazards in each segment are identified and ranked by the likelihood of causing significant spillage relative to other segment hazards. Hazards are defined as major causal factors for commercial vessel accidents, by type of accident, that could result in spillage of either bunker fuel or crude or product cargo. A generic list of hazards was derived from a combination of information from expert opinion, vessel casualty databases, and public input. The resulting list of 20 hazards appears in the Figure 2-2.

For each segment, the number of occurrences caused by each hazard over the period 1986-1996 were recorded and then converted to a relative frequency (probability) rating using a 0-1 scale. These ratings for a segment were weighted by the relative likelihood of a spill accident occurring in the segment compared to the waterway as a whole. This was derived for each segment by averaging the relative accident probability and relative spill probability for the past 10 years.

Similarly, expert judgment on the relative frequency of occurrence of the various hazards in a segment was weighted by the expert panel opinion on the relative likelihood that an accident would occur in a given segment (see Section 2.3 for discussion of the Expert Panel). Overall significance of each hazard for a segment was derived by simply averaging the results from the historical data and the experts and expressing that on a 0-1 scale where the higher the number, the higher the relative significance. Values were calculated for a table like that shown in Figure 2-2 (see Chapter 4 for results).

Figur 2.1
Methodology for assessing maritime hazards and safety measures

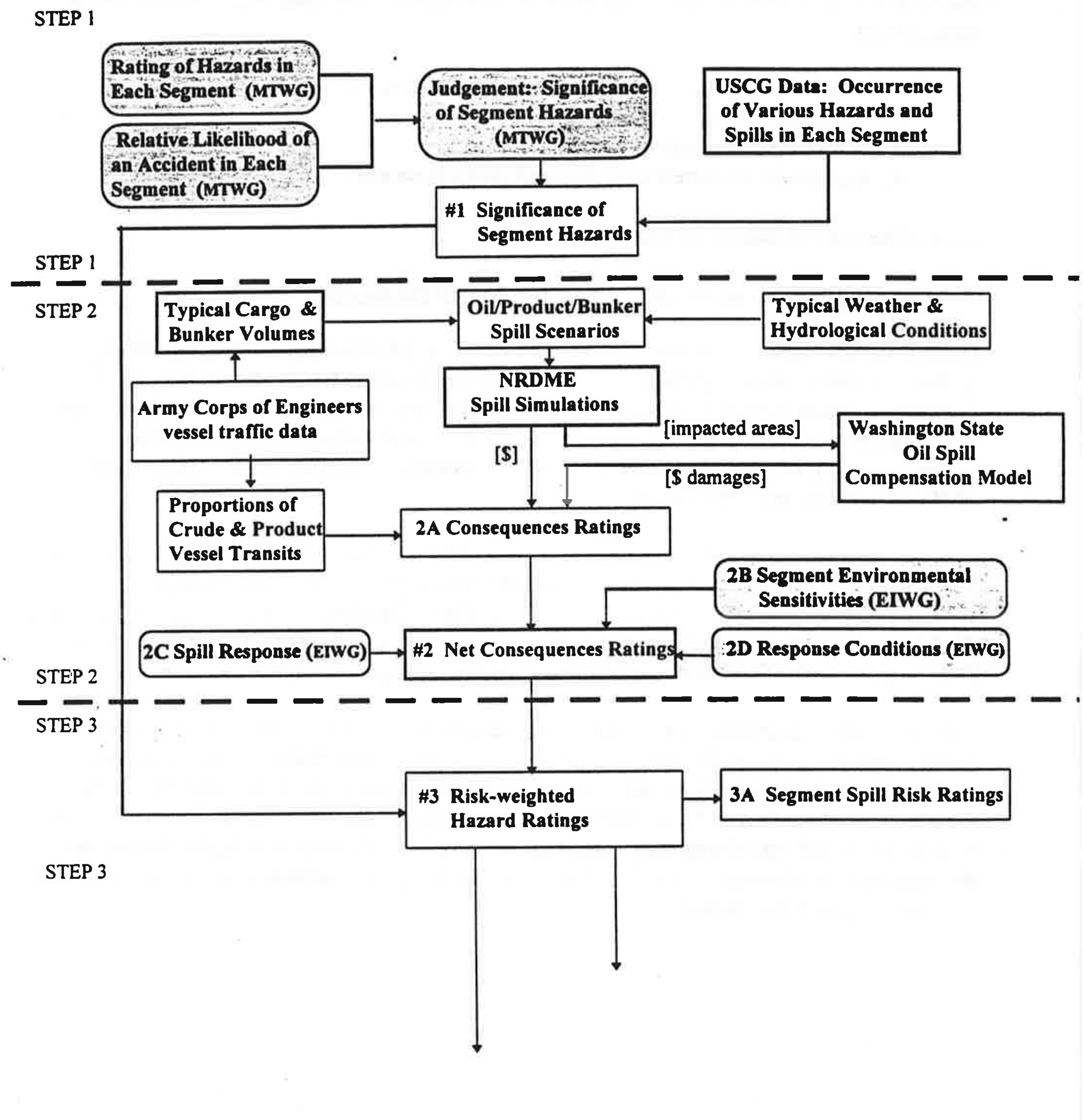


Figure 2-1 (continued)

Methodology for assessing maritime hazards and safety measures

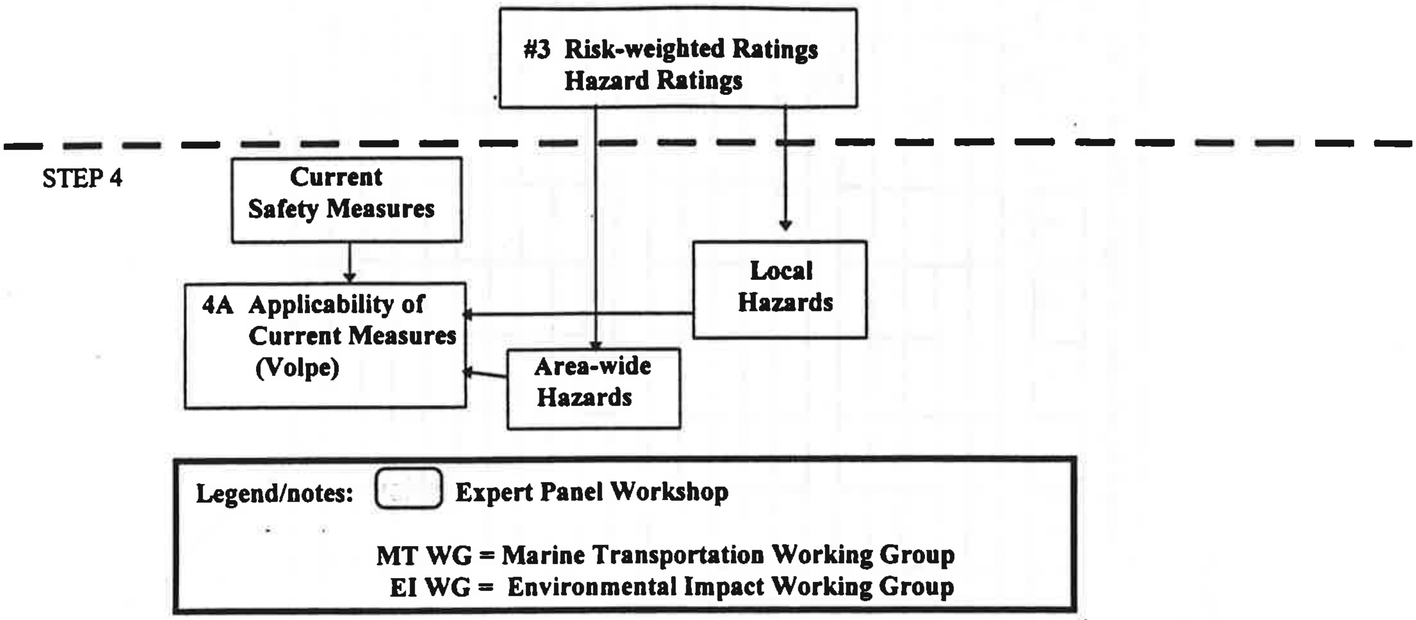


Figure 2-2

Significance of Segment Hazards

Hazards		Overall Significance of Segment Hazards (HS)								
		1	2	3	4	5	6	7	8	9
FACTORS IN COLLISIONS (C)										
C1	Poor Positional Information -									
C2	Vessel Control and Other Deficiencies & Failures									
C3	Human and Organizational Deficiencies-									
C4	Conflicting Vessel Operations -									
C5	Physical Features -									
FACTORS IN POWERED GROUNDINGS (P)										
P1	Poor Positional Information -									
P2	Vessel Control and Other Deficiencies & Failures									
P3	Human and Organizational Deficiencies-									
P4	Conflicting Vessel Operations -									
P5	Physical Features -									
FACTORS IN DRIFT GROUNDING (D)										
D1	Poor Positional Information -									
D2	Vessel Control and Other Deficiencies & Failures									
D3	Human and Organizational Deficiencies-									
D4	Conflicting Vessel Operations -									
D5	Physical Features -									
ALLISION										
FIRE/EXPLOSION										
STABILITY FAILURE										
STRUCTURAL FAILURE										
OTHER										

Arithmetic average of the Significance of Segment Hazards based on (1) USCG casualty data and (2) the voting of the Marine Transportation Working Group, where the higher the value, the greater the significance.

2.2.3 Estimation of Spill Consequences

Environmental damages from representative spills in each segment were estimated. These results were combined with expert judgment of environmental sensitivities for each segment to determine the relative consequences of a spill. The performance of spill response for the segment was then considered in arriving at a final rating for relative net consequences of oil spills for each segment. . The methodology for obtaining net consequence ratings is illustrated in Figure 2-3--findings are presented in Chapter 5.

Environmental damages/losses from representative spills were estimated using two damage assessment models, NRDAM (Natural Resources Damage Assessment Model from the U.S. Department of Interior/NOAA) and the Washington Department of Ecology (DOE)model used by the State of Washington. Spill scenarios for tank vessels were defined for each segment that reflected the nature of crude and product traffic, size of compartments, likely accident locations, and typical weather and hydrographic conditions. Scenarios for a bunker fuel spill of 10,000 gallons were also defined for each segment. The NRDAM model was run for all scenarios for spills in both the winter and the spring and dollar damages calculated. Two seasons were used to get a better idea of year round consequence. NRDAM projections for areas impacted were also subjected to the DOE model to obtain a second estimate of damages.

Results for spills of bunker, crude and/or product were combined to obtain an overall estimate of damages for a segment. In this process, crude and product damages were weighted by the proportion of those transits to the total transits of large commercial vessels. Damage estimates were converted into a 1-5 scale in which the lowest estimate was assigned a rating of 1 and the highest a 5. Ratings for the NRDAM and DOE models were averaged to obtain a composite rating for each segment for relative consequences of spills.

Environmental sensitivities for each of the segments were also estimated as a second way of assessing the consequences of spills. Expert judgment was used to rate the sensitivity of each of seven environmental categories for each of the nine segments, using a 1-5 scale where the higher the number, the higher the sensitivity (see Section 2.3 for discussion of the Expert Panel). Ratings for the seven categories were averaged to obtain an environmental sensitivity rating for the segment as a whole.

Relative effectivenesses of spill mitigation and cleanup in each segment were also evaluated by the experts-- both the relative quality of response (time and equipment on scene) and typical weather and hydrological conditions were considered. Spill containment and recovery, defensive measures to protect particularly sensitive areas, and vessel/cargo salvage were rated for both the assets available in the segment and the time it would take to bring those assets to bear.

Figure 2-3

Net consequences rating

Segment	2A Consequence Ratings NRDME (C_1)	WA Model (C_2)	Composite Rating $[(C_1 + C_2)/2 = C_C]$	2B Environmental Sensitivity (ES)	2C Spill Response (<SR>)	2D Response Conditions (<RC>)	Net Consequence Rating $[(3(C_C+ES)/2 + \langle SR\rangle + \langle RC\rangle)/5 = C_N]$
1							
2							
3							
4							
5							
6							
7							
8							
9							
average							

The rating from the worksheet is inverted about the mean for all segments to align the scale's orientation with those of 2A and 2B in which the higher the number, the worse the consequences. Note: The symbol <> denotes the inverted values.

A weighted average is used to obtain the overall rating in which the average of 2A and 2B, the consequences and sensitivity ratings, is deemed most significant. This is given a weight of 3. The effects of 2C and 2D are to somewhat increase or decrease the consequences of a spill and are each weighted 1.

Range of allowable values is from 1.0 to 5.0, where the higher the score, the higher the relative net consequences.

Segment ratings based on the environmental damage models and expert judgment were combined to obtain a net consequence rating. The composite consequence rating from the two models was averaged with the environmental sensitivity rating to obtain an overall consequence rating. This was adjusted by the ratings for segment spill response capability and typical response conditions to obtain a net consequence rating for the segment. A weighted average was used in which the consequence rating counted three times as much as either of the latter two ratings.

2.2.4 Weighting of hazards by the risk posed

In order to identify those hazards that most threaten the environment, it is necessary to weight them by the consequences should they occur and then rank order the result. In step 1, the significance (likelihood) of each of the generic list of 20 hazards was rated for each segment. In step 2, the net consequences of a spill in each segment was rated. Multiplying the significance rating by the net consequence rating yields a risk-based rating for each hazard, called the weighted hazard significance. This process is illustrated in Figure 2-4.

The weighted hazard significance totaled over all the segments is used to rank order the hazard list for the waterway as a whole. Thus, hazards near the top of the list (greatest weighted significance) are those of most concern throughout. The weighted hazard significance ratings for the various segments are used to create a ranked list of particularly significant local hazards, or "hot spots," which also deserve attention. The ranked list of hazards will be available for future use in the assessment of current and proposed safety measures.

Figure 2-4
Risk-weighted hazard ratings

Hazard	Segment 1 (Net Consequences, C_{N1} =)		Segment 2 (Net Consequences, C_{N2} =)			Waterway Total
	Hazard Significance (HS_1)	Weighted Hazard Significance [$WHS_1=HS_1*C_{N1}$]	Hazard Significance (HS_2)	Weighted Hazard Significance [$WHS_2=HS_2*C_{N2}$]		Weighted Hazard Significance [$WHS_1+WHS_2+...$]
FACTORS IN COLLISONS (C)						
C1 Poor Positional Information						
C2 Vessel Control and Other Deficiencies....						
C3 Human and Organizational Deficiencies						
C4 Conflicting Vessel Operations						
C5 Physical Features						
FACTORS IN POWERED GROUNDINGS (P)						
P1 Poor Positional Information						
P2 Vessel Control and Other Deficiencies						
...						

Values are used to produce a risk-ranked list of local hazards. For example -
#1 C2, segment 4
#2 D1, segment 7
#...

Values are used to produce a risk-ranked list of area-wide hazards.

2.2.5 Assessment of current and proposed safety measures

Before addressing measures proposed to enhance safety, an assessment of those measures already in place (or about to be implemented) is necessary. A compendium of existing laws, regulations, standard practices and other requirements promulgated by international agreement, federal, state and industry was created (see Appendix D). They were separated into two sets, those that apply uniformly throughout the study area (called "universal") and those that do not (called "non-universal"). The large number of safety measures was made manageable by grouping them into 22 categories, 11 universal and 11 non-universal.

To determine how current measures target the more serious hazards, hazards-measures matrices were created, one of which is shown in Figure 2-5. The applicability of each category of accident prevention measures to each of the (risk-ranked) list of hazards and the top "hot spots" (local hazards) was determined. The resulting picture shows whether or not the hazards of most concern are being addressed by current safety measures. In a similar fashion, the applicability of measures intended to mitigate the consequences of a spill accident were determined for five spill consequence factors: amount spilled, proximity of spill to sensitive resources, amount recovered, defensive protection, and restoration.

A listing of proposed measures was created from several sources, including public meeting transcripts and available literature. The experts organized these and additional nominations for accident prevention measures into nine categories. Then, they judged the general effectiveness of each of these categories of measures for each of the nine waterway segments through an allocation voting process, as detailed in Figure 2-6. Each expert also picked the five most important specific measures (not categories) and, then, the single most important measure. The environmental and spill response experts also produced a list of proposed measures, though not categorized because they were relatively few in number. They judged the effectiveness of each measure for each of four consequence factors, as illustrated in Figure 2-7.

The experts' findings were not formally incorporated into this report because the risk management aspect will be in the scope of subsequent efforts by waterway managers. The findings are available in the appendices to this report.

<u>Figure 2-5</u>

Applicability of current safety measures for accident prevention: Universal safety measures

Risk-ranked Hazards	Universal Safety Measures (UM)								
Area-wide	1	2	3	4	5	6	7	8	11
1									
20									
Local									
1									
10									

UM1 Crew proficiency and vessel manning
UM2 System requirements
UM3 Vessel screening
UM4 Systems status, testing/inspection & checks
UM5 Vessel operations
UM6 Positional information
UM7 Central vessel locational monitoring and control
UM8 Emergency procedures
UM9 Outflow mitigation [consequence mitigation only]
UM10 Spill Response planning & capability [" " "]
UM11 Financial responsibility/liability

In each cell is indicated the applicability of this (set of) measures to this hazard whereby -
■ = applicable
□ = not applicable
CP = counter productive (increases hazard)

Ratings in this section replicate corresponding cells of the section above.

Figure 2-6

Effectiveness of proposed safety measures for accident prevention

Proposed Safety Measure (category)	Segment									Waterway	
	1	2	3	4	5	6	7	8	9	Total	Score
Equipment											
Emergency Procedures											
Crew Enhancement											
Public Involvement											
Port State Contrl Enhancement											
Data Issues											
Systems Analysis											
Operational Modifications											
Other Training and Qualifications											

Each of the panel members and advisors allocated nine votes for the most effective measures for each of the waterway segments. Votes could be distributed in any manner among the nine categories Thus, if one felt that one category was much more effective in preventing accidents than the others, most, or all, 9 votes could be assigned to it; conversely, if there was little discrconseirable difference, all categories could be given a single vote.

The vote totals were converted into a 1-5 scoring scale, approximating a normal distribution, where -

1 2 3 4 5

low effectiveness → high effectiveness

Figure 2-7

Effectiveness of proposed safety measures for consequence mitigation

Proposed Safety Measures	Consequence Factors: Amount Spilled	Amount Recovered	Defensive Protection	Restoration	Overall Effectiveness
Better coastal response capabilities (e.g. spill response vessel in Neah Bay, Gray's Harbor)					
Station a spill response vessel at other critical environmentally sensitive location(s)					
Local rapid-salvage capability in sensitive areas					
Dedicated vessel for deploying prepositioned skimmers, booms and other equipment					
Outflow mitigation systems on tank/freight vessels (e.g. quick closure valves for tank vents)					
Vessel fittings to speed transfer of contents to other spaces & connect to offloading equipment					
Establish international training standards for response to additional types of incidents					
Response plans for all vessel types					
Facilitate salvage contracting to minimize delays (e.g., COTP or open forum contracting)					
Increased consideration of alternative response technologies (e.g., dispersants, in situ burning)					
AC review GRP response strategies for shallow-water areas					

Scored as follows:
1 low effectiveness — 2 — 3 — 4 → 5 high effectiveness
N/A = not applicable
CP = counter productive

Maximum score for all consequence factors, plus 1 if there is a second score greater than 3.

2.3 Expert Panel

The Expert Panel had for consideration the full complexity of the task in a short period of time. Their purview included both a risk assessment of the current state of the waterway and a consideration of risk management, i.e., what new measures might be appropriate for reducing risk.. In order to facilitate elicitation of their judgment, two working groups were formed, titled Marine Transportation (MT WG) and Environmental Impact (EI WG). The intent of this division of labor was to keep the working groups focused and manageably sized. The MT WG examined the probability and prevention of accidents, while the EI WG looked into the consequence portion of the risk equation.

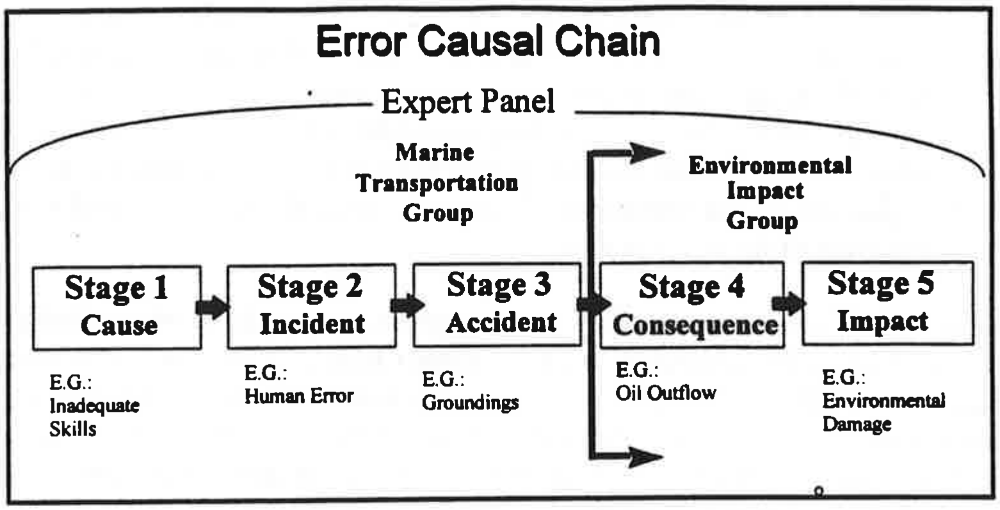
Two respected and knowledgeable chairpersons agreed to head the Working Groups, Dr. Edward Wenk, Jr. for Marine Transportation and Dr. Sharon Christopherson for Environmental Impact. The Panel worked effectively under their leadership, with the common understanding that expertise, not constituency, was paramount. All members participated with two goals in mind: 1) to discharge the immediate need of the study by answering critical questions for the project team; and 2) to move toward the ultimate objective of the safest possible waterway.

The makeup of each working group included expertise geared to its task and subject areas, as shown in Table 2-1. Figure 2-8 illustrates the Groups' work areas by use of a familiar risk assessment diagram.

Table 2-1
Expert Panel subject areas

MARINE TRANSPORTATION WG	ENVIRONMENTAL IMPACT WG
Pilotage	Marine/coastal environment
Shipping operations	Fisheries
Navigation/traffic	Spill response
Risk assessment	Towing/salvage
Macro-ergonomics	

Figure 2-8
Error causal chain



The Panel included people from industry, government, academia, and environmental advocacy. The critical component of local expertise provided the knowledge of operations and safety on the waterway (vessel handling, traffic and navigational hazards), as well as detailed sensitivity and response capability data. While the Panel had substantial expertise at the national level, both its usefulness and credibility depended on local knowledge and expertise.

The selection process began with a public notice of the Panel's formation and needs, and a call for resumes from interested parties through the Federal Register and advertisements placed by the Coast Guard. A team of Volpe Center and Coast Guard representatives evaluated the resumes and sent notice of selection to the applicants. The evaluation team assessed the makeup of the selected Panel and targeted gaps to fill by additional solicitation through local contacts.

2.3.1 Panel meeting protocol

The Expert Panel met over a three day period in Seattle during the week of April 21, 1997. There were plenary sessions at the opening and closing of the meeting, as well as at several junctures in between. Most of the Panel's time, however, was devoted to breakout sessions for the two working groups during which time the bulk of the technical work was done.

Group voting was on a 1-5 basis, as explained earlier; while consensus was a desirable goal, a result of a narrow band of scores was acceptable. The Panel began with an additional segregation of members into "experts" and "advisors", based on the initial premise that those seen as stakeholders should not have voting power. This distinction disappeared as it became apparent that the Panel could function more effectively as a single entity taking full advantage of all members' expertise. Discussion and voting were completely open.

2.3.2 Goals

The role of the Expert Panel was to provide subjective data to complement the available objective data. This is particularly important given the limited data set for the waterway, especially as concerns causal factors. The experts were asked a series of questions geared towards determining the likelihood of accidents leading to oil spills (Marine Transportation Working Group) and the consequences of oil spills, including salvage and response (Environmental Impact Working Group). Details of the Expert Panel's approach and findings may be found in Chapter 4 and Appendix D.

Both working groups were provided with background material and worksheets prior to the meeting, with additional worksheets provided during the meeting. The EI WG were able to complete the work in the framework as designed. The MT WG needed an alternate taxonomy, developed at the meeting, to form a workable mental model of waterway risk. Table 4-3 shows the working taxonomy, a primary sorting of accident types and secondary sorting of causality. The shift caused some difficulty as data could not be re-sorted on the spot.

The MT WG had three questions to answer in regard to risk assessment:

- What is the likelihood of an accident leading to a significant oil spill in each segment?
- Given an accident in a segment, what is the likelihood of different types of accidents occurring?
- Given an accident type in a segment, what is the likelihood of various causalities?

The particulars of definition and mathematics are in Chapter 4. It is sufficient to say that the Group qualitatively assessed the marginal probability of accidents which could cause serious spills (>10,000 gallons) and the conditional probabilities of accident types and causes. As previously explained, their scoring was on a 1-5 scale, normalized at a later stage of the risk calculation process.

The EI WG considered the consequence of oil spills for the nine waterway segments by answering three questions:

- What is the sensitivity to oil pollution?
- What is the response capability?
- How is response affected by environmental conditions (e.g., wind, waves)?

The first question was considered as a series of resource items such as fin fisheries and birds, with the mental model of a 10,000 gallon crude oil spill. Response capability was broken down into equipment and response time elements and, finally, a judgment of the spatial variation of response conditions was made.

The working groups were then asked to assess the effectiveness of a number of proposed safety measures. The first step was to edit a list of measures, compiled from docket comments, proceedings of public hearings, and literature, each group adding and deleting measures. The EI

WG voted a straight 1-5 scale as designed, for both universal measures and .hc ;e aimed at specific portions of the waterway.

The MT WG had two problems: 1) far too many candidate measures to handle individually; and 2) difficulty judging any measure on a waterway-wide basis. They therefore adopted a multi-voting scheme wherein nine categories of measures were assessed segment by segment. Details of the process and results are found in Appendix D.

2.4 Public input

As noted earlier, the considerable interest of public and private entities and individuals, made wide involvement and contribution to this assessment possible. Therefore, a cornerstone of the approach to this study was reliance on local knowledge of these waters, hazards as they exist today, and proposals to enhance safety. Stakeholders were contacted to obtain critical information needed through phone calls, several visits to the area, public dockets, public workshops, the Internet and all other available means. Concerns, information and comments were solicited and a public docket was set up to receive them. The contents of the docket as well as the one set up earlier for the ITOS study were reviewed. The public workshops were held on 6 March 1997 (two sessions) and 17 June 1997 in Seattle. At these two sessions, stakeholders relayed their concerns with respect to the risks of oil spills in the study area, discussed potential safety measures, outlined future trends, and identified data sources.

CHAPTER 3 WATERWAY CHARACTERIZATION

The first step of the process was the characterization of the waterway and the definition of smaller geographic entities, called "segments". The aim of this division was to recognize the spatial variability of hazard exposure (due to traffic patterns), physical environment, and environmental sensitivity, and to render more tractable the analysis of this large and complex waterway. This work preceded the judgment and analysis of hazards collectively described as Step 1 in the methodology, Figure 2-1.

3.1 Waterway description

As stated in Section 1.2, the waterway, for the purpose of this study, includes: 1) the outer coastal area comprising the seaward approaches to the "J" buoy at the mouth of the Strait of Juan de Fuca, and, more generally, the Olympic Coast National Marine Sanctuary and the associated "Area to be Avoided" (ATBA) designated by the International Maritime Organization; 2) the Strait of Juan de Fuca from its mouth east to Whidbey Island; 3) Puget Sound from Admiralty Inlet south to Olympia; and 4) the waters in and around the San Juan Islands, including Rosario and Haro Straits, the approaches to the ports of Anacortes, Bellingham, Cherry Point, and Ferndale, and the Strait of Georgia north to the Canadian border.

3.1.1 Geography

The offshore portion of the study area includes the waters west and south of the J buoy, the ocean coastal waters of the Olympic Peninsula and Vancouver Island, and the coasts themselves. The Olympic Coast National Marine Sanctuary lies off the coast of Washington State and includes a portion of the western end of the Strait of Juan de Fuca. It covers an area of approximately 3,300 square miles, extending from Neah Bay, Washington due north to the U.S./Canada international border, seaward to the 100 fathom curve, then south to a point due west of the mouth of the Copalis River, near Copalis Beach, Washington.

Roughly coincident with the sanctuary is an International Marine Organization (IMO) adopted Voluntary Area To Be Avoided (ATBA). This voluntary exclusion area applies only to tank barges or tank ships laden with bulk liquid oil or hazardous materials. The ATBA runs roughly from the shoreward boundary of the sanctuary to 25 nautical miles offshore for the entire length of the sanctuary from Cape Flattery in the north to the Copalis River in the south. In addition, Canada has designated a Tanker Exclusion Zone (TEZ) of roughly 50 miles width along the coast of Vancouver Island and north to the Queen Charlotte Islands and Dixon Entrance.

The Pacific coastal area of interest runs, in Washington, from Cape Flattery at the northwest extreme of Olympic Peninsula south to Gray's Harbor. This area includes beaches of the Olympic National Park, at least four Indian reservations (including the Makah, Quillayute, Hoh, Quinault nations), three National Wildlife Refuges, and a variety of other public and private lands bordering the sanctuary along the coastline.

In addition, the Vancouver Island coast includes the Pacific Rim National Park; various environmentally sensitive marine areas; the Pacific Biological Station in Bamfield, and a number of Native communities and lands.

The Strait of Juan de Fuca separates the south coast of Vancouver Island, Canada, from the north coast of Washington State. It is the principal waterway by which international and regional commerce moves to and from the Washington State ports of Port Angeles, Bellingham, Everett, Seattle, Tacoma, Olympia; the oil terminals at Anacortes and Ferndale; and the Canadian ports of Victoria, Vancouver and Roberts Bank.

The Strait is approximately 80 miles long. From its mouth to Race Rocks (opposite Port Angeles), approximately 50 miles east, it averages 12 miles in width. From Race Rocks to Whidbey Island, its eastern boundary, approximately 30 miles further east, the Strait widens to 16 miles. The traffic lanes are approximately one nautical mile wide. There are very few dangerous shoal areas, and the waters are generally deep, except near the shoreline. The depth of water in the traffic lanes regularly used by commercial oceangoing ships generally ranges from over 600 feet at the entrance of the Strait to 100 feet near the eastern end of the Strait.

The eastern portion of the Strait is the shipping crossroads of the waterway. Ocean going ships bound for Canada will turn north at Port Angeles, board pilots at Victoria, and proceed north via Haro Strait and Boundary Pass for Canadian ports on the Strait of Georgia. Ships for the United States board pilots at Port Angeles and proceed east through the Coast Guard Precautionary area. Those for south Puget Sound ports head due east for Admiralty Inlet, while shipping for Anacortes and Bellingham turn approximately northeast for Rosario Strait. Traffic separation schema are used in all cases. The crossroads area also sees a great deal of inland traffic trading between U.S. and Canada ports.

The San Juan Islands lie north of the eastern Strait of Juan de Fuca. This archipelago lies within the United States boundary and is known to residents and tourists alike for its natural beauty. Haro Strait (width from 1½-6 nautical miles), flowing roughly on a north-south axis to the islands' west, and Boundary Pass (minimum width of 2½ nautical miles), running east to west to the Islands' north, separate them from Vancouver Island and the Canadian Channel Islands. Ships on this route must make three sharp course changes.

The eastern rim of the waterway is marked by more areas of shallow water and extensive tidal marshes and mudflats in Padilla, Bellingham, Lummi, and Skagit Bays in Washington State, and Boundary Bay and Roberts Bank in Canada.

Rosario Strait (1¾-4 nautical miles wide) bounds the San Juans to the east. Tankers bound for the Anacortes refineries transit the narrow Guemes Strait between Fidalgo and Guemes Islands and terminate in Padilla Bay. Those for Cherry Point and Ferndale transit the entire Rosario Strait and enter the Precautionary Area between Lummi Bay and Alden Bank for approach to the terminals.

The southeastern portion of the waterway runs from Port Townsend at the mouth of Admiralty Inlet to Olympia and Hammersley at the southern extreme. Washington's population centers are here, as are the heaviest marine traffic concentrations. Admiralty Inlet (2½-5 miles width) runs roughly southeast for approximately 20 miles, past the mouth of the Hood Canal to Point No Point, where Puget Sound proper begins.

The Puget Sound channel runs about 40 miles in length to Commencement Bay at Tacoma, passing by approaches to harbors at Everett, Kingston, Seattle, Eagle Harbor, and Bremerton. Tacoma Harbor is on Commencement Bay, south of which there is no traffic separation scheme. Passage south to Olympia is quite narrow (in many places less than one mile) and has a number of sharp turns and shallows to negotiate. The approaches to both Olympia and Hammersley narrow to less than ½ mile in width.

3.1.2 Environmental values

The coast of the Pacific northwest and its adjacent waters are renowned for their great beauty and natural productivity. Land and water meet at coastal headlands, sand and cobble beaches, river deltas and mudflats, and bays and fjords. Circulation of the offshore California Current brings a steady flow of cold water southward along the outer coast. Seasonal solar effects cause variations in local currents and upwelling of deeper water. Nutrients in inland waters come from one of the highest deep-water estuary phytoplankton production rates in the world, from the discharge of many rivers and streams, the largest of which is the Fraser out of British Columbia, and from benthic habitats in the mudflats.

Marine habitats include open water, eelgrass beds, estuarine wetlands, and giant kelp beds, in which marine life of all kinds abounds, both in the Inland Sea and offshore[27]. Large varieties of shellfish, finfish (including many anadromous species such as salmon), shore and ocean birds, and mammals (seals, sea lions and otters, and whales, including orcas) are both resident and migratory through the area. The ocean here also supports the second largest, and still growing, aquaculture industry in the country, for which clean, nutritive sea water is critical.

Governments at all levels have recognized these outstanding environmental values by the designation of parks, wildlife refuges, and preserves. Notable among them are the Olympic National Park, which includes miles of ocean beaches, Pacific Rim Provincial Park on Vancouver Island, and the Olympic Coast National Marine Sanctuary. The outer coast (including many islands, rocks, and shoals) and Inland Sea are also home to many National Wildlife Refuges, among them Dungeness, Nisqually, Fidalgo, Gray's Harbor, San Juan Islands, Protection Island, Copalis, Flattery Rocks, and Quillayute.

The offshore area in particular has highly sensitive concentrations of sea birds and marine mammals. The entire United States population of gray whales migrates through the area, feeding in the shallows and occasionally spending the summer[50]. The inland waters of Puget Sound are an Estuary of National Significance under the Clean Water Act.

3.1.3 Weather and hydrography

A general discussion of weather and hydrography follows. A more detailed segment by segment characterization can be found in Section 3.4.

Hydrography

The study area may be generally divided into two areas subjects to different influences: ocean and inland.

Along the outer Washington coast, currents generally flow parallel to the coast. For the nearshore current, the summer months bring a southerly flow while a northerly flow is prevalent during the winter. The current farther offshore runs north to south year round. During both summer and winter, the net flow in the Strait of Juan de Fuca is out of the Strait toward the northwest. A detailed description of these flows is found in Appendix C.

Wave heights on the outer shelf average almost 5m during December through January with a maximum of 11m in January[32]. The most severe wave conditions are caused by winter storms originating near Japan that move onto the U.S. Pacific coast. Storm winds ahead of warm fronts can generate waves with significant wave heights up to 6-7 meters; winds associated with cold fronts can generate waves of 8-10 meters height.

Currents in the Strait of Juan de Fuca, Puget Sound, and the areas surrounding the San Juan Islands are dominated by tidal influences and the net outward flow due to discharge from the Fraser and other rivers. The complex of islands and channels makes for significant locally influenced tides and currents, particularly around the San Juan Islands and in southern Puget Sound. Tidal ranges run upward of 15 feet in some areas and local currents may be as strong as six knots.

Weather

The weather in this region is noted for its maritime influence, which brings mild temperatures year round, wet winters, and dry summers. The matrix of channels, bays, and islands is the cause of highly variable effects such as fog and local breezes.

During the summer, winds are predominantly from the northwest while southeast winds prevail during the winter along the Washington coast. In the Strait of Juan de Fuca, winds draw into the Strait from the northwest in the summer and out of the strait from the southeast in the winter.

However, there are localized effects that influence wind flow. Two examples of exceptions to this general pattern exist: (1) in the area east of Port Angeles, winds are predominantly from the west during the entire year; (2) in the Ferndale-Anacortes area, southerly winds prevail ten months out of the year, while during January and December, winds from the north are predominant. Winds in Puget Sound generally blow to the north in winter and southerly in the summer[54].

3.1.4 Trade and commercial aspects

The waters of Puget Sound, the Strait of Juan de Fuca, and in the area of the San Juan Islands, collectively known as the Inland Sea, have been the engine of the regional economy for thousands of years, both as a transport medium and as productive natural habitat. Today, the United States northwest and Canadian British Columbia are a thriving, growing region and the Inland Sea's commercial and intrinsic values are more important than ever. International and regional shipping ply the waters in great numbers and a growing population counts environmental quality as a prime attraction for residence there.

The quality of the marine environment in the Inland Sea is significant for many regional industries because of its direct or indirect benefits[33]. Fin and shell fishing industries are two which derive a clear and direct benefit from a healthy marine environment, as do recreation and tourism related industries, forestry, and agriculture. Among the many others whose benefit is indirect are "strategic industries" such as aerospace, advanced technology (e.g., software, biotechnology), international trade, general manufacturing, and tourism. These sectors rely on the quality of life in Puget Sound to attract and retain a highly qualified workforce.

Fishing from Puget Sound waters brings over $80 million per year into the Puget Sound economy including $19 million from aquaculture. The water dependent industries accounted for 7% of the Puget Sound workforce in 1993. This region is one of the two most productive in aquaculture nationally, in particular for oysters, and unlike the Chesapeake Bay, has seen increased production in recent years[33]. There is, of course, a far greater dependence in those communities and Native American tribes for whom fishing is essential, both in terms of livelihood and cultural identity. Examples are the towns of Ballard (fin fishing), Shelton (aquaculture),and Neah Bay (Makah Indian tribal lands).

Spill prevention is also great concern to shippers using the waterway. A serious spill and subsequent cleanup operation could constrict or even stop vessel traffic altogether.

Safeguarding water quality is a less critical, though still important, concern for shipping and marine port industries, as well as other waterfront users such as recreational facilities, hotels and conference centers. These industries may have less direct benefit from clean water, but must, to some extent, emphasize quality of life and environment as a matter of corporate responsibility.

Shipping

Vessel traffic transiting the region is comprised of all types calling at Washington State and British Columbia ports. Over 5,800 commercial deep draft vessel port calls were recorded in 1995 at the commercial ports of Puget Sound and the Port of Vancouver, Canada (this figure does not include Canadian domestic arrivals). In addition, there is significant daily tug and barge traffic throughout the area. Typical types of vessels trading into the region include tank vessels, roll-on/roll-off ships, car carriers, container ships, bulk carriers, log carriers, passenger ships, commercial fishing vessels and tenders[41].

The mix and density of traffic have been noted many times before, notably by Wenk[52], who also pointed out that ships of all kinds were (and, in some cases, still are) getting larger. Wenk also noted that ships whose size and speed are intended for safe, open seas operations may be less safe in confined waters, where risk is the greatest. This problem can be exacerbated by compressed port turnaround times and the attendant stress and fatigue on crews.

Vessel transits to Puget Sound ports overall have declined slightly from 1994 to 1996. The annual Washington Vessel Entries and Transits reports show that cargo and passenger ships bound for Washington ports via the Strait of Juan de Fuca rose from 2407 to 2510, while those through the Strait of Georgia declined. At the same time, tank barge transits in Puget Sound rose from 3030 to 4114[51]. All of the dramatic increase in barge traffic came in 1996; the implication for a long term trend is uncertain. The Port of Vancouver reports slight total commodity increases in that time from 67.6 million tons to 72.0 million tons[46].

The Strait of Juan De Fuca is the preferred route for ocean-going vessels calling at Puget Sound and Strait of Georgia ports, due to the relative shortness of the route and the deep and wide nature of the passage. Furthermore, the Canadian Government indicates that using the Inside Passage on the east side of Vancouver Island is undesirable, as it presents a greater risk to shipping and the environment than use of the Strait of Juan de Fuca.

Ocean going ships bound for Canada and the United States separate north of Port Angeles on the Washington coast. Ships for Canada go north, pick up pilots at Victoria, and travel through Haro Strait and Boundary Pass on their way to the Strait of Georgia and the Canadian ports. U.S. bound ships board pilots at Port Angeles and head through the eastern Strait of Juan de Fuca for the oil terminals and southern Puget Sound ports.

A detailed description of vessel traffic in the region is found in Section 3.2.

Oil shipping

Virtually all of the crude oil arriving in this area by tanker is bound for United States ports. Demand in British Columbia is met by Canadian domestic production and shipped by overland pipeline. In 1972, the crude oil requirement of Puget Sound refineries (notably Anacortes, Bellingham, and Seattle) was approximately 347,500 barrels per day, with Trans Mountain Pipeline supplying 80% and foreign imports the remaining 20%. Since 1977, TAPS oil has supplied most needs (in 1990, 99% of the requirement) via crude carriers operating from Valdez, Alaska (282 tanker transits in 1990)[41].

A significant amount of product is traded overseas from Vancouver. There is a busy regional trade in oil product over the waterway among ports in British Columbia and Washington State, including gasolines, bunkers, and various other distillates such as #2 heating oil. Much of this is carried in barges towed by tugs. Principal sources of the product are the refineries at Anacortes, Bellingham, and Vancouver; the regional destinations include Seattle, Tacoma, Olympia, Everett, Bremerton, Port Angeles, Victoria, B.C., and Sidney, B.C.

Inbound tankers are, generally, laden with crude oil cargo and outbound tankers are in ballast or carrying a cargo of non-persistent refined cargo. Occasionally, some outbound tankers carry partial crude oil cargo destined for a California port. Inbound tankers carry, on average, approximately 13.5 million gallons of crude oil. Outbound tankers carry an average of 5 million gallons of refined petroleum products. Large commercial cargo vessels may carry between 250,000 and 2 million gallons of bunker fuel. Approximately 95% of the crude oil transported by vessel to the Puget Sound refineries is carried in U.S. flag tankers[41].

Tanker movements are detailed in the traffic analysis of Section 3.2. Discussion of future regional oil market trends can be found in Chapter 7.

3.1.5 Native American rights

The vital importance of the marine environment to the coastal Native American tribes was the theme for the introduction to this report, and needs to be underscored by an explanation of their fisheries rights and the Government's obligations by treaty to safeguard those rights. These rights are intrinsically part of any discussion of environmental sensitivity, yet merit a separate discourse. The Memorandum of Understanding Between Federally Recognized Tribes of Washington State and the State of Washington succinctly tells the history and present day outlook of this relationship. The following are excerpts:

> *Fisheries and wildlife resources are of great value and importance to Washington citizens. Protection of these resources is a matter of high priority for Washington's Indian tribes and agencies and departments of Washington State government. The State and the Tribes are interested in making a major commitment to protecting the habitat and increasing production of the fisheries resource. Cooperative efforts between state agencies and Tribal governments will assure protection of habitat and full success of enhancement programs.*
>
> *Tribal governments in 1970 brought suit in United States* v. *Washington against the State seeking a declaration and enforcement of their treaty fishing rights...... basic harvest rights were affirmed by the United States Supreme Court in 1979 and the federal court has retained jurisdiction to fully implement those fishing rights.*
>
> *The parties recognize that the state will seek to cooperatively involve these private interests in achieving the objectives stated in the PREAMBLE to protect natural resources, improve where appropriate degraded habitat, and enhance potentially productive habitat.*
>
> *Accordingly, the parties join in this memorandum of understanding for the purpose of initiating a cooperative approach to protection, enhancement, and restoration of fisheries habitat.*

The Court recognized the fisheries rights of the tribes, who took the course of cooperative action with State authorities to ensure adequate protection of the marine environment. Native Americans see this protection as indivisible from their fishing rights; it is, therefore, logical that they view shipping safety regulation and protection of the ocean from oil pollution as a treaty rights issue. Such regulation is seen as a critical component of Federally guaranteed Treaty fishing rights.

Tribes who live in the affected coastal zones of the study region include the Elwha, Hoh, Lummi, Makah, Puyallup, Quileute, Quinault, Samish, Shoalwater Bay, S'Klallam, Skokomish, Squaxin, Suquamish, Swinomish, and Tulalip.

3.1.6 Jurisdictional aspects

This waterway presents a challenge for enforcement agencies and operators alike because of the several regulatory and enforcement regimes involved. Herein is a brief description of those jurisdictions, beginning with international instruments and moving to national and state rules.

International Maritime Organization (IMO)

The IMO provides several types of safety measures, including:

- **Conventions** have the standing of international safety regulations for ships which operate internationally, binding on member countries once ratified by a sufficient number. Examples are Safety of Life at Sea (SOLAS) which supplies safety and construction standards generally, and Prevention of Pollution of the Sea by Oil (MARPOL) which specifies some construction standards and accidental outflow standards for tankers, as well as operational pollution prevention rules. Others focus on the human element, e.g. Standards of Training, Watchstanding and Certification and International Safety Management.
- **Resolutions** lay down standards of policy and may supplement the conventions. They are not binding but can be guides for national action. A recent example concerns probabilistic damage stability, which at maturation will be in the code.
- **Codes** stand in stature between conventions and resolutions. Whereas a resolution may be experimental in character, codes have the weight of technically researched standards. They are often the basis of national regulations in member countries. These include intact and damage stability codes, and the high speed craft code[22].
- **Other-** The IMO has established a number of Areas to be Avoided (ATBA) around the world in order to safeguard designated marine resources, a measure that is voluntary in nature. Most of the Olympic Coast National Marine Sanctuary is an ATBA. The IMO has also sanctioned some traffic separation schemes (TSS). Among these is the Strait of Juan de Fuca TSS.

United States and Canada

Substantial portions of the study area are an international waterway, shared by the United States and Canada; these are 1) the seaward approaches to the J buoy, 2) the Strait of Juan de Fuca, and 3) the northern portion including Haro Strait, Rosario Strait, and the Strait of Georgia.

The U.S. Coast Guard is our national marine safety regulatory and enforcement agency. The Coast Guard evaluates and implements new national regulations, as well as enforcing current regulations. These are found in the Code of Federal Regulations (CFR), which distinguishes rules for international and Jones Act vessels. The latter are built and operated domestically and include a variety of sizes and types of vessels. The CFR includes all mandatory and many non-binding IMO measures and those written specifically for various sectors of the domestic fleet. Regulations of OPA 90 have a special niche since they were domestically legislated and developed, and were specifically applied to foreign ships trading here as well as domestic vessels.

Enforcement, screening, and inspection of cargo and tank vessels are Coast Guard functions in this waterway, again applying to international and domestic ships. The enforcement of international conventions on foreign ships-- "port state control"—is a critical component of the safety net. There are large numbers of smaller vessels which are minimally regulated or unregulated by Coast Guard. Small fishing vessels and recreational vessels have basic construction, lifesaving, and safety standards, but are not covered to the same degree as merchant vessels by licensing, engineering, communications, and other regulations. Since these are, at times, the most numerous craft in the waterway, they can cause safety problems such as conflicting operations with larger vessels.

The Coast Guard also provides substantial "best practice" guidance to industry in the form of Navigation and Inspection Circulars. These technical documents are not mandatory in nature, but are a vehicle for safety information outside the regulatory process. Operators also have a large body of internally developed safety standards and operating procedures, some of which reflect Coast Guard Circulars and IMO Resolutions. These non-mandatory tolls are not a part of the safety system formally considered for this study.

Canada also regulates shipping through its own Coast Guard. The Canadians rely more on international standards than does the United States; there is, for instance, no equivalent to OPA 90. Their measures may in some cases be voluntary, as is the case for tanker escort through Haro Strait. The purview of this report does not include Canadian national regulations, but focuses on those United States Federal and Washington State measures having direct effect on the study area.

Canada's Tanker Exclusion Zone (TEZ) is similar to the ATBA off the Washington coast. It establishes a voluntary no-tanker zone from 35 to 80 miles in width from southern Vancouver Island north to the Alaska border, based upon tug response and tanker drift times, and agreed to by the United States and Canadian Coast Guards and representatives of American TAPS tanker operators.

Most of the major traffic links in the study area have traffic separation schemes (TSS), an IMO recognized system for separating inbound and outbound shipping. The United States and Canada jointly control traffic through the Cooperative Vessel Traffic Service (CVTS), operating three separate VTS zones. There is a mature system of vessel "handoffs" among controllers of the zones; it is notable that each country has traffic control in some territorial waters of the other. A detailed description is found in Section 4.3.

Both countries employ aids to navigation (AtoN) in accordance with international standards. In U.S. waters, the Coast Guard conducts periodic evaluations of AtoN effectiveness through the Waterway Analysis and Management System (WAMS). A significant difference between the two may soon emerge as Canada has begun a program of replacing physical aids with electronic systems. Details of this program are not included here.

The United States Coast Guard is responsible for administration, maintenance, and operation of the National Response Plan and Area Contingency Plan (ACP) for oil spill response. The ACP posits worst case spills and matches the organizational and equipment resources to respond. These include public and private sector entities, and salvage, response, and clean-up assets.

Washington State

Washington State has put in place substantial overlay regulation to provide additional protection to their highly valued marine ecosystem. The State's regulatory focus is on risk management by: 1) training and preparedness of officers and crew; 2) operational and pre-arrival procedures for tank vessel personnel; 3) vessel screening through advance notice of entry (ANE), inspection, safety reports, and data management; and 4) oil spill prevention, emergency procedure, and response planning requirements.

In addition, the State has put in place several vessel equipment requirements, including Global Positioning System (GPS) navigation, two separate radar systems, and an emergency towing system. Washington Department of Ecology (DOE) has also prepared regional Geographic Response Plans to supplement the Coast Guard ACP with more locally specific information and planning. DOE has also developed time and equipment response standards for the State's coastal regions.

A compendium of applicable safety measures is found in Section 4.3, "Safety system"

3.2 Vessel traffic analysis

3.2.1 Data Sources

The primary source of data characterizing traffic in the Puget Sound area was the Army Corps of Engineers (ACE) Waterborne Commerce Statistical Database for 1993. Owners of commercial vessels calling on or departing from US ports report their vessel movements and commodities carried by origin and destination. These data provide a comprehensive picture of the amount of commercial traffic, types and sizes of vessels, and types and volumes of commodities moving on the waterway system.

However, certain movements are excluded from the database: military cargo movements in government vessels and other government agency vessel movements; local domestic fishing vessel trips; vessels carrying bunker fuel from shore to load onto vessels; general cargo ferry movements; and vessels passing through US waters from foreign ports bound for foreign ports. The ACE data include cargo moved for military agencies on commercial vessels.

ACE statistics were augmented by trip, commodity and routing data for vessels passing through our waters but not originating or terminating at any US port. Canada Vessel Traffic Service REF, Seattle Vessel Traffic Service (US Coast Guard)[39] and the British Columbia-States Oil Spill Task Force report[31] were additional sources of information on these movements.

Since ACE data do not provide the actual routes taken by the vessels as they travel through the area, the study team first assigned vessels and tonnages to shortest distance routes between the known origins and destinations. To refine this portrayal of the shipping routes and their traffic characteristics, they conducted extensive discussions with local experts on these matters.

The study team made extensive efforts to validate the resulting representation of traffic in the Puget Sound area. They compared traffic reports from Washington State[51], Canada VTS[9], and a University of Washington study[12], for the overall volumes and types of traffic. Representatives of Seattle VTS, Canada VTS, Puget Sound Pilots, and the Marine Exchange of Puget Sound reviewed the chartlets and tables. Finally, Expert Panel members had the opportunity to review and comment on the chartlets during the Seattle workshop.

3.2.2 Traffic Characterization

The three chartlets and two tables in this section provide a characterization of commercial traffic in the Puget Sound area in 1993. The discussions below highlight the key points shown by the chartlets and tables, as well as the caveats and limitations of the supporting data. Note that the chartlets and tables refer to "segments" of the waterway. Their delineation and supporting rationale appear in Section 3.3.

Chartlet 3-1 provides a comparison of the annual number of trips made throughout the Puget Sound area by vessels carrying crude oil, refined oil products, and all other commodities, excluding passenger ferries, and other vessels as described in the previous section. The width of the color-coded lines is proportional to the number of trips on each route. A trip is considered to be a vessel movement from an origin to a destination. Every vessel is counted separately; thus, a tug pulling an oil barge is counted as two trips, one "Crude Oil" trip and one "Other Commodity" trip. An escort tug guiding a crude oil tanker is counted as one "Other Commodity" trip, the tanker as a "Crude Oil" trip. A tug traveling from one point to another with no vessel in tow is counted in the "Other Commodity" category. Table 3-1 contains the supporting data for this chartlet. Appendix C summarizes the supporting data for this chartlet.

The chartlet shows that crude oil traffic in the Sound is confined to the primary tanker route through the Strait of Juan de Fuca, the Rosario Strait, Guemes Channel, and the Georgia Strait. Only a few vessels carry crude oil to the Tacoma terminal in the southern part of Puget Sound each year. By comparison, refined petroleum products (and other commodities) are more widely spread throughout the study area with two primary routes: one from the Bellingham refineries to southern Puget Sound, and the other from Vancouver via the Strait of Georgia, Haro Strait, and the Strait of Juan de Fuca to other ports.

Chartlet 3-1 indicates in all areas of Puget Sound that the number of non-petroleum laden trips far exceeds crude and refined petroleum product trips. Further, the number of trips made by vessels carrying refined petroleum products is generally greater than the number of trips by vessels carrying crude oil, even on most portions of the primary oil tanker routes. The lower number of crude oil trips occurs because large capacity tankers carry the bulk of crude oil, while smaller capacity product tankers and tank barges carry most refined petroleum products (see Tables 3-1 and 3-2).

Chartlet 3-2 reveals a different picture in comparing the total tonnage (short tons) of crude oil and refined petroleum products moving through the Puget Sound area in 1993. The width of the color-coded lines is proportional to the tonnage moving on each route. In terms of tonnage, crude oil, as opposed to refined petroleum products, is the predominant form of petroleum moving on the tanker routes to the refineries at Anacortes, Cherry Point and Ferndale. Refined petroleum products, however, still predominate in southern Puget Sound. Table 3-2 contains the supporting data for this chartlet.

Table 3-1

Trips by vessel type and segment

Vessel Type		Number of Trips								
		Seg. 1	Seg. 2	Seg. 3	Seg. 4	Seg. 5	Seg. 6	Seg. 7	Seg. 8	Seg. 9
Barges	Dry Cargo	607	513	1,483	4,236	3,324	305	8,162	558	358
	Tank	298	566	882	2,078	1,483	1,227	5,774	144	28
	Subtotal	905	1,079	2,365	6,314	4,807	1,532	13,936	702	386
Cargo ships	Dry Cargo	2,727	4,826	7,599	5,160	5,263	1,375	6,310	518	42
	Tankers	449	354	804	631	455	445	378	6	
	Subtotal	3,176	5,180	8,403	5,791	5,718	1,820	6,688	524	42
Tug/tow units		561	1,486	2,470	11,309	4,022	7,150	49,521	5,573	988
Others	Passenger vessels	77	373	450	1,894	1,214	11,256	90,304	1,751	27
	Other vessels	31	47	90	40	83	3	23	1	
	Subtotal Others	108	420	540	1,934	1,297	11,259	90,327	1,752	27
TOTAL		**4,750**	**8,165**	**13,778**	**25,348**	**15,844**	**21,761**	**160,472**	**8,551**	**1,443**

Table 3-2

Tonnage by Commodity Type, Vessel Type and Segment, 1993

		TONNAGE (000 SHORT TONS) PER SEGMENT								
COMMODITY	**VESSEL TYPE**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Crude Oil	Tanker barge units	0.5	0.1	0.5	154.5	192.1	115.3	154.5		
	Self-propelled units (Tankers)	25,217.6	798.1	26,015.8	25,229.7	192.4	23,683.8	1,546.0		
	SUB-TOTAL	**25,218.1**	**798.2**	**26,016.3**	**25,384.2**	**978.5**	**23,799.0**	**1,700.5**		
Refined Petroleum Products	Dry Cargo Barges	76.9	13.2	112.1	75.8	71.6	3.1	53.8		
	Tanker Barges	205.4	428.6	682.6	3,612.8	1,386.2	2,645.3	4,233.5	35.5	3.7
	Subtotal Barge Units	282.3	441.8	794.7	3,688.6	1,457.8	2,648.5	4,287.3	35.5	3.7
	Dry Cargo Vessels	16.7	63.9	80.6	81.0			81.6		
	Tankers	550.6	2,033.4	2,584.1	2,206.5	649.2	0.8	603.7	0.0	
	Subtotal Self-propelled Units	849.7	2,097.3	2,664.7	2,287.4	649.2	1,547.9	685.2	0.0	
	SUB-TOTAL	**849.7**	**2,539.1**	**3,459.4**	**5,976.1**	**2,107.0**	**4,197.2**	**4,972.6**	**35.5**	**3.7**
All Other Commodities	Dry Cargo Barges	725.9	494.8	1,391.4	5,661.6	4,868.5	1,993.4	7,623.8	441.3	181.3
	Tanker Barges	42.6	325.6	368.1	430.1	48.0	222.3	304.0	17.2	23.6
	Subtotal Barge Units	768.5	820.4	1,759.6	6,091.6	4,916.4	2,215.7	7,927.7	458.4	204.9
	Dry Cargo Vessels	1,718.4	24,646.4	26,397.8	26,872.4	593.7	671.9	25,549.5	1,316.7	271.8
	Tankers		563.3	563.3	563.3	0.0	303.5	259,8		
	Subtotal Self-propelled Units	1,718.4	25,209.7	26,961.1	27,435.7	593.7	975.3	25,809.3	1,316.7	271.8
	Tug/Tow Units	0.2	26.8	26.9	27.0	0.1	0.0	26.8	6.3	
	Other Units		4.8	4.8	4.8		4.5	0.4		
	SUB-TOTAL	**2,487.0**	**26,061.7**	**28,752.4**	**33,559.2**	**5,510.2**	**3,195.5**	**33,764.3**	**1,781.4**	**476.7**
SEGMENT TOTAL		**28,554.8**	**29,399.0**	**58,228.2**	**64,919.5**	**8,595.6**	**31,191.6**	**40,972.6**	**1,816.9**	**480.5**

Chartlet 3-3 completes the traffic characterization with the numerous passenger and ferry trips that are vital to mobility in the Puget Sound area. Major Washington State ferry routes connect Bainbridge Island and Bremerton with Seattle, Vashon Island with Seattle, Fauntleroy, Southworth and Tacoma, Admiralty Head with Point Wilson, Edwards Point with Point Jefferson, and the San Juan Islands with both Fidalgo Island and Sydney, British Columbia. Although not shown on this chartlet, British Columbia ferries operating in Canadian waters connect Vancouver Island with the Gulf Islands north of the San Juan Islands and the City of Vancouver. The frequent trips on the ferry routes cross the major shipping lanes in both North and South Puget Sound. The Washington State Ferry trips appear in the "Passenger Vessels" category in Table 3-1.

3.3 Waterway segments

The complexity of the northwest Washington State waterway compel its division into smaller pieces for tractable analysis. This approach has been followed in previous waterway risk assessments, e.g. Prince William Sound[18], Puget Sound[34] and the United Kingdom[13]. Moreover, public comment has indicated the perception that risk, both exposure and consequence, has considerable spatial variation in the waterway. Even a cursory examination reveals that the physical environment, vessel traffic patterns, and ecology all have distinctive features in different areas.

The approach taken identifies "segments" by their traffic characteristics and physical geography of the waterway, which are intrinsically bound together. This logic brings both accident prevention and environmental sensitivity into the selection. Since segment boundaries reflect the forms of physical geography and shipping operations, accident prevention may be addressed regionally and safety measures may be chosen based on marine traffic patterns. The segments also reflect a roughly logical division on ecological lines; each segment has its complexities, however, and these are described in Chapter 5.

3.3.1 Rationale

Chartlets 3-1 and 3-2 indicate the flow of all commercial traffic in the study area and are the reference for discussion of the specification of segment boundaries. The seaward approaches to the mouth of the Strait of Juan de Fuca are clearly distinct from the traffic lanes in the Strait east of the J buoy. Traffic generally approaches the J buoy from the northwest and the south and southwest. These approaches are designated Segments 1 and 2 and are distinct for two reasons. In the first place, each has its own restricted navigation area: the Canadian Tanker Exclusion Zone (TEZ) to the north, and the ATBA including most of the Olympic Coast National Marine Sanctuary to the south. The nature of the traffic in each approach differs; both have a general mix of cargo traffic to and from California and the Pacific Rim countries, but shipping in the northwest lanes includes nearly all the crude oil (Alaskan North Slope) coming into the waterway.

Segment 3 is the Strait of Juan de Fuca from the J buoy east to Port Angeles. It is a deep waterway with a well defined traffic separation scheme. Segment 3 ends at the point where Canadian and U.S. bound traffic diverge and where several operational restrictions (e.g., deadweight tonnage limit, pilot and escort requirements) for U.S. traffic begin.

Segment 4 is, generally, the eastern half of the Strait of Juan de Fuca, from Port Angeles to Whidbey Island, excluding the northwest lanes plied by shipping bound for Canada. It is the crossroads for the waterway, handling most deep draft hulls bound for U.S. ports, and all traffic between Washington and British Columbia ports. Segment 4 ends where "spurs" for specific destinations begin, i.e., Rosario Strait and Puget Sound.

Segment 5 comprises the route for all overseas shipping to Canada, from the split at Port Angeles to the Strait of Georgia. It includes the navigationally and operationally unique Haro Strait, the approaches to Victoria, and the Strait of Georgia north to the Canadian border. This segment was also separated so that Canadian traffic data could be dealt with in isolation.

Segment 6 includes, generally, the San Juan Islands and particularly Rosario Strait, which handles nearly all the tanker traffic for Anacortes, Ferndale, and Cherry Point. Rosario Strait also has the most non-universal safety measures in place in the waterway.

Segment 7 is the southern part of Puget Sound from Admiralty Inlet to Tacoma. Most overseas general cargo shipping for the U.S. transits the Sound for Seattle and Tacoma, as well as most inland traffic between the U.S. and Canada. Segment 7 also has the lion's share of ferry traffic, operated mostly by the Washington State Ferries.

Segments 8 and 9 are comparatively small areas of the waterway added to address lesser, but significant, flows of traffic to Everett/Skagit Bay and to Olympia, respectively. Olympia has a growing bulk trade and both segments have significant barge and tank barge traffic. The lack of VTS radar coverage in these areas is another distinguishing characteristic.

3.3.2 Description of segments

Brief spatial descriptions of the waterway segments follow. Additional information, including navigational hazards, from the Coastal Pilot appears in Appendix C. The local hazards are also a part of the hazard analysis in Chapter 4.

- Segment 1 runs in a west to east direction from the northerly approach to the Strait of Juan de Fuca and ends at the "J" buoy. The segment is bounded on the south at approximately latitude 48°30'N., the north by Vancouver Island, the west at longitude 125°40'W., and the east at about longitude 124°50'W, the J buoy.
- Segment 2 is the western approach to the J buoy, is bounded on the north at approximately latitude 48°30'N, the west at longitude 125°40'W, the south at latitude 47°07'N., and the east by the coast of Washington.

- Segment 3 begins at the J buoy and includes all the waters of the Strait of Juan de Fuca west to Port Angeles, at longitude 123°35'W.
- Segment 4 includes Port Angeles and the eastern half of the Strait of Juan de Fuca. The area extends northeast up to but not including, Rosario Strait and eastward up to, but not including, Admiralty Inlet. The area begins at a point in latitude 48°15'N., longitude 123°35'W., and the northeastern corner ends at latitude 48°25'N., longitude 122°45'W. The southeastern corner ends at latitude 48°10'N., longitude 122°50'W.
- Segment 5 runs from Port Angeles northeast to Victoria, past Discovery Island, and includes the shipping channel of Haro Strait but not the San Juan Islands' coastal waters. The segment encompasses the eastward turn at Turn Point and the shipping lane in Boundary Pass, the passage northward into Georgia Strait, and Georgia Strait north to the Canadian border.
- Segment 6 is bounded on the south by Segment 4, at the northern end of the convergence zone (about 48°28'), and includes all of the waters surrounding the San Juan Islands, and all of Rosario Strait, Guemes Channel, Bellingham Bay, and the approaches to Cherry Point and Ferndale. The northern reach includes the Strait of Georgia west to longitude 123°00'W, at Point Roberts.
- Segment 7 continues from the southeastern end of Segment 4, on the northwestern side of Point Wilson. It continues southeastward through Admiralty Inlet. The segment branches to include traffic through Puget Sound to Port Townsend, Bremerton, Lake Washington Ship Canal, the mouths of Hood Canal and Possession Sound, Seattle Harbor and Tacoma Harbor. The segment begins at a point in latitude 48°10'N., longitude 122°50'W (Point Wilson); the southern extreme is at latitude 47°18'N., longitude 122°33'W (Dalco Passage).
- Segment 8 includes, generally, the waters east of Whidbey Island along the eastern side of Puget Sound. The segment begins at Edwards Point and extends north, branching east to Everett Harbor and north through Skagit Bay to the fixed bridge on the south end of the Swinomish Channel. The segment begins at a point in latitude 47°48'N., longitude 122°25'W. The eastern branch ends at a point in latitude 47°59'N., longitude 122°13'W., and the northern branch ends at a point in latitude 48°25'N., longitude 122°30'W.
- Segment 9 is the southern extreme of Puget Sound beginning south of Tacoma Harbor, running southwest past Fox, McNeil, and Anderson Islands to the bend at Nisqually Reach. The segment then turns northwest past the northern tip of Johnson Point and branches southward into Olympia Harbor and northwestward to Hammersley Inlet. The segment begins at a point in latitude 47°18'N., longitude 122°33'W. The southern branch ends at a point in latitude 47°04'N., longitude 122°55'W., and the northwestern branch ends at a point in latitude 47°12'N., longitude 122°58'W.

3.4 Segment ratings

The final step of the waterway characterization is a relative ranking of the segments by two sets of navigational hazard factors. These are not an integral part of the numerical risk calculations (which include accident data and expert opinion elements), but serve as a check against those results.

3.4.1 Weather and hydrography

Weather and hydrography data was collected to the extent possible to characterize the physical environment of the waterway segments. Table 3-3 shows the raw data (details in Appendix C). Table 3-4 gives normalized ratings for each factor and overall ratings. Wave height ratings are included here and result partly from anecdotal information (conversations with local pilot and operators) since raw data is only available from offshore buoys and not for the Inland Sea.

Table 3-3
Segment environmental factors, raw data

SEGMENT	Wind Knots, average	Tide Range, feet	Current Knots, average	Fog Days/mo. <1/4 mile	Rain Inch/mo. average
1	13	9	0.2	5	7
2	9	9	0.2	4	9
3	11	9	0.9	4	4
4	9	7	0.9	3	2
5	5[1]	8	1.3	4[1]	3
6	5	8	2.0	4	3
7	8	11	1.0	4	3
8	8[2]	11	1.6	4[2]	3[2]
9	6	15	2.3	8	4

Note 1: Data not available. Assumed equal to Segment 6 data.
Note 2: Data not available. Assumed equal to Segment 7 data.

Table 3-4
Segment environmental factors, ratings

SEGMENT	Wind	Waves*	Tide	Current	Fog	Rain	Ave.	RATING
1	5	5	2	1	3	4	3.3	5
2	3	5	2	1	2	5	3.0	4
3	4	3	2	2	2	3	2.7	3
4	3	3	1	2	1	1	1.8	1
5	1	2	1	3	2	2	1.8	1
6	1	2	1	5	2	2	2.2	2
7	3	2	4	3	2	2	2.7	3
8	3	1	4	4	2	2	2.7	3
9	1	1	5	5	5	3	3.3	5

* Ratings based on correspondence with area experts.

3.4.2 Vessel traffic

The traffic model yields annual transits over the links in each segment, with a link defined as a connector between any two nodes (shown but not numbered in the traffic chartlets). Traffic density is meant to express the time spent by vessels in a segment and the navigable area within which the traffic flows. The former is available as vessel miles (transits X link lengths). Most links for harbor approaches and internal harbor movements are ignored. The notable exception is Port Angeles Harbor because of the multi-traffic density in the Coast Guard's designated Precautionary Zone. This area is host to mooring, lightering, tug escort, and pilot boat operations, and has been the scene of spills in the past; it is therefore included in the density calculation.

The areas used for the density calculation consist primarily of the designated traffic lanes (not including the separation zones); where such lanes are not designated, estimates of channel width were applied after inspection of the relevant charts. Also, in Segment 4, the Precautionary Zone around Port Angeles was included to account for the tug escort and other movements there. In Segments 1 and 2, the areas considered are the immediate approaches to the J Buoy only, i.e., the designated traffic lanes in the separation scheme. This agrees with the sense of the Expert Panel, and others, who have expressed concern about the concentration of traffic there.

Table 3-5 is based on the previously described traffic model (Section 3.2), and shows the traffic densities for the four types of vessels for which hard data is available. Table 3-6 normalizes those numbers to a 1-5 scale, as elsewhere; "Total traffic model" represents the normalized ratings only for those ships included in the data base. Here, Segment 7 (Admiralty Inlet to Tacoma) is clearly the busiest of the waterway, followed by Segments 6 (Rosario Strait), 3 (Strait of Juan de Fuca), and 5 (Haro Strait) in that order. The reader will note that Segment 3 has the highest density of "commercial vessels", i.e., deep draft cargo and tank ships, but that its total density is one third of Puget Sound's (Segment 7).

Table 3-6 includes subjective density ratings (from correspondence with a Puget Sound pilot and U.S. and Canada VTS personnel) for the remaining three vessel types, recreational boats, fishing vessels, and military vessels. "Total density ratings" normalize the totals of the seven type densities. The normalizing algorithm used is designed to compensate for "heavy ended" distributions; the results are sometimes non-proportional to the raw data. No weighting is used because the size of vessel and its operational activity (e.g., transiting versus crossing traffic lane, engaged in fishing, recreational) are confounding factors.

Adding the subjective judgments for military and unregulated vessels shift the total results only slightly. The rating for Segment 5 falls and those for 6 and 8 rise. Otherwise, they remain the same, with Segment 7 clearly the busiest.

Table 3-5
Traffic density raw data calculation
Vessel-miles/mile²

SEGMENT	1	2	3	4	5	6	7	8	9
AREA (NM²)	29	24	108	191	119	38	69	47	20
TRAFFIC TYPE	D	E	N	S	I	T	I	E	S
Commercial Ships (C)	1103	2026	4015	786	2347	1084	3416	139	22
Barges (B)	300	428	951	660	1040	614	4608	142	139
Tugs (T)	184	580	979	869	787	1884	6934	774	388
Ferries (F)	35	164	248	121	323	3012	4715	1956	13
TOTAL DENSITY	1623	3198	6194	2436	4497	6593	19673	3011	562

Table 3-6
Traffic density ratings

SEGMENT	1	2	3	4	5	6	7	8	9
Commercial Ships (C)	2	3	5	2	4	2	4	1	1
Barges (B)	1	2	2	2	2	2	5	1	1
Tugs (T)	1	2	2	2	2	3	5	2	2
Ferries (F)	1	1	1	1	1	4	5	3	1
TOTAL TRAFFIC MODEL	1	2	3	2	3	3	5	2	1
Recreational Boats (R)	1	1	2	2	3	5	5	4	3
Military (M)	1	1	2	2	1	1	3	3	1
Commercial Fishing (CF)	2	2	2	1	1	2	2	1	1
Raw Total	9	12	16	12	14	19	29	15	10
TOTAL DENSITY RATING	1	2	3	2	2	4	5	3	1

Shaded rows indicate subjective ratings.

National waterway comparison

A rough comparison of Puget Sound traffic with that of other U.S. ports follows, based on 1994 Army Corps of Engineers statistics. Table 3-7 shows the tonnage for Puget Sound area ports including Vancouver B.C.[46], along with the total for the waterway system. While these data are for cargo vessels only, they put the waterway traffic levels in some perspective. As shown, Puget Sound traffic levels are less than the top two U.S. ports for this year and in fact would rank 10th nationally. While the area of consideration has a great deal of shipping traffic, these numbers indicate that it is far from the busiest United States port.

Table 3-7
Comparative port tonnage (1994)

Port	Tonnage
Seattle	22,335,514
Tacoma	17,615,819
Anacortes	12,950,108
Everett	4,191,656
Port Angeles	1,695,048
Olympia	1,514,000
Bellingham	1,343,181
Vancouver, B.C.	67,633,000
Total Puget Sound	**129,278,326**
South Louisiana, LA, Port	**184,855,712**
Houston	**143,662,625**

CHAPTER 4 HAZARD ANALYSIS

Chapter 4 is the analysis of hazards and accident probabilities in the waterway, described in the methodology as Step 1 (see Figure 4-1). There are, in essence, two components in this process: expert elicitation and data analysis. Expert knowledge is, as previously mentioned, a critical element of any waterway analysis, given the unique physical and operational characteristics to account for, and the small amount of reliable local accident and spill data available. The data must be taken as an indicator of the risk record and balanced with the broader view available from the experts.

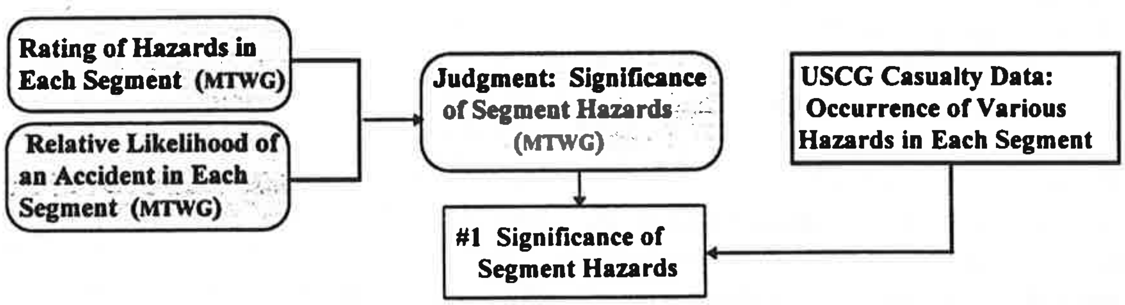
Validation of the results found is available from comparison to the weather and hydrography factors and traffic density tables of Chapter 3. In addition, the Washington DOE spill history can be contrasted with the Coast Guard accident data to help characterize the spatial risk distribution.

The chapter begins with a brief history of national and regional events which have shaped the management of this waterway, followed by a decomposition, by hazard, of the safety system now in place. The reader should note that the expert input and historical data are reflective of the waterway with this system in place. The system description lays the groundwork for a later discussion of how to approach the most worrisome hazards.

The evolution of the hazard taxonomy used here was a significant outcome of the expert elicitation and its outcome is found in that section. The taxonomy appears previously in the safety system description. Data sources and analytic tools discussion appear in the relevant sections.

Figure 4-1

Step 1



4.1 Background

4.1.1 Oil spills and regulation

The public consciousness of marine oil pollution traces its roots to the late 1960s, with the advent of very large crude carriers (VLCC) and the series of accidents demonstrating the huge outflows possible and the catastrophic environmental consequences. Despite 78 U.S. spills averaging

21,000 barrels between 1978-1992[3], the American public did not focus on the issue until the *Exxon Valdez* ran aground on Bligh Reef and spilled 35,000 tons of North Slope crude oil into Prince William Sound.

The *Exxon Valdez* disaster was a significant turning point in the history of the maritime industry, in particular the attitude toward marine safety and environmental protection management. The public would not tolerate a repeat of that spill. With OPA-90 leading the way, regulation at all levels, including international, came into existence to address the design, management, operations, insurance, and spill response planning of the industry.

The Alaska State investigation into the *Exxon Valdez* revealed a production and consumption "megasystem", where complacency in all quarters had fostered an environment where many causal factors could coalesce. Industry, government, and consumer alike had been lulled into, and jolted out of, an "oil induced stupor"[1]. The report's recommendations focused on the prime importance of spill prevention and highlighted first the need for changed attitudes toward oil transport safety, especially in industry.

4.1.2 Risk analysis and HOE

Attitude, or organizational culture, is at the heart of the risk element of human and organizational error (HOE), now recognized by many as the leading cause of accidents. Bea et al[6] defined organizational error as departure from acceptable practice leading to "unacceptable or undesirable quality", including "states" which influence individual error (these states may include incentive, information, culture). The importance of organizational commitment and individual training to an ongoing process of waterway risk management is clear.

There is also now a recognition that the reactive prescriptions of the past will not anticipate future problems, and may indeed cause their own. The maritime community has begun to find risk-based approaches more effective. These methods, which have been applied in the nuclear power and aviation industries, foster an atmosphere conducive to prevention of all possible accidents, not just those which have already occurred.

After a system is prescriptively rebuilt in response to a disaster, short term risk may drop but the longer term risk of complacency can set in. There has been a short term reduction in marine accidents; notably, the Canada Transportation Safety Board reports marine accidents both nationally and in western Canada peaking in 1990 and dropping to half that number in 1996 (65% of vessels involved were fishing vessels, 20% tugs/barges, 5% ferry/passenger, and 4% cargo/tanker)[35].

The post *Exxon Valdez* cadre of internal industry safety measures and oil spill prevention regulations is coming to maturity as public resources for enforcement diminish. As an example, the Washington Office of Marine Safety (OMS), formed in just 1990, is now being merged into the State Department of Ecology, with uncertain effects for the State marine safety program. In addition, the authority of the State to impose safety regulations on international shipping is being challenged in the courts by an industry group. These events, among others, signal to some a diminished collective vigilance only eight years after the *Exxon Valdez* spill.

Analytic risk assessment and management may forestall the cyclic effect of organizational and human complacency. Such an approach was first applied in this waterway by Wenk et al[52]. The authors were the first to combine maritime shipping data and expert opinion; they also highlighted the significance of human and organizational errors in the maritime industry. A similar approach has been used in a series of local waterway studies by Harrald, Grabowski, Mazzuchi, and others. They have developed risk-based marine safety criteria for Washington OMS and collaborated with others in the recently completed Prince William Sound Risk Assessment[18]. In the latter, a risk-based approach used both data and expert judgment to characterize waterway system safety.

In the regulation and enforcement sector, U.S. Coast Guard Headquarters recently developed the Risk Based Decision Making Guidelines[42], for use by local Captains of the Port in their waterway management responsibilities. The publication draws upon available research and methods to guide Coast Guard marine safety and environmental protection decision making. The approach here is similar to that described in the Guidelines, and the lessons learned from this study will be used by the Coast Guard to improve their risk based methodology.

4.1.3 Local matters

Washington State has its own significant regulatory regime, including crew and vessel screening, operations and inspection requirements, and vessel contingency planning. There is also a public/private incentive underway, the international tug of opportunity (ITOS). The first phase of ITOS implementation is a study of the availability of underway tugs. The primary coverage area is the Strait of Juan de Fuca from J buoy to Admiralty Inlet. The effectiveness of coverage in the western Strait and the offshore areas has been questioned, as well as the capability of tugs in the program.

The Washington DOE also has an important role in public waterway risk management, from the sensitivity analysis and spill response perspectives. They recently published a twenty-six year retrospective of oil spills in the state, obtaining a primary data set of 34 spills greater than 10,000 gallons (for vessels, pipelines, trains and facilities) and spills between 25 and 10,000 gallons since 1992[49]. Their spill-based approach is a pertinent counterpoint to the accident data used here.

Their data for spills greater than 10,000 gallons since 1970 show that vessels spilled 59% of oil by volume and 37% by the number of spills, followed by facilities, with 27% and 37% respectively. However, removal of a single vessel case, the *General M.C. Meiggs* (1972), flips the distribution, with vessels spilling 41% by volume compared to 56% by facilities. The strong sensitivity of results to a single spill highlights concerns about drawing firm conclusions from these data, as noted in their report.

DOE has a somewhat larger data set (136) for recent spills between 25 and 10,000 gallons, for which the contribution of vessels is again primary. It is likely that the majority of vessel spills are during transfer operations. Indeed, a query of the USCG databases for this study for underway spills greater than 50 gallons since 1986 revealed only 10 records (DOE's report added one additional spill to this report's baseline waterway characterization), and an extrapolation of DOE's four-year average small spill rate for vessels to the same 26 year period would result in a total spill volume of only 8.6% of the volume of major vessel spills. Future review of this information may highlight the need to study smaller, non-underway spills; these numbers, however, justify this study's focus on large underway spills.

The geographic distribution of major vessel spills reported by DOE is noteworthy for its near total concentration in two segments of the study. Of the eleven major marine spills since 1970, six were in or near the offshore area of Segment 2 and four in Segment 6, near the oil terminals at Anacortes and Bellingham. The remaining spill was in Port Angeles. These data will later provide a useful comparison to the results of expert and data analysis.

4.2 Safety system

Oil spill prevention in Washington's marine waters is provided for by a multi-level regulation and enforcement regime, as broadly described in Section 3.1. Here a system-wide view of the regulatory overlay is provided, with a focus on measures specific to parts or all of this waterway. It is not a detailed review of those international and Federal regulations addressing oil spill prevention. The inset below repeats the safety measures categories established in Chapter 2.

ROSTER OF UNIVERSAL MEASURES

UM1 - CREW PROFICIENCY AND VESSEL MANNING
UM2 - SYSTEM REQUIREMENTS
UM3 - VESSEL SCREENING
UM4 - SYSTEMS STATUS, TESTING/INSPECTION AND CHECKS
UM5 - VESSEL OPERATIONS
UM6 - POSITIONAL INFORMATION
UM7 - CENTRAL VESSEL LOCATIONAL MONITORING & CONTROL
UM8 - EMERGENCY PROCEDURES
UM9 - OUTFLOW MITIGATION
UM10 - SPILL RESPONSE PLANNING & CAPABILITY
UM11 - FINANCIAL RESPONSIBILITY/LIABILITY

Table 4-1 indicates how these measures are layered, corresponding to the taxonomy of accident-cause pairings developed by the project team and the Expert Panel; specific listings and details of the universal measures appear in Appendix D. Universal measures are those which apply uniformly throughout the waterway, e.g. crew standards promulgated by the Federal Code or international convention (roster below). Table 4-1 lists each category of universal measures applicable to a hazard, with the number of distinct measures within each shown parenthetically.

The list of actual measures can be found in Appendix F; it includes those judged to be substantive individual measures directed against the hazards identified herein. Canadian regulations are not shown; their VTS and AtoN entries would be duplicated in the table wherever they appear for the U.S. Coast Guard. Industry standards (such as vetting of charterers) are not included, but constitute a significant addition to the safety system..

Table 4-2 follows, describing the "non-universal" measures segment by segment.

There are many measures addressed severally by the waterway's authorities, some as redundancies, others as enhancement or cooperation. Noteworthy among the latter is the Cooperative Vessel Traffic Service (CVTS), operated jointly by the Canadian and United States Coast Guards. The Canadian Marine Communications and Traffic Services (MCTS) operates Tofino VTS, with responsibility for waters west of "J" Buoy north to Triangle Island and south to Cape Alava, Washington (including U.S. territorial waters and much of the OCNMS ATBA), and Vancouver VTS, controlling waters east of Vancouver Island from Victoria to Cape Caution (including U.S. territorial waters in Haro Strait and Boundary Pass[11, 40].

Vessels are required to contact Tofino Traffic 50 miles from Vancouver Island; as they proceed into the Strait of Juan de Fuca at Buoy "J", they are formally "handed-off" to Seattle Traffic. The U.S. Coast Guard operates VTS Puget Sound, with responsibility for Puget Sound, Rosario Strait, the San Juan Islands, and the Strait of Juan de Fuca. Through the Cooperative Vessel Traffic Services Agreement, VTS Puget Sound regulates vessel movements in both Canadian and US waters of the Strait, and Tofino Traffic assumes responsibility for vessels in Canadian and US waters at the approaches to the Strait. The reader should note that participation in the CVTS is mandatory throughout the waterway, with the exception of several classes of smaller craft whose length limits vary from 20 to 30 meters.

For most safety measures, the U.S. Coast Guard adopts the provisions of IMO conventions in many of the Federal shipping and navigation regulations and enhances others where the need exists. In some cases, a separate body of rules governs for specific classes of domestically operated vessels, e.g. small passenger boats. OPA 90 is, of course, the most prominent example of unilateral regulation enacted in the United States, affecting foreign as well as domestic shipping.

Finally, Washington has perhaps the most significant body of state marine regulations in the country with a strong added focus on the qualifications and condition of mariners, pre-arrival procedures and equipment inspections, and navigation equipment. All these measures are presented in more detail in Appendix D.

Table 4-1

Current universal measures vs. hazards

ACCIDENT/CAUSE	SAFETY MEASURES			
	TOTAL	IMO	U.S. COAST GUARD	WASHINGTON STATE
COLLISION				
Positional Information	13	UM5 [1]	UM2 [1], UM5 [3], UM6 [1], UM7 [4]	UM2 [1], UM5 [2]
Vessel Control	5		UM2 [1], UM5 [1]	UM4 [2], UM5 [1]
HOE	22	UM1 [2]	UM1 [3], UM3 [1]	UM1[7], UM3[8], UM5[1]
Conflicting Operations	9	UM5 [1]	UM2 [1], UM5 [3], UM7 [1]	UM2 [1], UM5 [2]
Physical Environment	4		UM6 [2], UM7 [2]	
POWERED GROUNDING				
Positional Information	13	UM5 [1]	UM2 [1], UM5 [3], UM6 [1], UM7 [4]	UM2 [1], UM5 [2]
Vessel Control	5		UM2 [1], UM5 [1]	UM4 [2], UM5 [1]
HOE	22	UM1 [2]	UM1 [3], UM3 [1]	UM1[7], UM3[8], UM5[1]
Conflicting Operations	9	UM5 [1]	UM2 [1], UM5 [3], UM7 [1]	UM2 [1], UM5 [2]
Physical Environment	4		UM6 [2], UM7 [2]	
DRIFT GROUNDING				
Positional Information	0			
Vessel Control	8		UM2 [1], UM5 [2], ITOS [1]	UM4[2], UM5[1], UM8[1]
HOE	22	UM1 [2]	UM1 [3], UM3 [1]	UM1[7], UM3[8], UM5[1]
Conflicting Operations	0			
Physical Environment	3		UM6 [2], UM8 [1]	
ALLISION				
Positional Information	12	UM5 [1]	UM5 [3], UM7 [4]	UM2 [2], UM5 [2]
Vessel Control	3		UM3 [1]	UM4 [2]
HOE	22	UM1 [2]	UM1 [3], UM3 [1]	UM1[7], UM3[8], UM5[1]
Conflicting Operations	9	UM5 [1]	UM2 [1], UM5 [3], UM7 [1]	UM2 [1], UM5 [2]
Physical Environment	3		UM7 [2]	
FIRE/EXPLOSION	1		UM2 [1]	
STABILITY FAILURE	1		UM2 [1]	
STRUCTURAL FAILURE	1		UM2 [1]	

Table 4-2
Current non-universal measures by segment

NON-UNIVERSAL MEASURE	**Desig n-ator**	**Segment 1 North J buoy approach**	**Segment 2 South J buoy approach**	**Segment 3 Western Strait Juan de Fuca to PA**	**Segment 4 Eastern Strait of Juan de Fuca**	**Segment 5 Haro Strt. Boundary Pass to BC**	**Segment 6 Rosario Strait and spurs**	**Segment 7 Puget Tacoma to Admiralty Inlet**	**Segment 8 Saratoga/ Skagit spur**	**Segment 9 Puget Snd. Tacoma to Olympia**
BRIDGE MANNING: CREW & PILOT (STCW throughout)	NM1				Pilot	Pilot	Pilot	Pilot	Pilot	Pilot
TRAFFIC CONTROLS: TSS, 1-WAY TRAFFIC	NM2	TSS	TSS	TSS	TSS	Turn point tanker safety area (Canada)	See below	X		
ATBA & OTHER SPECIAL AREAS	NM3	Canada TEZ, 50 mile zone from Vanc. Island	ATBA		Preca'ti'n-ary areas at PA and Admiralty Inlet		VTS Special area: tow, pass, cross, overtake specs.	Prohibited fishing areas during ferry OPS		
ACTIVITY RESTRICTIONS; SEE NOTES #1, 2	NM4		RNA	RNA	RNA	RNA	RNA	RNA	RNA	RNA
SPEED LIMITS; SEE NOTE #3	NM5						SOP: V=tug escort			
OPERATOR SOPS	NM6						See above			
VTS; **SEE NOTE #4**	NM7	X	X	X	X	X	X	X	X	X
ATON	NM8	X	X	X	X	X	X	X	X	X
TANKER SIZE LIMIT	NM9				125,000dwt	125,000dwt	125,000dwt	125,000dwt	125,000dwt	125,000 dwt
TUG ESCORTS	NM10				2-tug:spec'd tankers	Voluntary (100% use)	2-tug:spec'd tankers	2-tug:spec'd tankers	2-tug:spec'd tankers	2-tug: spec'd tankers
ITOS; SEE NOTE #5	NM11	X	X	X	X	X				

NOTE #1: COTP may restrict operations of any ship anywhere for adequate cause, e.g. inoperative radar. The VTS commander must in such cases grant or deny permission to transit special zones (49 CFR Part 161.11).
NOTE #2: Regulated navigation areas in any TSS (U.S. waters), situationally for fishing derbies, regattas, etc. COTP designates these. 11 knot speed limit for deep hull vessels. Indicated by RNA in matrix.
NOTE #3: Various industry SOPs for speed limits in tug escort areas. These vary and are most formalized in Rosario Strait area.
NOTE #4: VTS has radio coverage throughout waterway; radar covers all TSS and "shadows" only in Hood Canal, in Rich Passage, inside the San Juans, south of Tacoma, and east of Whidbey Island. Traffic advisories are universal in that VTS can communicate with all vessels anywhere in the subject waters.

4.3 Expert elicitation

The primary task of the Marine Transportation Working Group (MT WG) of the Expert Panel was to provide risk assessment data for the waterway. They did so, in essence, by answering three questions:

- What is the likelihood of an accident leading to a significant oil spill in each segment?
- Given an accident in a segment, what is the likelihood of different types occurring?
- Given an accident type in a segment, what is the likelihood of various causalities?

This section reports their approach, in brief, the results, and discussion of results. It should be noted that these calculations are for likelihood only, and not risk. The weighted hazard significance, or risk, is considered in Chapter 6, following consideration of spill consequences in Chapter 5. The details of the MT WG's deliberations appear in Appendix D.

4.3.1 Definitions and mathematics

The project team and the Expert Panel went through a process of defining an approach to the risk assessment by correspondence prior to the meeting in April, 1997. The MT WG meeting was, in part, a revisiting and modification of the elicitation's specifics. Most importantly, the Group discarded a proposed hazard analysis consisting solely of relative likelihoods of accidents for a detailed roster of causalities in favor of a consideration of accident types and causal categories. Accidents were the seven classical types shown below in Table 4-3 and the causal categories were as defined by Volpe Center.

The Group decided that their efforts should be concentrated on spills caused by collisions and groundings, and that other accident types could be discounted as insignificant (see Table 4-3). Later on, an interpretation of this result was necessary for reconciliation with the accident data set; see Section 4.5 for discussion.

The Group worked with a 1-5 rating scale for all relative likelihood of accidents and causality, running from low likelihood valued at 1 and high at 5. The mathematics of the combined probabilities is simply expressed by P[i, j, k], whose notation is defined in Table 4-4.

Table 4-3
Accident types and causes

Accident	Cause
Collisions	1) Poor positional information
	2) Vessel control and other deficiencies
	3) Human and organizational deficiencies
	4) Conflicting vessel operations
	5) Physical environment
Powered Groundings	Causes 1 - 5
Drift Groundings	Causes 1 - 5
Allisions	Causes 1 - 5
Fire/Explosion	Insignificant causality for major spills.
Structural Failure	" "
Stability Failures	" "

Table 4-4
Hazard notation

i = Location		j =Accident type		k =Causal factor	
1	Segment 1	1	Collision	1	Poor positional information
2	Segment 2	2	Powered Grounding	2	Vessel control or other failures/deficiencies
3	Segment 3	3	Drift Grounding	3	Human and organizational deficiencies
4	Segment 4	4	Allision	4	Conflicting vessel operations
5	Segment 5	5	Fire/Explosion	5	Physical features
6	Segment 6	6	Stability Failure		
7	Segment 7	7	Structural Failure		
8	Segment 8				
9	Segment 9				

The Law of Total Probability gives the conditional likelihood for an event of interest (e.g., collisions given accident in Segment 1) and combines them to determine marginal likelihood (e.g., collisions in the waterway). The 1 to 5 rating scale maps differently from the usual range of 0 to 1. Nonetheless, the experts' quantitative judgments were handled using the laws and calculus of probability. The individual and total probability formulations used are Equations 1, 2 and 3, using conditional probabilities to determine the hazard significance of individual segments, accident types, and causes.

Referring to the three primary questions addressed, the following equations pertain.

1. $HS_i \equiv$ Hazard Significance of Segment i = P[i] as rated directly by the experts
2. $HS_{j|i} \equiv$ Accident Type by Segment = P[j | i];

   Waterway Summation:

   $$HS_j \equiv \text{Hazard Significance of Accident Type } j = \sum_{i=1}^{9} P[j \mid i] * P[i]$$

3. $HS_{k|j|i} \equiv$ Accident cause by Segment = P[k | j, i]

   Waterway summation:

   $$HS_k \equiv \text{Hazard Significance of Accident Cause } k = \sum_{i=1}^{9}\sum_{j=1}^{3} P[k \mid j \cap i] * P[j \mid i] * P[i]$$

Finally, conditional likelihoods are multiplied to quantify causal factors in each segment for all accident types, as shown in Equation 4.

4. $$P[k \mid i] = \sum_{j=1}^{3} P[k \mid j \cap i] * P[j \mid i]$$

All results are based on averaged Group responses. The multiplication and summation of equations 1-4 are simple operations; the results shown here have been normalized to the 0-1 scale for all operands as described in Chapter 2, except when otherwise indicated.

4.3.2 Results

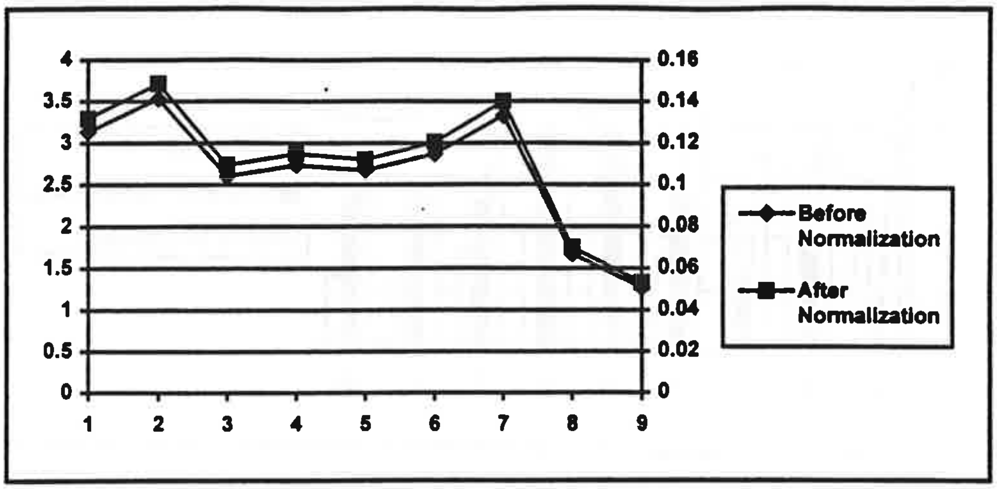
The first consideration was that of the likelihood of an accident resulting in a serious spill (defined as greater than 10,000 gallons), results of which appear in Figure 4-2. The left-hand y-axis is for raw averages of the experts' scores, while the right indicates the ratio of each score to the waterway aggregate score. The experts found a narrow range of relative likelihood across the waterway, excepting the low values for Segments 8 and 9. The highest values were in two areas: the offshore waters in Segments 1 and 2, and Puget Sound proper, Segment 7.

The peak values offshore were attributed to several factors:

- Physical (bad weather, fog, sea clutter on the radar).
- Organization of the traffic separation scheme (Canadian Tanker Exclusion Zone, ATBA, proximity of Duntze Rock to TSS).
- Traffic (fishing vessels and lighted night operations, crossing traffic at J Buoy, barges.)
- HOE (poor communications, fatigue of master, bridge resource management).

In Segment 7, traffic density, particularly of recreational boating, and crew fatigue were the concerns behind the high rating.

<u>Figure 4-2</u>
Segment accident likelihood



Question 2 involved the decomposition of accident types in each segment, given an accident in the segment. For this determination, the experts rated two pairs together, Segments 5 and 6, and 8 and 9, positing equivalence of the conditional likelihoods within those pairs.

Their results are shown in Figure 4-3. Here, several insights into the waterway system can be obtained. Collisions are overall the clear primary concern, followed by powered groundings. Drift groundings were viewed as a relatively low probability event. In addition, the experts saw collisions as the most likely event in all the individual segments but 5 and 6. There, powered groundings in narrow channels with many (Rosario Strait) or acute (Haro Strait) course changes were the primary concern (rated at nearly 4). The experts also felt that, east of Dungeness (Segments 4, 7, 8, and 9), the grounding type of most concern switches from drift to powered.

The summed result of accident likelihoods for the waterway (hazard significance) is provided in Table 4-4. The reader will note that the remaining four accident types (allision, fire/explosion, stability and structural failures) appear, with the minimum rating of one each. The MT WG felt that these were insignificant scenarios for serious oil spills. The minimum ratings were added in post processing for integration with the data analysis.

Figure 4-3
Accident likelihood by segment

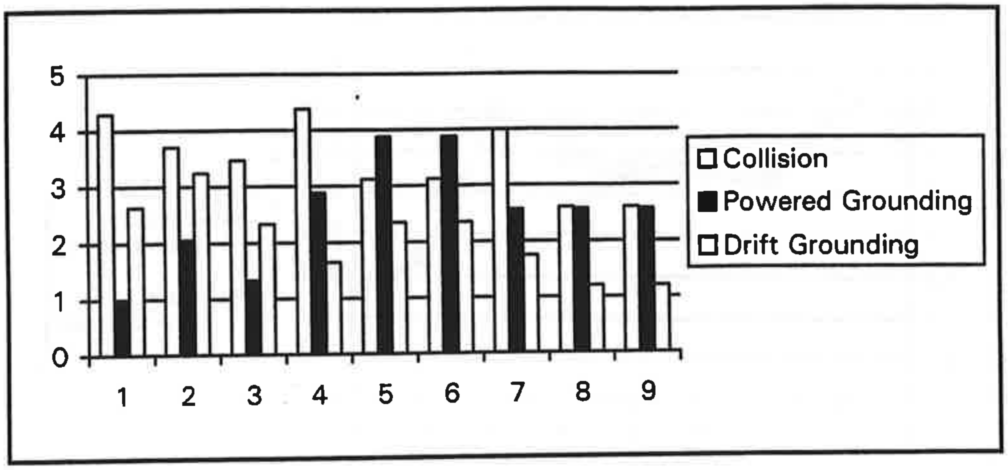
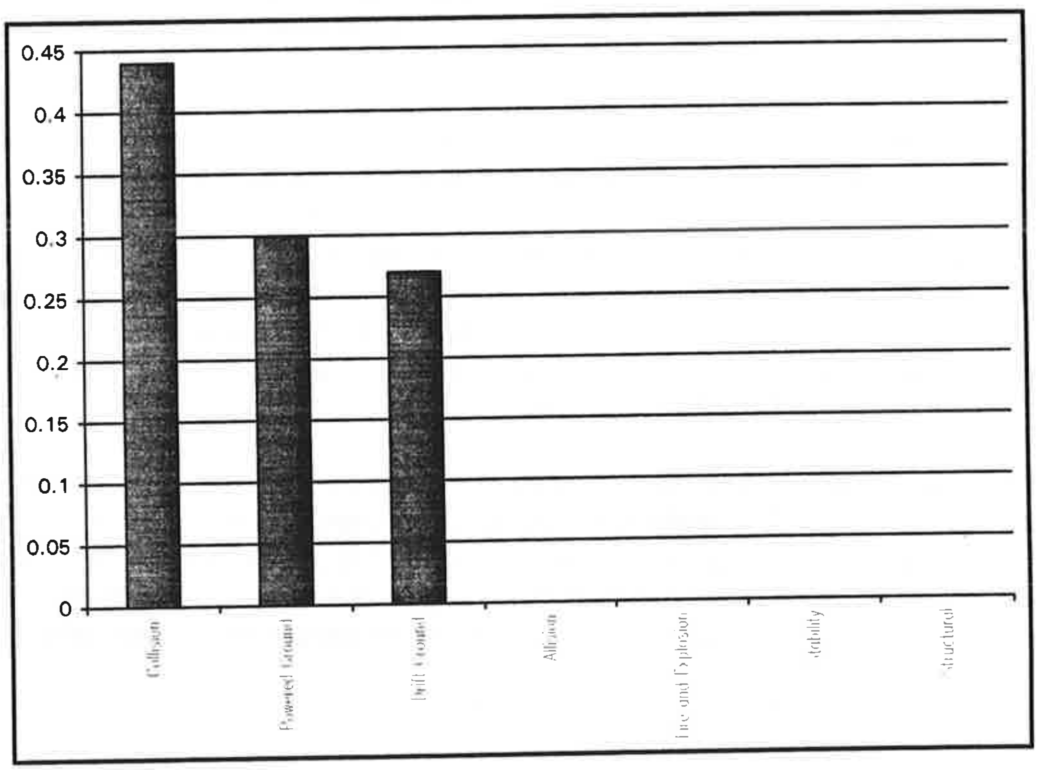


Figure 4-4
Total hazard significance



The Working Group next considered causality by segment and accident type, providing insight into causality in each segment. Individual segment results are not shown here, appearing as combined with data results in Section 4.5. However, the summed results combined with the previous expert judgments provide a system-wide look at the significance of the causal factors for all accident types (Figure 4-5). The marginal likelihoods for accident types in each segment are in Figure 4-6.

Human and organizational error is dominant factor, followed by vessel control, physical environment, conflicting vessel operations, and poor positional information. The primacy of human and organizational deficiencies, cited for all accident types, agrees with numerous other studies, notably by the United Kingdom Protection and Indemnity Clubs[36], Wenk[52], and the Coast Guard[43]. The Group clearly felt poor positional information has minor significance, no surprise given the nature of the waterway traffic control.

Figure 4-5
Causality significance, waterway

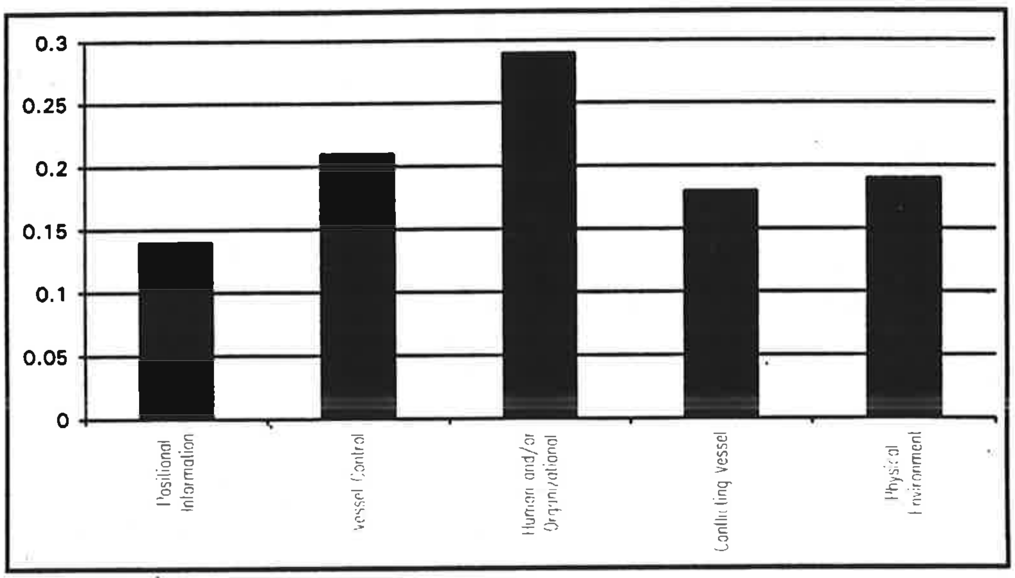
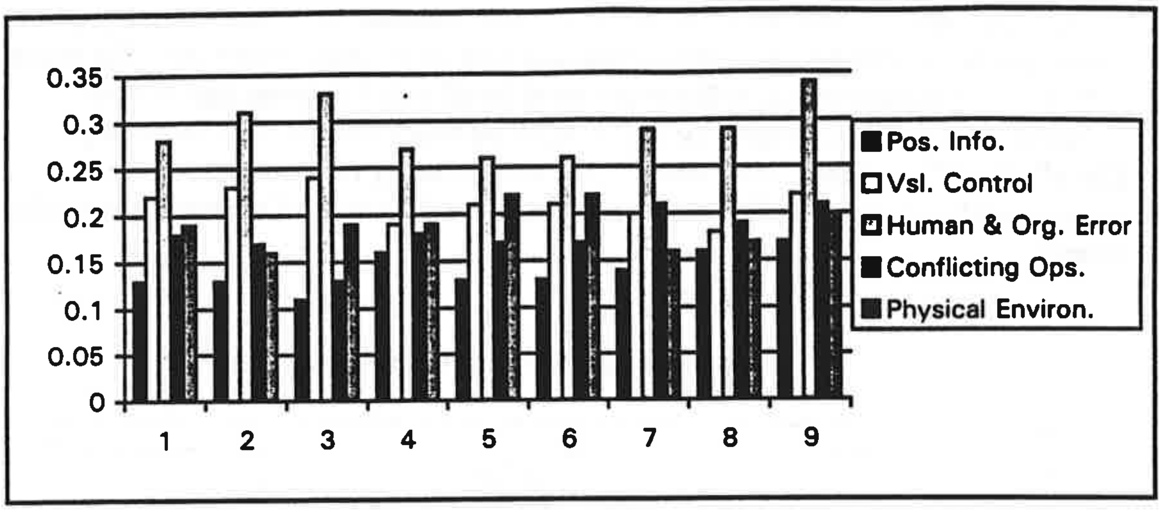


Figure 4-6
Causal factor likelihood by segment



4.3.3 Summary

The Expert Panel rated as moderate to low the likelihood of an accident which could result in a serious oil spill in the waterway. Segments 1, 2 and 7 were the segments judged most likely, although most segments were very close to the moderate rating of 3 (where 5 was high likelihood and 1 low likelihood). Collisions were seen as the most likely accident scenario, followed by powered groundings and drift groundings.

The Expert Panel found that human and organizational error was the dominant causal factor system-wide and in all segments. However, the order of the other four causal factors did vary by segment, in response to changing conditions of the waterway system. In segments 1, 2 and 3, vessel control was the second leading causal factor. However, once one moved out of segment 3 into segments 4, 5 and 6, the second leading causal factor was physical environment. Finally, in segments 7, 8 and 9, conflicting vessel operations was judged the second most likely cause, owing to higher traffic densities.

4.4 Accident data and histories

4.4.1 Approach

USCG data bases were the primary source for this portion of the study. Accident data available from Canada and the State of Washington were useful for validation but lacked either the detail or the reliability desired. Coast Guard data over the last ten years resides in the VCAS and MINMOD programs, and required considerable manipulation for this study. VCAS and MINMOD are the marine accident data bases used by the Coast Guard for the last ten years; it was necessary to scrub and reconcile the data from the two to get the ten year data set used here.

The search for underway spills greater than 50 gallons in the study area since 1986 revealed only 10 records; therefore the more general set of underway accidents was used in conjunction with spills. The greater number of accident data increased statistical confidence and brought our search one step further back on the causal chain described in Chapter 1. The first cut data set contained about 300 records; this set was scrubbed to eliminate incidents not resulting in accidents and "other" accidents including injuries and deaths. The MINMOD and VCAS queries were structured for the taxonomy developed by the Expert Panel, for the subject area waters and time frame (1986-1996). This provided the accident histories for segment, accident type and causal factors. The total number of accident records and vessels involved are shown in Table 4-5.

Table 4-5
Coast Guard accident data

Database	Number of Records	Number of Vessels
VCAS	92	114
MINMOD	44	68

Double counting of two accident types was not allowed, consistent with the data bases' structure. The project team decided to use records rather than vessels involved, as records are the events of interest, i.e., where oil can be spilled. It turned out that not only collisions (74% more vessels than records), but other accident types showed more vessels than records, e.g. allisions (58% more vessels than records). It appears that the "extra" vessels may be due to the involvement of tug and barge combinations.

The number of records are taken to represent a low bound on the risk exposure to spills, after elimination of some records and the decision not to include all vessels in the baseline accident count. The reader should note that the likelihood of significant spills for individual records was not estimated. Nonetheless, the number of records best represents the joint likelihood of accidents and spills, which is the variable of interest. This point will also be revisited when comparing the expert judgment and local data, as the experts were asked to consider the likelihood of vessel accidents that could result in a serious spill.

4.4.2 Results

The accident history over the last ten years is revealing. Most accidents (96%) occur in Segments 4 -9, east of Dungeness, primarily Segment 7 (Figure 4-7). Table 4-6 gives the segment likelihood ratings based upon both accident and spill data. Accident and spill ratings are arrived at separately by calculating segment incidents as percentages of the totals. These two sub-ratings are averaged to give the overall rating. The geographic distribution of accidents and spills in the last ten years is shown on Chartlets 4-1 (sorted by accident type) and 4-2 (sorted by vessel type).

Figure 4-7
Accident geographic distribution

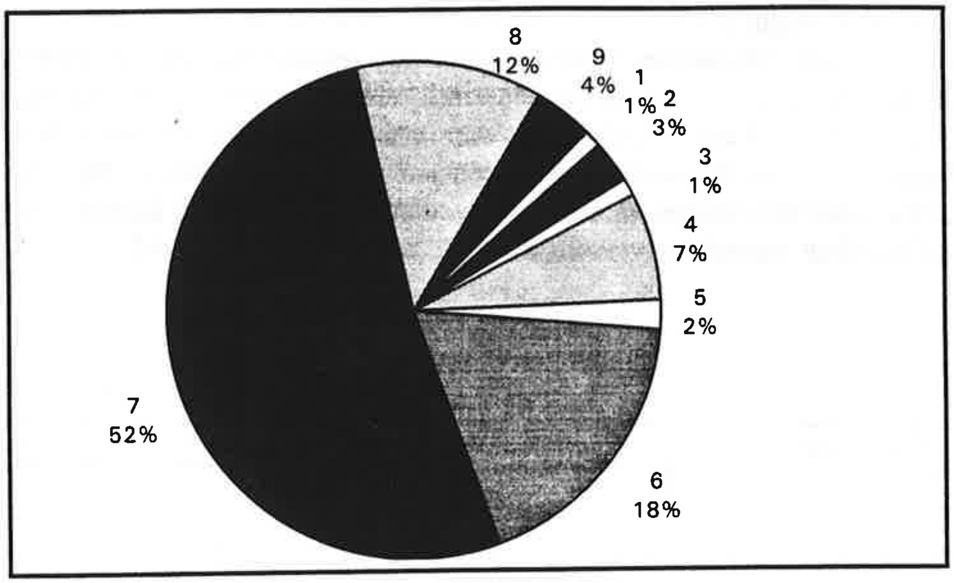


Table 4-6
Segment spill and accident ratings

Segment	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
# Accidents	1	4	1	9	3	25	71	16	6
Accident Rating	0.01	0.03	0.01	0.07	0.02	0.18	0.52	0.12	0.04
# Spills	1	2	2	2	0	2	2	0	0
Spill Rating	0.09	0.18	0.18	0.18	0.00	0.18	0.18	0.00	0.00
Overall Rating	**0.05**	**0.11**	**0.09**	**0.12**	**0.01**	**0.18**	**0.35**	**0.06**	**0.02**

Figure 4-8 shows the distribution of accidents by type. As shown, allisions were predominant, with 29% of all accidents, followed by powered groundings (23%), fire and explosion (15%), loss of stability (15%), collisions (14%), drift grounding (3%) and structural failures (1%). Here again, differences between local data and expert judgment exist, which will be discussed in the subsequent section.

Figure 4-8
Accident distribution by type

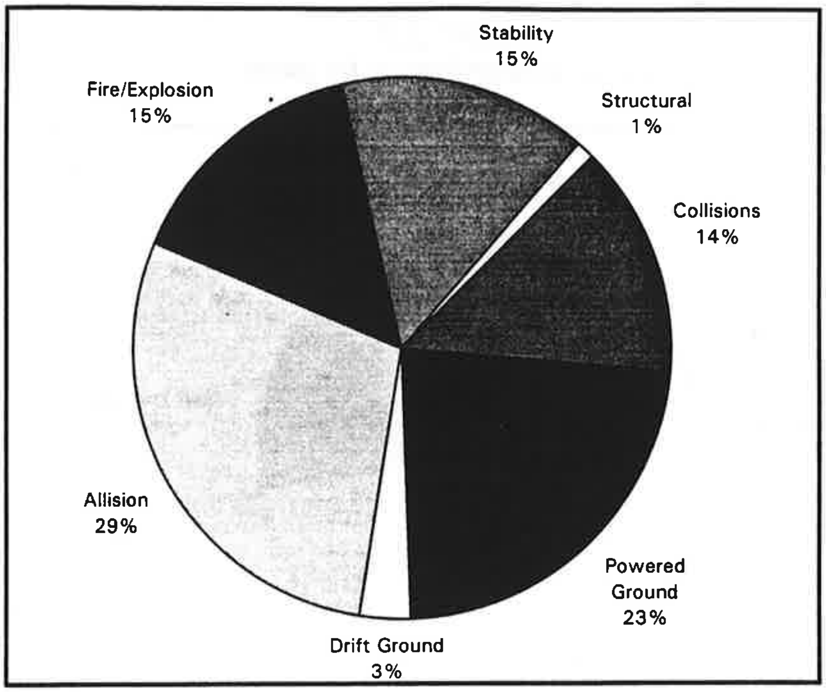


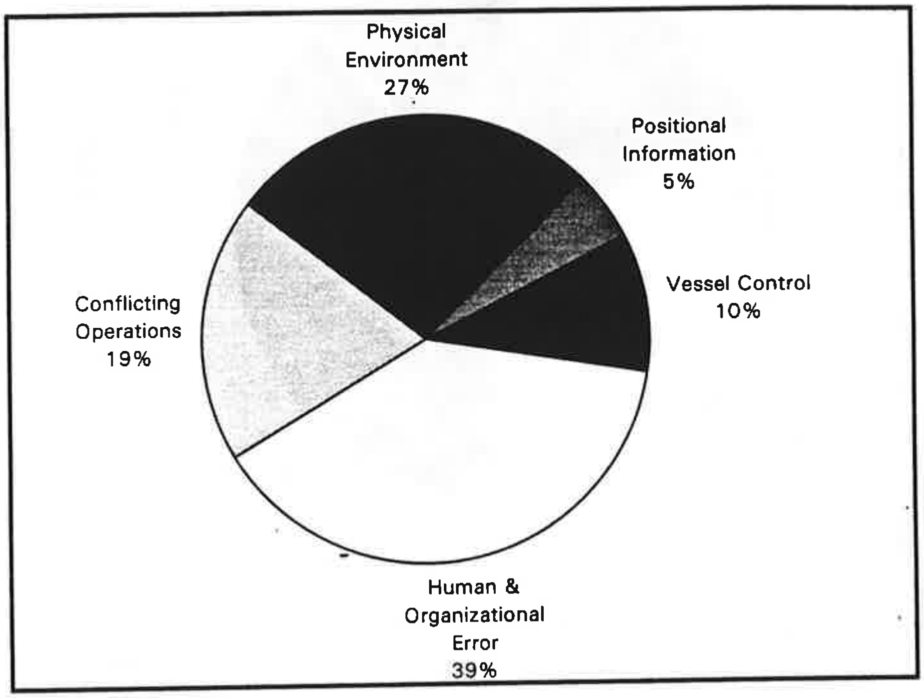
Table 4-7 shows again the preponderance of accidents in the eastern area, particularly allisions. Most collisions and powered groundings have occurred in the Inland Sea, where congestion and narrow passages are found. On manual examination of the data, the high number of stability failures turns out to involve many fishing vessels.

Table 4-7
Accident types by segment

Accident|Segment	1	2	3	4	5	6	7	8	9	Total
Collisions	1	0	0	1	0	3	12	2	0	19
Powered Groundings	0	1	0	2	1	10	10	5	2	31
Drift Groundings	0	0	0	0	1	0	1	2	0	4
Allisions	0	0	0	0	0	3	30	4	2	39
Fire/Explosion	0	1	0	3	0	6	8	1	2	21
Stability Failure	0	2	1	2	1	3	9	2	0	20
Structural Failure	0	0	0	1	0	0	1	0	0	2
TOTAL	**1**	**4**	**1**	**9**	**3**	**25**	**71**	**16**	**6**	**136**

The history of accident causes was also reviewed (see Figure 4-9). Human and organizational errors (HOE) are the most frequent cause (39%). This result agrees with national and international studies, as typified by the United Kingdom Protection and Indemnity Club's and the Coast Guard; these studies document greater incidence of HOE causality. The next most prominent category was physical environment, followed by conflicting vessel operations, vessel control and poor positional information.

Figure 4-9
Accident distribution by cause



4.5 Combined ratings

4.5.1 Results

The MT WG ratings and data probabilities are blended on a 1:1 basis, as explained in Chapter 2, to obtain the desired event likelihood and hazard significance data. The data sources have inherent and differing biases, which have both common sense and historical validity. As such, the 1:1 weighting provides a reasonable approach, averaging the two data sets along the lines of a Bayesian updating method.

The first calculation is for accident likelihood by segment, Figure 4-10. Results from the MT WG and the data base match well for Segments 2, 3, 4, 6, 8, and 9. The large discrepancies between local and expert data in Segments 1 and 5 may be explained by the lack of Canadian data there. In both Segments 1 and 2, the experts probably felt that the conditions for a serious accident and spill are high relative to other portions of the waterway. Segment 7, Puget Sound proper, has the highest historical accident rate, but the likelihood of significant spills may have been discounted by the experts because of low energy accidents involving piers and small vessels. Overall likelihood for Segment 7 is clearly the highest, followed by Segment 6 and a grouping at 1, 2, 3, and 4.

Figure 4-10
Accident likelihood by segment

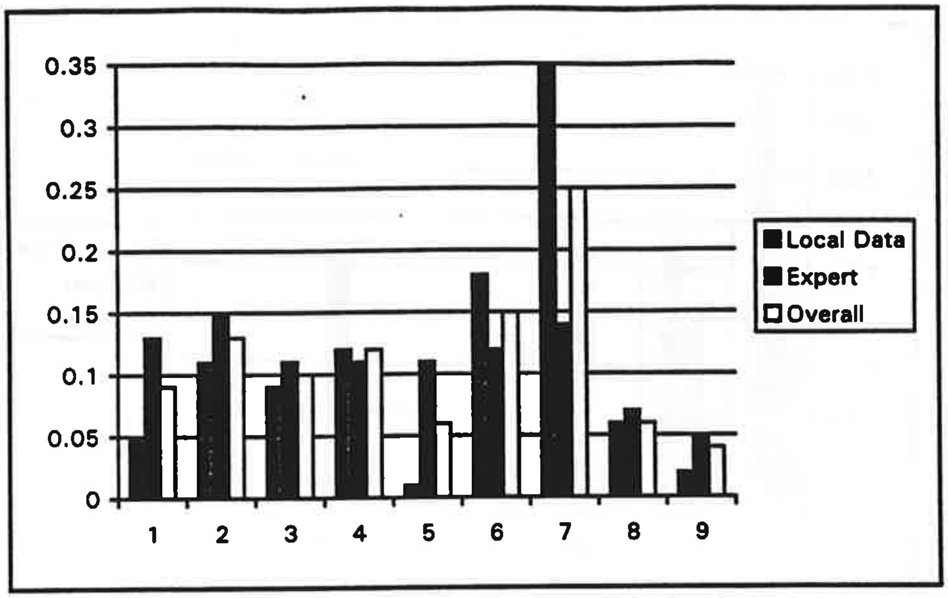


Figure 4-11 compares the likelihoods of accident types and arrives at the combined significance of local and expert data by the same process as accident likelihood. The figure indicates that collisions and powered groundings are the most significant accident types on the basis of likelihood only. The experts clearly discounted the possibility of serious oil spills from allisions, fire/explosions, and stability and structural failures (zero ratings). Drift groundings are a low probability event in the data base, but the experts, to the contrary, felt that this mode constitutes a real oil spill threat.

Allisions in this waterway are nearly certain to involve piers, rather than bridges, and thus are usually low energy affairs. Fires, explosions and structural failures show up in the data base from smaller vessels' casualties, which, given vessel size, are not likely to cause serious spills. The accident data show a fairly high incidence of stability losses; these, however, are most likely to involve smaller vessels. One exception to this general heuristic would be fuel and tank barges, which would be relatively susceptible to loss of stability. Additionally, flooding without sinking also qualifies as a loss of stability in the database. It is believed, but not empirically known, that such instances would be unlikely to result in serious oil spill.

Figure 4-12 depicts the combined ratings for accident causality in the waterway, calculated by summing the marginal and conditional probabilities for all accident types in all waterway segments. Human and organizational errors are the dominant cause, although not to the extent suggested by other national and international studies, as previously stated.

Figure 4-11
Significance of accident types

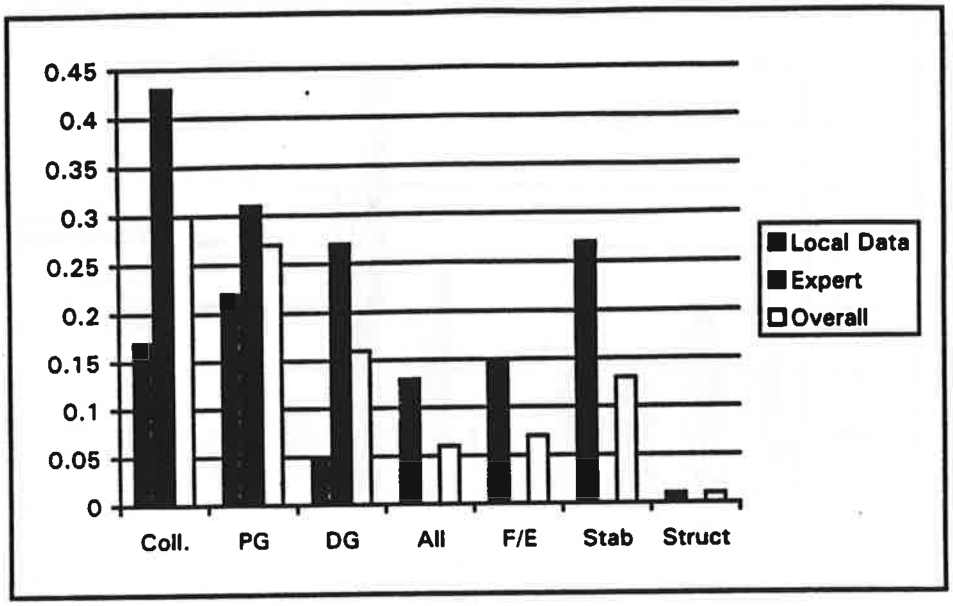
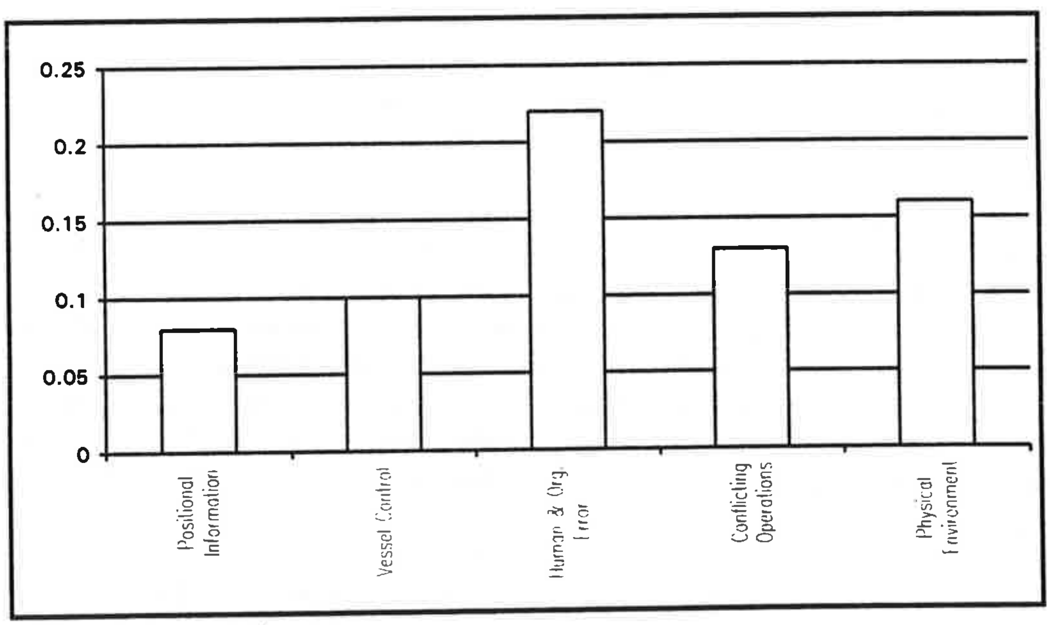


Figure 4-12
Causality significance, waterway



Figures 4-13 and 4-14 are the conditional likelihoods of causality by segment and accident type, respectively. Human and organizational error is foremost, by and large. In Segment 2 (offshore), physical environment is the main concern. The narrow, winding passages and currents in Segment 5 bring the hazard of vessel control to the top. Note that the probabilities do not sum to unity; this is due to incomplete causal information in the data bases.

Figure 4-13
Causality significance by segment

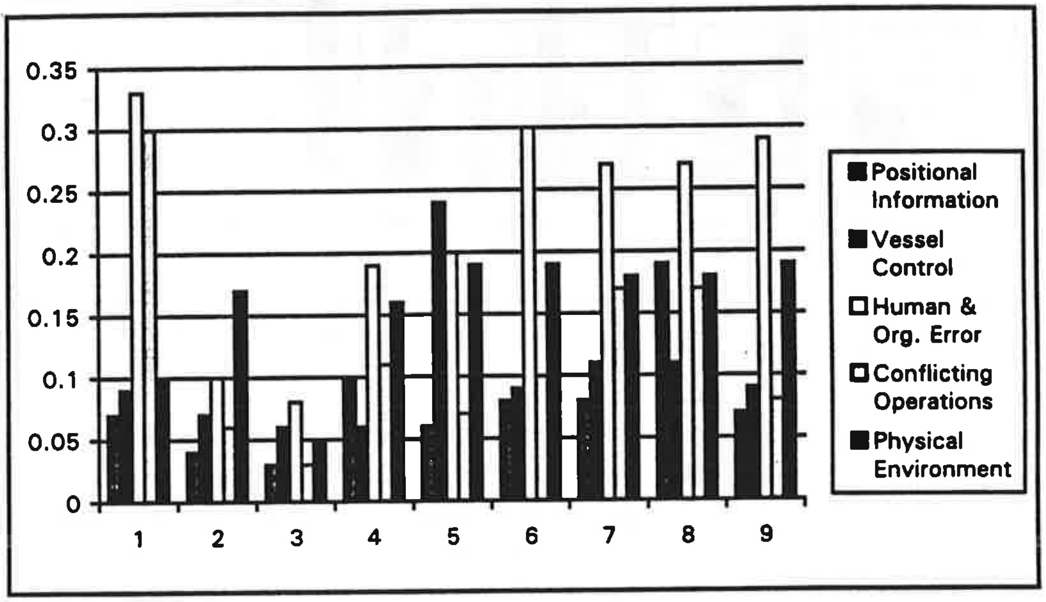
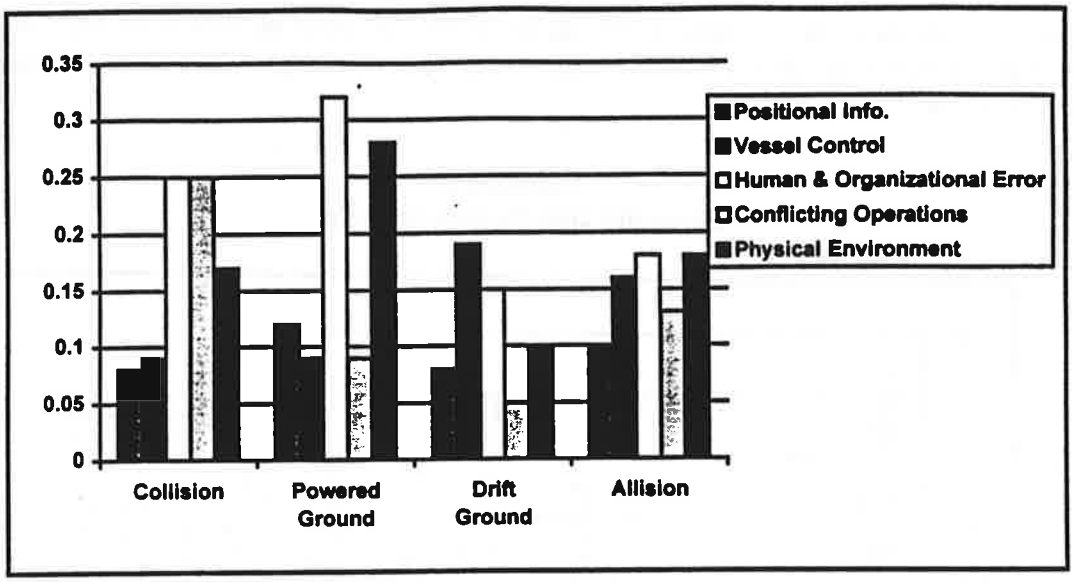


Figure 4-14 shows that HOE is the principal cause for two of the four accident types, and nearly so for the other two. For collisions, conflicting vessel operations and physical conditions are next. Physical environment is a significant factor in powered groundings; the MT WG attributed this to the width of the available natural channel or the established Traffic Separation Scheme (TSS). They in fact suggested several areas of possible improvement in the TSS.

Drift groundings' primary cause is seen as propulsion and steering failures; human and organizational error is most likely contributing in the form of failures to adequately maintain and support the vessel. Finally, the primary causes of allisions are human and organizational error and physical environment, according to the data base (the experts did not include allisions in their analysis). This may result from the high mental workloads due to increased congestion and irregular traffic flows in the eastern portion of the waterway (where all of the allisions were located).

Figure 4-14
Conditional likelihood of causality by accident type



4.5.2 Comparison

It is worthwhile to compare these results with those obtained elsewhere. The data and the experts give different pictures as to the most likely locality for oil spills. The experts' view is supported by a report prepared for the Canadian Council of Ministers of the Environment, which found that the entrance of the Strait of Juan de Fuca is the most likely place for spill of 1,000 to 10,000 barrels. The importance of physical factors emerged from both the experts and the data.

This is confirmed by comparison to the Wenk waterway study of 1981, where "physical environment" was found to be the most common cause of accidents, followed by HOE and equipment failure. It is possible that under-reporting of HOE could cause the juxtaposition of the first two causes; however, the relative significance of physical conditions to the other causes matches well with our finding. Wenk's causality findings also correlate: HOE was a strong indicator for collisions and causes were somewhat evenly distributed for groundings.

The distribution of accident types reported by the Washington OMS data base also correspond well with the Coast Guard data. The same can be said for the distribution by vessel type. OMS accident location data were not available.

The strong correlation between accidents and physical conditions has been pointed out in other studies, notably Ketkar and Babu[21], who noted that in spite of deeper and wider waterways on the United States west coast, accidents and spills occur more frequently there than in the east, attributable to rougher weather and "unfavorable hydrographic conditions".

Visibility and darkness are strong indicators also, as found by Romer et al[29] and Ramaswamy[29]. The latter found that 39 % of casualties studied in the Strait of Juan de Fuca occurred in restricted visibility. The Prince William Sound Risk Assessment[18] found that risk was dynamic in response to changing time of day, year, and operating conditions, implying strong correlations with visibility and hydrologoc conditions.

Table 4-8 (from waterway characterization in Chapter 3) indicates severe weather/hydrographic conditions in Segments 1 and 2; in spite of low traffic density, likelihood of a serious accident there must be considered high. Extremes (rating = 4-5) of either traffic density or conditions seem to correspond to high accident probabilities, while low or average scores for both factors imply low probabilities.

Table 4-8
Segment comparative characteristics

SEGMENT	1	2	3	4	5	6	7	8	9
Weather/hydrography	5	4	3	1	1	2	3	3	5
Traffic density	1	2	3	2	2	4	5	3	1

It should, conversely, be pointed out that accident/spill likelihood in the western Strait of Juan de Fuca (Segment 3) may be over-represented in the blended results found herein. The relatively low density of unregulated traffic, excellent traffic control, and navigational simplicity imply low risk here. That was the conclusion of a report for the Provincial government of British Columbia in 1981, which in fact proposed the siting of a new oil terminal at Low Point in the western Strait. The report stated that the navigational risk at existing terminals was at least twice that of proposed ports in the Strait and that tanker traffic in the Strait could triple with "only minimal increase in the number of expected spills along the approach route"[54].

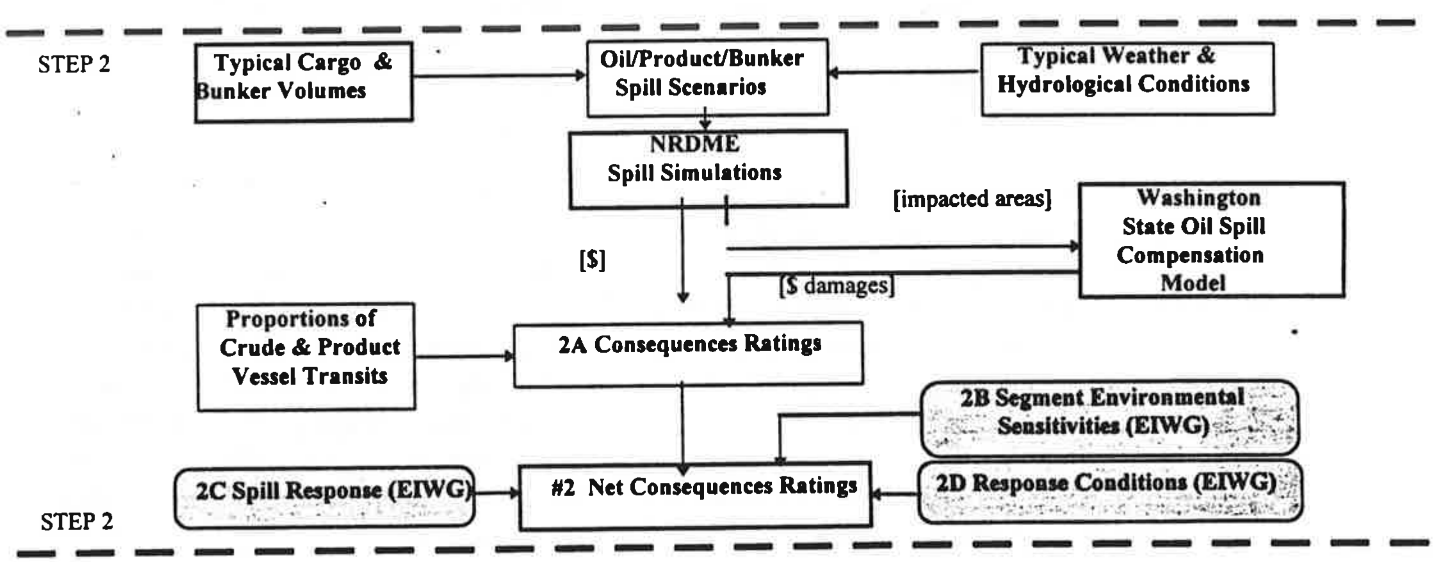
Additional background and comparative data may be found in Appendix D.

CHAPTER 5: SPILL CONSEQUENCES

Step 2 of the methodology calls for the development of Net Spill Consequences Ratings, that integrate the environmental consequences of spills in an area with the efficacy of spill response and cleanup activities, and the weather and hydrological conditions in which they occur. Environmental consequences were addressed in three different ways: 1) the Environmental Impact Working Group (EI WG) of the Expert Panel assessed the relative environmental sensitivity of the nine segments based on seven natural resource categories; 2) relative environmental damages were estimated for representative spill scenarios in each segment using the NOAA's Natural Resources Damage Assessment Model for Coastal and Marine Environments (NRDAM), greater damages indicating greater sensitivity; and 3) similarly, relative damages were estimated using the Washington State Department of Ecology's (DOE) Oil Spill Compensation Model.

The EI WG rated relative spill response capabilities and effects among the segments in four categories: containment and recovery, defensive measures, cleanup, and salvage. The EI WG also developed relative ratings among the segments for weather and hydrological conditions, considering winds, sea state, currents, tides and visibility in their assessment. The resulting Net Spill Consequences Rating was a weighted average of the ratings for environmental consequences, spill response, and response conditions. The methodology is described more fully in Chapter 2.

Figure 5-1
Step 2



5.1 Environmental Sensitivity

5.1.1 Expert Panel judgment

The EI WG rated the sensitivity of the seven natural resource categories in each segment on a scale of 1 (low sensitivity) to 5 (high sensitivity). To focus their thinking, they considered the effects of a medium-sized spill of medium thickness crude oil on the natural resources. "Sensitivity" was defined as the ability of a resource in a segment to recover and be as productive as it was before the spill, relative to other segments in the Puget Sound area, and not to other regions of the United States.

The EI WG had broad representation from a cross-section of agencies and interests, not just environmental scientists, who brought varied information resources to the table. However, they were somewhat limited in their ability to address the treaty rights of all Native American tribes and the interests of Canada, since only one Tribal entity, the Makah Nation, attended, and the Canadian representative was unable to attend. (The Ministry of Environment, Lands & Parks submitted detailed written materials for the Group's consideration. They are included in Appendix E). Since the group did not feel qualified to speak for the un-represented parties, in the rating process they uniformly assigned "5" ratings throughout the waterway for cultural and archaeological values, and assumed rough equivalencies between Canadian resource sensitivities in Segments 1, 3 and 5 and American resource sensitivities in Segments 2, 3 and 6, respectively.

The task was complicated because the segment boundaries, chosen primarily on the basis of vessel traffic characteristics, often included diverse habitats and weather and hydrological conditions. The EI WG was fortunate to have a parallel analysis conducted by Washington State DOE using the sensitivity indices in their Oil Spill Compensation Model, that ultimately confirmed the Panel's results.

Table 5-1 shows the sensitivity ratings. The EI WG established rating criteria for each resource; these are important for understanding the scores and are part of Appendix E, "Environmental Impact Working Group Executive Summary of Workshop Findings". Generally, the Panel assigned high sensitivity ratings for species resources when the segment contained large numbers of breeding individuals, populations already at risk, or large portions of an entire population. Habitats were rated highly where spilled oil would be relatively persistent, where biological diversity, density and productivity were great, or where impacts on foraging would be long term. Sensitivity of shoreline habitat was discounted where higher wave energy and cleaning action is expected, as on exposed beaches of the outer coast. Recreational parks were rated highly when spills would cause prolonged or frequent interruption of human use.

Table 5-1
Worksheet 2B: Sensitivity ratings by EI WG

Segment Number	Marine Mammals	Recreation and Parks	Birds	Cultural and Archaeological	Aqua-culture	Shoreline Habitats	Fin Fish	TOTAL
1	5	5	5	5	4	2	4	4.3
2	5	5	5	5	4	2	4	4.3
3	3	3	5	5	4	2.5	5	3.9
4	4	2	5	5	3	3	5	3.9
5	4	5	4.5	5	4	4	5	4.5
6	4	5	4.5	5	4	4	5	4.5
7	2	4	2	5	3	4	4.5	3.5
8	3	3	3	5	4.5	5	5	4.1
9	3	2	3	5	5	5	4	3.9

The EI WG then re-rated the above outcomes to improve the discrimination between segments. They gave Segments 1, 2, 5 and 6 new ratings of "5", Segments 3, 4, 8 and 9 new ratings of "4", and Segment 7 a new rating of "3". They did not use the full range of scores from 1 to 5, because they were reluctant to rate any segment as having "low sensitivity" due to the richness and variety of the natural resources throughout the Puget Sound area.

The final EI WG values are shown in Table 5-2 along with the results of an analysis performed by the Washington State DOE using the vulnerability scores in their Oil Spill Compensation Model (OSCM). The OSCM addresses the vulnerability of 37 marine and estuarine habitat types and six specific resources, including marine birds, marine fisheries, shellfish, salmon species, marine mammals, and marine and estuarine recreation. (This model is described in greater detail in Section 5.1.3.) For this analysis, the DOE averaged the vulnerability scores during the most sensitive season for categories within each segment to obtain the DOE ratings in Table 5-2. They agree with the EI WG ratings in all but Segment 8. Although both models recognized the large concentrations of eelgrass and kelp in Segment 8, the experts rated the segment more sensitive than did the DOE model because of the sensitivity of the other resources living there.

Table 5-2
Sensitivity rating comparison

Segment	EI WG Ratings	OSCM Ratings
1	5	5
2	5	5
3	4	4
4	4	4
5	5	5
6	5	5
7	3	3
8	4	2
9	4	4

5.1.2 Natural Resources Damage Assessment Model (NRDAM) results

The second element of the environmental consequence assessment was a comparison of resource damages in each segment due to oil spills. This was accomplished by running oil spill scenarios using the NRDAM. The spill scenarios were developed using likely locations, and types and amounts of oil based on the traffic analysis. Spill trajectories and impact areas were found with NRDAM, and the quantified damages from both NRDAM and the Washington State OSCM. Details and comparison of the results follow.

NRDAM

The NRDAM is a model developed by the U.S. Department of the Interior pursuant to Section 301(c) of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) to provide standard procedures for Type A damage assessments[5]. These are simplified assessments requiring minimal field observation of natural resource damages due to oil, refined petroleum product, and chemical spills. The dynamic model is comprised of a series of linked submodels and databases, that ultimately produce a damage claim for the cost to restore injured natural resources plus the compensable values of the resource injuries pending restoration. It is supported by a geographical information system supplying spatially gridded environmental and biotic information to the physical fates, biological effects, and restoration submodels.

The physical fates submodel computes the dynamic distribution of the spilled substance in the environment. Computations continue until all environmental exposure levels are below minimum toxic thresholds. The biological effects submodel computes the direct lethal effect on eggs, larvae, juvenile and adult fish, shellfish, birds, mammals, reptiles, and lower trophic level biota (for example, phytoplankton, forage fish), indirect and long-term effects involving eventual losses to these species, and indirect effects of food web losses on species without direct use values. The restoration submodel computes the costs of the most technically feasible restoration actions, and the compensable value submodel computes damages associated with injuries based on lost use values.

The NRDAM is a sophisticated computational model that takes a comprehensive look at the fate of spilled substances in the water, their effects on a broad range of living natural resources and habitats, and the costs of these damages to society. It models all U.S. coastal and marine environments on 470 different chemicals and oils which might be spilled. The geographical, environmental, biological, physical-chemical and toxicological characteristics in the databases and algorithms are simplified because of the wide ranges of coverage. The Puget Sound area contains two distinct biological "provinces": the outer coastal area and the inner Puget Sound area running eastward from the west end of the Strait of Juan de Fuca. Each province has a unique biological database associated with it, which contains individual species abundances by season of the year for up to approximately 540 fish species, and approximately 300 species of birds, reptiles and mammals. The provinces are divided into grids, each containing 2500 rectangular cells; each cell is coded as land or water, and as one of 21 ecological habitat types. Eight grids comprise the study area, two for the outer coastal area and six for the inner Sound.

The drawback of NRDAM for this study is that, because it is applicable to such a wide range of situations, some detail is sacrificed. The database is not detailed enough to identify precise locations of biological resources throughout the area, but distributes the resources uniformly over the provinces. For example, a major oil spill near one of the largest eagle breeding areas in the study area on San Juan Island may significantly reduce the overall eagle population in Puget Sound, but the NRDAM, using its provincial database which distributes the populations of bald and golden eagles uniformly over the entire inner Puget Sound, will not show the disproportionate effect of that spill on the general eagle population[4]. Thus, this study enhances the NRDAM results by incorporating a parallel damage assessment by the Washington State DOE Oil Spill Compensation model, which provides more geographically specific natural resource locations (para. 5.1.3).

Scenario Development

The scenarios were designed to represent typical or likely spills of oil and oil products in each waterway segment, based on the vessel sizes and types and the commodities transiting the waterway, and the accident history of the waterway. Forty-six scenarios were developed as described below and summarized in Table 5-6. An actual spill situation of the magnitude in the study scenarios would likely require a full scale assessment rather than rely on the NRDAM that was designed for smaller scale spills.

<u>Material Spilled</u> - ACE data on vessel traffic and commodities showed crude oil, residual fuel oil, and bunker fuel to be the largest trade commodities; others carried in large quantities included gasoline and distillate fuel oil no. 2. The decision was made to use crude oil and bunker fuel from the top three commodities, and distillate fuel oil no. 2 to capture the tug/barge trade and to vary the physical properties of the spilled materials. Table 5-3 shows the Washington DOE consequence indices for these oils[48].

The same three materials were spilled in each segment to maximize comparability of the damages among segments, except in Segments 8 and 9. ACE data showed that only bunker fuel was carried there in any significant quantity, which is therefore the only material spilled in those segments.

Table 5-3
Characteristics of spilled oils
(Index Scale from 1-low to 5-high)

Oil Class	Acute Toxicity	Mechanical Injury	Persistence
Prudhoe Crude Oil	0.9	3.6	5.0
Bunker Oil	2.3	5.0	5.0
Distillate Oil #2	2.3	3.2	2.0

Quantity Spilled - A variable amount was spilled in each segment based on the local traffic around the scenario site and on large spills in the accident history. For spills of cargo, the size was limited to 15% of the amount carried by the most common vessel type and size on each waterway. This is roughly the proportion of the Exxon Valdez cargo which spilled, but less than the spillage in total losses such as the Braer and the Torrey Canyon.

For crude oil spills, the ACE category of vessels "greater than 30' draft" was used. For distillate no. 2 oil, 15% of the average tanker load of fuel was used, unless the total barge volume of the commodity in the segment exceeded the tanker volume, in which case 15% of the average barge load was used.

For the first seven segments, bunker spills were set at a constant amount equal to 10% of 3,000 long tons, based upon bunker capacities for typical merchant vessels. 300 long tons is considered a serious bunker spill and assumes a greater degree of compartmentalization in the barges than that found in cargo oil tankers. Bunker oil spilled in Segments 8 and 9 could result from either a bunker fuel spill or a spill of residual fuel oil being carried as a commodity via barge. Fifteen percent of the average barge load was used.

Where Spilled - Scenarios were situated in segments where known hazards were identified and/or where casualties and near misses occurred in the past. This led the project team to choose the locations for the spill scenarios shown in Table 5-4.

Table 5-4
Spill scenario sites

Segment Definition	Spill Site and Rationale for Its Selection
1. Northerly ocean approach to the "J" buoy	5 miles WNW of the "J" buoy: convergence of 2 major approaches to the Strait of Juan de Fuca, often heavy sea state, poor weather conditions
2. Southerly ocean approach to the "J" buoy	30 miles SW of the "J" buoy in the Olympic Coast National Marine Sanctuary: voluntary approach not always adhered to by fishing vessels causing traffic conflicts, often heavy seas
3. Strait of Juan de Fuca	southern coast of the Strait of Juan de Fuca near Pillar Pt.: a vessel encountering trouble near the course change in the Strait of Juan de Fuca might lose power and go aground near Pillar Point
4. Area from Port Angeles, north to Haro Strait, east to Rosario Strait, and south to Admiralty Inlet (junction area)	1 mile north of Port Angeles: area known for congestion
5. Port Angeles through Haro Strait, Boundary Pass, and Georgia Strait	1 mile NE of Stuart Island: 90 degree turn in high currents, often with converging traffic
6. Rosario Strait to Anacortes and Cherry Point	Guemes Channel: tricky, narrow channel to navigate, with strong currents
7. Admiralty Inlet to Tacoma	East Passage between Seattle, Bainbridge Island, and Vashon Island: heavy congestion, crossing traffic patterns with ferries, site of many casualties in the past
8. Eastern passage from Edwards Point to Skagit	1 mile outside Everett Harbor: heavy traffic area, course changes occurring here
9. Puget Sound south of Tacoma	above Nesqually Reach: U-turn around Anderson Island

Weather and Hydrologic Conditions - Because the ecological profile changes greatly from season to season, the spill scenarios in each segment were run for two seasons. Washington State DOE suggested winter and spring are the two most highly productive seasons in terms of marine life. January 5 and May 5 were chosen.

Historical prevalent wind speed and directions by season and site of the spill scenario were obtained from numerous sources: five NOAA weather stations (Victoria, Olympia, Vancouver, Quillayute, and Whidbey Island) for more than thirty years of historical wind readings, the *Coastal Pilot*[45], British Columbia Ministry of Environment, Lands and Parks[8] and a local almanac[23].

Tidal currents were obtained mainly from British Columbia Ministry of Environment, Lands and Parks[8], local tide charts[23], discussions with local experts, and other references. Base currents representing the net outflow of water from Puget Sound into the Pacific Ocean are shown for each segment in Table 5-5.

Table 5-5
Base currents

Segment	Speed and direction of base current
3, 4	0.2 - 0.3 knot West
1, 2	0.2 knot North in January, South in May
5, 6	0.1 knot South
7, 9	0.2 knot North
8	0.1 knot South

Duration of spill - The material was released over a period of six hours for bunker fuel, and 48 hours for crude oil and distillate fuel oil no. 2.

Extent of cleanup - No cleanup efforts were assumed for the NRDAM. The aim of the methodology is to characterize sensitivity; the effects of local response capabilties are included in the methodology at a later point.

Price index for damages - Damages were determined in 1997 dollars, factored at 1.17 times NRDAM's 1991 values.

Recreational and port closures due to spill - The calculations assume no recreational or port closures due to the spill scenarios.

Scenario Results

NRDAM runs of each scenario produced detailed reports describing the spill trajectories, the effects of the spill on current and future individual populations of fish, birds and mammals, and on habitats, and the estimated dollar values for resulting injuries and economic damages. Each spill simulation continued to run until the model determined that the spilled material had been diluted, removed, or degraded to a point where it no longer produced a toxic effect on the environment, sometimes many years after the spill date.

NRDAM was unable to complete spill scenario runs for bunker fuel in January and crude oil in May in Segment 2, because the simulation spread the oil over too large a large surface area off the Washington and Vancouver Island coasts. Referring to the Expert Panel's assumption that Segments 1 and 2 were roughly equivalent in environmental sensitivity, the study team assumed in these cases that the ratio between January and May damages to Canadian resources in Segment 2 was the same as the ratio for Segment 1 damages. The maps and summaries for the May and January spills of crude oil in Guemes Channel, the spill site for Segment 6, are included in Appendix 5-3.

Table 5-6
Summary of scenario parameters for NRDAM

Segment Number & Site	Scenario 1 Bunker Fuel (with low volatility)	Scenario 2 Prudhoe Crude Oil (with low volatility)	Scenario 3 Distillate Fuel Oil no. 2 (with high volatility)	Background Current and Prevalent Wind
1. 5 miles WNW of the "J" buoy 48.527N; 124.812W	Amount: 94,280 gallons Duration: 6 hours	Amount: 3.70m gallons Duration: 2m gal in 24 hrs; 1.7 gal in 24 hrs	Amount: .25m gallons Duration: 24 hours	Background Current: .2 knot W Wind: Jan: SE 18 knots May: W 15 knots
2. 30 miles SW of "J" buoy 48.150N; 125.167W	Amount: 94,280 gallons Duration: 6 hours	Amount: 2.13m gallons Duration: 1.5 m gal in 24 hrs; .63 gal in 24 hrs	Amount: 1.34m gallons Duration: 24 hours	Background Current: .2knot N in Jan, S in May Wind: Jan: SE 7 knots May: WNW 6 knots
3. S coast of Strait of Juan de Fuca near Pillar Point 48.243N; 124.089W	Amount: 94,280 gallons Duration: 6 hours	Amount: 3.69m gallons Duration: 2m gal in 24 hrs; 1.69 gal in 24 hrs	Amount: 1.34m gallons Duration: 24 hours	Background Current: .2 knot W Wind: Jan: E 8 knots May: W 6 khots
4. 1 mile N of Port Angeles 48.167N; 123.403W	Amount: 94,280 gallons Duration: 6 hours	Amount: 3.69m gallons Duration: 2m gal in 24 hrs; 1.69 gal in 24 hrs	Amount: 1.33m gallons Duration: 24 hours	Background Current: .2 knot W Wind: Jan: SSE 8 knots May: W 10 knots
5. 1 mile NE of Stuart I. 48.681N; 123.275W	Amount: 94,280 gallons Duration: 6 hours	Amount: 2.58m gallons Duration: 1.5 m gal in 24 hrs; 1.08 gal in 24 hrs	Amount: 99,000 gallons Duration: 24 hours	Background Current: .1 knot S Wind: Jan: W 5 knots May: W 5 knots
6. middle of Guemes Channel 48.518N; 122.615W	Amount: 94,280 gallons Duration: 6 hours	Amount: 3.80m gallons Duration: 2m gal in 24 hrs; 1.8 gal in 24 hrs	Amount: 1.18m gallons Duration: 24 hours	Background Current: .2 knot WSW Wind: Jan: ESE 7 knots May: WSW 6 knots
7. E. Passage between Bainbridge I. & Alki Point 47.589N; 122.449W	Amount: 94,280 gallons Duration: 6 hours	Amount: 2.52m gallons Duration: 1.5 m gal in 24 hrs; 1.02 gal in 24 hrs	Amount: 1.70m gallons Duration: 24 hours	Background Current: .2 knot N Wind: Jan: SSW 8 knots May: SW 8 knots
8. 1 mile outside Everett Harbor 48.008N; 122.267W	Amount: 37,240 gallons Duration: 6 hours	N/A	N/A	Background Current: .1 knot S Wind: Jan: SSW 8 knots May: SW 8 knots
9. above Nesqually Beach 47.130N; 122.698W	Amount: 37,240 gallons Duration: 6 hours	N/A	N/A	Background Current: .1 knot N Wind: Jan: SSW 6 knots May: SSW 7 knots

Spills occur on January 5 and May 5 at low tide. No response activities or beach and recreation closures are entered into the model.
Currents flow *toward* the direction indicated. Winds blow *from* the direction indicated.

Damages due to spills of crude oil were greatest in January in the inner po tic ns of Puget Sound that do not enjoy the natural cleansing effects of the high energy outer coastal waves, allowing the persistent oil to inflict great on the large numbers of wintering birds, as well as shellfish beds. In May, damages from crude were more evenly felt by inner and coastal portions of the study area due to the departure of wintering birds and the universal presence of important fisheries. Bunker fuel spills exhibited similar patterns to crude for both winter and summer months; the smaller amounts of bunker fuel compared to crude oil made the resulting damages lower as well. Distillate fuel oil no. 2 is somewhat more toxic than crude oil and causes initial kills of fish, but as it is not very persistent, its effects are short-term on fisheries and bird populations.

Table 5-7 contains the NRDAM results and shows how they are used in the study methodology in Worksheet 2A, "Consequence Rating". The "Percent transits" columns were derived from data in Appendix C. Winter and spring damages for each oil type are averaged and weighted by the percent transits. The "Percent transits" column under "Crude" is the percent of all commercial transits in the segment that are carrying crude oil, both tankers and tank barges. The "Percent transits" column under "Product" is the percent of all commercial transits that are carrying refined petroleum products. The "Percent Transits" column under "Bunker" is the percent of all commercial transits carrying bunker fuel for powering the vessel. Note that a tow vessel pulling a barge is counted as two transits in the commercial transit denominator for the above percents.

5.1.3 Washington State DOE Oil Spill Compensation Model (OSCM) results

The third element in the assessment of oil spill environmental consequences was the Washington State DOE OSCM, used to compare natural resource damages from the same oil spill scenarios run by the NRDAM.

The OSCM grew out of the 1989 Washington State Resource Damage Assessment Act (ESHB 1853), which directed the DOE to develop a simplified approach for determining public resource damages created by oil spills in state waters. The legislation prescribed the creation of a Scientific Advisory Board composed of several subcommittees, each designated to address a specific element of the model, and a Resource Damage Assessment (RDA) committee. The committees were composed of resource experts from state and federal agencies, academic institutions, consulting firms, Native American Tribes, and environmental organizations.

These committees were instrumental in the development of the resource ranking databases on which the spreadsheet model is based. The marine waters of the state were divided into 131 subregions, for which the committees rated the vulnerability of each of seven resource categories by season of the year on a 1-low to 5-high scale. The seven categories are: marine birds, marine mammals, marine fish, shellfish, salmon, habitat, and recreation. Additionally, the committees developed a 1-to-5 ranking based on the severity of effects of each oil on resources.

Table 5-7

Worksheet 2A: Consequence rating for NRDAM

SEG	Crude Damages Winter (W)	Crude Damages Spring (S)	Crude % Transits	Crude Weighted Damage C	Product Damages Winter (W)	Product Damages Spring (S)	Product % Transits	Product Weighted Damage P	Bunker Damages Winter (W)	Bunker Damages Spring (S)	Bunker % Transits	Bunker Weighted Damage B	Consequences Overall (C+P+B)	Consequences Rating
1	$224,381	$493,487	5.9	$21,177	$34,397	$31,216	6.4	$2,100	$150,851	$165,368	81.5	$128,859	$152,136	1.84
2	$132,178	$290,703	0.3	$634	$123,203	$106,409	2.0	$2,296	$21,427	$23,489	86.3	$19,381	$22,312	1.00
3	$561,317	$712,929	2.3	$14,654	$55,218	$196,841	3.5	$4,411	$31,983	$299,176	82.7	$136,934	$155,999	1.86
4	$1,535,145	$699,044	1.3	$14,522	$430,969	$53,531	3.7	$8,963	$363,881	$119,915	75.0	$181,424	$204,909	2.18
5	$1,111,905	$640,319	0.4	$3,154	$218,578	$117,282	5.6	$9,404	$321,913	$146,612	69.4	$162,578	$175,136	1.99
6	$1,876,046	$1,605,983	1.3	$23,155	$43,736	$290,226	3.2	$5,343	$70,619	$318,596	92.5	$180,012	$208,511	2.20
7	$983,671	$574,121	0.04	$312	$475,856	$243,629	1.1	$3,957	$392,561	$104,506	91.3	$226,911	$231,180	2.35
8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	$90,399	$86,153	91.8	$81,037	$81,037	1.38
9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	$933,663	$808,487	73.6	$641,111	$641,111	5.00

Table 5-8

Worksheet 2A: Consequence rating for Washington State DOE OSCM

SEG	Crude Damages Winter (W)	Crude Damages Spring (S)	Crude % Tran-sits	Crude Weighted Damage C	Product Damages Winter (W)	Product Damages Spring (S)	Product % Tran-sits	Product Weighted Damage P	Bunker Damages Winter (W)	Bunker Damages Spring (S)	Bunker % Tran-sits	Bunker Weighted Damage B	Consequences Overall (C+P+B)	Consequences Rating
1	$51,985,000	$74,888,000	5.9	$3,742,754	$2,895,000	$5,582,500	6.4	$271,280	$1,748,894	$4,081,381	81.5	$2,375,837	$6,389,871	5.00
2	$20,831,400	$71,120,700	0.3	$137,928	$10,988,000	$35,443,000	2.0	$464,310	$1,406,658	$1,638,586	86.3	$1,314,023	$1,916,261	1.76
3	$82,951,200	$99,851,400	2.3	$2,102,230	$24,363,750	$29,305,800	3.5	$939,217	$2,778,432	$3,338,455	82.7	$2,529,333	$5,570,780	4.41
4	$82,951,200	$109,888,200	1.3	$1,253,456	$24,363,750	$31,574,200	3.7	$1,034,852	$2,778,432	$3,650,522	75.0	$2,410,858	$4,699,166	3.77
5	$72,214,200	$82,018,200	0.4	$277,618	$2,233,440	$2,529,450	5.6	$133,361	$3,448,762	$3,912,620	69.4	$2,554,400	$2,965,379	2.52
6	$102,676,000	$115,824,000	1.3	$1,453,025	$25,582,400	$28,261,000	3.2	$861,494	$3,322,427	$3,711,804	92.5	$3,253,332	$5,567,851	4.40
7	$52,945,200	$69,577,200	0.04	$24,504	$28,764,000	$37,706,000	1.1	$365,585	$2,587,043	$3,396,908	91.3	$2,731,674	$3,121,763	2.63
8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	$929,510	$1,316,434	91.8	$1,030,888	$1,030,888	1.12
9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	$1,090,015	$1,274,725	73.6	$870,224	$870,224	1.00

The model sums vulnerability scores for the seven resources in the most sensitive subregion affected by the spill, adjusts the sum by the type of oil to get a dollar per gallon damage figure, and multiplies by the number of gallons spilled to get the damage assessment total. This model is designed for compensation, and extrapolates the worst local damage over to the entire spill volume. Its results can thus be biased toward high end values. Vulnerability scores are factored up with a multiplier of 1.5 if kelp or seagrass is present, and another multiplier of 1.5 if threatened or endangered species are present in the subregion.

Inputs

Maps displaying the trajectories of the simulated spills and the extent of surface and coastal oiling from NRDAM were produced for the 46 scenarios, and sent to the Washington State DOE, along with the scenario parameters in Table 5-6. These provided information for the DOE to run their model for the same scenarios. Key assumptions they made were:

- damage assessment was conducted on the most sensitive subregion exposed to a significant percentage of the spilled oil;
- the breakdown of the subregion into habitat types was estimated at a very general level given the lack of detail in shoreline impact projections;
- special feature factors, for example, kelp, were applied based on general assumptions and trends rather than specific population data; and
- for many of these spills, full resource damage studies would be conducted rather than using the OSCM.

Scenario Results

Table 5-8 contains the OSCM results and shows how they are used in Worksheet 2A, "Consequence Rating" in the study methodology. Appendix 5-3 contains results of two scenarios from the OSCM for a spill of crude oil in Segment 6 in January, and bunker fuel in Segment 4 in May.

Although the actual values of the damages from the OSCM and the NRDAM are sometimes orders of magnitude apart, the final ratings of the two models are generally comparable, with one major exception. While NRDAM identified Segment 9 as having the most significant consequences from a typical spill, the OSCM identified it as one of the least affected segments. This dramatic difference may be a case of local effects for a particular case (discussion below), and certainly does not reflect on the relative quality of the two models.

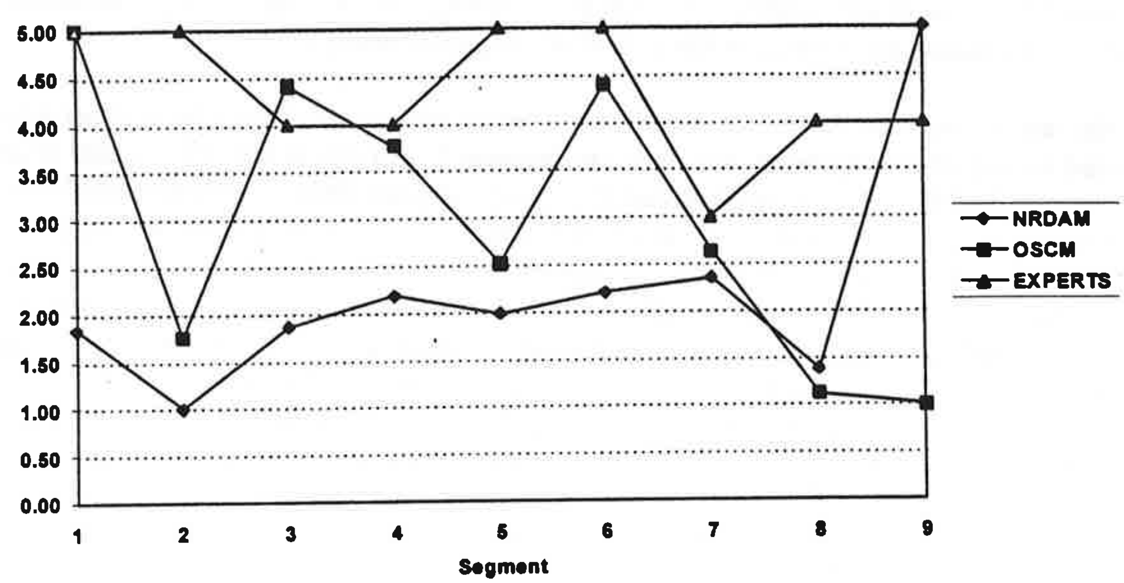
This contrast highlights the strengths and weaknesses in both models and the different applications for which they were intended. The OSCM, developed by the State of Washington for Washington waters, has quite a different perspective from the NRDAM, developed by the U.S. Department of the Interior for all U.S. waters. The OSCM has a more geographically specific biological database for Washington State waters and shoreline habitats, while the NRDAM contains a more sophisticated dynamic model of the fate of a spilled substance in the environment and simulates the effects of the substance on resources until it becomes harmless, sometimes for years after the spill. Further, both models were designed to determine the dollar value of resources damaged by a spill of oil or a hazardous substance for purposes of compensating the owners of those resources. However, the study uses these dollar values as a proxy for the environmental consequences in the locality of the spill, and dollar values may not always be the most appropriate indicator where living resources are concerned. (The study was aware of this potentiality, and thus incorporated expert panel findings into the methodology as an additional measure for arriving at the overall consequence rating.)

In the case of Segment 9, the OSCM calculates one of the highest dollar damages per gallon spilled for any of the segments, but since the Segment 9 spill size is the smallest size of any scenario at 37,240 gallons of bunker fuel, the model, very sensitive to spill size, produces low damages relative to other segments. Because bunker fuel is very toxic and persistent, the NRDAM simulates the effects of the spill, though small, for 21 years in an area of wetlands that is not exposed to the flushing action of the open coast. Because NRDAM places an extremely high value on bald eagles, which eat contaminated wildlife and birds in wetlands and tidal flats, and because NRDAM assumes a uniform distribution of bald eagles throughout the Sound, when there are likely fewer near the Segment 9 spill site than in some other parts of the Sound, the NRDAM damages for this segment are extremely high relative to the other segments.

5.1.4 Overview of environmental sensitivity

After normalization of the dollar damages for the two spill models, it is seen that the Expert Panel assigned high sensitivity ratings overall throughout the waterway, especially in Segments 2, 5, and 8 (see Figure 5-2). The Panel's view of the environment was broader than that of the models. Unlike the models, the Panel considered archaelogical and cultural values, as well as recreational uses of the waterways and surrounding park areas, and in the case of archaelogical values, the Panel gave all segments a value of "5".

Figure 5-2
Comparison of NRDAM, OCSM and Expert Panel ratings



5.2 Spill response and salvage effects

Spill response and salvage have variable mitigating effects on oil spill impacts depending on the available resources and response time at a particular spill location. The EI WG rated the relative response capabilities in the nine segments using reference materials, including the Coast Guard Area Contingency Plan (ACP), Washington State Geographic Response Plans (GRP), and information provided by panel members' expertise on spill response and salvage resources (see Appendix 5-2). As with environmental sensitivity, the EI WG rated, without Canadian representation, the Canadian segments the same as their nearest geographical United States segments, modified as Panel members' best knowledge and experience suggested.

The EI WG considered the criteria below in developing their ratings. The ratings are shown in Table 5-9 containing Worksheet 2C, "Spill Response".

- For containment and recovery response, the Panel used a 24-hour window as a benchmark to evaluate relative capability to respond to spills in all segments.
- In rating defensive response measures, they considered the existence of the appropriate assets, both mechanical and alternative measures such as in situ burning and chemical dispersants, and the means to get equipment on-scene to protect important resources, especially in shallow waters.

- In rating cleanup response, the EI WG did not include the cleaning of birds and mammals, and rated a segment downward if it contained a large amount of shallow waters and mudflats not able to be cleaned by mechanical means that inflict as much damage or more than the spilled substance itself. Timing was not rated for cleanup because timing is not the issue. The limiting factors are a matter of technology and logistics.
- In rating salvage response, the EI WG evaluated the ability to bring the appropriate equipment and technology to stem the outflow of a spill resulting from a stranding or collision within the first 24-hour period. The Panel felt that the Pacific Northwest has reliable salvage equipment; the ratings focus on the effects that weather and the physical environment have on the salvage response. In fact, the EI WG felt that professional salvage is the most effective of the response measures at minimizing the consequences of a casualty to the environment. This will be evident in Chapter 7, in the discussion of EI WG-recommended proposed safety measures.
- In considering how to combine the ratings for individual response measures into an overall response rating, the EI WG believed that certain response measures were more effective than others in any given situation, and that the choice of a measure should include an evaluation of the complete environmental effects of each potential response strategy. After reviewing the result of equal weighting of the four response measure categories, they believed the overall weightings were appropriate, and did not revise the equal weighting system.
- The EI WG panelists emphasized that response organizations are all in full compliance with all applicable laws and specifications regarding spill response readiness. The variation in the following ratings derives from inherent elements of the ACP and GRPs presently in force.. These documents reflect realities of traffic density and efficacy of response across the waterway.

Table 5-9
Worksheet 2C: Spill response capabilities

Segment Number	Containment/ Recovery Equipment		Defensive Measures		Clean-up	Salvage		Average	Ratings
	Assets	Time	Assets	Time		Assets	Time		
1	2	2	1	1	1	2	2	1.5	1
2	2	2	2	1	2	2	2	1.9	2
3	3	3	3	3	3	3	2	2.9	3
4	5	5	4	3	3.5	4	3	4.0	4
5	4	4	4	3	2	3	3	3.1	3
6	4	4	4	2	2	4	3	3.1	3
7	5	5	5	3	4	5	5	4.5	5
8	5	5	4	3	2	5	5	3.9	4
9	4	4	3	3	2	4	3	3.1	3

5.3 Response Conditions

The EI WG rated response conditions in the Puget Sound area by considering weather and hydrological conditions prevalent in the nine segments. The Panel felt it had enough general knowledge and experience with the environmental conditions in each segment to give relative ratings to the segments without rating each condition (winds, sea state, current, tides and visibility) separately. Table 5-10 shows the ratings ("1" is worst, "5" is best) from Worksheet 2D, "Response Conditions". It is evident that the response conditions improve as the location of the spill site moves from offshore to the innermost part of the Sound. This is due mainly to the improvement in sea state, winds, and visibility as one moves away from the open ocean. Current and tides become more of a factor in spill response for the inner segments; hence no segment received a "5" rating.

The ratings do not track completely with those developed in Table 3-4, where tidal and current influences were weighted more highly than in the mental model of the EI WG. The worst discrepancy is in Segment 9, which has the most pronounced tides and currents in the waterway.

Table 5-10
Worksheet 2D: Response conditions ratings

Segment	Rating
1	1
2	1
3	2
4	2
5	3
6	2.5
7	3
8	4
9	4

5.4 Net Consequences

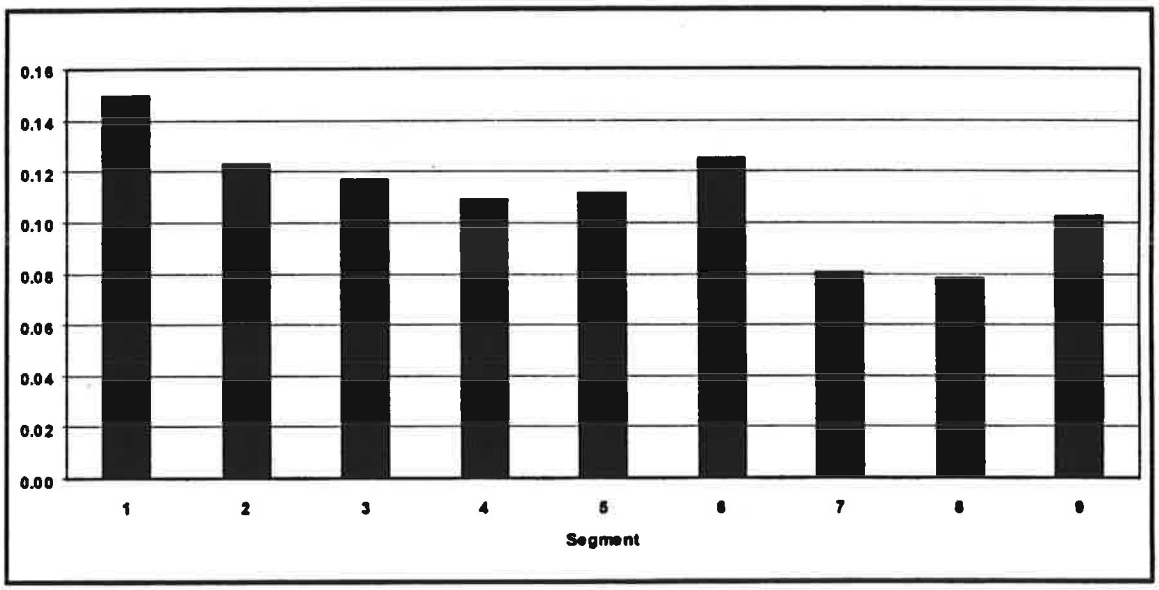
Table 5-11 and Figure 5-3 show the net consequences of combining the environmental consequences and sensitivity, spill response and salvage effects, and response conditions. Note that extra weight is assigned to consequence and sensitivity elements, relative to response. The Consequence Rating in the table below was obtained by averaging the normalized 1-5 ratings for the NRDAM and the OSCM.

Table 5-11
Worksheet 2: Net consequences rating

Segment	1	2	3	4	5	6	7	8	9
Consequence Rating (A)	3.42	1.38	3.14	2.98	2.25	3.30	2.49	1.25	3.00
Environmental Sensitivity (B)	5.00	5.00	4.00	4.00	5.00	5.00	3.00	4.00	4.00
Spill Response (C)	5.00	4.00	3.00	2.00	3.00	3.00	1.00	2.00	3.00
Response Conditions (D)	5.00	5.00	4.00	4.00	3.00	3.50	3.00	2.00	2.00
Net Consequence*	**4.53**	**3.71**	**3.54**	**3.29**	**3.38**	**3.79**	**2.45**	**2.37**	**3.10**

* Net Consequence = {[1.5(A+B) + C + D]/5}, where C and D are the inverse of the final rating.

Figure 5-3
Net consequence rating by segment



The results (Figure 5-3) reveal a general trend of decreasing net consequences as one moves from northwest to southeast in the study area. Figure 5-4 illustrates how higher spill consequences coincide with poorer response ability and conditions in Segments 1, 2, 3 and 6 resulting in greater net consequences. Conversely, lower spill consequences are matched with greater response ability and conditions in Segments 7, 8, and 9. In the figure, "Consequences" is the average of the Expert Panel and the model ratings (A and B from Table 5-11), and "Response" is the average of the response capabilities and conditions ratings (C and D from Table 5-11).

Figure 5-4
Comparison of consequences and response by segment

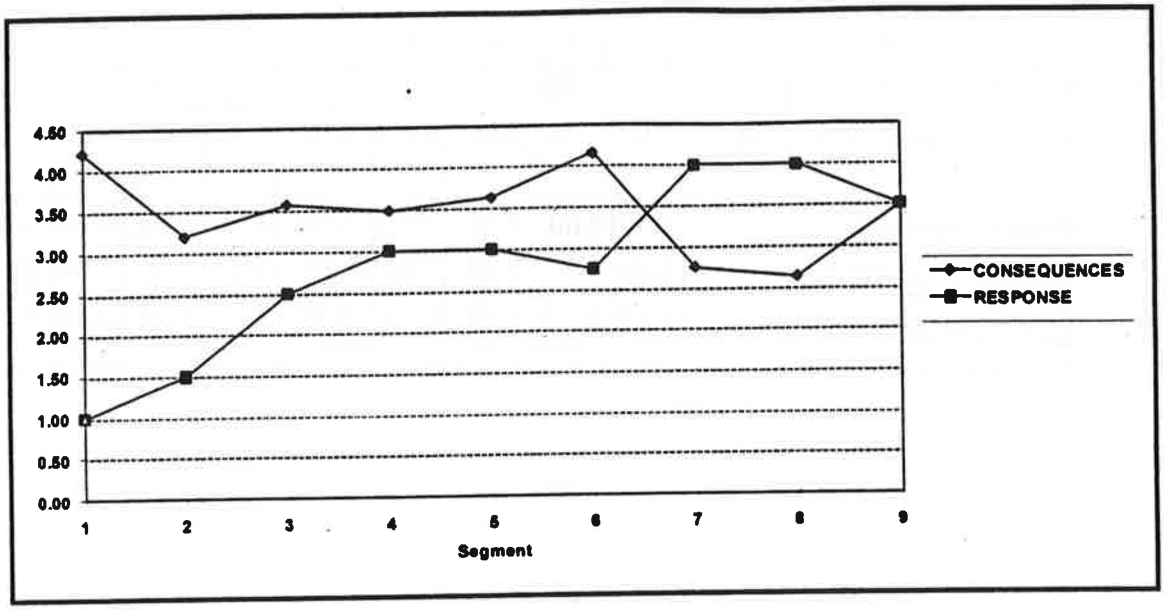


Figure 5-4 shows a clear divergence of sensitivity and response efficacy. Environmental sensitivity generally drops as one moves west to east while response efficacy increases. This trend has clear implications for risk in the waterway, as discussed in Chapter 6.

CHAPTER 6: WATERWAY RISK AND THE SAFETY SYSTEM

6.1 Waterway and segment spill risk ratings

The primary objective of this assessment of safety is to identify where in the study area the highest oil spill risks lie. Risk varies significantly from segment to segment because neither the likelihood of an accident, the consequences should one occur, nor their product ("risk") are the same. In chapter 4, segment ratings for the likelihood of an accident (based upon casualty data and the judgment of the expert panel) were presented, followed in chapter 5 by the ratings for net consequences.

The risk ratings are arrived at by simple multiplication of the two sets of results. Some discussion of the two sets of conditions assumed for each end of the risk equation is in order, since they yield a set of joint results. Specifically, the element of calendar time and the implicit and explicit assumptions of worst conditions must be reconciled. Accident probabilities were arrived at by a combination of accident data (which were independent of clock or calendar time) and expert judgment (where the marginal accident probabilities were from a mindset of adverse rather than benign conditions). Ratings for spill consequences were developed on a more explicit worst case basis. The EI WG worked with a worst case mental model for rating segment sensitivities, considering the most sensitive seasons and populations. The dates chosen for spill scenarios run in the NRDAM and DOE consequence models (January and May) are at seasonal peaks of activity by birds and other potential receptors.

Do these worst case conditions coincide? The Tofino Centre Vessel Traffic issued statistics for 1995 showing considerable variation in the monthly numbers of transits through its offshore jurisdiction, i.e., summer higher than winter, with August the highest (1782) and January the lowest (1242)[9]. Small vessel traffic, while not documented, is surely higher in the summer also, particularly in the inland areas of the waterway. Yet, the Washington DOE reports that vessel and facility spills resulting in oil on the water, over a four year period, peaked in January and were about at the yearly average in spring months[49]. DOE opined that the winter peak may result from HOE issues, i.e., operations in dark, cold conditions and during the holiday season, agreeing in essence with studies cited in Chapter 4 which have concluded that weather and visibility are strongly correlated with accident risk.

6.1.1 Risk by segment

Figure 6-1 and Table 6-1 present the results of multiplying the probability and consequence ratings for each segment.

Segments 7 and 6 evidence the highest level of risk, for different reasons. In Segment 7 (Puget Sound from Admiralty Inlet to Tacoma), the high rating is due primarily to the very high accident likelihood rating. Traffic management and spill response systems are mature in this area, but the accident likelihood suggests that further spill prevention efforts may be necessary.

Figure 6-1
Spill risk rating by segment

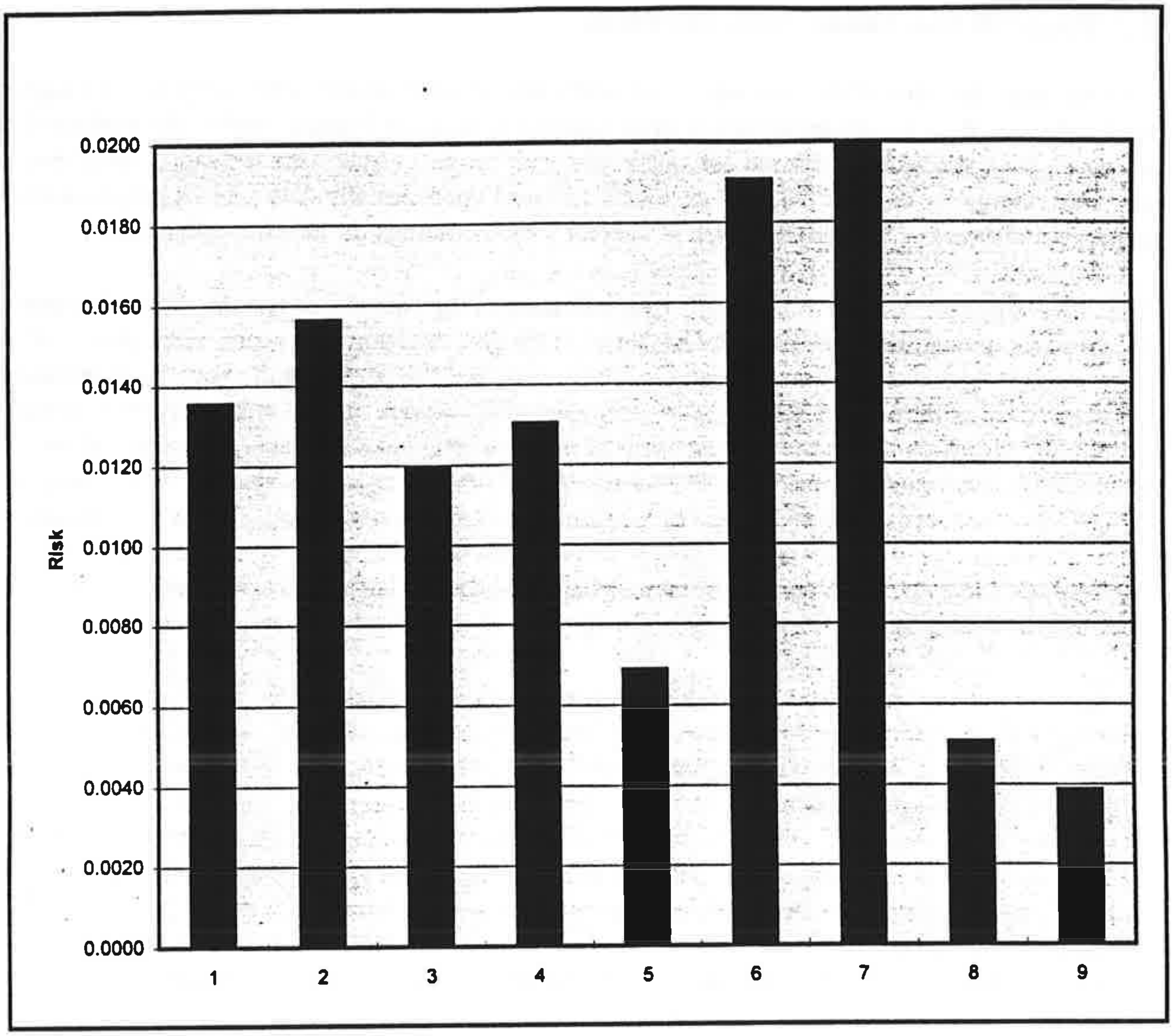


Table 6-1
Segment spill risk rating

Segment	$[A_U, A_M]$	Relative likelihood of accident (P_i)	Net consequence rating (C_i)	Interim result (P_i x C_i)	Spill risk rating
1	[0.05, 0.13]	0.09	0.15	0.0136	3
2	[0.11, 0.15]	0.13	0.12	0.0156	4
3	[0.09, 0.11]	0.10	0.12	0.0120	3
4	[0.12, 0.11]	0.12	0.11	0.0130	3
5	[0.01, 0.11]	0.06	0.11	0.0069	2
6	[0.18, 0.12]	0.15	0.13	0.0191	5
7	[0.35, 0.14]	0.25	0.08	0.0200	5
8	[0.06, 0.07]	0.06	0.08	0.0051	1
9	[0.02, 0.05]	0.04	0.10	0.0039	1

Note 1: Interim results for all 9 segments are rescaled on a 1-5 basis where 5 = high risk..
Note 2: Arithmetic average of segment's ratings for accident likelihood based on (1) USCG casualty data (A_U) and Marine Transportation WG judgment (A_M).

The risk in Segment 6, Rosario Strait and the San Juan Islands, is roughly equal to the Segment 7 value, due to the second highest accident likelihood and net consequence ratings, the latter despite highly rated spill response capability and relatively benign conditions. This suggests that shipping safety there may need re-examination, in spite of a strong regime of local safety measures. Segment 5 should be re-assessed when Canadian accident data are available to update the risk model and should meanwhile be considered at roughly the risk as Segment 6.

The open ocean approaches to the Strait of Juan de Fuca, Segments 1 and 2, fall into the next highest risk category, due primarily to high net consequences. The accident likelihood for Segment 1 is, as previously mentioned, artificially low since no data for Canadian accidents were available. We suggest that it should be taken as the rough equivalent of that for Segment 2, as should the risk rating, and that the two segments be considered together. The accident probability ranks third in the waterway, despite low traffic density (Table 3-6), due to congested and conflicting traffic around the "J" Buoy and severe environmental conditions. As stated in Chapter 4, the relative probability of an accident leading to a serious oil spill may be underestimated here because physical conditions and the converging and crossing nature of the deep draft vessel traffic are indicators of such low probability events.

Severity of wind and waves in the offshore area drives the poor ratings for spill response capability and conditions which, with fairly high environmental sensitivity, result in very high consequence ratings. The foregoing suggests that both vessel safety and spill response measures should be re-assessed in Segments 1 and 2.

The Strait of Juan de Fuca (Segments 3 and 4) had average individual and overall risk ratings. The accident rating for the western Strait (Segment 3) was driven by two small spills; otherwise only one accident was found in the data base. These results do not indicate the need for targeted measures.

Segments 8 and 9 have the lowest accident ratings as well as low consequence ratings. There is no apparent need here for new targeted safety measures.

6.1.2 Risk-weighted accidents and causality

In order to identify those accident types and hazards that most threaten the environment, it is necessary to weight them by the consequences should they occur and then rank order the result. Here the results of Steps 1 and 2 are multiplied to yield a risk-based rating for accidents and hazard, called weighted significance. The results are found for the waterway as a whole and for segments, to create a ranked list of particularly significant local hazards, or "hot spots".

Figures 6-2 and 6-3 show weighted accident and causality significance for the waterway. They confirms what has already been shown: 1) collisions are the primary concern for accident types, followed by grounding scenarios; and 2) HOE is the prime causality concern, followed by physical conditions and conflicting operations.

Figure 6-2

Risk weighted accident significance, waterway

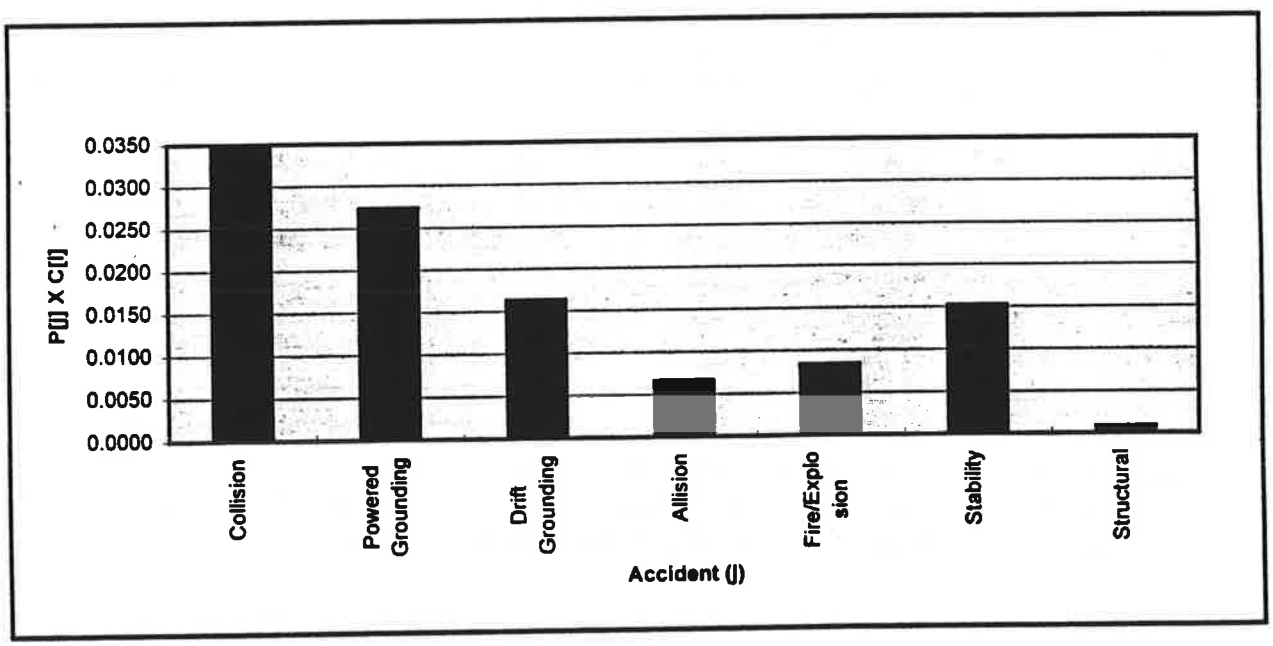
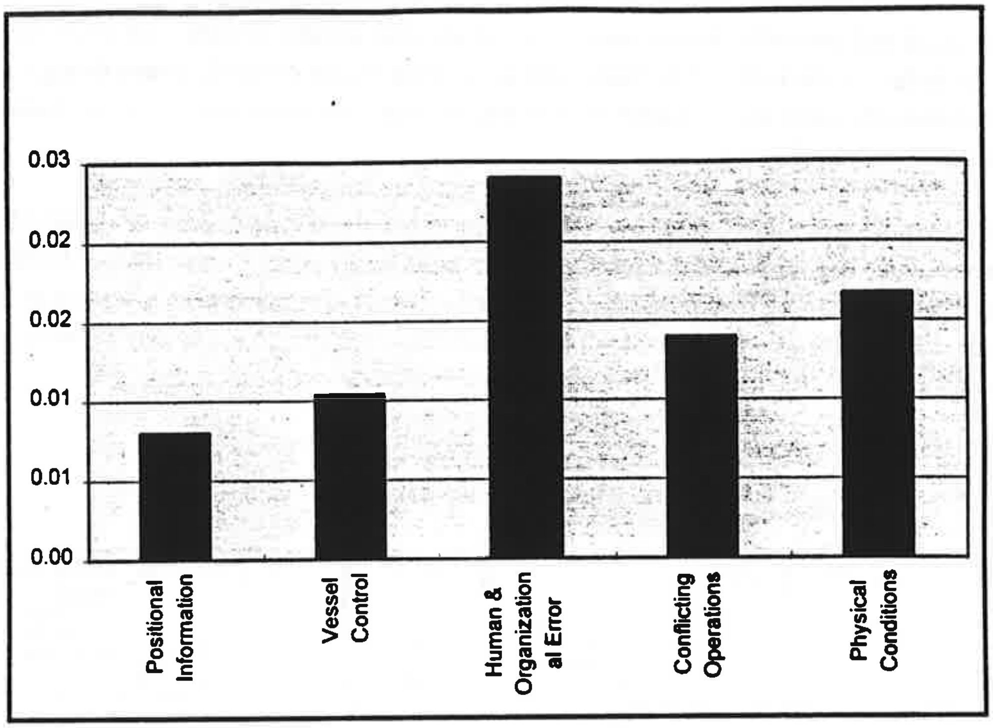


Figure 6-3
Risk weighted hazard significance, waterway



6.2 Universal safety measures

The universal safety measures for the waterway may be sorted to see which hazards they influence. In Table 6-2, the top seven risk weighted hazards appear, defined by accident type and causality combinations, with the safety measures corresponding to the hazards. The risk ratings are sums of the consequence weighted likelihoods for the entire waterway. A more detailed description of existing safety measures appears in Appendix F.

The hazards themselves may not all be said to be "universal" as they vary greatly in different waterway segments; again, the ratings are sums of segment specific values. HOE may be the only instance where the hazard and the measures are truly universal. Here, there are a great many safety measures in place. and yet HOE remains the dominant concern. This suggests two things: 1) that improved external oversight and resources may be the correct course to address human and organizational error; and 2) internal cultural changes must take place. There are several national (e.g., Coast Guard's Prevention Through People program) and international (International Safety Management Code) initiatives underway to foster those internal changes, but positive results may be a long rather than short term proposition. The potential payoff to reduction of HOE is nearly system-wide, as HOE is most often a contributor to vessel control and conflicting operations problems as well.

Vessel control, physical environment, and conflicting operations are closely grouped as the second most worrisome factor, (positional information is of lesser importance) and each is the object of considerable attention in the regulations (e.g., ship equipment and crew qualifications). Yet there is an important local factor in each (see Section 6.3). Conflicting operations are addressed by eleven external control mechanisms and equipment requirements (e.g., VTS, shipboard radar) and procedural requirements, but are also clearly linked with HOE factors not explicitly included in the table. The same can be said of vessel control, where design and equipment standards have clear influence, but where poor human control or maintenance can be primary or contributing factors.

As for "physical environment", humans can only monitor, report, and warn of natural features (e.g., weather reporting, aids to navigation) and in most cases cannot alter them. Traffic separation schemes are an effective human overlay. Vessel control is also affected by waves and weather, yet designs for power and maneuvering are not at present tied to any weather performance criterion.

Table 6-2
Universal measures and high risk hazards

HAZARDS		Risk	Total	Universal Safety Measures (UM)							
Accident	Causal Factor	Rating	UMs	1	2	3	4	5	6	7	8
Powered Grounding	HOE	0.009900	22	12		9		1			
Collision	HOE	0.009872	22	12		9		1			
Collision	Conflicting Operations	0.009614	11		2			6	2	1	
Powered Grounding	Physical Conditions	0.007935	4						2	2	
Collision	Physical Conditions	0.005453	4						2	2	
Drift Grounding	Vessel Control	0.003633	8		1		2	2		1	2
Powered Grounding	Positional Information	0.003565	12		2			5	1	4	

6.3 Local safety measures

The risk associated with accident/causality combinations in each segment are shown in Table 6-3. The values shown are risk weighted as in Table 6-2. The highest three ratings for each hazard are in bold face and the ten highest of those are in shaded cells. These are indicators of "hot spots".

Risk again is the highest in the offshore segments (due to collision), in Puget Sound (due to collision and powered grounding), and Rosario Strait (due to powered grounding). As for causality, HOE and physical conditions each occupy four of the top ten risk weighted hot spots and conflicting operations the other two. HOE is a high risk element in all scenarios, but is, as previously stated, a universal hazard. Conflicting operations and physical conditions are more truly local (or non-universal) hazards and therefore more tractable by non-universal measures.

Comparison to the local measures in force (Table 4-2) reveals that significant steps have been taken in Puget Sound and the passages around the San Juan Islands, particularly Rosario Strait (Segment 6) against collisions and groundings. Pilots, tug escorts, and operational restrictions add bridge redundancy and save capability, yet high physical conditions ratings indicate the unchangeable nature of natural conditions in those areas. The concentrations of unregulated vessels (see Table 3-6), especially recreational boats, are highest in these segments; the experts suggested that improved qualifications and licensing of those operators may be the best opportunity for risk reductions.

Table 6-3

Risk weighted local hazards by segment

ACCIDENT TYPE	CAUSALITY	SEGMENT RISK (ACTUAL VALUES X 1,000)								
		1	2	3	4	5	6	7	8	9
Collisions	Positional Information	**0.78**	**0.24**	0.17	0.31	0.05	0.21	**0.70**	0.12	0.07
	Vessel Control	**0.72**	0.22	0.30	0.33	0.11	**0.40**	**0.77**	0.09	0.05
	HOE	**4.08**	0.45	0.46	**1.17**	0.16	1.14	**2.10**	0.20	0.12
	Conflicting Operations	**3.86**	0.38	0.25	**1.11**	0.13	1.02	**1.90**	0.85	0.10
	Physical Conditions	**1.01**	0.31	0.27	**1.01**	0.13	**1.55**	**1.02**	0.09	0.05
Powered Groundings	Positional Information	0.09	0.32	0.09	**0.95**	0.25	**1.04**	**0.37**	0.34	0.12
	Vessel Control	0.09	**0.33**	0.11	0.30	0.23	**0.70**	**0.42**	0.18	0.14
	HOE	0.09	0.65	0.22	**1.09**	0.95	**3.92**	**1.84**	0.45	0.68
	Conflicting Operations	0.09	**0.38**	0.06	0.27	0.24	**0.72**	**0.49**	0.14	0.11
	Physical Conditions	0.09	**2.07**	0.09	0.96	0.90	**1.38**	**1.37**	0.71	0.37
Drift Groundings	Positional Information	0.08	**0.10**	0.07	0.06	0.09	**0.10**	**0.13**	**0.44**	0.03
	Vessel Control	**0.42**	**0.52**	0.32	0.17	**1.31**	0.36	0.36	0.10	0.08
	HOE	**0.35**	**0.43**	0.30	0.17	0.28	**0.33**	**0.33**	0.12	0.10
	Conflicting Operations	0.08	**0.10**	0.07	0.08	0.09	**0.10**	**0.11**	0.06	0.05
	Physical Conditions	0.19	**0.24**	0.21	0.13	**0.26**	**0.31**	0.20	0.08	0.07

Segments 1 and 2, on the other hand, have limited local measures in place. While the overall traffic density was low relative to other segments (Table 3-6), the nature of the bottleneck at J Buoy with converging inbound and diverging outbound deep draft ships, crossing coastal traffic, and sporadic concentrations of fishing boats indicated a more serious situation to the Expert Panel. Voluntary exclusion zones (ATBA and TEZ) keep most tank vessels some distance from highly valued shorelines in Washington and Vancouver Island. The TSS forks westward from the J Buoy to accept traffic from two directions. The experts gave some indication that a thorough reassessment of the traffic management in the offshore area is needed. Revamping the TSS would address the high ratings for both "conflicting traffic" and "physical environment".

No local measures are suggested by the table for Segments 3, 8, and 9, each of which have zero or only one top three hazard rating. High ratings in Segment 4 are driven mainly by collisions in the data base and experts' concerns about congestion around Port Angeles. Segment 4 has the full benefit of all existing measures in the waterway and no particular new measures there have been suggested in public discourse or by the experts. Universal measures may have a long term beneficial effect here. Segment 5's low ratings must be viewed in the context of the lack of accident data there, as previously stated.

A detailed description of existing local safety measures appears in Appendix F.

CHAPTER 7
FUTURE TRENDS AND SENSITIVITY

In this study, we have characterized the current state of waterway risk; the dynamic environment of world trade means that the picture can change swiftly. While a full sensitivity analysis of this dynamic is not possible here, the following are qualitative estimates of the effects of some anticipated major trends. These are not exhaustive; a separate study would be necessary for a full evaluation.

7.1 Future trends

7.1.1 Trade and traffic

The steady growth in maritime commerce in this region will probably continue in the future, especially given the waterway's strategic position relative to the emerging Pacific Rim economies. Future growth trends for both oil and dry cargo have an uncertain implication for the number of transits in the waterway, the resulting rate of accidents, and the consequences of accidents.

Examination of the proceedings of public dockets, meetings, and workshops reveals the following major topics of concern:

- Near future trade patterns for Alaska North Slope (ANS) crude.
- The long term supply of oil and demand in the Pacific northwest.
- The outlook for the TAPS fleet
- Future dry cargo trade pattern.
- Risk implications of ship design trends.
- Other waterway traffic.

Trade patterns for Alaska North Slope (ANS) crude

There is concern that lifting the ANS oil export ban will cause an influx of foreign flagged, lower quality tankers into Puget Sound, as ANS oil would be routed elsewhere. However, transportation consultants and oil industry representatives have pointed out that, as a matter of geography and economics, the West Coast will remain the prime market for ANS crude demand and that only surplus which now goes to the Gulf and East Coasts would be exported. Furthermore, Puget Sound refineries are configured for processing ANS oil; shifts to other oil types would require modifications to refinery operations.

Oil supply and demand

Population on the West Coast, in the northwest in particular, continues to grow at a faster rate than the rest of the United States. Washington's population is expected to grow from about 5.3 million (1994) to 8.1 million by 2010 [Census, 1996]. As Washington State had the 12th highest energy consumption per capita of the 50 states in 1992, while paying the 10th lowest price per capita, oil demand can be expected to increase in the future as it has in recent years[16].

Meanwhile, capacity and production have dropped off in Prudhoe Bay field, despite improving technologies for field production[16]. The Canadian Trans Mountain Pipeline may supply any future shortfall as ANS supply declines. According to the Canadian Association of Petroleum Products, Canadian crude oil deliveries to Washington State have increased from a low of 6,000 barrels per day in 1990 to an average of 84,000 barrels per day in 1995. Furthermore, they project a increase to the 180,000 barrels per day capacity of the pipeline within the next few years[44].

It is most likely that, for the foreseeable future, Puget Sound will remain the prime destination for ANS crude oil, sustained at levels roughly equal to those at present. Any decline in Alaskan oil supplies to this region is likely to be offset by Canadian pipeline oil.

The TAPS fleet

Age, not the overall capacity, of the TAPS fleet is likely to emerge as the main concern. Since the TAPS trade is likely to continue at roughly the same levels, maintaining, rather than increasing, tonnage will be necessary, within the OPA 90 replacement regime. Operators will have more design options as improved maneuvering and equipment redundancy features come to the fore. One major operator is now considering a series of double hulled tankers with full engineering (propulsion, steering, electrical systems) redundancy and bow thrusters for better maneuverability. Such improvements offer the prospect of reduced risk from collisions and drift groundings, particularly in the offshore areas where weather and wave conditions can be the most severe.

Newer vessels should reduce both the likelihood and consequence of accidents, both because of new pollution prevention technology and more robust engineering plants, but because age generally is a strong indicator for accident risk, as previously cited. Some caution is appropriate in regard to the new generation of tankers. It is well to bear in mind Charles Perrow's admonitions about the implications of new technology, i.e., the over-reliance on and abuse of technological improvements as a primary factor in maritime accidents (he cited cases of "radar assisted collision" among other examples)[24].

New double hull tankers will, in the present regime, be freed from the OPA 90 requirement for tug escort. While more capable vessels may arguably have less need for escort, fewer escort tugs in the waterway will have other implications. Emergency response requires the availability of tugs and/or other vessels for assistance, especially for the drift grounding scenario. The International Tug-of Opportunity System (ITOS), developed to enhance the ability to respond to these drift grounding, relies in part on the availability of these vessels. As escorts are phased out with the new hulls, tug availability may decline, unless an equivalent demand is found for other reasons. As such, while tanker risk will likely decrease, the risk for other traffic types may increase.

Size of individual tankers will remain below 125,000 dwt east of the Magnusen Line for the foreseeable future. The option of allowing trade with very large crude carriers (VLCC) may re-emerge when and if overseas sources of oil are again significant for the region. In this case, risk managers would have to consider all sides of the equation for this new input, including reduced numbers of transits (potentially lower accident likelihood) and and larger cargo capacities (potentially heavier outflows in the case of an accident).

Dry cargo trade

Expanding dry cargo trade in Puget Sound can be expected as ports increase capacity and make other improvements to attract additional trade with the Pacific Rim nations (Sea Land has conservatively estimated a 7% market growth in both eastbound and westbound trade in 1997 (Marine Digest, 1997). The growth means hundreds of more jobs in a region where 1 in 5 jobs is trade related (compared to U.S. average of 1 in 13). These port improvements include:

- Port of Seattle-- $260 million upgrade to double American President Line's container operations, and expand Seattle's port capacity by approximately 25%.
- Port of Everett-- 170 acres expansion along the Snohomish River.
- Port of Vancouver—new Deltaport terminal will double container handling capacity to approximately 1.1 million TEU. This new capacity, along with Hanjin's shift from Portland to Vancouver, could mean record years in the future for Vancouver trade.

Although ports are in competition with each other, and gains for one may come at the expense of another, the projected increase in trade should produce an increased volume of goods shipped. The reader should note that the trend towards larger ships may mitigate or negate the growth of waterway transit numbers. Port expansion (both pier capacity and dredging) in fact is, in large part, to keep pace with the rapid growth in size of modern container ships (up to 6,000 TEU post-Panamax). Seattle handled its first 4,000 TEU Hanjin ship last year, with the expectation of more to follow.

Some experts have raised the possibility of port consolidation and cooperation in the future as port and land transport systems approach their capacities[26]. The British Columbia Environment Ministry has also suggested that economic promotion of ports cannot be decoupled from larger safety and environmental protection aspects. They, and others, have proposed that port and other fees be structured to encourage safer vessels, similar to the "Green Award" program established by the Port of Rotterdam[7].

Vessel size implications

Increasing commodity volumes do not necessarily correlate to increasing numbers of transits, particularly as regards containers. Recent trends towards increased vessel size and capacity, and cooperative arrangements to more productively use vessel and port capacity, offset, at least to some extent, increased commodity volume. In fact, total numbers of transits into the waterway have declined slightly in recent years, whether or not the calculation includes Canadian ports.

However, increasing vessel size can result in increased risk if prevention and response systems do not keep pace. Of course, accidents involving larger vessels can lead to more severe consequences.

While transit numbers may not increase swiftly, the assessment of risk must account for the increased size and capacity of the ships. Power and maneuverability of the vessels in severe wind or waves is a growing concern, as well as the capability (horsepower) of vessels called to assist in case of emergency. This study did not specifically analyze the effects of the trend towards larger vessels on risk, although that is one item that could be considered in future efforts.

Other waterway traffic

Waterway risk managers must be wary of the potential growth of regional traffic, i.e. ferry services and smaller vessels, both of which will be driven by growing population. The Washington Ferry system has grown with the sprawl of urban areas, congestion of surface roads, and increased tourism, all likely to continue an upward trend. Recreational boats are also likely to increase in number; the hazards associated with these "un-regulated" vessels could also rise unless training and qualifications improve.

Activity of the inland fishing fleet is currently depressed due to the state of fish stocks, but could rebound as pollution prevention and fisheries management efforts take effect. This is another un-regulated user sector which will need monitoring by waterway managers.

7.1.2 Safety management

New human and organizational standards

There are two new international safety instruments, now in beginning of their implementation phase, which are geared towards reducing the risks of accidents due to human and organizational errors. They are the International Safety Management (ISM) Code and the Standards for Training and Certification of Watchkeepers (STCW). The ISM requires that vessel operators have a functioning, certificated safety management system, including clear lines of responsibility and routine audits, and is geared toward the organizational causes of mishaps. STCW, on the other hand, is aimed at the individual mariner and shipboard human errors. It includes certification of the world's maritime training institutes and also specifies minimum work and rest requirements for the first time.

It is not clear how effective these instruments will be, or how long before the benefits of their internal application will be felt. The implementation details of both conventions are not yet known, nor can their effectiveness be estimated in advance of the learning and improvement process. As such, these two conventions should be considered as future changes to the safety system.

Data collection

Several organizations, both national and in the Puget Sound area, have pointed out the need the need for improved marine safety data collection and management. Washington State OMS has made a start with their vessel risk data base, and the Coast Guard manages a national data base. Both are lacking in causality and "near miss" data. The Puget Sound Safe Marine Transportation Forum (SMART) has begun development of a safety reporting system, whose goal is an integrated reporting and management system for all safety managers in the waterway[25]. Additionally, the Coast Guard has recently make strong progress toward developing a national near miss reporting system. This is a hopeful trend, and one which, in fruition, could improve managers' knowledge significantly.

7.1.3 National accident trend

National marine spill rates have been in recent decline. While spill and spill removal rate trends in the U.S. and worldwide do not necessarily correlate to Puget Sound area waters, some inferences may be drawn. In a recent report submitted to Congress, the Coast Guard reported a decreasing trend in the amount of oil spilled per million gallons of oil shipped[43] (see Figure 7-1). Although fluctuations can be expected, there is a strong indication that the national, normalized spill volume will decrease. The same report showed that major (>100,000 gallons) and medium (between 10,000 and 100,000 gallons) oil spills per billion tons shipped are also in decline.

Figure 7-1
Gallons of oil spilled per million gallons of oil shipped

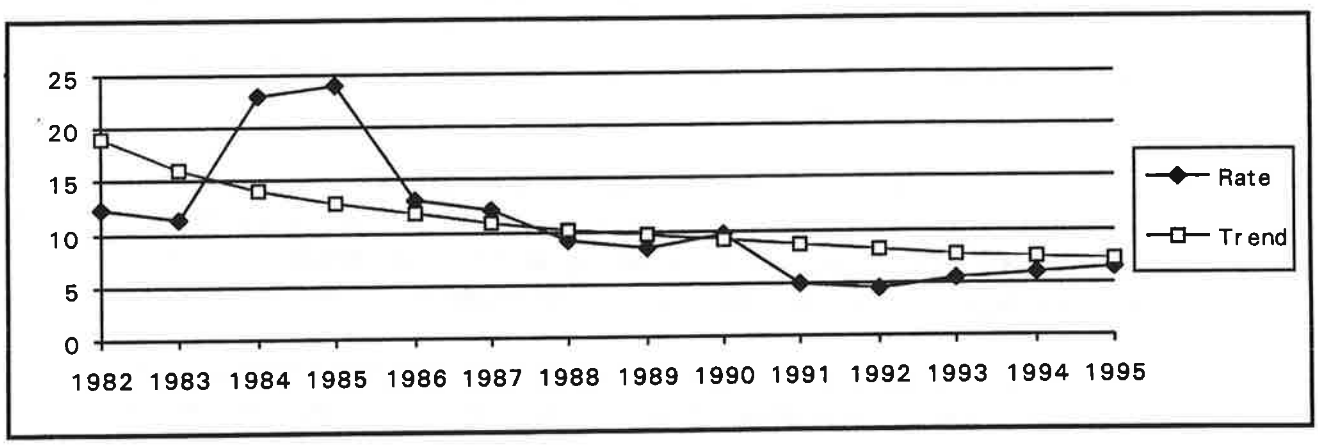
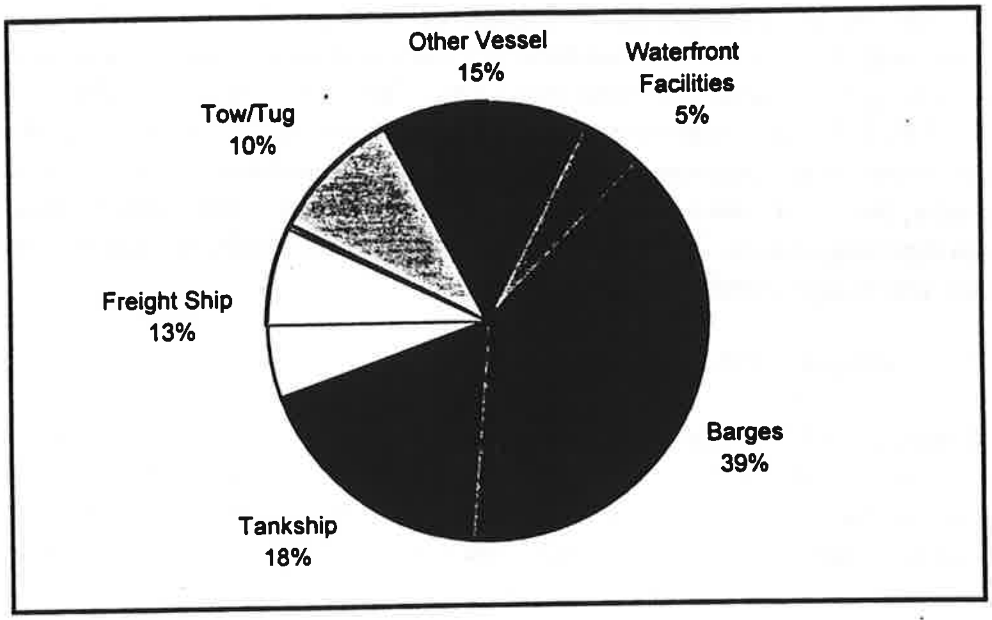


Figure 7-2 breaks down the major and medium oil spills for 1994-1996 by vessel type[43], and shows that barges represent the primary risk. While this was not normalized (by number of transits or volume shipped), and represents one indicator only (volume of spills may paint a completely different picture), it does shed some light on the national breakdown of spills. Rising volume of barge traffic in the Washington waterway should be examined in this light.

Figure 7-2
Number of major and medium oil spills by source (1994-1996)



7.1.4 Consequences

This study did not examine increasing sensitivity of the ecosystem to oil spills. The consequences of an oil spill in the area of study are very high, and likely to get higher. The British Columbia government reported that accident costs will rise with rising dependency on a clean marine environment for tourism, habitation, recreation and industry[7]. Both direct and indirect users have a large stake in the health of the system.

Direct users, such as commercial shellfish growers, tribal fisheries, marine transportation, recreation and tourism related industries and others rely on the Puget Sound waterway system for their livelihood's. A major spill on the waterway would directly affect these users and their way of life. Their dependence on the waterway system has grown over the last decade[33].

Indirect users include the population generally, who cite the natural beauty of the waterway as a major benefit of residing in the Puget Sound region. Furthermore, local businesses, including the rapidly emerging high tech industries, count the natural environment as a real attraction for prospective workers.

A useful example for the projection of the rising consequence trend involves the direct dependence of marine transportation on a clean and navigable waterway. Closing a port area for clean-up of a major oil spill would have an extremely harsh effect on the local economy and trade. Trade to and from the region could potentially be blocked by such a spill, which could have long-lasting impacts if shippers did not return to the region after diverting elsewhere during clean-up operations. Where this increasing consequence is directly related to the growth of trade in the region, others would similarly track with increasing population, tourism, and recreation.

7.2 Sensitivity

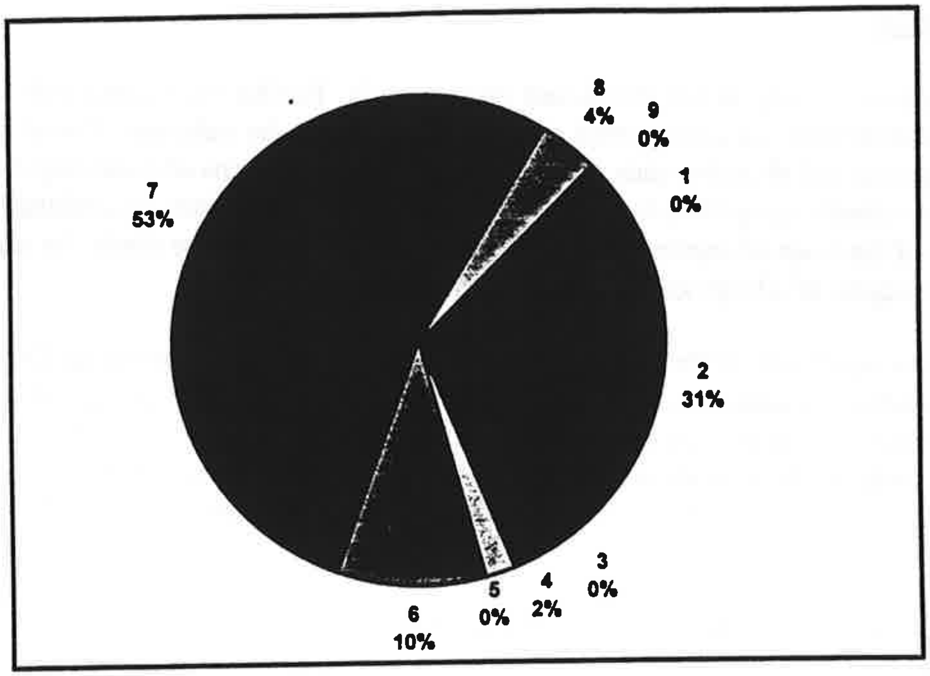
No full sensitivity analysis was conducted for this study. For the most part, modeling and analysis uncertainties had little known or projected affect on the outcome. Use of the combined expert judgment and objective data provided for an effective means of providing detailed insights which are relatively insensitive to minor changes in the input of either. Additionally, averaging the ratings of the team of experts further reduced the sensitivity of the results by using the collective insights of a large group versus a few individuals.

Details of the sensitivity of the results to various data inputs were discussed in Chapters 4. The lack of Canadian accident data is a factor in lower accident likelihood ratings inSegments 1 and 5. This deficiency was somewhat offset, however, by the expert ratings. As such, while segments 1 and 5 were believed to have slightly lower risk ratings than actual, the inaccuracy is not pronounced. The model should be exercised again when better data are available for those segments.

Another area where the results may be somewhat sensitive is the assessment of the contribution of accident types to the overall risk. While experts were told to evaluate the likelihood of a particular accident type occurring and leading to a significant oil spill, lack of spill data precluded consideration of this joint likelihood. As such, to be fully accurate, the objective data would require additional consideration of the likelihood of a spill given an accident type in a segment. Data for this consideration were not available and this step could not be taken. As discussed in Chapter 4, this is believed to have produced results which overstated the risks due to allisions, fires, structural and stability failures, which can be considered to have a low likelihood of spills given occurrence.

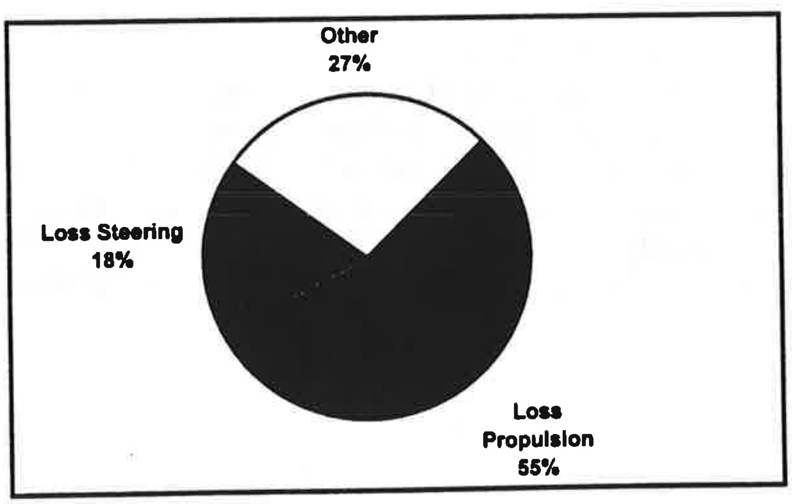
There is an additional concern that incidents (e.g., power failures) were not included in the analysis. As discussed in Chapter 4, use of incident data with accident data is inappropriate, given the significant difference in hazard significance between the two. Furthermore, these incidents represented cases where the waterway safety system worked, as neither spills nor accidents occurred. Figure 7-3 demonstrates that the distribution of incidents in the waterway do not represent a dramatically different picture. The incident distribution followed a similar pattern as that for accidents, with the biggest differences being found for Segments 2, 6 and 8.

Figure 7-3
Distribution of incidents by segment



Incidents types are shown in Figure 7-4, where loss of propulsion emerges as the dominant type, followed by loss of steering and other (which included primarily auxiliary equipment failures that met the reportable marine casualty criteria).

Figure 7-4
Distribution of incidents by cause



Loss of propulsion scenario can result in drift groundings, allisions and collisions. Of these, drift groundings would be the most significant scenario for this study. Collisions would not be as likely to result, and allisions would not be as likely to result in a significant spill in this waterway.

In isolation, these incidents imply increased opportunity for drift grounding, although other incidents not captured by Coast Guard data (i.e., other near misses such as course deviations and the like) could have the same implication for other accident types.

The impact of these data (captured and not), however, would not be significant for this analysis, as the focus here was on spills and accidents. As such, incidents having no significant impact on the waterway system, would not have a significant effect on the results obtained here. It should be noted, however, that analysis of a robust incident data set would be an important study in its own right and should be considered in the future, when such data are available.

The results of this study are therefore essentially sound and represent a valid first analysis of the waterway. Furthermore, they correlate well with results obtained from other studies of this and other waterway systems, as shown in Appendix F.

CHAPTER 8
FINDINGS

The presentation of these findings follows the organization of the report. A set of general findings is followed by the particulars relating to: 1) risk in the waterway, as measured by hazard characterization and accident probability and spill consequence values; and 2) existing and proposed measures. Findings in each section are organized as elsewhere in the report, i.e., "universal" applying to the entire waterway and "non-universal" to particular areas of the waterway. Finally, there are comments on the methodology of the study.

8.1 General

The following are findings on the nature of the waterway and management strategy for oil pollution prevention.

- Value and complexity of the waterway. The northwest Washington State marine waterway has very high environmental, aesthetic, economic, and cultural value. It also features complexities of vessel traffic flow, weather, geography, hydrography, and governmental jurisdiction which, taken together, present a significant waterway management challenge.
- Vessel traffic. The Puget Sound waterway is busy with a variety of vessel traffic. Heavy commercial and some fishing vessel traffic characterize the offshore area, particularly in the vicinity of the "J" Buoy. The western Strait of Juan de Fuca has the highest concentration of deep draft ships as traffic to all ports enters and exits by those waters. Deep draft traffic diffuses but overall complexity increases in the eastern Strait of Juan de Fuca as pilot boats, tug escorts, and barge traffic intensify. Puget Sound and the passages around the San Juan Islands carry the highest concentrations of traffic overall, including heavy commercial traffic (deep and shallow draft) and the highest densities of recreational, fishing, and ferry vessel traffic, especially in Puget Sound and Rosario Strait. South Puget Sound to Olympia and east Sound in the Everett area have significantly lower traffic densities.
- Safety system. The existing safety system has many well established assets including cooperative vessel traffic control, port state controls by the U.S. and Canadian Coast Guards and Washington State, American and Canadian aids to navigation, and a variety of special measures like tanker size limits, tug escorts, and navigational restrictions. There are also a number of recent measures whose full effects are yet to be felt, including OPA 90 double hull replacement and international crew and organization standards.
- Risk distribution. Waterway risk is unevenly distributed due to the nature of vessel traffic and operating conditions, environmental sensitivity, and feasibility of spill response.
- Risk management strategy. Spill prevention must be the main focus of a risk management strategy. In spite of advances in response technology, most spilled oil remains in the environment even under the best cleanup conditions. This finding echoes that of other studies, including the States/B.C. Oil Spill Task Force[34].

8.2 Waterway risk

The following are the specific findings of this report as regards oil spill risk, divided into the two component aspects of risk: accident probability and consequences.

8.2.1 Accident likelihood

- The principal spill scenarios of concern in this waterway are collisions, followed by powered and drift groundings.
- The main contributory causes are 1) human and organizational error (HOE), including many factors such as poor communication, poor training, and lack of maintenance, 2)traffic congestion, particularly as regards non-regulated vessels, and 3) severe environmental conditions such as high wind and waves. HOE proved the dominant causal accident factor, confirming findings by others, and has a clear link to problems of conflicting operations, as well as the lesser hazards of positional information and vessel control.
- The locations with the highest likelihood of an accident resulting in a serious spill are, in order, Segments 7 (Puget Sound), 6 (Rosario Strait), and 2 and 1 (offshore area). The most likely cause of such an accident would be a collision, except in Segment 6, where powered grounding is the most likely scenario.

8.2.2 Consequences

All segments of the waterway are seen as having unique and highly sensitive environmental values and were therefore scored in a narrow high-end range. However, the net consequences of oil spills are considerably more varied after taking account of the feasibility of response in different segments.

- High environmental sensitivity. Sensitivity is the highest in the offshore area (Segments 1 and 2) and the waters around the San Juan Islands (Segments 5 and 6). These segments are rated as highly sensitive in all categories, with the exception of shoreline habitats for Segments 1 and 2. Here the high wave energy of exposed coastlines results in low sensitivity ratings.
- Lower sensitivity. Scores in Puget Sound (Segments 7/8/9) are lower primarily because of low bird and marine mammal ratings. The Strait of Juan de Fuca scores are also lower, because of lower shoreline and park and recreation values.
- Spill response As measured by available assets, response time, and response conditions, response ratings are lowest on the outer coast (Segments 1 and 2) and rose generally moving toward the eastern part of the waterway. The best response outlook is in Segments 4, 7, and 8.
- Net consequences. Net consequences take account of all sensitivity and response aspects. The offshore area (Segments 1 and 2) and Rosario Strait (Segments 6) are the highest rated.

8.2.3 Risk

Risk combines the factors of accident probability and environmental consequences. The following findings are based on the "significance" of hazard, causality, or location, i.e., the consequence-weighted probability of accident scenarios.

- Accident scenarios. Collisions and powered groundings are the most significant risk weighted hazards for the waterway. HOE, conflicting operations, and sever environmental conditions are the most likely associated causes.
- Highest risk areas. Segments 7 and 6 evidence the highest levels of risk. Segment 7 (Puget Sound from Admiralty Inlet to Tacoma) has the highest accident likelihood rating (traffic density by far the highest in the waterway and a mature traffic management system) and a relatively low net consequence rating (partly due to mature spill response systems). The risk in Segment 6, Rosario Strait and the San Juan Islands, is roughly equal to the Segment 7 value, due to the second highest ratings both in accident likelihood and net consequence ratings, the latter despite highly rated spill response capability and relatively benign response conditions.
- High risk areas. The open ocean approaches to the Strait of Juan de Fuca, Segments 1 and 2, fall into the next highest risk category, due primarily to high net consequences. Severity of wind and waves in the offshore area drives the poor ratings for spill response capabilities and conditions. The accident probability ranks third in the waterway, due to congested and conflicting traffic around the "J" Buoy and severe environmental conditions. These factors contribute to an historically high rate of serious spills in that area.
- Canadian waters. The risk rating for Segments 1 and 5 is artificially low because specific accident data were not available to the project team. Any reappraisal of waterway risk should include more detailed data for accidents occurring in Canadian waters, with an effort to reconcile these to U.S. Coast Guard data.
- Strait of Juan de Fuca. The Strait of Juan de Fuca (Segments 3 and 4) is found to be at average risk for the waterway. The accident rating for the western Strait is driven by two small spills; otherwise only one accident was found in the data base.
- Low risk areas. Segments 8 and 9 have the lowest accident ratings as well as low consequence ratings.
- Local hazards. The top ten risk weighted hazards by segment confirm waterway trends for accident and causality. HOE and severe environmental conditions, followed by conflicting operations, are the most common causes for high risk local scenarios. Risk is the highest in the offshore segments (due to collision), in Puget Sound (due to collision and powered grounding), and Rosario Strait (due to powered grounding).

8.3 Safety measures

The analysis of measures herein focuses primarily on the existing safety net. These findings do not recommend specific new measures, but point out where risk is high and what kind of mitigation strategy is suggested by the analysis, i.e., enforcement enhancements or new measures.

8.3.1 Marine transportation

- Human and organizational error. There are a great many safety measures in place addressing HOE, yet it remains the dominant safety concern in the waterway. This suggests two things: 1) that improved external oversight and resources may be the best course to address human and organizational error; and 2) internal cultural changes must take place, particularly in industry (operators, owners, classification societies, etc.). There are several national (e.g., Coast Guard's Prevention Through People program) and international (International Safety Management Code) initiatives underway in this area, but positive results may be long rather than short term. The potential payoff could be felt across all parts of the waterway for most accident scenarios of concern, as HOE is most often a contributor to vessel control and conflicting operations problems as well.
- Conflicting operations. Conflicting operations are addressed by eleven external control mechanisms and equipment requirements (e.g., VTS and shipboard radar, respectively) and procedural requirements. While it is possible that some traffic control enhancement could be effective, vessel operation is essentially a human factors issue. The HOE enhancements now coming into effect would pertain here for commercial cargo traffic, but suggestions that qualifications and licensing for presently unregulated vessel operators (recreational and small fishing boats) should be seriously considered. This aspect of operational safety was strongly emphasized by the Expert Panel and would address both HOE and conflicting operations risk elements in the densely populated eastern waterway, where recreational boating is a concern, and in the offshore areas, where fishing vessel concentrations can exacerbate other traffic problems.
- Physical conditions. Physical conditions emerged as a high risk item, particularly in the offshore area and in Rosario Strait. Since natural features cannot readily be altered, improved monitoring, reporting, and warning of them should be investigated, e.g., better weather reporting. The experts also suggested that a re-examination of the traffic separation schemes is worthwhile at this time, particularly west of the "J" Buoy at the entrance of the Strait of Juan de Fuca. Vessel control is also affected by waves and weather; new designs for redundant power and improved maneuvering could reduce risk due to physical conditions as well as conflicting operations. It is noteworthy that a major oil carrier has, at this writing, contracted to build two new double hull, redundant propulsion tankers for the TAPS trade to Puget Sound.
- Offshore traffic management. High risk ratings for HOE, conflicting operations, and severe environmental conditions in the offshore waters suggest that the traffic management system be re-examined there. The Expert Panel included traffic separation schemes as physical features of the waterway. Several changes in special area designations have occurred in that

area since the original TSS was put in place. The high risk profile there (confirmed by the incidence of serious spills over the last 25 years reported by Washington DOE) indicates the need for a system review.

- Positional information. There appears to be no basis for improving positional information measures.
- There is no apparent need for new local safety measures in Segments 3, 4, 8, and 9.
- Data management. There is an overarching need for better accident, causality, and incident data. All safety managers in the area should work together on an improved, common basis for data management. The Puget Sound Safe Marine Transportation Forum report on this subject represents a good start.

8.3.2 Spill Response

Our examination of the spill response system is based on the Environmental Impact Working Group's assessment of the existing response system They also suggested several new response measures; these have been filtered through the results of the risk assessment to arrive at the risk management topics following:

- Salvage. Enhanced salvage capability, defined to include fire fighting, patching, ballast adjustments, lightering and towing, is the measure likely to be the most effective in spill mitigation. Several specific options for effecting this enhancement are identified in the Group's report in Appendix E, including improved valving for control and transfer of oils from cargo vessels. All segments would benefit.
- Outer coast response. Several options to improve outer coastal response capabilities were identified including dedicated spill response vessels and equipment, more expeditious procedures for approval and use of alternate spill response technologies, and administrative actions to require improved spill response capability.

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